Cancer Control
2017, Vol. 24(3) 1–6

DOI: 10.1177/1073274817729234
journals.sagepub.com/home/ccx

Minimally Invasive Approaches for Surgical Management of Primary Liver Cancers

Rachel E. Beard, MD[1] and Allan Tsung, MD[1]

Abstract

The benefits of minimally invasive approaches in oncologic surgery are increasingly recognized, and laparoscopic liver surgery has become increasingly widespread. In light of the complexity and technical challenges of hepatobiliary procedures, robotic approaches are also employed. The utility, safety, and oncologic integrity of these methods in the management of primary liver cancers are reported. PubMed was used to search the medical literature for studies and articles pertaining to laparoscopic and robotic liver surgery. Studies that particularly addressed hepatocellular carcinoma and cholangiocarcinoma were identified and reviewed. Laparoscopic liver surgery, including for major resections, has been shown to be safe in experienced hands without any compromise of oncologic outcomes for either hepatocellular carcinoma or intrahepatic cholangiocarcinoma. Some studies show improved clinical outcomes including shorter hospital stays and lower complication rates when compared to open surgery, particularly for patients with cirrhosis. Robotic liver surgeries seem to have equally acceptable clinical outcomes; however, there is limited data regarding oncologic integrity and considerable additional expense. Laparoscopic and robotic liver resections are both feasible and safe for the management of primary liver tumors. Future studies should aim to clarify specific indications and optimize applications of these approaches.

Keywords

minimally invasive liver surgery, liver resection, robotic hepatectomy, laparoscopic liver resection

Received September 26, 2016. Accepted for publication November 04, 2016.

Introduction

The benefits of minimally invasive surgery in enhanced patient recovery and reduced morbidity are increasingly recognized. This is especially important in oncologic surgery where time to recovery postoperatively can impact the initiation of adjuvant chemotherapy. Colorectal surgeons were among the earliest practitioners to widely adopt minimally invasive approaches, and studies in that field have shown decreased complication rates, decreased to time to chemotherapy, and decreased margin positivity for patients with colorectal cancer who underwent minimally invasive surgery as compared to open procedures.[1-4] None of these studies demonstrated a significant difference in time to initiation of chemotherapy between patients undergoing robotic or laparoscopic surgery; however, rates of conversion from a minimally invasive approach to an open approach were significantly lower with a robotic approach.[2,5,6]

The introduction of the da Vinci Surgical System (Intuitive Surgical, Inc, Sunnyvale, California) in the early 2000s aimed to address some of the technical limitations of laparoscopic surgery. This alternative minimally invasive approach offers a greater range of motion, enhanced instrument dexterity, minimization of surgeon tremor, and a 3-dimensional view of the surgical field. Several early series demonstrated its safety and success when employed in abdominal surgery to treat a variety of diseases including antireflux operations, cholecystectomy,

[1] Division of Hepatobiliary and Pancreatic Surgery, Department of Surgery, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA

Corresponding Author:
Allan Tsung, Division of Hepatobiliary and Pancreatic Surgery, Department of Surgery, University of Pittsburgh School of Medicine, Pittsburgh, PA, USA.
Email: tsunga@upmc.edu

bariatric procedures, and colonic, gastric, and adrenal resections.[7-9] Although a few of these studies described robotic liver resections—7 out of 153 procedures in one study, 3 of 207 in another—they constituted a small minority of robotic surgeries performed.[8,9] This trend has continued with colorectal, bariatric, foregut, cholecystectomy, and, more recently, pancreatic procedures being the most commonly approached with a robotic technique and the most widely studied within the field of general surgery.[10,11]

Given the predominantly positive outcomes observed in other fields, minimally invasive techniques are increasingly employed in hepatobiliary surgery and for the resection of primary liver tumors. The liver presents significant technical challenges for the application of minimally invasive techniques. The need to mobilize the liver attachments including those that are very posterior, the limited space in which to maneuver, the complex and variant hepatic vascular and biliary anatomy, and the friable or fibrotic parenchyma, in patients with steatosis or cirrhosis, all present significant challenges. Laparoscopic liver resections are increasingly being performed and reported, and the theoretical benefits of robotic surgery in liver resections are apparent. Many studies comparing outcomes after minimally invasive liver resection to those after open resection demonstrate encouraging results. A recent large comparative analysis of the National Surgical Quality Improvement Program database by Bagante et al reviewed 3064 patients undergoing hepatectomy and compared 609 open resections to 609 minimally invasive resections, including laparoscopic and robotic cases, with propensity matching.[12] The incidence of wound infection, blood transfusions, pulmonary embolism, liver failure, and biliary leakage were all lower after minimally invasive resections when compared to open procedures. Hospital stays were shorter and 30-day mortality and readmission rates were comparable.

Laparoscopic Liver Resection

Laparoscopy in liver surgery was initially employed for predominantly benign lesions and nonanatomic resections in part due to fear that oncologic outcomes may be compromised with a laparoscopic approach and that port site seeding may occur. One large literature review in 2009 by Nguyen et al[13,14] looked at over 2800 cases and found that 45% of the procedures were wedge or single-segment resections with an additional 20% reported as left lateral segmentectomies, all technically easier resections to perform laparoscopically. Early laparoscopic liver surgery was well tolerated and safe, with reported mortality rates of 0% to 0.3% and morbidity reported at 10.5% to 12%. Eventually, its application became more widespread and larger, and anatomic resections were performed. One study looked exclusively at laparoscopic major hepatectomies at 6 major international centers and reported on 210 cases performed between 1997 and 2008. Overall complications were low with liver-specific complications being even lower, 13.8% and 8.1%, respectively, and only 2 patients died in the postoperative period.[15]

In 2008, an international consensus conference was held to address the topic of laparoscopic liver surgery, and the Louisville Statement was issued in 2009.[16] They concluded that (1) currently acceptable indications for laparoscopic liver surgery include solitary lesions of 5 cm or less and located in segments 2 to 6; (2) laparoscopic left lateral sectionectomy should be considered standard of care; (3) major laparoscopic liver resections should be performed exclusively by experienced surgeons; (4) conversion to an open procedure should be readily considered for reasons of patient safety, long operating times, and difficulty of resections; and (5) a hand-assisted or hybrid approach may be beneficial. Although the feasibility and safety of laparoscopic liver resection has been shown, multiple studies have shown the learning curve for laparoscopic to be significant, with 45 to 75 cases needed for competency.[17-21] This is a potentially limiting factor in its widespread adoption and implementation.

Robotic Liver Resection

With the safety of minimally invasive liver surgery well established, robotic approaches were increasingly employed to address the technical difficulties of laparoscopy. An additional appeal was the possibility of reducing the significant learning curve that had been demonstrated in laparoscopic liver surgery. One recent review by Ocuin et al[22] summarized 14 major series[22-36] in the literature that included 439 patients who underwent robotic-assisted liver resection. An overall conversion rate of 7% was reported, which was slightly higher than the 4% conversion rate reported in the large review of laparoscopic liver resection by Nguyen et al.[13] The overall complication rate was reported to be 21% with individual series ranging from 0% to 43%. The most common complications were bile leak and intra-abdominal collections, and no perioperative mortality was reported in any study. Operative times ranged from 90 to 812 minutes and blood loss ranged from 50 to 413 mL; and as reported by Tsung et al,[26] both of these parameters seemed to downtrend as the surgeons and operative teams gained more experience.[26]

Studies have compared outcomes after robotic liver resection to both open and laparoscopic approaches. One study from Memorial Sloan Kettering[37] reported on a case-matched series of 64 patients undergoing open hepatectomy compared to 64 patients undergoing robotic hepatectomy. They found significantly shorter operative times, lower blood loss, and shorter hospital stays with the robotic cohort. Ocuin et al[22] summarized 8 series that statistically compare robotic to laparoscopic liver resections published between 2010 and 2014.[23,25-27,33-36] Some studies such as Tsung et al[26] and Spampinato et al[33] showed longer operative times with robotic surgeries, though this seemed to improve with experience. The majority of studies did not demonstrate a difference in operative times, blood loss, complications, or length of hospital stay between the 2 cohorts. A few studies such as Troisi et al[35] had a higher conversion rate (20% vs 8%) with robotic approach than with laparoscopy, but again the majority of studies did not show a difference. A more recent review and meta-analysis by Qiu et al[38] included 9 studies and 774 patients and compared robotic to laparoscopic liver resection. They found significantly longer operative times with robotic procedures but no significant differences in blood loss, hospital stay, morbidity, mortality, or surgical margins.

Oncologic and Clinical Outcomes for Primary Liver Tumors

Hepatocellular Carcinoma

A plethora of studies have largely allayed fears that oncologic outcomes would be compromised with a laparoscopic approach to liver surgery. Both meta-analyses and case-controlled series have shown similar rates of margin positivity, recurrence, and survival when comparing laparoscopic and open liver resections for hepatocellular carcinoma (HCC), with several showing improved clinical outcomes with laparoscopic approaches. One meta-analysis examined 9 studies and 550 patients, 234 who had undergone laparoscopic liver resection and 316 who had open liver resection. No difference in tumor recurrence or margin positivity was demonstrated and patients who underwent laparoscopic surgery were found to have significantly lower blood transfusion requirements, shorter hospital stays, and lower rates of liver failure and ascites postoperatively.[39] Another large, case-matched analysis looked at 436 patients undergoing laparoscopic resection and 2969 patients undergoing open liver resection for HCC from 2000 and 2010 at 31 Japanese centers. This study also demonstrated no significant difference in survival or disease-free survival between the 2 groups but showed lower median blood loss, shorter median hospital stays, and lower complication rates in patients undergoing laparoscopic liver resection.[40]

One criticism that is often raised with such studies is that open surgery, rather than minimally invasive, is still more widely employed for larger, more difficult to access tumors, which may affect the clinical outcomes when comparing the 2 groups. A study from China specifically looked at HCC arising in the posterosuperior segments of the liver, for which open surgery is traditionally used due to difficult accessibility. When comparing 41 laparoscopic resections to 86 open resections for such tumors, they also found significantly shorter hospital stays, lower complication rates, and lower intraoperative blood loss after laparoscopic surgery, with no difference in overall or disease-specific survival at 1 and 3 years.[41] Another study more specifically addressed the issue of large tumor size by comparing 97 laparoscopic liver resections to 178 open resections, all done for HCC tumors between 5 and 10 cm. They also showed lower rates of complications and shorter hospital stays for the laparoscopic group, with similar rates of recurrence and overall and disease-free survival at 1 and 3 years.[42]

Concerns have also been raised about the safety of minimally invasive approaches in patients with cirrhosis. Port site access can be more challenging due to recanalized veins in the abdominal wall, and there are concerns that the friable liver parenchyma may be more prone to bleed during mobilization and transection. Additional studies looked exclusively at laparoscopic versus open liver resections for HCC in patients with established cirrhosis and showed similarly improved clinical outcomes following laparoscopic surgery without a negative impact on oncologic outcomes. One study from Japan compared 63 laparoscopic to 99 open HCC resections in cirrhosis and showed lower rates of morbidity and ascites and shorter hospital stays following laparoscopic compared to open resection, without a demonstrable difference in survival.[43] Another study from France compared patients with cirrhosis undergoing laparoscopic versus open HCC resection with 45 patients in each group and again showed lower rates of morbidity and ascites, shorter hospital stays, and shorter operative times after laparoscopic procedures. Survival at 1, 5, and 10 years was not significantly different, and interestingly, higher rates of R0 resections were actually observed following laparoscopic compared to open procedures (95 vs 85%; $P = .03$).[44] Another French study[45] looked specifically at peripheral HCC tumors in patients with cirrhosis and compared 36 patients undergoing laparoscopic resection to 53 who underwent open resection, with similar resection margins and survival rates at 5 years and shorter hospital stays in the laparoscopic group. A recent literature review and meta-analysis[46] summarized 4 cohort studies including 420 patients with cirrhosis undergoing HCC resection and demonstrated several improved outcomes after laparoscopic compared to open surgery including significantly less blood loss, reduced transfusions, wider resection margins, shorter hospital stays, and lower morbidity in the laparoscopic cohort.

Less data exist on the application of robotic surgery for HCC; however, a recent study[47] from Korea compared 99 minimally invasive resections to 198 open resections using a 1:2 propensity-score matched analysis, and their minimally invasive cohort included 83 laparoscopic resections and 16 robotic resections. Similar to purely laparoscopic cohorts, they found less blood loss, lower complication rates, and shorter hospital stays after minimally invasive approach, without a difference in disease-free or overall survival. In the review summarizing 14 major series of robotic liver resections by Ocuin et al,[22] the indication for surgery for 147 of the 439 cases reported was HCC. Most series reported on a mix of tumor types, but 2 studies[23,24] reported almost exclusively on HCC. One series[24] from China reported on 41 patients with consecutive HCC who underwent 42 robotic liver resections. The majority were wedge resections, segmentectomies, or left lateral sectionectomies, but 10 procedures were major hepatectomies. The R0 resection rate was 93% and the inhospital mortality and morbidity were 0% and 7%, respectively. At 2 years, the overall and disease-free survival rates were 94% and 74%, respectively. In a subgroup analysis of the minor robotic liver resections as compared to laparoscopic resections, they found similar blood loss, morbidity, mortality, and R0 resection rates between the 2 groups. Another study by Wu et al[23] compared 69 laparoscopic liver resections to 52 robotic resections at a single Taiwanese center. Forty-one (59%) of the laparoscopic cases were done for HCC as were 38 (73%) of the robotic cases. In looking specifically at the HCC subgroup, they found the conversion rate, length of hospital stay, morbidity, and mortality to be comparable between the 2 groups, though robotic cases did have significantly more blood loss and longer operative times than did laparoscopic cases, and the tumor sizes and resections performed in the robotic cohort were also significantly larger.

Cholangiocarcinoma

The overall published data for minimally invasive resections of cholangiocarcinoma is far less than what is reported for HCC. This is likely owing to both the much lower incidence of cholangiocarcinoma compared to HCC and the technical challenges associated with cholangiocarcinoma resections including the need for major liver resection and lymphadenectomy. The available studies, however, suggest that laparoscopic approaches to liver resection for intrahepatic cholangiocarcinoma have also shown comparable clinical outcomes with no difference in oncologic outcomes. One small study[48] out of Korea compared 23 open to 14 laparoscopic resections for intrahepatic cholangiocarcinomas and found comparable complication rates and length of hospital stays between the 2 groups. Oncologic outcomes were also similar with no statistical difference in the number of lymph nodes harvested, overall survival, and recurrence-free survival at 3 years. Another small Korean study[49] looked specifically at patients with T stage T2b or lower cholangiocarcinomas undergoing open resection, 26 cases, versus laparoscopic resection, 11 cases, and showed no differences in resection margins, operative times, transfusions, mortality, or length of hospital stay. Recurrence rates and 3- and 5-year overall and disease-free survival rates were similar. A case-matched analysis[50] from Italy compared 20 patients with cholangiocarcinoma undergoing laparoscopic resection to 60 patients undergoing open resections and found that less blood loss and faster functional recovery were observed in the laparoscopic group. Disease-free and overall survival rates were comparable, and number of lymph nodes harvested was not significantly different.

The technical challenges of cholangiocarcinoma resection make a robotic approach to these cases theoretically very appealing, especially when there is extrahepatic disease spread requiring dissection of the portal triad and biliary reconstruction. This approach is not yet widely employed, however. In the review by Ocuin et al,[22] intrahepatic cholangiocarcinoma was the indication for only 7 of the 439 reported robotic liver resections. One recent study[51] from China described an initial single institution series of 10 fully robotic radical resections for hilar cholangiocarcinoma and compared them to 32 contemporary patients undergoing open surgery. Robotic surgeries took longer time, were significantly more expensive, and had higher morbidity rates (90% vs 50%; $P = .031$). Additionally, 3 of 10 patients in the robotic group had serious complications (Clavien-Dindo grade III or higher), and 1 patient in that group died of liver failure in the postoperative period. Finally, recurrence-free survival for the robotic group was significantly lower than for the open group ($P = .029$) with higher rates of peritoneal and multisite metastasis in the robotic group, though these values did not reach statistical significance (60% vs 25%; $P = .059$). Hilar cholangiocarcinomas have also been approached laparoscopically, with 1 small series[52] of 5 patients from Korea showing negative margins in 4 of 5 patients and only 1 serious complication of biliary leak that resolved spontaneously. More studies are needed to determine whether minimally invasive techniques are appropriate for hilar cholangiocarcinoma resections.

Cost of Minimally Invasive Surgery

In 2009, the cost of the da Vinci robotic surgical system was reported at US$1.2 million, with an additional yearly cost of US$138 000 for maintenance.[53,54] A number of studies have compared the expense of robotic liver resection to that of open and laparoscopic approaches. One recent single institution retrospective study[55] from the University of Washington compared cost data for 71 robotic hepatectomies to 88 open procedures and found that despite higher perioperative costs for the robotic procedures, the postoperative costs and subsequent direct hospital costs were lower when compared with open procedures (US$14 754 vs US$18 998; $P = .001$), perhaps owing to a 2-day shorter hospital stay on average after robotic procedures (4.2 vs 6.5 days; $P < .001$). A Chinese series[32] published in 2011 compared the cost of 13 robotic-assisted laparoscopic hepatectomies to 20 traditional laparoscopic and 32 open resections. They found that combined cost of the robotic procedures (US$12 046) was higher than the cost of both the laparoscopic (US$7618) and open procedures (US$10 548). Hospital stays were shortest after laparoscopic procedures (5.2 days), followed by robotic procedures (6.7 days) and longest after open procedures (9.6 days). Yu et al[36] examined cost data from their Korean series comparing laparoscopic to robotic liver resections and found that when comparing 13 patients who underwent robotic liver resection with 17 patients who underwent laparoscopic liver resection, the cost of robotic procedures was significantly higher (US$11 475 vs US$6 762; $P < .001$), despite a trend toward shorter hospital stay (7.8 vs 9.5 days; $P = .053$). The increased cost of minimally invasive techniques is certainly significant, but data thus far are inconsistent and are likely to change as the market surrounding this technology evolves.

Conclusion and Future Aims

The safety and utility of laparoscopic surgery for HCC have been well established, and many studies have demonstrated improved clinical outcomes following laparoscopic surgery even when applied for tumors that are large, difficult to access, or in the setting of cirrhosis. Studies consistently show equivalent or improved perioperative parameters with laparoscopy when compared to open surgery including lower estimated blood loss, fewer transfusions requirements, fewer complications including liver failure and ascites, and shorter hospital stays. Outcomes after resection of intrahepatic cholangiocarcinoma are similar with clinical outcomes either equivalent or better when compared to open surgeries, with no compromise in oncologic results. For both pathologies, oncologic outcomes including overall and disease-free survival remain the comparable between laparoscopic and open cohorts, and quality measures such as R0 margin status and adequate staging with lymph node harvest are not compromised with laparoscopy. It may even be reasonable to consider laparoscopy the standard of care for liver resection in appropriate patients, with the overarching caveat being that both the surgeon and the operative team must have adequate training and expertise with such approaches and technology. The data on robotic surgery for resection of primary liver tumors are more limited and results are more mixed. The considerable expense incurred with this technology, which several studies show is not compensated for even with shorter hospital stays, cannot be ignored. In moving ahead, the challenge will be to continue to clarify indications for different surgical approaches based on patient and tumor characteristics and surgeon expertise, in order to optimize perioperative parameters, postoperative recovery, long-term oncologic outcomes, and health-care costs.

Authors' Note

No significant relationships exist between the authors and the companies/organizations whose products or services may be referenced in this article.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Jung YB, Kang J, Park EJ, Baik SH, Lee KY. Time to initiation of adjuvant chemotherapy in colon cancer: comparison of open, laparoscopic, and robotic surgery. *J Laparoendosc Adv Surg Tech A*. 2016;26(10):799-805.
2. Moghadamyeghaneh Z, Hanna MH, Carmichael JC, Pigazzi A, Stamos MJ, Mills S. Comparison of open, laparoscopic, and robotic approaches for total abdominal colectomy. *Surg Endosc*. 2016;30(7):2792-2798.
3. Midura EF, Hanseman DJ, Hoehn RS, et al. The effect of surgical approach on short-term oncologic outcomes in rectal cancer surgery. *Surgery*. 2015;158(2):453-459.
4. Trastulli S, Cirocchi R, Listorti C, et al. Laparoscopic vs open resection for rectal cancer: a meta-analysis of randomized clinical trials. *Colorectal Dis*. 2012;14(6):e277-e296.
5. Speicher PJ, Englum BR, Ganapathi AM, Nussbaum DP, Mantyh CR, Migaly J. Robotic low anterior resection for rectal cancer: a national perspective on short-term oncologic outcomes. *Ann Surg*. 2015;262(6):1040-1045.
6. Trastulli S, Farinella E, Cirocchi R, et al. Robotic resection compared with laparoscopic rectal resection for cancer: systematic review and meta-analysis of short-term outcome. *Colorectal Dis*. 2012;14(4):e134-e156.
7. Hanly EJ, Talamini MA. Robotic abdominal surgery. *Am J Surg*. 2004;188(4A suppl):19S-26S.
8. Tomulescu V, Stanciulea O, Balescu I, et al. First year experience of robotic-assisted laparoscopic surgery with 153 cases in a general surgery department: indications, technique and results. *Chirurgia (Bucur)*. 2009;104(2):141-150.
9. Giulianotti PC, Coratti A, Angelini M, et al. Robotics in general surgery: personal experience in a large community hospital. *Arch Surg*. 2003;138(7):777-784.
10. Jung M, Morel P, Buehler L, Buchs NC, Hagen ME. Robotic general surgery: current practice, evidence, and perspective. *Langenbecks Arch Surg*. 2015;400(3):283-292.
11. Ballantyne GH. Telerobotic gastrointestinal surgery: phase 2—safety and efficacy. *Surg Endosc*. 2007;21(7):1054-1062.
12. Bagante F, Spolverato G, Strasberg SM, et al. Minimally invasive vs open hepatectomy: a comparative analysis of the National Surgical Quality Improvement Program database. *J Gastrointest Surg*. 2016;20(9):1608-1617.
13. Nguyen KT, Gamblin TC, Geller DA. World review of laparoscopic liver resection: 2,804 patients. *Ann Surg*. 2009;250(5):831-841.
14. Nguyen KT, Laurent A, Dagher I, et al. Minimally invasive liver resection for metastatic colorectal cancer: a multi-institutional, international report of safety, feasibility, and early outcomes. *Ann Surg*. 2009;250(5):842-848.
15. Dagher I, O'Rourke N, Geller DA, et al. Laparoscopic major hepatectomy: an evolution in standard of care. *Ann Surg*. 2009; 250(5):856-860.
16. Buell JF, Cherqui D, Geller DA, et al. The international position on laparoscopic liver surgery: the Louisville Statement, 2008. *Ann Surg*. 2009;250(5):825-830.
17. Lin CW, Tsai TJ, Cheng TY, et al. The learning curve of laparoscopic liver resection after the Louisville statement 2008: will it be more effective and smooth? *Surg Endosc*. 2016;30(7):2895-2903.
18. Kluger MD, Vigano L, Barroso R, Cherqui D. The learning curve in laparoscopic major liver resection. *J Hepatobiliary Pancreat Sci*. 2013;20(2):131-136.
19. Brown KM, Geller DA. What is the learning curve for laparoscopic major hepatectomy? *J Gastrointest Surg*. 2016;20(5):1065-1071.
20. Vigano L, Laurent A, Tayar C, Tomatis M, Ponti A, Cherqui D. The learning curve in laparoscopic liver resection: improved feasibility and reproducibility. *Ann Surg*. 2009;250(5):772-782.
21. Nomi T, Fuks D, Kawaguchi Y, Mal F, Nakajima Y, Gayet B. Learning curve for laparoscopic major hepatectomy. *Br J Surg*. 2015;102(7):796-804.
22. Ocuin LM, Tsung A. Robotic liver resection for malignancy: current status, oncologic outcomes, comparison to laparoscopy, and future applications. *J Surg Oncol*. 2015;112(3):295-301.
23. Wu YM, Hu RH, Lai HS, Lee PH. Robotic-assisted minimally invasive liver resection. *Asian J Surg*. 2014;37(2):53-57.
24. Lai EC, Yang GP, Tang CN. Robot-assisted laparoscopic liver resection for hepatocellular carcinoma: short-term outcome. *Am J Surg*. 2013;205(6):697-702.

25. Packiam V, Bartlett DL, Tohme S, et al. Minimally invasive liver resection: robotic versus laparoscopic left lateral sectionectomy. *J Gastrointest Surg*. 2012;16(12):2233-2238.
26. Tsung A, Geller DA, Sukato DC, et al. Robotic versus laparoscopic hepatectomy: a matched comparison. *Ann Surg*. 2014; 259(3):549-555.
27. Berber E, Akyildiz HY, Aucejo F, Gunasekaran G, Chalikonda S, Fung J. Robotic versus laparoscopic resection of liver tumours. *HPB (Oxford)*. 2010;12(8):583-586.
28. Casciola L, Patriti A, Ceccarelli G, Bartoli A, Ceribelli C, Spaziani A. Robot-assisted parenchymal-sparing liver surgery including lesions located in the posterosuperior segments. *Surg Endosc*. 2011;25(12):3815-3824.
29. Chan OC, Tang CN, Lai EC, Yang GP, Li MK. Robotic hepatobiliary and pancreatic surgery: a cohort study. *J Hepatobiliary Pancreat Sci*. 2011;18(4):471-480.
30. Choi GH, Choi SH, Kim SH, et al. Robotic liver resection: technique and results of 30 consecutive procedures. *Surg Endosc*. 2012;26(8):2247-2258.
31. Giulianotti PC, Coratti A, Sbrana F, et al. Robotic liver surgery: results for 70 resections. *Surgery*. 2011;149(1):29-39.
32. Ji WB, Wang HG, Zhao ZM, Duan WD, Lu F, Dong JH. Robotic-assisted laparoscopic anatomic hepatectomy in China: initial experience. *Ann Surg*. 2011;253(2):342-348.
33. Spampinato MG, Coratti A, Bianco L, et al. Perioperative outcomes of laparoscopic and robot-assisted major hepatectomies: an Italian multi-institutional comparative study. *Surg Endosc*. 2014; 28(10):2973-2979.
34. Tranchart H, Ceribelli C, Ferretti S, Dagher I, Patriti A. Traditional versus robot-assisted full laparoscopic liver resection: a matched-pair comparative study. *World J Surg*. 2014;38(11): 2904-2909.
35. Troisi RI, Patriti A, Montalti R, Casciola L. Robot assistance in liver surgery: a real advantage over a fully laparoscopic approach? Results of a comparative bi-institutional analysis. *Int J Med Robot*. 2013;9(2):160-166.
36. Yu YD, Kim KH, Jung DH, et al. Robotic versus laparoscopic liver resection: a comparative study from a single center. *Langenbecks Arch Surg*. 2014;399(8):1039-1045.
37. Kingham TP, Leung U, Kuk D, et al. Robotic liver resection: a case-matched comparison. *World J Surg*. 2016;40(6):1422-1428.
38. Qiu J, Chen S, Chengyou D. A systematic review of robotic-assisted liver resection and meta-analysis of robotic versus laparoscopic hepatectomy for hepatic neoplasms. *Surg Endosc*. 2016; 30(3):862-875.
39. Xiong JJ, Altaf K, Javed MA, et al. Meta-analysis of laparoscopic vs open liver resection for hepatocellular carcinoma. *World J Gastroenterol*. 2012;18(45):6657-6668.
40. Takahara T, Wakabayashi G, Beppu T, et al. Long-term and perioperative outcomes of laparoscopic versus open liver resection for hepatocellular carcinoma with propensity score matching: a multi-institutional Japanese study. *J Hepatobiliary Pancreat Sci*. 2015;22(10):721-727.
41. Xiao L, Xiang LJ, Li JW, Chen J, Fan YD, Zheng SG. Laparoscopic versus open liver resection for hepatocellular carcinoma in posterosuperior segments. *Surg Endosc*. 2015;29(10):2994-3001.
42. Ai JH, Li JW, Chen J, Bie P, Wang SG, Zheng SG. Feasibility and safety of laparoscopic liver resection for hepatocellular carcinoma with a tumor size of 5-10 cm. *PloS One*. 2013;8(8):e72328.
43. Yamashita Y, Ikeda T, Kurihara T, et al. Long-term favorable surgical results of laparoscopic hepatic resection for hepatocellular carcinoma in patients with cirrhosis: a single-center experience over a 10-year period. *J Am Coll Surg*. 2014;219(6):1117-1123.
44. Memeo R, de'Angelis N, Compagnon P, et al. Laparoscopic vs. open liver resection for hepatocellular carcinoma of cirrhotic liver: a case-control study. *World J Surg*. 2014;38(11):2919-2926.
45. Truant S, Bouras AF, Hebbar M, et al. Laparoscopic resection vs. open liver resection for peripheral hepatocellular carcinoma in patients with chronic liver disease: a case-matched study. *Surg Endosc*. 2011;25(11):3668-3677.
46. Twaij A, Pucher PH, Sodergren MH, Gall T, Darzi A, Jiao LR. Laparoscopic vs open approach to resection of hepatocellular carcinoma in patients with known cirrhosis: systematic review and meta-analysis. *World J Gastroenterol*. 2014;20(25): 8274-8281.
47. Han DH, Choi SH, Park EJ, Kang DR, Choi GH, Choi JS. Surgical outcomes after laparoscopic or robotic liver resection in hepatocellular carcinoma: a propensity-score matched analysis with conventional open liver resection. *Int J Med Robot*. 2016;12(4): 735-742.
48. Lee W, Park JH, Kim JY, et al. Comparison of perioperative and oncologic outcomes between open and laparoscopic liver resection for intrahepatic cholangiocarcinoma. *Surg Endosc*. 2016; 30(11):4835-4840.
49. Uy BJ, Han HS, Yoon YS, Cho JY. Laparoscopic liver resection for intrahepatic cholangiocarcinoma. *J Laparoendosc Adv Surg Tech A*. 2015;25(4):272-277.
50. Ratti F, Cipriani F, Ariotti R, et al. Safety and feasibility of laparoscopic liver resection with associated lymphadenectomy for intrahepatic cholangiocarcinoma: a propensity score-based case-matched analysis from a single institution. *Surg Endosc*. 2016;30(5):1999-2010.
51. Xu Y, Wang H, Ji W, et al. Robotic radical resection for hilar cholangiocarcinoma: perioperative and long-term outcomes of an initial series. *Surg Endosc*. 2016;30(7):3060-3070.
52. Lee W, Han HS, Yoon YS, et al. Laparoscopic resection of hilar cholangiocarcinoma. *Ann Surg Treat Res*. 2015;89(4): 228-232.
53. Amodeo A, Linares Quevedo A, Joseph JV, Belgrano E, Patel HR. Robotic laparoscopic surgery: cost and training. *Minerva Urol Nefrol*. 2009;61(2):121-128.
54. Patel HR, Linares A, Joseph JV. Robotic and laparoscopic surgery: cost and training. *Surg Oncol*. 2009;18(3):242-246.
55. Sham JG, Richards MK, Seo YD, Pillarisetty VG, Yeung RS, Park JO. Efficacy and cost of robotic hepatectomy: is the robot cost-prohibitive? *J Robot Surg*. 2016;10(4):307-313.