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REVIEW ARTICLE

# Robotic hepatic surgery in malignancy: review of the current literature

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**Abstract**

The use of minimally invasive liver surgery, such as laparoscopic and robotic surgery, is increasing worldwide. Robot-assisted laparoscopy is a new surgical technique that improves surgical handling. The advantage of this technique is improved dexterity, which leads to increased surgical precision and no tremor or fatigue. Comparable oncological results were documented for laparoscopic and open surgery. Currently, "conventional" laparoscopic liver surgery has limitations with respect to the treatment of lesions in the posterior-superior segments, and there are limited technical features for the reconstruction steps. These limitations might be overcome with the use of robotic surgery. The use of robotic surgery for hepatic procedures originated because of the technical potential to overcome several of the major technical limitations known from conventional laparoscopy and the possibility of performing more extended liver resections. Additionally, there is increasing evidence indicating that robotic hepatic surgery is feasible and safe in resections of the posterior segments. Studies showed that using the robotic technique is associated with a decreased or at least equal amount of intraoperative blood loss compared to that of the conventional laparoscopic or open technique. There is increasing evidence that robotic liver surgery might be as safe as conventional laparoscopic procedures in cancer cases in terms of resection margins, disease-free and overall survival. Furthermore, robotic surgery might be more favorable with respect to postoperative patient recovery. Despite promising results, still large, multicenter, randomized and prospective studies are needed to analyze the exact value of robotic liver surgery in patients with malignant liver tumors.

**Keywords** Robotic surgery · Liver surgery · Malignancy · Learning curve · Surgical technique

## Background

The use of minimally invasive liver surgery including laparoscopic and robotic hepatic surgery is increasing worldwide. The initial reports of laparoscopic hepatic procedures were published in the 1990s [1–3]. Robot-assisted laparoscopy was a new minimally invasive surgical technique that improved surgical handling [4]. Although the procedure was first developed during the 1980s for military purposes, the robotic technique has considerable civil utility and is valuable in clinical research and in many routine surgical procedures. The major expected advantage of this surgical technique is improved dexterity and increased degrees of freedom in surgical manipulation, which leads to increased surgical precision and reduced tremors and fatigue [5–8]. Furthermore, using 3D visualization to navigate the surgical instruments improves the visual depth perception [5, 6]. Despite the first report of robotic hepatic surgery in 2003 [9], this minimally invasive technique is still not used extensively for liver resections [10]. In the current literature, the indications for robotic hepatic surgery include both malignant and benign diseases. A review of 12 major series indicated that 70% of all patients suffered from malignant disease and that hepatocellular carcinoma (HCC) was the leading cause, which was followed by colorectal metastases [11]. The presence of tumor invasion of the major hepatic vessels, tumor infiltration of the diaphragm or extensive tumor size are all considered as relative or absolute contraindications for the robotic approach [11].

Robotic surgery still has several limitations including missing haptic feedback, prolonged surgical duration, and higher costs [12]. Therefore, the value in clinical routine use is still under discussion. However, there are several promising reports showing that robotic hepatic surgery can be

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performed safely [12–15], even in cases of living liver donation procedures [16, 17].

The reduced trauma to the abdominal wall improves the postoperative diaphragmatic function and respiratory complications and reduces postoperative pain and ascites in patients with cirrhotic livers due to improved venous drainage in minimally invasive liver surgery [11]. The disadvantages of laparoscopic liver surgery are restricted degrees of motion of the surgical instruments, moving camera, two-dimensional vision, and missing haptic information [11, 18]. These shortcomings should be improved with the use of robot-assisted laparoscopy [10].

This review summarizes the current literature on robotic liver surgery in malignant disease and focuses on the technical, surgical and oncological aspects.

## Technical aspects

The majority of robotic programs currently use the da Vinci Si Surgical System. During the operation, the patient is positioned in a 20° supine anti-Trendelenburg. After induction of a pneumoperitoneum, the first trocar is placed, and the diagnostic laparoscopy is performed. The patient is then docked with the chart of the robot. There are three robotic instrument arms and one camera arm available. The trocars for the robotic arms are inserted depending on the planned resection, localization of the hepatic lesion and the patient's constitution (see Fig. 1). Then, the two trocars for the surgical assistant and one camera trocar are placed. There are different instruments available for tissue and vessel transection (see Table 1). In addition, it is possible to perform intraoperative ultrasound to detect lesions and define the transection plane [19].

The use of indocyanine green (ICG) fluorescence imaging improves the identification of biliary and vascular structures and facilitates the identification of the resection line and helps the surgeon maintain the exact resection plane during parenchymal transection [24, 25]. In addition, ICG fluorescence imaging is used for evaluation of tissue perfusion and identification of lymphatic structures and can distinguish between healthy liver and tumor tissue [20, 25].

## Surgical aspects

The expansion of laparoscopic liver surgery has been limited in contrast to other surgical procedures such as in urology, gynecology or colorectal surgery [5]. The limitation

**Table 1** Overview of available instruments for tissue and vessel transection during robotic hepatic surgery [22, 23]

| Transection instrument | Technical aspects |
|---|---|
| Maryland bipolar forceps | Dissection, grasping and coagulation |
| Dissecting forceps | Parenchymal dissection |
| Vessel sealer | Vessel and parenchymal transection |
| Clips (e.g., titanium clips, Hem-o-Lok clips) | Closure of vessels |
| Ultracision Harmonic Scalpel | Parenchymal dissection |
| Stapler devices | Parenchymal or vessel dissection |

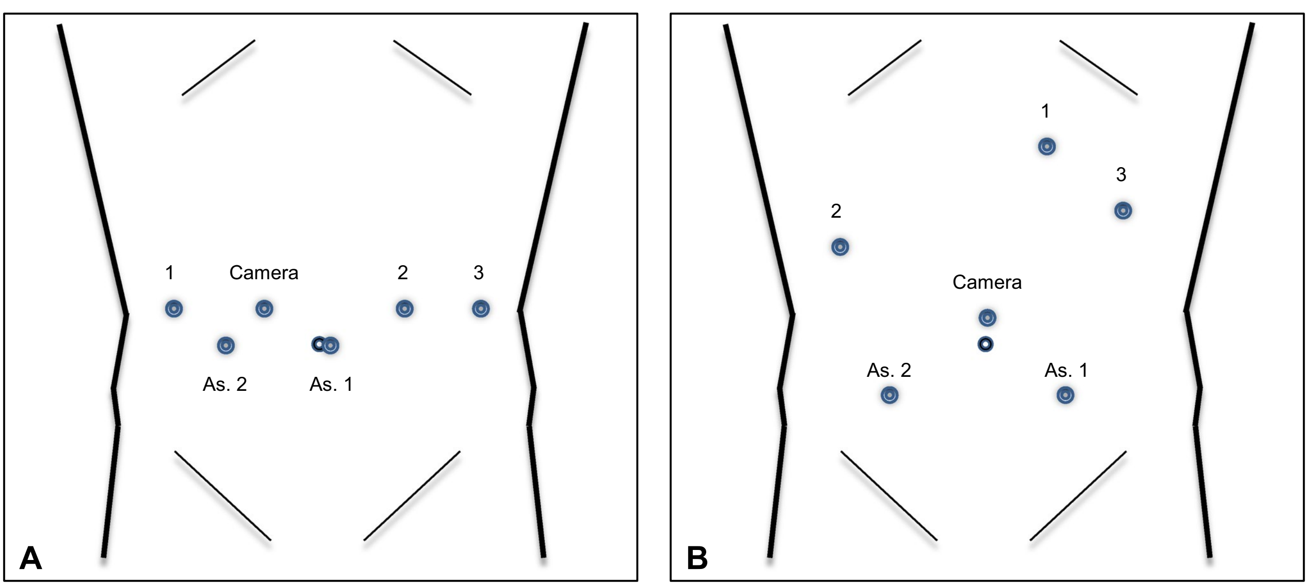


**Fig. 1** Schematic trocar placement in robotic right hepatectomy (modified [20] (**a**), and in robotic left hepatectomy (modified [21] (**b**). Numbers indicate robotic arms, *As* assistant port

of laparoscopic liver surgery is mainly due to the technical complexity associated with a limited approach to all liver segments (e.g., postero-superior segments) and the fear of uncontrollable bleeding [5, 26, 27]. The use of robotic surgery for hepatic procedures originated because of the technical potential to overcome several of the major technical limitations known from conventional laparoscopy and the possibility of performing more extended liver resections (see Table 2) [5]. Additionally, there is increasing evidence indicating that robotic hepatic surgery is feasible and safe in resections of the posterior segments [5, 10, 22, 23, 28].

Previous studies show that using the robotic technique is associated with a decreased or at least equal amount of intraoperative blood loss compared to that of the conventional laparoscopic or open technique [5, 12, 14, 23]. This result is probably due to the larger degrees of freedom, three movable arms and the 3D optics used to obtain excellent visualization; these advantages enable a safer dissection of the liver tissue and hepatic vessels and lead to improved extrahepatic vessel control in case of acute intraoperative bleeding [5, 12, 23].

Interestingly, a matched pair comparison of robotic and conventional laparoscopic liver surgery showed using the conventional laparoscopic technique was associated with a higher rate of hand-assisted or hybrid techniques than that of the robotic technique [5]. In this study, only the length of operation room time and duration of surgery favored the conventional laparoscopic technique. However, the complication rate, length of hospital stay, mortality rate or oncological aspects such as the negative resection margins were not different between the two groups in minor and major liver resections compared to those of another meta-analysis evaluating laparoscopic and robotic hepatic surgery [5, 37].

**Table 2** Overview of published series of major robotic hepatectomy in cancer patients with at least ten patients treated

| Author | Year | Cases (*n*) | Malignancy (%) |
|---|---|---|---|
| Giulianotti et al. [29] | 2011 | 27 | 60 |
| Choi et al. [30] | 2012 | 20 | 70 |
| Spampinato et al. [31] | 2014 | 25 | 68 |
| Tsung et al. [5] | 2014 | 21 | 71 |
| Wu et al. [32] | 2014 | 20 | 100 |
| Han et al. [33] | 2016 | 16 | 100 |
| Lee et al. [34] | 2016 | 10 | 100 |
| Lai et al. [35] | 2016 | 100 | 100 |
| Croner et al. [36] | 2016 | 10 | 100 |
| Magistri et al. [23] | 2017 | 22 | 100 |

## Learning curve

Several studies have investigated the effect of the learning curve on parameters such as blood loss, duration of operation and length of hospital stay [5]. In a series of 183 robotic procedures including minor and major hepatectomies, Chen et al. evaluated in their retrospective study the learning curve for operation time and blood loss [38]. The authors found that the learning curve had three phases. In the first phase, the duration of the operation time was improved, and then during phase two, the amount of blood loss was reduced. In the last phase, both parameters were improved [38]. Importantly, the surgical team already had 4 years of experience with laparoscopic hepatectomies before starting with robotic liver surgery; therefore, the learning curve of an initial phase of 15 procedures and an intermediate phase of 25 procedures in their study might be accelerated [38]. In comparison to these results, the learning curve for laparoscopic liver surgery is reported to be long and may require up to 75 major hepatectomies [39–41]. In other studies, investigating the learning curve of robotic liver surgery, the improvements of blood loss, duration of operation, overall operation room time and length of hospital stay were noted after seven to 25 cases [5, 30, 42]. There is evidence that experiences in conventional laparoscopic liver surgery are helpful and necessary before starting a robotic hepatic surgery program [43]. Understanding the liver anatomy and developing practical skills of open liver surgery require adequate training in laparoscopic surgery, and further training in robotic surgery is mandatory to establish a successful robotic program [44]. Whether specialized training with virtual-reality training consoles or the robotic dual console will overcome this problem might be analyzed in further studies [45].

### Oncological results of minimally invasive surgery

Achieving complete resection margins is critical for disease- and recurrence-free survival. It is currently still under investigation if minimal invasive techniques with reduced haptic feedback and technical difficulties performing intraoperative ultrasonography result in the same oncological results as open surgery. In a case-matched study of laparoscopic versus open liver resection in HCC patients, the incomplete tumor resections and positive resection margins were worse in the laparoscopic surgery cases [46]. However, a subsequent meta-analysis comparing laparoscopic and open liver surgery showed that there was no difference in tumor recurrence rate between the two groups [47].

Recent studies have shown laparoscopic liver surgery is both feasible and safe, and the oncological outcomes are comparable to open surgery after an implementation process [26]. In a multicenter study of 2,238 patients, there were tumor-free resection margins obtained in 91% of all patients, and the median resection margin width was 5 mm [26]. There was tumor recurrence in 39.5% of HCC patients and 56.9% of patients with colorectal liver metastasis. The 1-, 3-, 5-year recurrence-free survival rates were 79%, 55% and 50% for HCC and 66%, 46% and 37% for colorectal liver metastasis patients, respectively [26]. These results are comparable to those for open surgery. Thus, the oncological safety of laparoscopic liver surgery seems to be acceptable in terms of tumor recurrence [26, 48, 49].

In robot-assisted liver resections, there are tumor-free resection margins obtained in 89.5–100% patients [5, 23, 29, 30, 36, 50–52]. One study demonstrated that using a laparoscopic approach significantly reduced the time between surgery and adjuvant chemotherapy without affecting oncological radicalness compared to that of open surgery [53].

Only few reports are available regarding disease-free and overall survival of robotic-assisted liver surgery in oncologic diseases. But these studies showed similar results compared to open surgery in disease-free and overall survival with 91.5% (79.2% open surgery) and 100% (98.4% open surgery) respectively [54]. Berber et al. and Lai et al. compared robotic-assisted and laparoscopic procedures and showed similar results regarding disease-free and overall survival during their follow-up of HCC patients [35, 55]. In the case of colorectal liver metastasis, one study showed that there was no difference in disease-free survival between robotic-assisted and laparoscopic surgery [50].

One disadvantage of the minimal invasive techniques is port-site metastases, and previous studies have encountered this oncological problem [56–58]. In the current literature, there are only a few reported cases with port-site metastasis after laparoscopic liver surgery [59]. There are currently no reported cases of tumor seeding at the port site after robotic hepatic surgery; however, this might be possible, so meticulous surgical techniques should be used to prevent tumor cell dissemination to the abdominal wall. All cases showing new nodules in clinical or radiological examinations require surgical removal to obtain a histological confirmation of the entity [59].

## Costs

Intuitive Surgical Inc. (ISI) was founded in 2003 and had an estimated 80% market share in 2016 [60]. Furthermore, ISI is the only supplier of instruments used in robotic liver surgery [60]. It is predicted that during the next few years, the sales of robotic instruments will increase to 18 billion dollars per year [60]. Thus, new companies will enter the market and introduce new technical innovations and further expand robotic approaches that should lower the costs [60]. Although there are not many systematic analyses of costs for robotic liver surgery compared to those of laparoscopic or conventional open liver surgery, the direct and indirect costs of robotic liver surgery are higher than those of laparoscopic or open liver surgery [14, 18, 55, 61, 62]. For example, Ji et al. reported $ 5000 higher general hospital costs after robotic surgery compared to those of laparoscopic interventions [14]. In another study, the costs of operating room supplies were compared between laparoscopic and robotic liver surgery; the result also showed that there were higher costs in patients treated with robotic surgery [18]. Croner et al. showed there was a higher proportion of surgical costs relative to the overall costs after robotic surgery than that in open or laparoscopic surgery [12]. However, in most of these studies, the acquisition costs and amortization were not included in the calculation. It is currently unclear how the costs will be affected in the future after the introduction of new robotic systems and competition in the marketplace, but it is expected that the costs will decrease [20].

## Future technical innovations

A survey in Germany showed that a limited number of centers are already performing robotic liver surgery and that most are minor resections. The survey results also indicated many centers have planned to establish robotic liver surgery in the future, and this will lead to further substantial developments [63]. There will be several surgical innovations available in the near future that will change surgery in general and specifically robotic liver surgery. Beyond the technical improvements of surgical instruments, imaging and intraoperative cancer detection, new technological developments in data processing, including new computer interfaces, will affect the operating room of the future [20, 64]. Furthermore, the process of freeing the marketplace will lead to new robotic systems from several companies, and we expect further technical innovations and changes in costs [60].

## Conclusion

The role of minimally invasive liver surgery has increased in recent years. Since the introduction of robotic surgery, both minor and major hepatectomies and robotic-assisted hepatic interventions or living liver donation for liver transplantation have been performed. In contrast to other surgical procedures, the expansion of robotic liver surgery has been slower. First, only minor hepatectomies or left-sided lobectomies have been performed. Today, more complex liver resections (e.g., posterior-superior segments) and right-sided lobectomy are safely performed in experienced hands. There is increasing evidence that robotic liver surgery might be as safe as conventional laparoscopic procedures in cancer cases in terms of resection margins, disease-free and overall survival. Furthermore, robotic surgery might be more favorable with respect to postoperative patient recovery. But still large, multicenter, randomized and prospective studies are needed to analyze the exact value of robotic liver surgery in patients with malignant liver tumors. Increased competition in the marketplace will lead to further improvements of the surgical equipment and probably will decrease costs. These innovations in robotic liver surgery will make the field more interesting and will further expand the use of robotic surgery.

## Compliance with ethical standards

**Conflict of interest** R. Fahrner received travel support of Biotest, F. Rauchfuss received lecture fees and travel support of Astellas, Novartis, Roche and Biotest, A. Bauschke, H. Kissler, U. Settmacher and J. Zanow have no conflict of interests.

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