# Robotic *vs.* laparoscopic liver surgery: what are the advantages of the robot?

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**Background:** Laparoscopic liver surgery is safe and feasible. The robot adds some new technical features which might be of advantage in specific cases. But it is unclear if the robot is superior to conventional laparoscopy. For this reason, we summarized the literature of the last 10 years which focused on this issue and compared it with own experiences.

**Methods:** A PubMed research was performed including keywords for laparoscopic and robotic liver surgery. Original articles comparing patients which underwent robotic-assisted liver resection (RLR) *vs.* laparoscopic liver resection (LLR) were selected for further analysis. Patients which underwent left lateral liver resection with RLR or LLR between 2015–2020 were selected from the Magdeburg registry of minimally invasive liver surgery (MD-MILS). Perioperative outcome from the literature review and own data were analyzed and compared.

**Results:** We identified 29 studies including 1,392 patients which underwent RLR and 1,965 patients which underwent LLR. The mean operative time ranged between 121–425 min in RLR and 130–565 min in LLR. The conversion rates were 0–20% in RLR and 0–30.9% in LLR. In major liver resections the conversation rate in the RLR group were 4.0–14.3% and 4.0–25.0% in the LLR patients. Mean estimated blood loss was 30–500 mL in RLR *vs.* 30–513 mL in LLR. Blood transfusion was needed in 0–25.0% of patients which underwent RLR and 0–23.1% of patients which were operated as LLR. Perioperative overall morbidity was reported in 0–68.0% in RLR cases and 0–35.3% of LLR. The mortality was 0–10% in the RLR and 0–5% in the LLR cases. Margins with residual tumor (R1) in case of malignancy were present in 0–11.1% of RLR cases and 0–23.1% in LLR procedures. In major liver resections the R1 resection rate were 0–8.3% in RLR and 7.4–25.0% in LLR. Costs were generally calculated higher in RLR *vs.* LLR and there were no significant differences in disease-free survival (DFS) and overall survival (OAS) in malignancies. The 22 selected cases from MD-MILS showed a mean operation time for RLR of 243.2 [standard deviation (SD) 80.2] *vs.* 160.1 (SD 39.8) min in LLR (P=0.01). Other perioperative data were not statistically significant different and confirmed the results from the literature.

**Conclusions:** Robotic liver surgery is safe and not inferior to conventional laparoscopy. It might have some advantages in major liver resections regarding decreased conversion rate and less positive margins. This has to be proven in further studies.

**Keywords:** Robotic surgery; laparoscopic surgery; liver resection; hepatectomy; liver; liver cancer; liver metastasis; DaVinci

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## Introduction

Minimally invasive liver surgery (MILS) ads less morbidity and mortality to the patients compared to open procedures. The first laparoscopic liver resections (LLRs) were performed in the 1990s. After an initiation phase especially, the removal of smaller tumors (<5 cm) on good reachable liver segments (II–VI) was recommended (1). Later all liver segments were considered for laparoscopic resections (2). After expert meetings and consensus conferences (2008, 2014, 2016) no limitations for selected malignant liver tumors such as hepatocellular carcinomas (HCC) or colorectal liver metastases (CLM) were identified for the use of laparoscopic liver surgery (3). The oncological outcome of MILS is similar to open procedure (4-7). Today, it is clear that major liver resections, associating liver partition and portal vein ligation for staged hepatectomy (ALLPS) and living donor liver resections can be performed minimally invasive (2,8,9). Behind these facts MILS has been recommended as standard of care for selected liver resections such as left lateral segment removals (10). The problem is that there is a quiet high learning curve for MILS (11). Surgeons need to be trained in hepatobiliary and minimally invasive surgery. This needs dedicated people and high-volume centers which can offer the volume load for the learning curves.

The robotic platform offers some innovations which may facilitate MILS (12). Several maneuvers might be easier compared to standard laparoscopy which could reduce the learning curve. Especially the Endowrist, which gives more degrees of freedom at the tip of the instruments, is a new helpful tool. Hereby the instrument's tip can be handled like the surgeon's prolonged hand in the patient's body. Sewing and vessel dissection becomes easier and more precise. The control of three instruments and the camera by the console surgeon offers excellent control of the operation situs. This is helpful especially in case of emergency situations like unexpected bleeding. Moreover, the robot makes minimally invasive surgery less exhausting compared to conventional laparoscopy. The surgeon can sit in a relaxed manner at the console and needs not like sometimes in conventional laparoscopy strength killing positions. Nevertheless, the robot has its limitations. The missing haptic is the most important limitation. In conventional laparoscopy this can sometimes be compensated by palpating structures with the instrument. The surgeon gets feedback via the tool through the hand which gives him an idea of the consistence. In robotics this is not possible. The so called visual haptic which means the behavior of the structure by palpating it with the robotic tool gives you an idea of its consistence based on your experience, is currently the way to compensate the missing haptic feedback. Furthermore, the current robots are no really robots. They are tele-manipulators. All movements of the instruments are driven by a surgeon from a console. Nevertheless, the implementation of robots in minimally invasive surgery is rising worldwide and the trend continues. For liver surgery, the robot has been considered as safe and effective tool (13).

Regarding the endpoints of outcome in perioperative data or oncological outcome there are not many studies, which demonstrated a clear superiority of the robot *vs.* conventional laparoscopy. Especially in MILS there are no randomized trials comparing these issues. Based on the literature experiences on a decade (2010–2020) comparing laparoscopic with robotic liver surgery we summarize the results of the current literature and add our own experience.

## Methods

### *Literature research*

A PubMed research was performed on February 15th 2021 restricted to articles in English language. The following terms were searched in title, abstract, keywords: robotics, robot, laparoscopic, laparoscopy, and liver surgery. Only articles were selected for the study, which compared laparoscopic with robotic-assisted liver resections (RLRs) based on original data. Meta-analysis and reviews were excluded from the study. Perioperative and if tangible data regarding cost analysis or oncological outcome were summarized and compared between LLR and RLR.

### *Patient selection*

Patients which underwent minimally invasive left lateral liver resection between 2015 and 2020 were selected from the Magdeburg registry of minimally invasive liver surgery

 

(MD-MILS). The data were collected prospectively and analyzed in a retrospective procedure. Only patients with solid tumors were included in the study. Patients with cystic lesions, liver resection for trauma or ablation without liver resection were excluded. Perioperative parameters were selected and compared between laparoscopic versus robotic performed liver resections. Overall and liver surgery related morbidity were quantified. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the ethical board University Hospital Magdeburg (R03-21) and the individual consent for this retrospective analysis was waived.

### *MILS*

LLR was performed in a complete laparoscopic technique. No cases of hand-assisted laparoscopy or hybrid techniques were included. The trocar placement and the technical details of MILS were described elsewhere (14). For parenchymal dissection, we used a harmonic scalpel or the laparoscopic CUSA (cavitron ultrasonic surgical aspirator) or an aquajet. In case if there was no scar from previous surgery, the specimens were placed in a retrieval bag and removed via a Pfannenstiel incision. For RLR, the DaVinci System (Intuitive, Santa Clara, USA) was used. Our techniques of RLR have been described elsewhere in detail (14-19).

### *Statistical analysis*

We analyzed patient characteristics, perioperative parameters and type of procedures between the two groups (LLR *vs.* RLR). Data analysis was performed using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA). Cross tables and chi-squared test were used for the descriptive analysis and significance test for dichotomous variables. We used number of cases and percentage for data presentation here. The independent samples *t*-test was applied for the continuous variables.

## Results

### *Review of the literature*

Between 2010 and 2020, 29 papers were selected regarding the inclusion criteria. In one study the analyses were divided in substudies regarding major or minor liver resections (20). Taking this into account, nine studies included only patients with minor and five studies with major liver resections (14,20-31). Fifteen studies enrolled patients with major and minor liver resections (32-46). These studies included 1,392 patients which underwent robotic and 1,965 patients which underwent conventional LLR. The mean age of patients in RLR was 50.4–66.6 years while it was 47.0–66.7 year in LLR. The mean body mass index (BMI) in the RLR was 24.0–31.0 kg/m$^2$ *vs.* 23.5–29.5 kg/m$^2$ in the LLR procedures. The mean tumor size in the RLR cases was 3.2–7.1 cm while it was 2.36–7.0 cm in the LLR patients (*Table 1*).

The mean operative time was between 121–425 min in the RLR and 130–565 min in the LLR cases. The conversion rates were around 0–20.0% in the RLR and 0–30.9% in the LLR studies. Mean estimated blood loss was 30–500 mL in the RRL *vs.* 30–513 mL in the LLR patients. Blood transfusion was needed in 0–25.0% of patients which underwent RLR and 0–23.1% of patients which were operated by conventional laparoscopy. Perioperative overall morbidity was reported in 0–68.0% in RLR cases and 0–35.3% of LLR procedures. The mortality was 0–10.0% in the RLR and 0–5.0% in the LLR cases. Margins with residual tumor (R1) in case of malignancy were present in 0–11.1% of RLR cases and 0–23.1% in LLR procedures (*Table 2*).

### *Minor and major minimally invasive liver resections*

The nine studies including only minor MILS included 157 patients which underwent RLR and 356 patients which underwent LLR (14,20,21,23,24,26-28,30). The mean BMI of theses RLR cases was 26.1–31.0 kg/m$^2$ and 23.2–29.0 kg/m$^2$ in the LLR patients. The mean tumor size was between 2.67–5.59 cm in the RLR and 2.36–4.95 cm in the LLR groups. The mean operation time in the RLR studies including only minor cases was 121–321 min and 148–295 min in the compared LLR cases. The conversation rate in the RLR groups was 0–14.3% and 0–9.7% in the LLR patients. The mean estimated blood loss in minor cases was 30–415 mL in the RLR and 30–437 mL in the LLR cases. The transfusion rate varied between 0–14.2% in the RLR and 0–4.7% in the LLR groups. The morbidity and mortality in minor cases was 0–25.0% and 0–2.8% in the RLR *vs.* 4.7–19.5% and 0–3.6% in the LLR groups. The R1 resection rate was 0–11.1% in the RLR and 0–12.5% in the LLR minor cases (*Tables 1,2*).

Five studies compared only major liver resections (20,22,25,29,31). These studies included 196 patients

 

**Table 1** Selected studies comparing robotic-assisted (RLR) with laparoscopic (LLR) liver resection

| First author | Year | Country | RLR (n) | LLR (n) | Age (years), mean or median | | BMI (kg/m$^2$), mean or median | | Largest tumor size (cm), mean or median | | Type of liver resection |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | RLR | LLR | RLR | LLR | RLR | LLR | |
| Berber | 2010 | USA | 9 | 23 | 66.6 | 66.7 | N.A. | N.A. | 3.2±1.3 | 2.9±1.3 | Minor |
| Ji | 2011 | China | 13 | 20 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | Minor and major |
| Packiam | 2012 | USA | 11 | 18 | 57 | 52 | 31 | 29 | 4.73±3.48 | 4.72±3.62 | Minor |
| Troisi | 2013 | Belgium | 40 | 223 | 64.6 | 54.1 | N.A. | N.A. | 5.18±3.76 | 4.97±3.77 | Minor and major |
| Spampinato | 2014 | Italy | 25 | 25 | 63 | 62 | 24 | 25 | N.A. | N.A. | Major |
| Tranchart | 2014 | France | 28 | 28 | 66.5 | 66.0 | 26.1 | 23.2 | 4.13±2.70 | 4.69±3.08 | Minor |
| Tsung | 2014 | USA | 57 | 114 | 58.4 | 58.7 | N.A. | N.A. | 3.42±2.24 | 3.85±3.00 | Minor and major |
| Wu | 2014 | China | 38 | 41 | 60.9 | 54.1 | N.A. | N.A. | 3.4±1.7 | 2.5±1.6 | Minor and major |
| Yu | 2014 | Korea | 13 | 17 | 50.4 | 52.5 | N.A. | N.A. | 3.11±1.60 | 3.48±1.82 | Minor and major |
| Montalti | 2016 | Italy | 36 | 72 | 62.0 | 56.8 | N.A. | N.A. | 4.44±3.06 | 4.95±3.50 | Minor |
| Lee | 2016 | China | 70 | 66 | 58 | 58 | N.A. | N.A. | 3.06±2.32 | 2.84±1.79 | Minor and major |
| Croner | 2016 | Germany | 10 | 19 | 64 | 59 | 28 | 26 | 5.59±2.46 | 4.42±1.82 | Minor |
| Efanov | 2016 | Russia | 16 | 35 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | Minor and major |
| Salloum | 2017 | France | 16 | 80 | N.A. | N.A. | N.A. | N.A. | 5.45±3.68 | 3.64±1.95 | Minor |
| Kim | 2016 | Korea | 12 | 31 | 54.1 | 56.4 | N.A. | N.A. | 2.67±1.34 | 2.36±1.01 | Minor |
| Lai | 2016 | China | 100 | 35 | 62.1 | 57.9 | N.A. | N.A. | 3.3±1.9 | 2.7±1.3 | Minor and major |
| Magistri | 2017 | Italy | 22 | 24 | 60.9 | 66.6 | 26.8 | 26.5 | 3.40±1.35 | 2.26±1.13 | Minor and major |
| Cortolillo | 2019 | USA | 204 | 520 | 57.5 | 60.1 | N.A. | N.A. | N.A. | N.A. | Minor and major |
| Marino | 2018 | Poland | 14 | 20 | 58.3 | 62.3 | 28.2 | 27.9 | 4.51±0.51 | 4.48±0.81 | Major |
| Al-Temimi | 2019 | USA | 123 | 123 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | Minor and major |
| Fruscione | 2019 | USA | 57 | 116 | 58.1 | 53.2 | 28.1 | 29.5 | N.A. | N.A. | Major |
| Hu | 2019 | China | 58 | 54 | 52.2 | 48.9 | 24.7 | 23.8 | 4.7±2.6 | 4.7±2.8 | Minor |
| Lee | 2019 | Korea | 13 | 10 | 62.2 | 58.8 | 24.6 | 23.5 | 4.13±2.38 | 3.28±1.80 | Minor and major |
| Rho | 2019 | Korea | 169 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | Minor and major |
| Wang | 2019 | China | 92 | 48 | 54.1 | 49.4 | 24.2 | 23.7 | 7.1±3.3 | 7.0±3.3 | Major |
| Mejia | 2020 | USA | 8 | 13 | 62 | 47 | 28.6 | 29.1 | 6.91±4.38 | 5.99±3.90 | Major |
| Mejia | 2020 | USA | 35 | 85 | 65 | 55 | 27.0 | 27.6 | 4.46±3.48 | 3.73±2.64 | Minor |
| Chong | 2020 | China | 91 | 92 | 58.7 | 59.8 | 24.6 | 23.5 | N.A. | N.A. | Minor and major |
| Rahimli | 2020 | Germany | 12 | 13 | 63.5 | 62.1 | 26.2 | 28.3 | N.A. | N.A. | Minor and major |

Minor liver resection ≤2 segments, major liver resection ≥3 segments. N.A., not available.

which underwent RLR and 222 patients which received LLR. The mean BMI of theses RLR cases was 24.0–28.6 kg/m$^2$ and 23.7–29.5 kg/m$^2$ in the LLR patients. The mean tumor size was between 4.51–7.10 cm in the RLR group and 4.48–7.00 cm in the LLR group. The mean operation time in the major liver resection studies was 194–456 min in the RLR group and 195–565 min in LLR group. The conversation rate in the RLR cases was 4.0–14.3% and 4.0–25.0% in the

**Table 2** Perioperative outcomes in robotic-assisted (RLR) *vs.* laparoscopic (LLR) liver resection

| First author | Year | Country | Mean operative time (min) | | Conversion to open (%) | | Mean estimated blood loss (mL) | | Transfusion (%) | | Morbidity (%) | | Mortality (%) | | Malignancy (%) | | R1 Resection (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | RLR | LLR | RLR | LLR | RLR | LLR | RLR | LLR | RLR | LLR | RLR | LLR | RLR | LLR | RLR | LLR |
| Berber | 2010 | USA | 259 | 234 | 11.1 | 0 | 136 | 155 | N.A. | N.A. | 11 | 17 | 0 | 0 | 100 | 100 | N.A. | N.A. |
| Ji | 2011 | China | 338 | 130 | 0 | 10 | N.A. | N.A. | 0 | 15 | 7.8 | 10.0 | 0 | 0 | 61.5 | N.A. | N.A. | N.A. |
| Packiam | 2012 | USA | 175 | 188 | 0 | 0 | 30 | 30 | 0 | 0 | N.A. | N.A. | 0 | 0 | 55 | 45 | N.A. | N.A. |
| Troisi | 2013 | Belgium | 271 | 262 | 20.0 | 7.6 | 330 | 174 | N.A. | N.A. | 12.5 | 12.6 | 0 | 0 | 70.0 | 60.2 | 7.5 | 5.4 |
| Spampinato | 2014 | Italy | 456 | 375 | 4 | 4 | 625 | 513 | 44 | 16 | 16 | 36 | 0 | 4 | 68 | 92 | N.A. | N.A. |
| Tranchart | 2014 | France | 210 | 176 | 14.3 | 7.1 | 200 | 150 | 14.2 | 3.6 | 17.9 | 17.9 | 0 | 3.6 | 53.6 | 60.7 | N.A. | N.A. |
| Tsung | 2014 | USA | 253 | 199 | 7.0 | 8.8 | 200 | 100 | 3.8 | 7.4 | 19.3 | 26.0 | 0 | 1.8 | 70 | 68 | N.A. | N.A. |
| Wu | 2014 | China | 380 | 227 | 5.0 | 12.2 | 325 | 173 | N.A. | N.A. | 8 | 8 | 10 | 0 | 75 | 63 | N.A. | N.A. |
| Yu | 2014 | Korea | 241 | 292 | 0 | 0 | 389 | 343 | 0 | 0 | 0 | 11.7 | 0 | 0 | 76.9 | 29.4 | N.A. | N.A. |
| Montalti | 2016 | Italy | 306 | 295 | 13.9 | 9.7 | 415 | 437 | N.A. | N.A. | 19.4 | 19.4 | 2.8 | 0 | 75.0 | 70.8 | 11.1 | 12.5 |
| Lee | 2016 | China | 252 | 215 | 5.7 | 12.1 | 100 | 100 | 1.5 | 4.3 | 11.4 | 4.5 | 0 | 0 | 74.3 | 86.4 | 1.8 | 1.6 |
| Croner | 2016 | Germany | 321 | 242 | N.A. | N.A. | 356 | 306 | N.A. | N.A. | 32 | 16 | 0 | 5 | 100.0 | 26.3 | 0 | 0 |
| Efanov | 2016 | Russia | N.A. | N.A. | 6 | 3 | N.A. | N.A. | N.A. | N.A. | 31 | 14 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Salloum | 2017 | France | 190 | 162 | 13 | 3 | 247 | 206 | 7 | 0 | 13 | 11 | 0 | 1 | 56 | 60 | 0 | 2 |
| Kim | 2016 | Korea | 337 | 216 | 0 | 3.2 | 225 | 150 | N.A. | N.A. | 25 | 19 | 0 | 0 | 58.3 | 77.4 | N.A. | N.A. |
| Lai | 2016 | China | 207 | 134 | 4.0 | 5.7 | 335 | 336 | 9.0 | 11.4 | 14 | 20 | 0 | 0 | 100 | 35 | 4.0 | 8.6 |
| Magistri | 2017 | Italy | 318 | 211 | 0 | 16.7 | 400 | 328 | 4.5 | 4.2 | 68 | 0 | 0 | 0 | 100 | 100 | 4.5 | 4.2 |
| Cortolillo | 2019 | USA | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 0.5 | 2.1 | N.A. | N.A. | N.A. | N.A. |
| Marino | 2018 | Poland | 425 | 565 | 14.3 | 25.0 | 335 | 424 | N.A. | N.A. | 21.42 | 15.00 | 0 | 0 | 85.71 | 100.00 | 8.34 | 15.00 |
| Al-Temimi | 2019 | USA | 191 | 159 | 9.8 | 30.9 | N.A. | N.A. | 14.6 | 6.5 | 26.0 | 19.5 | 0.8 | 0 | N.A. | N.A. | N.A. | N.A. |
| Fruscione | 2019 | USA | 194 | 204 | N.A. | N.A. | 250 | 400 | N.A. | N.A. | 28.1 | 35.3 | N.A. | N.A. | 76.0 | 73.3 | 8.1 | 7.4 |
| Lee | 2019 | Korea | 205 | 172 | 0 | 10 | 320 | 393 | 0 | 0 | 7.7 | 10.0 | N.A. | N.A. | 84.6 | 80.0 | N.A. | N.A. |
| Wang | 2019 | China | 196 | 199 | 1.09 | 10.42 | 243 | 346 | N.A. | N.A. | 13.04 | 10.42 | 0 | 0 | 66.3 | 50.0 | N.A. | N.A. |
| Mejia | 2020 | USA | 222 | 195 | N.A. | N.A. | 500 | 250 | 25.0 | 7.7 | 0 | 23 | N.A. | N.A. | 87.5 | 30.8 | 0 | 25 |
| Mejia | 2020 | USA | 121 | 148 | 3 | 1 | 150 | 135 | 8.6 | 4.7 | 0 | 4.7 | N.A. | N.A. | 62.8 | 37.6 | 9.1 | 9.4 |
| Chong | 2020 | China | 259 | 217 | 7.7 | 12.0 | 275 | 212 | N.A. | N.A. | 9.9 | 5.4 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Rahimli | 2020 | Germany | 342 | 200 | N.A. | N.A. | 450* | 412.3* | 16.7 | 23.1 | 15.4 | 25.0 | N.A. | N.A. | 100 | 100 | 0 | 23.1 |

Minor liver resection ≤2 segments, major liver resection ≥3 segments. Morbidity: in hospital morbidity, 30- or 90-day morbidity. *, measured blood loss. N.A., not available.

LLR patients. The mean estimated blood loss in major cases was 243–625 mL in the RLR and 250–513 mL in the LLR cases. The transfusion rate varied between 25.0–44.0% in the RLR group and 7.7–16.0% in the LLR group. The morbidity and mortality in major cases was 0–28.1% and 0% in the RLR group *vs.* 10.4–36.0% and 0–4.0% in the LLR group. The R1 resection rate was 0–8.3% in the RLR and 7.4–25.0% in the LLR major case series (*Tables 1,2*).

### *Cost analysis*

In five papers the costs regarding RLR or LLR were analyzed (20,24,27,34,36). Cortolillo *et al.* calculated $24,983±$18,329 for the robotic procedures and $30,194±$26,977 for the laparoscopic operations regarding the initial admission. In case of readmission costs for RLR were $18,211±$33,267 and $14,927±$16,818 for LLR. Ji *et al.* analyzed hospital costs of $12,046 for robotics and $7,618 for laparoscopy. Kim *et al.* reported of about $8,183 costs for RLR and $5,190 LLR. Mejia *et al.* calculated mean total charges for minor cases of $39,054.9 [standard deviation (SD) 14,858.3] for full laparoscopy and $50,395.4 (SD 18,224.1) for robotic procedures. For major liver resections in cases of laparoscopy $54,850.3 (SD 13,746.6) and in case of robotics $61,333.2 (SD 19,682.2) were estimated. Packiam *et al.* calculated full surgical supply costs of $6,553 for robotics *vs.* $4,408 for laparoscopy (P=0.021).

### *Oncological outcome*

In three papers data about oncological outcome were reported (21,24,41). Berber *et al.* reported during an observation period of 14 months in patients with HCC and CLM of an equivalent outcome in terms of disease-free survival (DFS) and overall survival (OAS) between robotic and laparoscopic cases. Kim *et al.* included HCC and CLM cases as malignant tumors in their study. They found no significant differences in DFS and OAS between RLR *vs.* LLR. The 2- and 5-year DFS were 63.2% and 36.5%, the median DFS was 56 months in both groups. The 2- and 5-year OAS were 96.8% and 91.4% in the RLR and LLR groups. Rahimli *et al.* included CLM in their study only. They described 1-, 3- and 5-year OAS rates of 84.0%, 56.9%, and 48.7% and 1- and 3-year recurrence-free survival rates of 49.6% and 36.2%, without significant differences between RLR and LLR.

### *Left lateral liver resections MD-MILS*

Twenty-two patients were identified in the MD-MILS regarding the selection criteria. Of these 13 patients underwent RLR and 9 LLR (*Table 3*). The mean age of the patients was 63.8 years of age, the mean BMI was 28.5 kg/m$^2$ (range, 22.0–44.8 kg/m$^2$). In 15 cases malignant [HCC: n=8, CLM: n=4, cholangiocarcinoma (CCC): n=2, melanoma metastasis: n=1] and in 7 patients benign disease (FNH: n=3, haemangioma: n=3, adenoma: n=1) was identified. The mean tumor size of the liver lesions was 5.8 (SD 3.6) cm. Abdominal adhesions as a result of prior abdominal surgery were present in 45.5% of all cases. Mean operation time was 243.2 (SD 80.2) min in the RLR group *vs.* 160.1 (SD 39.8) min in the LLR group (P=0.01). All other perioperative parameters showed no statistically significant differences between RLR *vs.* LLR (*Table 3*). The overall morbidity was 15.4% in the RLR and 22.2% in the LLR, while there was no postoperative liver surgery related morbidity in both groups. No patient died during the hospitalization period.

## Discussion

The robot is the next step of evolution in MILS which offers technical innovations that might overcome some laparoscopic limitations. But these technical limitations depend on the experiences and skills of the laparoscopic surgeon and cannot be summarized as general rule for everybody. Various fantastic solutions for technical challenges have been developed by creative surgeons throughout the years. Nevertheless, the Endowrist at the tip of the instruments at the robotic platforms is a clear step forward which provides an enormous benefit in terms of sewing and vessel dissection. This new feature generates an enhanced mobility of minimally invasive instruments, which helps to work very precisely in narrow spaces. This facilitates in MILS the mobilization of the liver from the vena cava, vessel dissection at the hepatoduodenal ligament and control of the hepatic veins (15,16). The surgeon handles three instruments from the console including the camera. Usually, an assistant at the table supports the operation with a further laparoscopic instrument. So, taken together there are four instruments in the abdomen to handle the situs. This generates a very stable operation field which enables fast and controlled maneuvers especially in emergency cases such as unexpected bleeding. Behind these

**Table 3** Perioperative parameter of patients which underwent robotic or laparoscopic left lateral liver resections at the University Hospital Magdeburg

| Parameter | Robotic left lateral liver resection, n (% or SD) | Laparoscopic left lateral liver resection, n (% or SD) | P value |
|---|---|---|---|
| Total | 13 | 9 | – |
| Operating time; minutes | 243.2 (80.2) | 160.1 (39.8) | 0.010 |
| LOS (days) | 8.0 (4.7) | 8.8 (3.1) | 0.235 |
| Intraoperative blood loss (mL) | 180.8 (176.2) | 242.2 (227.9) | 0.794 |
| Intraoperative blood transfusion | 0 (0.0) | 1 (11.1) | 0.409 |
| Overall morbidity | 2 (15.4) | 2 (22.2) | 1.000 |
| Liver surgery related morbidity | 0 (0.0) | 0 (0.0) | – |
| Previous abdominal surgery | 8 (61.5) | 2 (22.2) | 0.099 |
| Conversion | 0 (0.0) | 1 (11.1) | 0.409 |
| R status in malignant cases | | | |
| R0 | 7 (100.0) | 7 (87.5) | 1.000 |
| R1 | 0 (0.0) | 1 (12.5) | |

LOS, length of stay; SD, standard deviation.

facts the robot may provide benefits especially in advanced cases of MILS. During our review we figured out that in major liver resections in bigger tumors the conversion rate and the R1 resection rate was reduced and in RLR *vs.* LLR. Even the of morbidity and mortality rates for major cases was reduced in RLR compared to LLR. Although we selected only left lateral liver resections from the MD-MILS, we observed a similar trend in these patients but without statistical significance. Summarizing the findings throughout the reviewed literature, benefits added by the robot in major and more challenging liver resections becomes visible. This hypothesis is supported by a recent review which confirms our findings (47).

Nevertheless, surgery with the robot is more time consuming compared to LLR. Even in the MD-MILS patients the operating time was significantly increased in the RLR *vs.* LLR. In all studies which calculated costs for the procedures, the robot seemed to be a factor to increase this parameter (20,24,27,34,36). Depending on the region where the study was performed and the factors which were included into the calculation the results vary extremely. But it became obvious during our review that robotic is an independent cost enhancer. In a previous analysis we described that the main proportion of costs for the robot occur during surgery itself, driven by the high material and maintenance costs for the robot. This can partially be compensated by reduced hospitalization of the patients during MILS compared to open surgery. But this benefit becomes irrelevant when RLR is compared to LLR, because there is no difference in hospitalization. Regarding oncological outcome in malignant disease there are only limited results throughout the studies (21,24,41). That MILS has no disadvantage for the patients regarding OAS, DFS and median survival compared to open surgery has already been proven. In our review no significant differences between RLR and LLR could be identified.

The limitations of the current robotic approach may result from the fact that these new tools are currently not really used as robots. The instruments are driven from a console by a surgeon. That makes the robots to a kind of tele-manipulator. No autonomous actions are driven by the machine itself. So, the current technology can be interpreted as an intermediate step to real robotic. Image driven navigation and artificial intelligence are needed to foster an automated system for surgery. This could make surgery faster, more precise and safer for the patients. It depends on the surgeons if they are willing to implement this into routine or if this will be blocked by ethical or legal considerations.

In summary the current robotic systems offer technical innovations which lifts minimally invasive surgery to another level. Dramatic differences at the endpoints of the minimally invasive procedures comparing RLR *vs.* LLR cannot be evaluated. Maybe in advanced cases the robot has some benefits. The small differences between the procedures regarding their study endpoints are not surprising because at the end the operation stays a minimally invasive procedure no matter if it was performed with the robot or conventional laparoscopy. This brings up the question if we measure the right parameters to compare the procedures. Maybe we should focus less at endpoints and concentrate on intraoperative measures to evaluate the benefits for the operating surgeon who really feels a difference in comfort between robotic and conventional laparoscopy. Nevertheless, the robot provides a technical platform which has the potential to drive surgery in partial or complete automatization which could be of benefits for the patients. It remains the surgeons' decision if this will be pushed and can be happen in the near future.

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## References

1. Buell JF, Cherqui D, Geller DA, et al. The international position on laparoscopic liver surgery: The Louisville Statement, 2008. Ann Surg 2009;250:825-30.
2. Ishizawa T, Gumbs AA, Kokudo N, et al. Laparoscopic segmentectomy of the liver: from segment I to VIII. Ann Surg 2012;256:959-64.
3. Cho JY, Han HS, Wakabayashi G, et al. Practical guidelines for performing laparoscopic liver resection based on the second international laparoscopic liver consensus conference. Surg Oncol 2018;27:A5-A9.
4. Ciria R, Cherqui D, Geller DA, et al. Comparative Short-term Benefits of Laparoscopic Liver Resection: 9000 Cases and Climbing. Ann Surg 2016;263:761-77.
5. Khan S, Beard RE, Kingham PT, et al. Long-Term Oncologic Outcomes Following Robotic Liver Resections for Primary Hepatobiliary Malignancies: A Multicenter Study. Ann Surg Oncol 2018;25:2652-60.
6. Wakabayashi G, Cherqui D, Geller DA, et al. Recommendations for laparoscopic liver resection: a report from the second international consensus conference held in Morioka. Ann Surg 2015;261:619-29.
7. Wakabayashi G, Cherqui D, Geller DA, et al. Laparoscopic hepatectomy is theoretically better than open hepatectomy: preparing for the 2nd International Consensus Conference on Laparoscopic Liver Resection. J Hepatobiliary Pancreat Sci 2014;21:723-31.
8. Yan Y, Cai X, Geller DA. Laparoscopic Liver Resection: A Review of Current Status. J Laparoendosc Adv Surg Tech A 2017;27:481-6.
9. Zhang B, Pan Y, Chen K, et al. Laparoscopy-Assisted versus Open Hepatectomy for Live Liver Donor: Systematic Review and Meta-Analysis. Can J Gastroenterol

Hepatol 2017;2017:2956749.
10. Belli G, Gayet B, Han HS, et al. Laparoscopic left hemihepatectomy a consideration for acceptance as standard of care. Surg Endosc 2013;27:2721-6.
11. Gumbs AA, Hilal MA, Croner R, et al. The initiation, standardization and proficiency (ISP) phases of the learning curve for minimally invasive liver resection: comparison of a fellowship-trained surgeon with the pioneers and early adopters. Surg Endosc 2021;35:5268-78.
12. Gravetz A, Sucandy I, Wilfong C, et al. Single-Institution Early Experience and Learning Curve with Robotic Liver Resections. Am Surg 2019;85:115-9.
13. Liu R, Wakabayashi G, Kim HJ, et al. International consensus statement on robotic hepatectomy surgery in 2018. World J Gastroenterol 2019;25:1432-44.
14. Croner RS, Perrakis A, Hohenberger W, et al. Robotic liver surgery for minor hepatic resections: a comparison with laparoscopic and open standard procedures. Langenbecks Arch Surg 2016;401:707-14.
15. Croner R, Arend J, Franz M, et al. Robot-Assisted Right Hemi-Hepatectomy. Zentralbl Chir 2021;146:235-8.
16. Croner R, Franz M, Arend J, et al. Indocyanine-Green-Guided, Robot-Assisted Left Hemihepatectomy. Zentralbl Chir 2021;146:377-80.
17. Croner R, Perrakis A, Grützmann R, et al. Robotic-Assisted Liver Surgery. Zentralbl Chir 2016;141:154-9.
18. Croner RS, Perrakis A, Brunner M, et al. Pioneering Robotic Liver Surgery in Germany: First Experiences with Liver Malignancies. Front Surg 2015;2:18.
19. Croner RS, Rahimli M, Andric M, et al. Robotic Left Hemihepatectomy with Synchronous Right Hemicolectomy using Complete Mesocolic Excision for Advanced Metastatic Colon Carcinoma. Biomedical Journal of Scientific & Technical Research 2019;4:15260-5.
20. Mejia A, Cheng SS, Vivian E, et al. Minimally invasive liver resection in the era of robotics: analysis of 214 cases. Surg Endosc 2020;34:339-48.
21. Berber E, Akyildiz HY, Aucejo F, et al. Robotic versus laparoscopic resection of liver tumours. HPB (Oxford) 2010;12:583-6.
22. Fruscione M, Pickens R, Baker EH, et al. Robotic-assisted versus laparoscopic major liver resection: analysis of outcomes from a single center. HPB (Oxford) 2019;21:906-11.
23. Hu M, Liu Y, Li C, et al. Robotic versus laparoscopic liver resection in complex cases of left lateral sectionectomy. Int J Surg 2019;67:54-60.
24. Kim JK, Park JS, Han DH, et al. Robotic versus laparoscopic left lateral sectionectomy of liver. Surg Endosc 2016;30:4756-64.
25. Marino MV, Shabat G, Guarrasi D, et al. Comparative Study of the Initial Experience in Performing Robotic and Laparoscopic Right Hepatectomy with Technical Description of the Robotic Technique. Dig Surg 2019;36:241-50.
26. Montalti R, Scuderi V, Patriti A, et al. Robotic versus laparoscopic resections of posterosuperior segments of the liver: a propensity score-matched comparison. Surg Endosc 2016;30:1004-13.
27. Packiam V, Bartlett DL, Tohme S, et al. Minimally invasive liver resection: robotic versus laparoscopic left lateral sectionectomy. J Gastrointest Surg 2012;16:2233-8.
28. Salloum C, Lim C, Lahat E, et al. Robotic-Assisted Versus Laparoscopic Left Lateral Sectionectomy: Analysis of Surgical Outcomes and Costs by a Propensity Score Matched Cohort Study. World J Surg 2017;41:516-24.
29. 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;28:2973-9.
30. Tranchart H, Ceribelli C, Ferretti S, et al. Traditional versus robot-assisted full laparoscopic liver resection: a matched-pair comparative study. World J Surg 2014;38:2904-9.
31. Wang ZZ, Tang WB, Hu MG, et al. Robotic vs laparoscopic hemihepatectomy: A comparative study from a single center. J Surg Oncol 2019;120:646-53.
32. Al-Temimi MH, Lee JH, DiFonzo AL. Is robotic hepatectomy superior to laparoscopic hepatectomy? A case-matched analysis of the NSQIP database. HPB (Oxford) 2019;21:S63.
33. Chong CCN, Lok HT, Fung AKY, et al. Robotic versus laparoscopic hepatectomy: application of the difficulty scoring system. Surg Endosc 2020;34:2000-6.
34. Cortolillo N, Patel C, Parreco J, et al. Nationwide outcomes and costs of laparoscopic and robotic vs. open hepatectomy. J Robot Surg 2019;13:557-65.
35. Efanov MG, Alikhanov RB, Cvirkun VV, et al., Application of novel difficulty scoring system for comparison of laparoscopic and robotic-assisted liver resection. Surg Endosc 2016;30:38.
36. Ji WB, Wang HG, Zhao ZM, et al. Robotic-assisted laparoscopic anatomic hepatectomy in China: initial experience. Ann Surg 2011;253:342-8.
37. Lai EC, Tang CN. Long-term Survival Analysis of Robotic Versus Conventional Laparoscopic Hepatectomy

 

for Hepatocellular Carcinoma: A Comparative Study. Surg Laparosc Endosc Percutan Tech 2016;26:162-6.
38. Lee KF, Cheung YS, Chong CC, et al. Laparoscopic and robotic hepatectomy: experience from a single centre. ANZ J Surg 2016;86:122-6.
39. Lee SJ, Lee JH, Lee YJ, et al. The feasibility of robotic left-side hepatectomy with comparison of laparoscopic and open approach: Consecutive series of single surgeon. Int J Med Robot 2019;15:e1982.
40. Magistri P, Tarantino G, Guidetti C, et al. Laparoscopic versus robotic surgery for hepatocellular carcinoma: the first 46 consecutive cases. J Surg Res 2017;217:92-9.
41. Rahimli M, Perrakis A, Schellerer V, et al. Robotic and laparoscopic liver surgery for colorectal liver metastases: an experience from a German Academic Center. World J Surg Oncol 2020;18:333.
42. Rho SY, Latorre K, Chong JU, et al. Robotic versus Laparoscopic Liver Resection for Hepatocellular Carcinoma: Short-term and Long-term Oncologic Outcomes. HPB (Oxford) 2019;21:S364.
43. Troisi RI, Patriti A, Montalti R, et al. 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;9:160-6.
44. Tsung A, Geller DA, Sukato DC, et al. Robotic versus laparoscopic hepatectomy: a matched comparison. Ann Surg 2014;259:549-55.
45. Wu YM, Hu RH, Lai HS, et al. Robotic-assisted minimally invasive liver resection. Asian J Surg 2014;37:53-7.
46. Yu YD, Kim KH, Jung DH, et al. Robotic versus laparoscopic liver resection: a comparative study from a single center. Langenbecks Arch Surg 2014;399:1039-45.
47. Ziogas IA, Giannis D, Esagian SM, et al. Laparoscopic versus robotic major hepatectomy: a systematic review and meta-analysis. Surg Endosc 2021;35:524-35.

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