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Review

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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[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[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[8,9], and the Brisbane 2000 nomenclature is utilized to define minor and major hepatectomy in the field of liver surgery[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[11]. The first series on laparoscopic liver resections consisted mostly of minor liver resections[3,4,12,13]. The first laparoscopic major hepatectomy (LMH) was performed in 1997[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[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[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[18]. The first large series of robotic liver resection was reported in 2002[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 about the outcomes 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[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[11]. 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[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[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
Giulianotti *et al.*[72] 2011	Italy & USA	Mar 2002-Mar 2009	70	27	5	20
Ji *et al.*[83] 2011	China	Apr 2009-Jul 2009	13	9	6	2
Tsung *et al.*[20] 2014	USA	Nov 2007-Dec 2011	57	21	n/a	n/a
Spampinato *et al.*[94] 2014	Italy	Jan 2009-Dec 2012	25	25	7	16
Yu *et al.*[105] 2014	South Korea	May 2010-Oct 2011	13	3	3	0
Wu *et al.*[22] 2014	Taiwan	Jan 2012-Dec 2012	52	14	0	0
Felli *et al.*[23] 2015	Italy	Apr 2013-May 2014	20	2	2	0
Lee *et al.*[24] 2016	China	Sep 2010-Jan 2015	70	14	10	4
Kingham *et al.*[25] 2016	USA	2010-2014	64	6	4	2
Lai *et al.*[26] 2016	China	May 2009-Feb 2015	100	27	6	20
Lee *et al.*[27] 2016	China	Sep 2010-Apr 2015	15	5	3	2
Sham *et al.*[28] 2016	USA	May 2011-Dec 2014	71	17	n/a	n/a
Chen *et al.*[29] 2016	Taiwan	May 2013-Aug 2015	13	13	0	13
Chen *et al.*[30,31] 2017	Taiwan	Jan 2012-Oct 2015	183	92	32	41
Quijano *et al.*[32] 2017	Spain	Oct 2010-Apr 2016	21	5	2	1
Magistri *et al.*[33] 2017	Italy	Jan 2012-May 2016	22	2	0	2
Efanov *et al.*[34] 2017	Russia	May 2010-Jun 2016	40	2	2	0
Daskalaki *et al.*[35] 2017	USA	Jan 2009-Dec 2013	68	29	2	21
Choi *et al.*[36] 2017	South Korea	Dec 2008-May 2016	70	54	27	12
Khan *et al.*[37] 2018	International	2006-2016	61	16	8	8
Goja *et al.*[38] 2019	India	Feb 2015-Jan 2016	21	6	3	3
Lim *et al.*[39] 2019*	France	2011-2017	61 (55)	9 (4)	n/a	n/a
Marino *et al.*[40] 2019	Italy	Apr 2016-Mar 2017	14	14	0	14
Marino *et al.*[41] 2019	Italy	Apr 2015-May 2017	35	35	35	0
Fruscione *et al.*[42] 2019	USA	2011-2016	57	57	20	20
Gravetz *et al.*[43] 2019	USA	2013-2017	33	8	n/a	n/a
Magistri *et al.*[44] 2019	Italy	Jul 2014-Sep 2017	60	3	1	2
Lee *et al.*[45] 2019	South Korea	Jun 2016-Apr 2018	13	8	8	0
Mejia *et al.*[46] 2020	USA	Aug 2013-Sep 2018	43	8	4	4
Sucandy *et al.*[47] 2020	USA	2013-2018	80	24	14	6
Beard *et al.*[48] 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.*[14] 1997	Italy	1993-Dec 1995	20	14	6	5
Gigot *et al.*[49] 2002	Europe	Feb 1994-Dec 2000	37	2	n/a	n/a
O'Rourke *et al.*[6] 2004	Australia	Nov 1999-Sep 2002	12	12	0	12
Dulucq *et al.*[50] 2005	France	Jan 1995-Jan 2004	32	11	4	6
Vibert *et al.*[51] 2006	France	Jan 1995-Dec 2004	89	38	3	27
Topal *et al.*[52] 2007	Belgium	n/a	2	2	0	2
Gayet *et al.*[53] 2007	France	n/a	41	41	0	37
Koffron *et al.*[12] 2007	USA	Jul 2001-Nov 2006	300	119	47	64
Dagher *et al.*[54] 2007	France	Feb 1999-Jan 2006	70	19	5	12
Gumbs *et al.*[55] 2008	France	n/a	3	3	0	0
Gumbs *et al.*[56] 2008	France	n/a	5	5	0	0
Cho *et al.*[57] 2008	South Korea	Jan 2004-Dec 2007	128	47	23	13
Buell *et al.*[13] 2008	USA	Jan 2001-Apr 2008	253	69	24	33
Topal *et al.*[58] 2008	Belgium	Oct 2002-Jun 2007	109	21	4	14
Dagher *et al.*[59] 2008	France	Since Feb 1999	20	20	0	20
Wakabayashi *et al.*[60] 2009	Japan	Jul 1995-Apr 2008	176	39	10	12
Castaing *et al.*[61] 2009	France	Jan 1997-May 2007	60	26	0	22

Nguyen *et al.*[62] 2009	USA & Europe	Feb 2000-Sep 2008	109	49	10	31
Vigano *et al.*[63] 2009	France	Jan 1996-Aug 2008	174	35	n/a	23
Bryant *et al.*[64] 2009	France	May 1996-Dec 2007	166	31	11	19
Yoon *et al.*[65] 2009	South Korea	Oct 1998-Jun 2007	46	21	21	0
Cho *et al.*[66] 2009	South Korea	May 2003-Apr 2007	40	12	0	5
Baker *et al.*[67] 2009	USA	Jan 2006-May 2008	33	33	0	33
Dagher *et al.*[68] 2009	International	1997-2008	210	210	74	136
Cai *et al.*[69] 2009	China	2005-2007	19	19	19	0
Dagher *et al.*[70] 2009	France	Feb 2002-Aug 2007	22	22	0	22
Yoon *et al.*[71] 2010	South Korea	Sep 2003-Nov 2008	69	21	2	6
Nitta *et al.*[7] 2010	Japan	Nov 2002-Dec 2008	42	42	16	14
Dagher *et al.*[73] 2010	Europe	1998-2008	163	16	4	10
Martin *et al.*[74] 2010	USA	Jan 2000-Jun 2009	90	90	50	40
Ji *et al.*[83] 2011	China	Apr 2009-Jul 2009	20	4	3	1
Shafaee *et al.*[75] 2011	USA & Europe	1997-2009	68	22	1	12
Cho *et al.*[76] 2011	Japan	Aug 2005-Feb 2010	27	20	5	10
Abu Hilal *et al.*[77] 2011	UK	2006-2009	36	36	0	36
Bhojani *et al.*[78] 2012	Canada	Jun 2006-May 2010	57	19	5	8
Topal *et al.*[79] 2012	Belgium	Oct 2002-Dec 2008	20	20	4	13
Cannon *et al.*[80] 2012	USA	2004-2010	35	19	4	14
Gumbs *et al.*[81] 2012	USA	Nov 2008-Oct 2010	53	25	8	13
Abu Hilal *et al.*[82] 2013	UK	Mar 2006-Nov 2011	84	38	0	38
Tsung *et al.*[20] 2014*	USA	Nov 2007-Dec 2011	114	42	n/a	n/a
Spampinato *et al.*[94] 2014	Italy	Jan 2009-Dec 2012	25	25	8	15
Yu *et al.*[105] 2014	South Korea	Jul 2007-Oct 2011	17	11	11	0
Wu *et al.*[22] 2014	Taiwan	Jan 2012-Dec 2012	69	4	0	0
Medbery *et al.*[84] 2014	USA	May 2008-Mar 2012	48	48	0	48
Zhang *et al.*[85] 2014	China	July 2011-Mar 2013	25	25	0	25
Ahn *et al.*[86] 2014	South Korea	Jan 2005-Feb 2013	51	2	2	0
Benkabbou *et al.*[87] 2015	Morocco	Jun 2010-Feb 2013	13	2	1	1
Xiao *et al.*[88] 2015	China	Jan 2010-Dec 2012	41	4	0	0
Takahara *et al.*[89] 2015*	Japan	2000-2010	436 (387)	46 (42)	n/a	n/a
Allard *et al.*[90] 2015	France	Jan 2006-Dec 2013	176	80	14	63
Beppu *et al.*[91] 2015*	Japan	Jan 2005-Dec 2010	210 (171)	12 (10)	n/a	n/a
de'Angelis *et al.*[92] 2015	France	Jan 2000-Dec 2013	52	18	2	15
van der Poel *et al.*[93] 2016	UK	Aug 2003-Mar 2015	159	159	54	105
Lee *et al.*[24] 2016	China	Nov 2003-Jan 2015	66	2	2	0
Lai *et al.*[26] 2016	China	Oct 1998-Feb 2015	35	1	0	1
Takahara *et al.*[95] 2016	Japan	Jan 2011-Dec 2013	929	929	238	234
Cipriani *et al.*[96] 2016	UK	Aug 2004-Apr 2015	133	65	8	43
Ratti *et al.*[97] 2016	Italy	2008-2014	25	6	4	2
Tranchart *et al.*[98] 2016	International	1997-2013	89	7	3	4
Untereiner *et al.*[99] 2016	France	Jan 2012-Jan 2015	18	2	2	0
Komatsu *et al.*[100] 2016	France	Jan 2006-May 2014	38	38	10	28
Martinez-Cecilia *et al.*[101] 2017*	Europe	Jan 2005-Dec 2012	287 (225)	49 (47)	n/a	n/a
Sotiropoulos *et al.*[102] 2017	Greece	Jan 2012-Jan 2017	42	1	1	0
Peng *et al.*[103] 2017	China	Jan 2013-Oct 2016	36	15	15	0
Chen *et al.*[104] 2017	China	Apr 2015-Sep 2016	225	126	26	43
Efanov *et al.*[34] 2017	Russia	May 2010-Jun 2016	91	11	2	9
Lim *et al.*[39] 2019*	France	2011-2017	111 (55)	15 (8)	n/a	n/a
Marino *et al.*[40] 2019	Italy	Apr 2016-Mar 2017	20	20	0	20
Fruscione *et al.*[42] 2019	USA	2011-2016	116	116	22	46
Jang *et al.*[106] 2019	South Korea	Jan 2014-Jul 2017	37	17	9	8
Cipriani *et al.*[107] 2019	Italy	Jan 2005-Nov 2017	145	145	59	86
Chen *et al.*[108] 2019	Taiwan	Dec 2010-Dec 2016	436	90	31	52
Lee *et al.*[45] 2019	South Korea	Jun 2016-Apr 2018	10	3	3	0
Mejia *et al.*[46] 2020	USA	Jun 2005-Sep 2018	171	46	13	33
Cipriani *et al.*[109] 2020	Europe	Jan 2007-Feb 2016	597 (545)	597 (545)	215 (172)	382 (351)
Beard *et al.*[48] 2020*	International	Jul 2002-Oct 2017	514 (115)	53 (21)	17 (n/a)	33 (n/a)

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

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.*[83] 2011	20	4	13	9
Tsung *et al.*[20] 2014	114	42	57	21
Spampinato *et al.*[94] 2014	25	25	25	25
Yu *et al.*[105] 2014	17	11	13	3
Wu *et al.*[22] 2014	69	4	52	14
Lee *et al.*[24] 2016	66	2	70	14
Lai *et al.*[26] 2016	35	1	100	27
Efanov *et al.*[34] 2017	91	11	40	2
Lim *et al.*[39] 2019*	111 (55)	15 (8)	61 (55)	9 (4)
Marino *et al.*[40] 2019	20	20	14	14
Fruscione *et al.*[42] 2019	116	116	57	57
Lee *et al.*[45] 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

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 rime 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 240-402) 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.*[94] also showed that operating time was longer in RMH (430, 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 hepatobiliary surgeons[42]. 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)[45]. 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[40]. 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[114] and 380 ± 505 mL[18], respectively. The pooled mean EBL for the LMH arm in a systematic review comparing LMH to open major hepatectomy was 450.6 ± 563.2[116], which is comparable to the pooled rates reported in the RMH systematic reviews[18,114]. However, major deviations were found between the individual RMH or LMH studies themselves included in each systematic review. Cipriani *et al.*[109] 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[20,40,42,94].

LENGTH OF STAY

Two prior systematic reviews on RMH reported a pooled mean hospital length of stay (LOS) of 10.5 ± 4.8[114] and 11 ± 6 days[18], respectively. The mean LOS of most individual studies included in a systematic review on LMH[115] 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[116]. Cipriani *et al.*[109] 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[20,40,42,94].

COMPLICATIONS, SURVIVAL AND ONCOLOGIC OUTCOMES

When comparing RMH and LMH, Tsung *et al.*[20] 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[20]. Similar complication rates were documented by Spampinato *et al.*[94] 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[94]. Marino *et al.*[40] 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[40]. The largest and most recent comparative study between RMH and LMH was performed by Fruscione *et al.*[42] 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[42]. 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[20,40,42,94].

ECONOMIC COST

Mejia *et al*.[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)[117-120] and annual maintenance cost ($90,000-$175,000)[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

Availability of data and materials

Not applicable.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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