Robotic vs. laparoscopic major hepatectomy

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Abstract

The introduction of laparoscopic technology and surgical robots in hepatobiliary surgery in the 1990s and 2000s, respectively, has dramatically revolutionized the field. Even though laparoscopic and robotic major hepatectomy was slower to adopt compared to minimally-invasive minor hepatectomy, the number of major hepatectomies performed with both approaches worldwide has significantly increased and is still rising. Despite the few comparative studies between laparoscopic and robotic major hepatectomy, most studies are focused on describing the procedures or reporting the outcomes of each method, either separately, or mixed with minor hepatectomies. Based on the available data, the direct comparison between the two techniques has shown that when robotic major hepatectomy is performed by experienced hepatobiliary surgeons in high-volume centers, it can lead to similar operating times, estimated blood loss, hospital length of stay, complication and mortality rates compared to its laparoscopic counterpart. The likelihood of achieving a margin-negative resection in cancer patients, as well as long-term disease-free and overall-survival are comparable between the groups. However, broader adoption of the robotic approach might be a hurdle in low-volume centers due to the high fixed capital and annual maintenance cost of the surgical robot.

Keywords: Hepatectomy, liver resection, major hepatectomy, laparoscopic, robotic, minimally-invasive
INTRODUCTION

The introduction of minimally-invasive technology in the approach of liver disorders in the early 1990s has since revolutionized the field of liver surgery\(^\text{[1-5]}\). Laparoscopic liver surgery does not only include pure laparoscopy, but also hand-assisted laparoscopic, as well as hybrid approaches, where the initial part of the procedure (i.e., liver mobilization, early dissection) is done laparoscopically, while later a small incision is made to complete the transection of the liver parenchyma\(^\text{[6,7]}\). The liver is classified in individual territories according to the segmentation of the vessels and bile ducts, introduced by Couinaud in the 1950s\(^\text{[8,9]}\), and the Brisbane 2000 nomenclature is utilized to define minor and major hepatectomy in the field of liver surgery\(^\text{[10,11]}\). Minor hepatectomy is defined as the resection of two or fewer Couinaud segments, while major hepatectomy is the removal of three or more Couinaud segments\(^\text{[10]}\). The first series on laparoscopic liver resections consisted mostly of minor liver resections\(^\text{[3,4,12,13]}\). The first laparoscopic major hepatectomy (LMH) was performed in 1997\(^\text{[14]}\). The higher risk for uncontrolled hemorrhage and the requirement of advanced technical expertise, particularly related to major vessel dissection, have slowed the broader adoption of minimally-invasive approaches for major hepatectomy\(^\text{[15]}\).

The technological advances of our era have also led to the broader implementation of robotics in several fields of surgery, including liver surgery. The ability to obtain three-dimensional and magnified intraoperative vision, the significant decrease in hand tremor, as well as the benefit for the surgeon of operating under more relaxed and comfortable circumstances, have led to a considerable growth in robotic surgery, which can overcome the rigid instrumentation and the limited two-dimensional vision associated with laparoscopic surgery\(^\text{[16,17]}\). These characteristics, along with the advent of wristed instruments, can lead to improved dexterity and higher precision in surgical dissection; this is of particular benefit to liver resection, as hilar dissection, curved transection of the liver parenchyma and the resection of lesions in the posterosuperior segments can be more feasible with the use of a robot\(^\text{[18]}\). The first large series of robotic liver resection was reported in 2002\(^\text{[19]}\), and although most current experience is based on minor resections, several studies have reported robotic major hepatectomy (RMH). This review aims to summarize the current state of evidence after LMH vs. RMH. We acknowledge that there is still a very important role for open hepatectomy in cases of multiple bilobar liver tumors or large tumors near critical vascular structures. However, we will focus on the differences between LMH and RMH, as a full review of open major hepatectomy is beyond the scope of this review.

INTERNATIONAL CONSENSUS AND LEARNING CURVES

Before engaging in a head-to-head comparison between LMH and RMH, it is worth mentioning two points that may favor the former approach. First, LMH has been performed for many more years than its robotic counterpart; second, irrespective of the procedural, hospitalization, and total economic cost, the cost of purchasing a robot for a hospital is considerable and has been a major limiting factor to the broader adoption of robotic liver surgery. These two points are of paramount importance, as data suggest that outcomes improve as experience with a surgical approach grows\(^\text{[20]}\). It is also worth mentioning that during the second international consensus on laparoscopic liver surgery (Morioka 2014), the jury concluded that laparoscopic minor hepatectomy had at that point already become standard practice, while LMH was still considered to be an innovative procedure still under exploration\(^\text{[21]}\). According to the 2018 international consensus statement on robotic hepatectomy, RMH was deemed to be as safe and feasible as both LMH and open major hepatectomy\(^\text{[21]}\).

For the purpose of this review, we performed a non-systematic search of the PubMed bibliographic database using combinations of the following terms: “laparoscopic”, “robotic”, “minimally invasive”, “hepatectomy”, “major hepatectomy”, “liver resection”, and “major liver resection” (last search March 2020). We included comparative or non-comparative studies reporting on the number of LMH and RMH cases. Tables 1, 2, and 3 present the previously published cases of RMH and LMH\(^\text{[6,7,12-14,20,22-109]}\), and it is apparent that the experience with LMH is greater than that of the robotic approach.
Table 1. Previously published reports on robotic major hepatectomy

| Author               | Country/region   | Study period          | Total number of robotic cases | Robotic major hepatectomy |
|----------------------|------------------|-----------------------|-------------------------------|--------------------------|
|                      |                  |                       |                               | Total major | Left hepatectomy | Right hepatectomy |
| Giulianiatti et al.[35] 2011 | Italy & USA | Mar 2002-Mar 2009 | 70                           | 27           | 5               | 20               |
| Ji et al.[36] 2011 | China            | Apr 2009-Jul 2009    | 13                           | 9            | 6               | 2                |
| Tsung et al.[37] 2014 | USA              | Nov 2007-Dec 2011    | 57                           | 21           | n/a             | n/a              |
| Spampinato et al.[38] 2014 | Italy        | Jan 2009-Dec 2012    | 25                           | 25           | 7               | 16               |
| Yu et al.[39] 2014  | South Korea      | May 2010-Oct 2011    | 13                           | 3            | 3               | 0                |
| Wu et al.[40] 2014  | Taiwan           | Jan 2012-Dec 2012    | 52                           | 14           | 0               | 0                |
| Felli et al.[41] 2015 | Italy            | Apr 2013-May 2014    | 20                           | 2            | 2               | 0                |
| Lee et al.[42] 2016 | China            | Sep 2010-Jan 2015    | 70                           | 14           | 10              | 4                |
| Kingham et al.[43] 2016 | USA             | 2010-2014            | 64                           | 6            | 4               | 2                |
| Lai et al.[44] 2016 | China            | May 2009-Feb 2015    | 100                          | 27           | 6               | 20               |
| Lee et al.[45] 2016 | China            | Sep 2010-Apr 2015    | 15                           | 5            | 3               | 2                |
| Sham et al.[46] 2016 | USA              | May 2011-Dec 2014    | 71                           | 17           | n/a             | n/a              |
| Chen et al.[47] 2016 | Taiwan           | May 2013-Aug 2015    | 13                           | 13           | 0               | 13               |
| Chen et al.[48] 2017 | Taiwan           | Jan 2012-Oct 2015    | 183                          | 92           | 32              | 41               |
| Quijano et al.[49] 2017 | Spain          | Oct 2010-Apr 2016    | 21                           | 5            | 2               | 1                |
| Magistri et al.[50] 2017 | Italy          | Jan 2012-May 2016    | 22                           | 2            | 0               | 2                |
| Efano et al.[51] 2017 | Russia          | May 2010-Jun 2016    | 40                           | 2            | 2               | 0                |
| Daskalaki et al.[52] 2017 | USA             | Jan 2009-Dec 2013    | 68                           | 29           | 2               | 21               |
| Choi et al.[53] 2017 | South Korea     | Dec 2008-May 2016    | 70                           | 54           | 27              | 12               |
| Khan et al.[54] 2018 | International   | 2006-2016            | 61                           | 16           | 8               | 8                |
| Goja et al.[55] 2019 | India            | Feb 2015-Jan 2016    | 21                           | 6            | 3               | 3                |
| Lim et al.[56] 2019  | Canada           | 2011-2017            | 61 (55)                      | 9 (4)        | n/a             | n/a              |
| Marino et al.[57] 2019 | Italy           | Apr 2016-Mar 2017    | 14                           | 14           | 0               | 14               |
| Marino et al.[58] 2019 | Italy           | Apr 2015-May 2017    | 35                           | 35           | 35              | 0                |
| Fruscione et al.[59] 2019 | USA            | 2011-2016            | 57                           | 57           | 20              | 20               |
| Gravetz et al.[60] 2019 | USA             | 2013-2017            | 33                           | 8            | n/a             | n/a              |
| Magistri et al.[61] 2019 | Italy          | Jul 2014-Sep 2017    | 60                           | 3            | 1               | 2                |
| Lee et al.[62] 2019  | South Korea     | Jun 2016-Apr 2018    | 13                           | 8            | 8               | 0                |
| Mejia et al.[63] 2020 | USA              | Aug 2013-Sep 2018    | 43                           | 8            | 4               | 4                |
| Sucandy et al.[64] 2020 | USA             | 2013-2018            | 80                           | 24           | 14              | 6                |
| Beaud et al.[65] 2020 | International   | Jan 2008-Oct 2016    | 115                          | 17           | 6               | 9                |

*Numbers in parentheses represent the number of cases after propensity score-matching. n/a: not available.

Table 2. Previously published reports on laparoscopic major hepatectomy

| Author               | Country/region   | Study period          | Total number of laparoscopic cases | Laparoscopic major hepatectomy |
|----------------------|------------------|-----------------------|------------------------------------|--------------------------------|
|                      |                  |                       |                                    | Total major | Left hepatectomy | Right hepatectomy |
| Huscher et al.[66] 1997 | Italy           | 1993-Dec 1995        | 20                                 | 14           | 6               | 5                |
| Gigot et al.[67] 2002 | Europe          | Feb 1994-Dec 2000    | 37                                 | 2            | n/a             | n/a              |
| O’Rourke et al.[68] 2004 | Australia    | Nov 1999-Sep 2002    | 12                                 | 12           | 0               | 12               |
| Dulucq et al.[69] 2005 | France         | Jan 1995-Jan 2004    | 32                                 | 11           | 4               | 6                |
| Vibert et al.[70] 2006 | France         | Jan 1995-Dec 2004    | 89                                 | 38           | 3               | 27               |
| Topal et al.[71] 2007 | Belgium         | n/a                  | 2                                  | 2            | 0               | 2                |
| Gayet et al.[72] 2007 | France          | n/a                  | 41                                 | 41           | 0               | 37               |
| Koffron et al.[73] 2007 | USA             | Jul 2001-Nov 2006    | 300                                | 119          | 47              | 64               |
| Dagher et al.[74] 2007 | France         | Feb 1999-Jan 2006    | 70                                 | 19           | 5               | 12               |
| Gumbs et al.[75] 2008 | France          | n/a                  | 3                                  | 3            | 0               | 0                |
| Gumbs et al.[76] 2008 | France          | n/a                  | 5                                  | 5            | 0               | 0                |
| Cho et al.[77] 2008  | South Korea     | Jan 2004-Dec 2007    | 128                                | 47           | 23              | 13               |
| Buell et al.[78] 2008 | USA             | Jan 2001-Apr 2008    | 253                                | 69           | 24              | 33               |
| Topal et al.[79] 2008 | Belgium         | Oct 2002-Jun 2007    | 109                                | 21           | 4               | 14               |
| Dagher et al.[80] 2008 | France         | Since Feb 1999       | 20                                 | 20           | 0               | 20               |
| Wakabayashi et al.[81] 2009 | Japan       | Jul 1995-Apr 2008    | 176                                | 39           | 10              | 12               |
| Castaing et al.[82] 2009 | France       | Jan 1997-May 2007    | 60                                 | 26           | 0               | 22               |
| Authors                     | Region          | Study Period       | Number of Cases |
|----------------------------|-----------------|--------------------|-----------------|
| Nguyen et al.[(62) 2009    | USA & Europe    | Feb 2000-Sep 2008  | 109             |
| Vigano et al.[(63) 2009    | France          | Jan 1996-Aug 2008  | 174             |
| Bryant et al.[(64) 2009    | France          | May 1996-Dec 2007  | 166             |
| Yoon et al.[(65) 2009      | South Korea     | Oct 1998-Jun 2007  | 46              |
| Cho et al.[(66) 2009       | South Korea     | May 2003-Apr 2007  | 40              |
| Baker et al.[(67) 2009     | USA             | Jan 2006-May 2008  | 33              |
| Dagher et al.[(68) 2009    | International   | 1997-2008          | 210             |
| Cai et al.[(69) 2009       | China           | 2005-2007          | 19              |
| Dagher et al.[(70) 2009    | France          | Feb 2002-Aug 2007  | 22              |
| Yoon et al.[(71) 2010      | South Korea     | Sep 2003-Nov 2008  | 69              |
| Nitta et al.[(72) 2010     | Japan           | Nov 2002-Dec 2008  | 42              |
| Dagher et al.[(73) 2010    | Europe          | 1998-2008          | 163             |
| Martin et al.[(74) 2010    | USA             | Jan 2000-Jun 2009  | 90              |
| Ji et al.[(75) 2011        | China           | Apr 2009-Jul 2009  | 20              |
| Shafaei et al.[(76) 2011   | USA & Europe    | 1997-2009          | 68              |
| Cho et al.[(77) 2011       | Japan           | Aug 2005-Feb 2010  | 27              |
| Abu Hilal et al.[(78) 2011| UK              | 2006-2009          | 36              |
| Bhjani et al.[(79) 2012    | Canada          | Jun 2006-May 2010  | 57              |
| Topal et al.[(80) 2012     | Belgium         | Oct 2002-Dec 2008  | 20              |
| Cannon et al.[(81) 2012    | USA             | 2004-2010          | 35              |
| Gumos et al.[(82) 2012     | USA             | Nov 2008-Oct 2010  | 53              |
| Abu Hilal et al.[(83) 2013 | UK              | Mar 2006-Nov 2011  | 84              |
| Tsung et al.[(84) 2014     | USA             | Nov 2007-Dec 2011  | 114             |
| Spampinato et al.[(85) 2014| Italy           | Jan 2009-Dec 2012  | 25              |
| Yu et al.[(86) 2014        | South Korea     | Jul 2007-Oct 2011  | 17              |
| Wu et al.[(87) 2014        | Taiwan          | Jan 2012-Dec 2012  | 69              |
| Medbery et al.[(88) 2014   | USA             | May 2008-Mar 2012  | 48              |
| Zhang et al.[(89) 2014     | China           | Jul 2011-Mar 2013  | 25              |
| Ahn et al.[(90) 2014       | South Korea     | Jan 2005-Feb 2013  | 51              |
| Benkabbou et al.[(91) 2015]| Morocco         | Jun 2010-Feb 2013  | 13              |
| Xiao et al.[(92) 2015      | China           | Jan 2010-Dec 2012  | 41              |
| Takahara et al.[(93) 2015* | Japan           | 2000-2010          | 436 (387)       |
| Allard et al.[(94) 2015    | France          | Jan 2006-Dec 2013  | 176             |
| Beppu et al.[(95) 2015*    | Japan           | Jan 2005-Dec 2010  | 210 (171)       |
| deAngelis et al.[(96) 2015]| France         | Jan 2000-Dec 2013  | 52              |
| van der Poel et al.[(97) 2016| UK             | Aug 2003-Mar 2015  | 159             |
| Lee et al.[(98) 2016       | China           | Nov 2003-Jan 2015  | 66              |
| Lai et al.[(99) 2016       | China           | Oct 1998-Feb 2015  | 35              |
| Takahara et al.[(100) 2016]| Japan          | Jan 2011-Dec 2013  | 929             |
| Cipriani et al.[(101) 2016]| UK             | Aug 2004-Apr 2015  | 133             |
| Ratti et al.[(102) 2016    | Italy           | 2008-2014          | 56              |
| Tranchart et al.[(103) 2016]| International  | 1997-2013          | 89              |
| Unterreiner et al.[(104) 2016]| France       | Jan 2012-Jan 2015  | 18              |
| Komatsu et al.[(105) 2016  | France          | Jan 2006-May 2014  | 38              |
| Martinez-Cecilia et al.[(106) 2017*| Europe | Jan 2005-Dec 2012  | 287 (225)       |
| Sotiropoulos et al.[(107) 2017]| Greece       | Jan 2012-Jan 2017  | 42              |
| Peng et al.[(108) 2017     | China           | Jan 2013-Oct 2016  | 36              |
| Chen et al.[(109) 2017     | China           | Apr 2015-Sep 2016  | 225             |
| Efano et al.[(110) 2017    | Russia          | May 2010-Jun 2016  | 91              |
| Lim et al.[(111) 2019*     | France          | 2011-2017          | 111 (55)        |
| Marino et al.[(112) 2019   | Italy           | Apr 2016-Mar 2017  | 20              |
| Fruscone et al.[(113) 2019]| USA             | 2011-2016          | 116             |
| Jang et al.[(114) 2019     | South Korea     | Jan 2014-Jul 2017  | 37              |
| Cipriani et al.[(115) 2019]| Italy           | Jan 2005-Nov 2017  | 145             |
| Chen et al.[(116) 2019     | Taiwan          | Dec 2010-Dec 2016  | 436             |
| Lee et al.[(117) 2019      | South Korea     | Jun 2016-Apr 2018  | 10              |
| Mejia et al.[(118) 2020    | USA             | Jun 2005-Sep 2018  | 171             |
| Cipriani et al.[(119) 2020]| Europe          | Jan 2007-Feb 2016  | 597 (545)       |
| Beard et al.[(120) 2020*   | International   | Jul 2002-Oct 2017  | 514 (115)       |

*Numbers in parentheses represent the number of cases after propensity score-matching. n/a: not available
Determining the learning curve for each approach is also of major significance. The learning curve is “the improvement in performance over time or the change in the ability to complete a task until failure is decreased to a constant acceptable rate”[110]. Data suggest that the learning curve for LMH is around 45-60 cases[93,111-113]. van der Poel et al.[93] reported that 55 is the “golden” number for LMH; however, all surgical operations were performed by two experienced hepatobiliary surgeons with at least three years of additional experience on minor laparoscopic hepatectomy. For RMH, Chen et al.[30] described an initial phase of 15 patients followed by an intermediate phase of 25 patients. The accumulated experience of the first 15 cases (defined as the “initial learning curve”), mostly comprised of right and left hemihepatectomies, was followed by more complex cases, such as trisectionectomy and 8-5-4 trisegmentectomy, in the next 25 cases (“phase of increased competency”). Their last 52-case “matured phase” was associated with an overall improvement in outcomes. However, the authors did not mention who their “learning curve” refers to, as “all procedures were performed by the same operative team”, but they do not specify their prior experience with minor robotic resections or even with LMH. Tsung et al.[20] reported that the outcomes of their robotic cases between 2010-2011 were superior to those of the robotic cases between 2007-2010, but the authors pooled together both minor and major resections for this comparison.

**OPERATING TIME**

A systematic review and pooled analysis of outcomes on robotic liver resections showed that the mean operating time for RMH (≥ 4 segments) was 405 ± 100 min[18], while another more recent systematic review reported similar pooled mean operating time for RMH (≥ 3 segments) of 403.4 ± 107.5 min[114]. A systematic literature review on LMH[115] showed that mean operating time in all individuals studies was lower than the pooled operating times reported in the RMH systematic reviews[18,114]. Additionally, in a systematic review comparing LMH to open major hepatectomy, the pooled mean operating time in the LMH arm was 285 ± 105.6 min[116]. Similarly, in a large multicenter study from Europe, Cipriani et al.[109] reported a median operating time of 300 min (IQR 205-380) for LMH, and more specifically 300 min (IQR 160-240) for right hepatectomy and 270 min (IQR 160-290) for left hepatectomy. Tsung et al.[20] compared RMH vs. LMH, and showed that both overall operating room time (452 min vs. 348.5 min) and operating time (330 min vs. 280.5 min) were significantly longer in the RMH group. Spampinato et al.[44] also showed that operating time was longer in RMH (330, IQR 240-725 min) when compared to LMH (360, IQR 180-600 min), while all procedures were performed by surgeons experienced in minimally-invasive liver surgery. Notably, a more recent study showed no difference in median operating time between RMH (194, range 152-255 min) and LMH (204, 149-280 min), and all of the operations were again performed by experienced minimally-invasive

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Table 3. Previously published reports on the comparison of laparoscopic and robotic liver resection along with the number of major hepatectomy cases in each group

| Author       | Total laparoscopic | Laparoscopic major hepatectomy | Total robotic | Robotic major hepatectomy |
|--------------|--------------------|-------------------------------|--------------|---------------------------|
| Ji et al. [41] 2011 | 20 | 4 | 13 | 9 |
| Tsung et al. [20] 2014 | 114 | 42 | 57 | 21 |
| Spampinato et al. [28] 2014 | 25 | 25 | 25 | 25 |
| Yu et al. [105] 2014 | 17 | 11 | 13 | 3 |
| Wu et al. [33] 2014 | 69 | 4 | 52 | 14 |
| Lee et al. [46] 2016 | 66 | 2 | 70 | 14 |
| Lai et al. [48] 2016 | 35 | 1 | 100 | 27 |
| Efanov et al. [34] 2017 | 91 | 11 | 40 | 2 |
| Lim et al. [56] 2019* | 111 (55) | 15 (8) | 61 (55) | 9 (4) |
| Marino et al. [35] 2019 | 20 | 20 | 14 | 14 |
| Fruscione et al. [42] 2019 | 116 | 116 | 57 | 57 |
| Lee et al. [36] 2019 | 10 | 3 | 13 | 8 |
| Mejia et al. [46] 2020 | 171 | 46 | 43 | 8 |
| Beard et al. [48] 2020* | 514 (115) | 53 (21) | 115 | 18 |

*Numbers in parentheses represent the number of cases after propensity score-matching.
hepatobiliary surgeons. A Korean group recently published the initial experience of a single surgeon with robotic liver surgery and showed that there was no difference in operating time between robotic and laparoscopic left hepatectomy (248.6 ± 37.5 min vs. 226.7 ± 26.6 min). Another recent study comparing robotic vs. laparoscopic right hepatectomy demonstrated that operating time was significantly shorter in the robotic group compared to the laparoscopic one (425 ± 139 min vs. 565.18 ± 183.73 min), and all procedures were performed by the same young surgeon. That may serve as an indicator that as experience with RMH grows, operating time seems to decrease and to be equivalent to, or even shorter than, that of LMH. However, a major confounding factor is surgeon’s surgical expertise and prior experience with minimally-invasive major hepatectomy; thus, future studies comparing operating time, as well as other parameters, between RMH and LMH should always mention primary surgeon’s prior experience and should make sure that the two comparison groups are equivalent regarding this parameter.

ESTIMATED BLOOD LOSS
The pooled estimated blood loss (EBL) in RMH based on two systematic reviews was 543.4 ± 371 mL and 380 ± 505 mL, respectively. The pooled mean EBL for the LMH arm in a systematic review comparing LMH to open major hepatectomy was 450.6 ± 563.2 mL, which is comparable to the pooled rates reported in the RMH systematic reviews. However, major deviations were found between the individual RMH or LMH studies themselves included in each systematic review. Cipriani et al. reported a median EBL of 350 mL (IQR 125-1350) for LMH, and more specifically 400 mL (IQR 200-800) for right hepatectomy and 300 mL (IQR 50-260) for left hepatectomy. Studies directly comparing EBL between RMH and LMH showed that EBL in RMH was lower than that in LMH, while the difference was not statistically significant in any of the individual studies.

LENGTH OF STAY
Two prior systematic reviews on RMH reported a pooled mean hospital length of stay (LOS) of 10.5 ± 4.8 and 11 ± 6 days, respectively. The mean LOS of most individual studies included in a systematic review on LMH was shorter than that of the two RMH systematic reviews. Another systematic review showed that the pooled mean LOS for LMH was 10 ± 8.7 days. Cipriani et al. reported a median LOS of 6 days (IQR 4-10) for LMH, and more specifically 7 days (IQR 4-13) for right hepatectomy, and 5 days (IQR 4-10) for left hepatectomy. Studies reporting on the direct comparison of RMH vs. LMH did not demonstrate any statistically significant difference between the two arms.

COMPLICATIONS, SURVIVAL AND ONCOLOGIC OUTCOMES
When comparing RMH and LMH, Tsung et al. reported that no difference was observed between the two groups with a complication rate of 24% (n = 5/21) vs. 32% (n = 13/42), respectively, while only one patient in the RMH group experienced a major complication (Clavien-Dindo grade ≥ 3) (4.8% vs. 0%, respectively). The 90-day mortality rate was 0% in both groups. Similar complication rates were documented by Spampinato et al. RMH: 20% (n = 5/25) vs. LMH: 36% (n = 9/25), with 4% (n = 1/25) and 12% (n = 3/25) of the patients experiencing a major complication (Clavien-Dindo grade ≥ 3), respectively. However, one patient in the LMH group died. Marino et al. also failed to show a difference in morbidity with 21.4% (n = 3/14) of the patients in the RMH arm vs. 15% (n = 3/20) in the LMH group experiencing any complications, while no major complications occurred. Ninety-day mortality was 0% in both groups. The largest and most recent comparative study between RMH and LMH was performed by Fruscione et al. and also did not show a significant difference in complications between the two groups. Specifically, the complication rate for RMH was 28.1% (n = 16/57) and for LMH 35.3% (n = 41/116), with 7% (n = 4/57) and 9.5% (n = 11/116) being classified as major complications (Clavien-Dindo grade ≥ 3). No death was reported in either of the comparison arms. Additionally, when RMH and LMH were performed for liver malignancies, none of the four studies showed a difference in surgical margin status between the two approaches (positive margins: 0%-8.3% vs. 7%-15%, respectively), and long-term outcomes were comparable when reported.
ECONOMIC COST
Mejia et al.\cite{46} reported that the adjusted room and board charges were significantly lower in the LMH vs. the RMH group, with no other difference between the two groups regarding economic cost. Of note, when comparing the cost of LMH vs. RMH, the fixed capital cost ($1,000,000-$2,600,000 for a robotic system with a 10-year longevity period)\cite{117-120} and annual maintenance cost ($90,000-$175,000)\cite{120} for a hospital to purchase and maintain a surgical robot, should also be taken into consideration. The addition of this cost can be burdensome, particularly for low-volume liver surgery centers, and this remains a significant driving factor for the slow spread of RMH and robotic liver surgery in general. It should also be noted that access to the robot in the operating room can be a challenge due to competition with other surgical service lines.

CONCLUSION
The introduction of laparoscopy and robotic surgical systems in liver surgery has significantly changed the current state of practice. Although both approaches have been more widely tested for minor liver resections, the number of LMHs and RMHs performed worldwide has significantly increased over recent years, and is still on the rise. Although there is a considerable deviation in outcomes after RMH, especially during early experience, when RMH is performed by experienced surgeons in high-volume liver centers, it can be associated with equivalent operating time, EBL, LOS, morbidity and mortality, and comparable oncologic outcomes in terms of achieving a margin-negative resection and long-term overall survival. The fixed capital and annual maintenance costs for the robotic surgical system may pose a significant obstacle in the broader adoption of RMH, particularly in low-volume centers.

DECLARATIONS
Authors’ contributions
Study concept, data acquisition, data analysis and interpretation, drafting, critical revision, final approval of the manuscript: Ziogas IA, Tohme S, Geller DA

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