Robotic Approach in Liver Surgery

Subjects: Surgery

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In parallel with the historical development of minimally invasive surgery, the laparoscopic and robotic approaches are now frequently utilized to perform major abdominal surgical procedures. Nevertheless, the role of the robotic approach in liver surgery is still controversial, and a standardized, safe technique has not been defined yet. Minimally invasive liver surgery has been extensively associated with benefits, in terms of less blood loss, and lower complication rates, including liver-specific complications such as clinically relevant bile leakage and post hepatectomy liver failure, when compared to open liver surgery. Furthermore, comparable R0 resection rates to open liver surgery have been reported, thus, demonstrating the safety and oncological efficiency of the minimally invasive approach.

Keywords: liver ; surgery ; robotic surgery

1. Introduction

Minimally invasive surgical systems have been continuously evolving due to technological developments, the need to eliminate human error, to facilitate the surgeon in performing procedures that are challenging both by the open and minimally invasive approach, and the continuous need to improve clinical outcomes. The increasing and widening use of the minimally invasive approach has also led to the swift adoption of the robotic approach in major abdominal surgical procedures. The robotic approach has also been adopted in many other fields, for example, breast cancer and reconstruction surgery [1]. Although the effectiveness of robotic surgery has been proven for several indications, its use is still limited due to relatively high costs, technical difficulties, and insufficient strong evidence of its usefulness in challenging procedures such as liver resections [2][3].

Nevertheless, experienced centers have reported several benefits of minimally invasive liver surgery (MILS) in selected patients. In this context, less postoperative pain, less bleeding, a lower surgical site infection rate and a shorter hospital stay are commonly mentioned advantages. However, whether robotic liver surgery has merits over laparoscopic liver surgery is still very much a matter of debate [4][5][6].

2. Intraoperative Outcomes

2.1. Operative Time

Operation time is the time from the induction of anesthesia to wound closure. A longer operation time has frequently been associated with early postoperative complications in the literature, and it has been reported that the duration of surgery may be a modifiable risk factor in the prevention of these complications [7][8][9]. For open liver surgery, a study has found that the rate of pulmonary complications increases as the operation time increases, and a shorter operation time after completion of the learning curve has been associated with better postoperative outcomes in this regard [9]. For laparoscopic liver surgery, Dagher et al., in their study conducted to determine risk factors causing postoperative complications, correlated each one-hour increase in operation time with a 60% increased risk of complications, and they emphasized the importance of a shorter operative time for good outcomes in minimally invasive liver surgery [8].

The reported data on the operative time for robotic liver resections are heterogeneous, mainly because many studies have not made the distinction between minor and major liver resections. The reported mean operative times for robotic major liver resections range from 229.4 to 621 min, and for minor liver resections from 175 to 403 min [10][11][12][13][14][15][16][17][18]. In a comparative study conducted by Yu et al., the operative time for laparoscopic and robotic liver surgery was not significantly different (240.9 ± 68.6 and 291.5 ± 85.1 min, respectively) [19]. In a recently published meta-analysis by Kamarajah et al., robotic liver resections were associated with a significantly longer operative time when compared to laparoscopic liver resections [20]. The major factor that might prolong the operative time of robotic liver resections is the unavailability of the Cavitron Ultrasonic Surgical Aspirator (CUSA). When the CUSA or an equivalent transection technique can be used in robotic liver surgery, the operative time will likely shorten.

2.2. Blood Loss

Intraoperative blood loss is one of the commonly used outcome measures to evaluate the intraoperative course, although its measurement methods are controversial. Extensive intraoperative blood loss and a need for the perioperative transfusion of blood products is associated with higher postoperative complication rates and shorter long-term survival [21]. Moreover, the adoption of surgical techniques that reduce the amount of intraoperative bleeding, and advances in surgical technology—especially in minimally invasive surgery, help to limit the amount of blood loss during surgery [22].

In the literature, it is commonly stated that robotic liver surgery is associated with less blood loss when compared to open liver surgery [4][5][23]. Proponents of the robot have suggested that the improved dexterity of the robotic approach would also make it superior, in terms of blood loss, when compared to the laparoscopic approach. There is some evidence that supports this theory, reporting a blood loss of 20 to 100 mL during robotic liver surgery versus 50 to 250 mL in laparoscopic liver surgery [24][25]. Additionally, less intraoperative blood loss was reported in subgroup analyses of complex resections performed with a robotic approach [26].

2.3. Conversion

Disease extent, anatomical variations, previous abdominal surgery, technical difficulties, and life-threatening intraoperative incidents are the main reasons for conversion during minimally invasive liver surgery. During minimally invasive surgery, an ‘elective’ (proactive) conversion can be performed as a precautionary measure before any complication develops, or it can be ‘emergent’ (reactive), as a result of an intraoperative unfavorable incident [27]. Elective conversions have been associated with better postoperative outcomes than emergency conversions [28][29]. In a study including the data from liver centers across Europe, in which the relationship between conversions and postoperative outcomes was investigated, emergent conversions were associated with five times higher complication and 90-day mortality rates [30]. In a study comparing conversions in robotic and laparoscopic rectal surgery, Crippa et al. reported that the emergent conversion rate was comparable for robotic and laparoscopic procedures, while the elective conversion rate was lower in the robotic surgery group [31]. This result suggests that a stricter patient selection process is applied for robotic surgery, thereby creating a bias possibly influencing the conversion rates and other perioperative outcomes in studies comparing the laparoscopic and robotic approach.

Nevertheless, robotic surgery has generally been associated with a lower conversion rate, compared to the laparoscopic approach, for various surgical procedures [32][33]. This difference becomes more evident when the volume-weighted conversion rate is calculated [34]. In the development phase of robotic liver surgery, conversion rates as high as 10% were reported. In the recent literature, conversion rates of 5% after completion of the learning curve are reported, which is lower than the conversion rates reported for laparoscopic liver surgery [35][36]. Robotic surgical platforms especially seem to offer a benefit for the resection of lesions in the posterosuperior segments, which are relatively difficult to reach, and major liver resections [11][17]. Aside from this, the fact that major intraoperative complications can be managed more easily with robotic surgery, compared to laparoscopic surgery, supports lower conversion rates [36].

3. Postoperative Outcomes

3.1. Bile Leak

Bile leakage is one of the most commonly occurring postoperative complications after liver surgery with reported rates up to 8.7%, despite technological developments and current mitigation strategies, and it adversely affects the postoperative course by increasing the rate of intraabdominal infections, liver failure, and increasing the length of stay [37][38]. The type of surgery, parenchymal transection technique, resection type, vessel sealing strategy, intraoperative air leak test, cholangiography, fibrin glue usage and drain usage are the main modifiable factors and techniques that are used for both the diagnosis and prevention of postoperative bile leakage [39][40][41][42].

In a study assessing the occurrence of bile leakage after minimally invasive and open liver surgery, minimally invasive surgery was associated with significantly lower bile leak rates in the overall cohort that included both major and minor resections. However, no statistically significant difference between the two groups was found in the major liver resection subgroup [43]. Patient selection criteria for minimally invasive surgery are thought to be responsible for these results. In a study conducted by Abu Hilal et al. in which 13,379 patients from 15 centers were included, significantly less clinically relevant postoperative bile leakage was detected in the laparoscopic liver resection group compared to open surgery (2.6% vs. 6%) [44].

3.2. Post Hepatectomy Liver Failure

Post hepatectomy liver failure is a serious complication and is defined by the International Study Group of Liver Surgery as a worsening of the liver's synthetic, excretory and detoxifying functions, which is supported by an elevated INR and bilirubin level after postoperative day five [45]. Its incidence varies according to liver pathology, and it is seen more frequently in primary liver malignancies such as hepatocellular carcinoma and cholangiocarcinoma than in secondary liver malignancies such as colorectal liver metastasis. In addition to the pathology treated, the type of surgery is one of the main factors affecting post hepatectomy liver failure.

Post hepatectomy liver failure rates as high as 13% have been reported, and it is one of the most important causes of mortality after liver resections [46]. Fortunately, the rate of post hepatectomy liver failure has decreased in the current era, especially following the introduction of minimally invasive approaches [47][48]. Zhang et al. even reported zero liver failure following robotic liver resections, versus 0.6% liver failure in the open liver resection group, in their propensity score matched study [4]. In a study by Tee et al. including only elderly patients, the grade B/C liver failure rates were significantly different following open and minimally invasive resections (4.84% versus 0.41%, respectively) [49]. In a nationwide study comparing open, laparoscopic, and robotic liver resections, the robotic group had the lowest liver failure rate (1.1%, 1.1%, and 0.7%, respectively) [50].

3.3. Length of Hospital Stay

The length of hospital stay is an outcome that has a direct impact on patients, in terms of physical and social healing, and society, in terms of overall costs. It is now clearly known that one of the most important advantages of minimally invasive surgery is a faster functional recovery, which leads to a shorter length of hospital stay [51][52]. A significantly shorter length of hospital stay was also reported for robotic surgery, compared to open surgery, for minor liver resections in the posterosuperior liver segments by Nota et al. (4 versus 8 days, respectively) [53]. Steward et al. also reported that robotic liver surgery had a shorter hospital stay with 2.2 days versus 6.2 days in their study that compared robotic and open minor liver resections [54]. In a meta-analysis conducted by Qui et al. comparing robotic and laparoscopic liver resections, no statistically significant difference in the length of hospital stay of the two groups could be found [55]. A meta-analysis conducted by Hu et al. confirmed this finding [56].

3.4. Cost-Effectiveness

The most important factor limiting the spread of robotic surgery is thought to be cost. Further widespread use of robotic surgery mainly requires a lower cost of robotic systems. Therefore, cost-reducing methods in minimally invasive surgery have always attracted the attention of surgeons and medical device manufacturers.

The clinical advantages provided by minimally invasive surgery, such as lower complication rates, readmission rates, less pain, and a shorter length of hospital stay offer a cost advantage by reducing the costs associated with postoperative patient care by allowing a faster recovery process. Functional recovery and the length of hospital stay are directly related to direct and indirect healthcare costs. Although it is a well-known fact that minimally invasive surgery is associated with higher surgical costs, the total hospital costs are generally lower for patients treated with a minimally invasive approach due to the improved postoperative outcomes [57][58][59]. Specifically for robotic surgery, Wu et al. reported higher perioperative costs with low inpatient care costs [60].

An up-to-4-days shorter length of hospital stay (2.2 vs. 6.2 days) and decreased complication rates after robotic surgery have also been reported in the literature as the main factors decreasing the overall costs in comparison to open surgery [54]. Stewart et al. revealed that the total costs of minor liver resections increased by an additional $2483 when patients had postoperative complications, while readmissions within 1 month resulted in an additional cost of $2516 [54]. This result confirms the cost-reducing effect of the more often uneventful healing process following minimally invasive surgery.

Another factor that is likely to reduce the costs of robotic surgery is the competition in the market that is expected to occur with the launch of newly developed robotic surgical platforms. Aside from this, a greater implementation and wider expansion of robotic liver surgery would increase the experience with this technique, and probably improve its associated perioperative outcomes, likely reducing its associated costs.

3.5. Resection Margin

The resection margin is one of the important quantitative postoperative findings after oncologic surgery that is directly associated with long-term outcomes such as recurrence-free and overall survival. Technological advances have allowed minimally invasive surgical techniques to achieve R0 resection rates that are comparable with the traditional open approach. The reported R0 resection rates of robotic resections for colorectal liver metastases range from 73.7 to 100%. A comparative study by Beard et al. assessing the oncological outcomes after robotic and laparoscopic liver resections for colorectal liver metastases reported a 73.7% R0 resection rate in the robotic liver surgery group, which was comparable to the rate of 77.4% in the laparoscopic group [61]. Two recent meta-analyses reported similar results for liver resections performed for all indications [62][63].

3.6. Complex Procedures

Resections involving three or more contiguous segments, resections for lesions situated in the posterosuperior segments, resections following modulation of the future liver remnant, two-stage hepatectomies, redo resections or resections requiring a concomitant bilio-enteric anastomosis are deemed complex [64]. The robotic approach might have advantages that are especially useful in these types of situations, such as improved control of the surgical field, bleeding control, and suturing capacity due to the articulation capability of patient-side manipulators. A recently published propensity score-based analysis supports this view, reporting no clinically significant benefits of the robotic approach over the laparoscopic approach for procedures of low- and intermediate difficulty, but merits the use of the robot during technically complex cases in terms of less blood loss and conversions [65]. Despite the advantages of the robots' improved dexterity during complex surgical procedures, the lack of a specific energy device for the liver transection is an important disadvantage in this setting. For this reason, it may still be necessary to use laparoscopic energy devices or conventional methods, such as the clamp crush technique adapted to robotic arms using force bipolar, during the liver parenchyma transection phase. In addition to this, Croner et al. described the three device (3D) method that enables the exposition of the intrahepatic vascular and biliary tracts using the monopolar scissors and bipolar Maryland forceps of the robot, and a laparoscopic-guided waterjet [66].

Tumor size is another important parameter for resection planning. In parallel with surgical and technological developments, a better understanding of liver anatomy and improvements in preoperative patient preparation have enabled liver surgery to be performed safely for large tumors. Rahimli et al., in their study comparing laparoscopic and robotic surgery for liver colorectal metastases, showed that although patients in the robotic surgery group had larger tumors and more often needed a major resection, robotic surgery had comparable results and was even associated with a higher R0 resection rate [67]. Magistri et al. reported that robotic surgery had comparable R0 resection rates with the laparoscopic approach and that robotic surgery provided safe access to difficult-to-resect segments such as segments I, VII, and VIII, while patients had significantly larger tumors in the robotic surgery group, supporting the superiority of the robotic approach for complex procedures and large tumors [68]. Although it is thought that large tumors may cause high conversion rates and difficulty in obtaining negative surgical margins during minimally invasive surgery, Beard et al. reported lower conversion rates in the robotic surgery group, compared to laparoscopic surgery (5.2% vs 12.2%, respectively), while more patients in the robotic surgery group had large tumors (>5 cm) [61]. In a meta-analysis conducted by Rahimli et al. including comparative studies for robotic and laparoscopic liver surgery, six studies were included in the meta-analysis of tumor size, and it was reported that the tumor size was significantly larger in the robotic group [69]. However, in the results of a survey on the implementation of minimally invasive liver surgery by Zwart et al., a large tumor size (>10 cm) was mentioned as a contraindication to minimally invasive liver surgery by 29% of the participants [70].

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