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Defining global benchmarks for robotic liver resections: an international multicenter study

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Declarations

We confirm all the authors are accountable for all aspects of the work

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Abstract

Objective: This study aimed to establish global benchmark outcomes indicators for robotic liver resections (R-LR).

Background: In recent years, minimally invasive liver resections and in particular R-LR has seen an increase in uptake in recent years. Although, benchmark outcomes have been recently established for laparoscopic (L) -LR, this has not been established for R-LR.

Methods: This is a post hoc analysis of a multicenter database of 5,213 patients undergoing R-LR in 51 international centers between 2016 and 2022. Benchmark cutoffs for 16 outcome indicators of low-risk R-LR were established. The 75th percentile of individual center medians for a given outcome indicator was set as the benchmark cutoff. Four procedures were selected for benchmarking: left lateral sectionectomy(LLS)/H23, left hepatectomy(LH)/H234±1, right hepatectomy(RH)/H5678±1 and right posterior sectionectomy/H67 (RPS).

Results: There were 1,654 R-LR cases (528 LLS/H23, 432 LH/H234±1, 408 RH/H5678±1, 286 RPS/H67) performed in 24 expert centers, of which 518 (31.3%) R-LR cases qualified as low risk benchmark cases. Benchmark outcomes were established for R-LLS/H23, R-LH/ H234±1, R-RH/ H5678±1 and R-RPS/H67 for operation time (190, 323, 474, 413) min, open conversion rate (0.0, 0.0, 1.3, 0.0)%, estimated blood loss (100, 250, 600, 550) mls, blood transfusion rate (0.0 ,0.0, 20.0, 29.2)%, postoperative major morbidity (0.0 ,0.0, 20.9, 16.7)%, 90-day mortality (0.0, 0.0,0.0, 0.0)% and textbook outcome (12.5,24.3,0,0)%.

Conclusions: The present study established the first global benchmark values for R-LR. It provided an up-to-date reference of best achievable outcomes for auditing and benchmarking.

Keywords: robotic; liver resection; hepatectomy; benchmark; global;

Introduction

Benchmarking serves as a reference tool in surgery of the best achievable outcomes and provides a metric to which centers can work towards improving healthcare outcomes [1]. This is of importance particularly during clinical audits or where novel interventions are being evaluated [1]. Over the past 2 decade, there has been a rapid rise in the adoption of minimally-invasive liver resections in particular laparoscopic liver resections (L-LR) [2,3]. More recently, there has been a trend towards increasing uptake of robotic(R)-LR [4]. International benchmark outcomes have been recently established for L-LR [5,6] focusing on 4 established and standardized LR procedures such as left lateral sectionectomy/H23 (LLS), left hepatectomy(LH)/H234±1, right hepatectomy(RH)/H5678±1 and right posterior sectionectomy(RPS)/H67 [5,6]

Presently, with the increasing adoption of R-LR globally [4] it is imperative to establish benchmark values in order to promote safe, achievable outcomes and enable clinical auditing of this emerging approach. Hence, the present study was conducted with the primary objective of establishing various clinically-relevant intraoperative and postoperative benchmark values for R-LR from low-risk patients who underwent surgery at high-volume expert centers globally.

Methods

This was a post-hoc analysis of an international multicenter database of 30,535 minimally-invasive liver resections performed at 71 centers globally between January 2016 to December 2022. Of these, 5,213 patients who underwent R-LR performed 51 at centers were identified. All participating institutions obtained their respective ethical board approvals according to their local requirements. Each individual center collected and entered their deidentified data into a standard excel data collection sheet. All data were collated and analyzed centrally at the Singapore General Hospital. The data were audited and checked for accuracy by the coordinating center and in the event of ambiguity, the contributing center was contacted to verify its accuracy. The Singapore Health Services Institution Review Board provided waiver for this study due to its retrospective nature and use of only deidentified data.

Study Design

High volume experienced centers

The study utilized a standardized methodology previously reported for various surgical procedures such as L-LR [5,6], open living donor hepatectomy [7], liver transplant [8], pancreatic surgery [9], bariatric surgery [10], living donor liver transplant [11], resection of perihilar cholangiocarcinoma [12] and open major liver resections [13]. Centers which met the following criteria: (i) cumulative experience of over 80 MI-LR [benchmark] including over 25 R-LR [14], (ii) average case load ≥ 20 MI-LR including ≥ 10 R-LR per annum between 2016-2022 [15, 16] and (iii) academic interest in MI-LR as evidenced by ≥ 1 PubMed-indexed publication on MI-LR were defined as a high-volume expert center in this study. Twenty-five of 51 centers met the study criteria for high volume expert center. These included from 10 from the East and 15 from the West. Twenty-six centers which did not meet criteria formed the control group. All centers' identities were anonymized. Four R-LR procedures: R-LLS/ H23, R-LH/ H234±1, R-RH/H5678±1 and R-RPS/H67 were selected for benchmarking. These procedures were previously selected for benchmarking for L-LR [5,6]

Low risk procedures

Only patients with a low-preoperative risk profile were selected for benchmarking [5,9]. The inclusion criteria included: (i) patients aged between 18 to 70 years old and ii) a low American Society of Anesthesiology (ASA) score of ≤2. The exclusion criteria [5,6] included: patients with very large tumors ≥10 cm; BMI ≥ 35 kg/m; Child's B liver cirrhosis or portal hypertension; previous liver resections (repeat liver resections) or associating liver partition and portal vein ligation for staged hepatectomy, bilio-enteric anastomoses, hilar lymph node clearance; concomitant major operations such as colectomies, bowel resections and stoma reversals with R-LR; ≥ 1 multiple minor liver resections with R-LLS/H23 and ≥ 2 multiple minor liver resections with R-LH/ H234±1, R-RH/H5678±1 and R-RPS/H67. Notable, R-LR performed for living donor hepatectomies were also specifically excluded as these technically complicated procedures required highly specialized techniques and skillsets which differ from tumor resection surgery.

Definitions

R-LLS/ H23, R-LH/ H234±1, R-RH/H5678±1 and R-RPS/H67 were classified according to the 2000 Brisbane classification [17] and New World terminology [18]. Both RH and LH with and without caudate lobe resections were included per the Institut Montsouris Mutualiste (IMM) classification as proposed Kawaguchi et al [3]. Post-operative complications were classified according to the Clavien-Dindo classification [19] and recorded for up to 90 days. Major complications were defined as complications > Clavien-Dindo grade two. R1 resection was defined as a close resection margin of less than one mm. Difficulty of resections were also graded according to the Iwate score [20, 21]. Failure-to-rescue (FTR) rate was defined as the ratio of the number of 90-day mortalities in patients with major complications (numerator) to the total number of patients with major complications (denominator)[22]. The definition of textbook outcomes (TO) were according to that reported by Hobeika et al [23] and was considered in patients fulfilling six clinical outcomes including absence of blood transfusion, absence of postoperative morbidity, R0 surgical margin, absence of unplanned 30-day readmission, absence of postoperative mortality and absence of prolonged hospital stay defined as postoperative stay of ≤50th percentile of the total cohort of the particular procedure (LLS/H23, LH/H234±1, RH/H5678±1 or RPS/H67.

Outcome indicators

As previously reported, 16 clinically relevant intra- and postoperative outcomes indicators were selected to establish benchmark cutoffs [5, 6]. The intra-operative outcomes included operation time, estimated blood loss, blood loss ≥ 500mls, blood loss ≥ 1000mls, need for intraoperative blood transfusion and open conversion. The postoperative outcomes included were postoperative 90-day morbidity, postoperative 90-day major morbidity (defined as > Clavien-Dindo grade two), postoperative length of stay (LOS), postoperative 30-day and 90-day mortality, 90-day reoperation, 30-day unplanned readmission rates, R1 resection (< one mm margin for malignant tumors) and FTR.

Benchmark values and statistical analysis

A benchmark value was subsequently established for each of the 16 outcome indicators from patients who underwent the 4 different procedures. As previously reported, we utilized the 75th percentile (indicator of poor outcome) of individual centers medians for a given outcome indicator as the benchmark cutoff [1,5-13]. Mann-Whitney U test was used for continuous variables, while Fisher's exact test and Pearson's $\chi 2$ test were used for categorical variables. All statistical analyses were performed using IBM SPSS V23.0 and Stata V17.0 (StataCorp, College Station, TX, USA). We also reported the benchmark outcomes for L-LR which were published previously [5,6] as a reference.

Comparative cohorts

Two separate cohorts of patients: high risk cases who underwent R-LR in experienced expert centers and low risk R-LR meeting benchmark outcomes criteria who underwent resection at centers which did not meet the inclusion criteria as an expert center were used as control groups to test the benchmark values. We also performed comparative analysis of benchmark cases performed in Eastern expert centers with Western expert centers.

Results

Overall, 5,213 R-LR were performed in 51 centers. There were 603 R-LLS/H23, 484 R-LH/H234±1, 445 R-RH/H5678±1 and 318 R-RPS/H67. Twenty-four centers met study criteria as an expert center and 27 centers did not meet study criteria. 1,654 cases including 528 R-LLS, 432 R-LH, 408 R-RH and 286 R-RPS were performed in 24 expert centers and 196 cases including 75 R-LLS, 52 R-LH, 37 R-RH and 32 R-RPS were performed in non-expert centers. There were 518 benchmark cases performed in expert centers and 71 benchmark cases in non-expert centers. Of the 518 benchmark cases in expert centers, 340 cases (65.6%) were performed in 10 Eastern centers and 178 cases were performed in 14 Western centers

The flow chart demonstrating the selection of cases is summarized in **Figure 1.** Of these, 518 R-LR met the criteria for low-risk benchmark cases performed in expert centers. The proportion of benchmark cases in the 24 benchmark centers ranged from 2.7% to 81.8% (**Figure 2**). The baseline clinicopathological features and outcomes of these 518 benchmark cases performed at the 24 expert centers are summarized in Supplementary 1 and 2, Supplemental Digital Content 1, http://links.lww.com/SLA/F547. Fourteen cases required conversion to the open approach due to tumor extend/ oncological reasons (n=7), adhesions (n=4), poor exposure (n=2) and cirrhosis (n=1).

Benchmark outcomes

The 16 benchmark cutoffs were summarized in **Tables 1 and 2**. When referenced to L-LLS benchmark outcomes which we had previously reported [5], the benchmark values for R-LLS seemed to be lower for operation time, estimated blood loss, blood loss ≥ 500 mls, open conversion rate and R1 resection compared L-LLS. Benchmark values for blood transfusion rate, major morbidity, FTR and 30-day/ 90-day mortalities were similar, while readmission rate, post-operative morbidity and LOS benchmark values for R-LLS were higher than L-LLS [5].

For R-LH, the benchmark outcomes established for blood loss, blood transfusion rate, open conversion rate, major morbidity and reoperation were lower than previously reported for L-LH [5]. The benchmark values for FTR, 30-day/90-day mortality and LOS were similar, while operation time, post-operative 90-day morbidity, readmission rate and R1 resection benchmark values for R-LH were higher than that reported for L-LH [5].

With regards to R-RH, open conversion rate, readmission rate and R1 resection benchmark values were lower than previously reported for L-RH [5]. However, operation time, blood loss, blood loss >500/1000 mls, blood transfusion rate and length of stay were higher for R-RH. Benchmark values for 90-day morbidity, major morbidity, reoperation rate, FTR and 30-day/90-day mortality were similar between R-RH and L-RH.

For R-RPS, open conversion rate and achieving TO was lower than previously reported for L-RPS [6]. The benchmark values for operation time, blood loss, blood loss >500/1000 mls, blood transfusion rate, readmission rate, 90-day morbidity and major morbidity were higher than reported for R-RPS [6]. Benchmark values for LOS, reoperation rate, FTR, R1 resection and 30-day/90-day mortality were similar between R-RPS and L-RPS [6]. Supplementary 3, Supplemental Digital Content 1, http://links.lww.com/SLA/F547 summarizes the common major complications occurring in the benchmark cases performed in benchmark centers.

Outcome comparisons

We validated the applicability of benchmark outcomes in 2 separate cohort of patients: high-risk R-LR performed in benchmark expert centers and low-risk R-LR performed in non-benchmark centers (**Tables 3 and 4**).

Comparison with high-risk cases in benchmark centers

In the cohort of high-risk cases performed in benchmark expert centers, for R-LLS; operation time, blood loss, LOS, readmission, morbidity and TO were within benchmark values but blood transfusion rate, blood loss > 500/1000 mls, open conversion rate, major morbidity, reoperation, 30/90-d mortality, FTR and R1 resection were beyond. For R-LH, operation time, blood loss, blood loss > 500 mls, LOS, R1 resection and TO were within benchmark values whereas blood transfusion rate, blood loss > 1000 mls, open conversion rate, readmission, morbidity, major morbidity, reoperation, 30/90-d mortality and FTR were beyond.

With respect to R-RH, operation time, estimated blood loss, intraoperative blood transfusion, blood loss >500/ 1000 mls, LOS, morbidity, major morbidity and TO were within benchmark values whereas open conversion rate, readmission rate, reoperation, 30/90-day mortality, FTR and R1 resection were beyond. For R-RPS, operation time, intraoperative blood transfusion, blood loss, blood loss > 500/1000 mls, morbidity, major morbidity, LOS and TO were within benchmark values but open conversion rate, readmission rate, reoperation, 30/90-day mortality, FTR and R1 resection were beyond benchmark values.

Comparison with low-risk benchmark cases performed in non-benchmark centers

In the cohort of low-risk cases performed in non-benchmark centers, for R-LLS; intraoperative blood transfusion, blood loss, blood loss > 500/1000 mls, open conversion rate, LOS, morbidity, major morbidity, reoperation, 30/90-day mortality, FTR, R1 resection and TO were within benchmark values whereas operation time and readmission rates were beyond. For R-LH, blood loss > 500 mls, open conversion rate, LOS, reoperation, 30/90-day mortality, FTR, R1 resection and TO were within benchmark values whereas operation time, intraoperative blood transfusion, blood loss, blood loss > 1000mls, morbidity and major morbidity were beyond.

With regards to R-RH; operation time, blood loss. blood loss > 500/1000 mls, LOS, readmission, morbidity, major morbidity, 30/90-day mortality, FTR and TO were within benchmark values whereas intraoperative transfusion, open conversion, reoperation and R1 resection were beyond. For R-RPS, operation time, estimated blood loss, blood loss > 500/1000 mls, open conversion rate, LOS, readmission, morbidity, major morbidity, reoperation, 30/90-day mortality, FTR and TO were within benchmark values whereas blood transfusion rate and R1 resection were beyond.

Comparison between Eastern and Western centers

Three hundred and forty benchmark cases (65.6%) were performed in 10 Eastern centers and 178 benchmark cases were performed in 14 Western centers. Comparison between the baseline characteristics of benchmark patients operated at Asian centers demonstrated that these patients were significantly more likely to be male, had a lower BMI, increased frequency of malignancy and cirrhosis compared to patients operated in Western centers (supplementary 4, Supplemental Digital Content 1, http://links.lww.com/SLA/F547). There was a significantly higher proportion of HCC and intrahepatic cholangiocarcinoma operated in Eastern Centers compared to a higher proportion of liver metastases operated in Western centers.

Benchmark cases of Eastern and Western centers were compared with respect to their outcomes (Supplementary 5 and 6, Supplemental Digital Content 1, http://links.lww.com/SLA/F547). In Eastern centers, R-LR was associated with a shorter operation time (R-LLS, R-LH, R-RH, R-RPS), lower estimated blood loss (R-LLS, R-LH, R-RH), lower major morbidity (R-RH, R-RPS), lower rate of R1 resection (R-LH, R-RPS) but longer postoperative length of stay compared to Western centers (R-LLS, R-LH, R-RPS).

Discussion

In this study, we established 16 benchmark values for perioperative outcomes of R-LR for 4 standardized procedures: R-LLS, R-LH, R-RH and R-RPS utilizing a large international multicenter database which are summarized in **Tables 1** and **2**. To our knowledge, this is the first study to date to establish global benchmarks for R-LR. Presently, the adoption of R-LR globally is increasingly rapidly even at a much quicker pace than L-LR in recent years [4]. This may be due to the purported advantages of R-LR over L-LR especially during the early learning phase [4,24-26]. Hence, it is timely that benchmarks outcomes are established for R-LR to enable surgeons and centers embarking on R-LR to audit their outcomes and evaluate their surgical performance.

Global benchmark outcomes were recently established for L-LR with respect to

R-LLS, R-LH, R-RH and R-RPS [5,6]. These benchmark cutoffs are summarized in **Tables 1** and **2**. One of the key findings in the present study was that the benchmark values for open conversion rate were extremely low for R-LR [R-LLS, 0%; R-LH, 0%; R-RH, 1.3%; R-RPS, 0%). These cutoffs were lower than those previously reported for L-LR [L-LLS, 2.1%; L-LH, 13.4%; L-RH, 13.0%; L-RPS,12.5%] [5,6]. The present findings are consistent with recently published studies which reported that R-LR were associated with a lower open conversion rate when compared to L-LR for various types of LR [24-26]. It also provides further supporting evidence that the robotic platform may provide technical advantageous over laparoscopy resulting in a lower conversion rate as the benchmark cases in both studies represent a selected relatively homogenous group of low risk cases. Hence, this limits the possible confounding effect of case selection bias.

Previous studies had previously established that R-LR were associated with a longer operation time compared to L-LR [27]. In the present study, the benchmark operation time was for R-LR was longer when compared to L-LR with regards to R-LH, R-RH and R-RPS but not R-LLS. It is also imperative to highlight that the benchmark outcomes for FTR, 30-day/ 90-day mortality and reoperation rates established for R-LR in this study were low and similar to that previously established for L-LR [5,6]. These findings suggest that both minimally-invasive approaches can now be performed safely in expert centers globally.

In this study, we further tested these newly-established benchmark outcomes in two separate cohorts of patients: a cohort of high-risk cases who underwent R-LR in the experienced, expert centers and a group of low-risk cases who underwent R-LR at centers which did not meet the inclusion criteria as an expert center **(Tables 3 and 4**).

We found that when comparison was made with the cohort of high-risk cases performed in expert centers, the open conversion rate, reoperation rate, 30-day mortality rate, 90-day mortality rate and FTR were beyond benchmark outcomes. These findings were not unexpected as patients with significant comorbidities would be expected to have a higher mortality rate compared to low risk patients [28]. Furthermore, LR for huge-sized tumors and patient with more advanced cirrhosis would be expected to be more technically challenging and would be associated with a higher open conversion rate [29,30].

Comparison with the cohort of low-risk R-LR cases performed in non-benchmark centers surprisingly demonstrated that most outcomes fell within or close to benchmark cut-offs. This was contrary to previous studies which reported significantly poorer outcomes in non-benchmark centers which suggested that operative volume and experience played a critical role in patients' surgical outcomes [5,6]. We hypothesize that the current observation may be due to the fact that most non-benchmark R-LR centers in this study had extensive prior experience with L-LR. Hence, although these centers did not meet the criteria for an expert R-LR, it is well-known that the learning curve for experienced L-LR surgeons to adopt R-LR is relatively short [10]. Furthermore, it is also imperative to note that the sample size of patients in this cohort was very small and ranged from only 13-25 patients which predisposed this analysis to Type 2 errors.

Although the present benchmark study, integrated the experiences of both Eastern and Western experiences, we cannot overlook the differences in outcomes between the 2 regions. Similar to previous studies defining benchmark outcomes for living donor liver transplant [11] and resection for perihilar cholangiocarcinoma [13), benchmark cases performed in Eastern centers were generally associated with superior short-term outcomes with the exception of a longer postoperative stay. In general, we found that R-LR performed at Eastern centers were associated with a shorter operation time, decreased blood loss, lower R1 resection rate and lower major morbidity especially for complicated R-LR (Supplementary 5 and 6, Supplemental Digital Content 1, http://links.lww.com/SLA/F547) despite a higher proportion of patients with cirrhosis. Part of the rationale probably lies in surgical expertise, whereby the case volume of Eastern centers was on average higher than West centers in this series. In this study, 340 benchmark cases (65.6%) were performed in 10 Eastern centers, whereas 178 benchmark cases were performed in 14 Western centers. The higher R1 resection rate in Western centers may be partially explained by the geographical variation with respect to indications for resection. In Western centers, there was a higher frequency of R-LR for metastases rather than primary liver cancer whereby narrower resection margins and R1 resections are acceptable compared to resection for hepatocellular carcinoma.

It is also important to highlight that the complexity and outcomes of R-LR are influenced by various factors such as indications for resection (HCC vs metastases vs benign conditions), tumor size [29] and cirrhosis [30] which may confound the outcomes of liver resections even in this relatively homogenous cohort of low risk cases.

Finally, it is important to highlight several limitations in the present study. Firstly, due to the retrospective nature; study may be affected by biases and confounders, although most of the centers had a prospective database. This limitation can only be mitigated by performing a prospective clinical trial. Secondly, R-LR remains a relatively novel procedure as reflected by the relatively low number of cases even amongst these international expert centers. Hence, the procedure may not have completely matured even in these expert centers. As R-LR matures with increasing center experience in future, it would be important to update these reported benchmark values. Thirdly, there was like variability amongst the different participating centers in terms of surgical technique, proficiency in R-LR and perioperative management which would have impacted outcomes. Fourthly, this study only focused on short-term perioperative outcomes after R-LR. As R-LR is frequently performed for malignancies, future large-scale studies would be important in understanding the long-term oncologic outcomes of R-LR. Finally, due to the relatively small number of R-LR cases per center and the further significant reduction of the study population to benchmark cases for each specific procedure, there is a potential risk that the representation of cases would be biased to a few selected centers and disproportionately influence the study outcomes. Nonetheless, despite these limitations, this is the first international multi-center study to establish global benchmark outcomes for R-LR. Another strength of this study is the relatively large sample size, which enabled us to focus the analysis on a relatively homogenous group of low-risk patients undergoing 4 specific R-LR procedures: LLS/H23, LH/H234±1, RH/H5678±1 and RPS/H67. We were able to exclude various confounding factors such as multiple resections, concomitant major surgery, previous liver resections (redo hepatectomy), huge tumors, portal hypertension and Childs B cirrhosis.

In conclusion, we have established the first global benchmark values for R-LR for 4 standardized procedures: LLS/H23, LH/H234±1, RH/H5678±1 and RPS/H67 utilizing a large international multicenter database. These cases selected for benchmarking were low-risk cases operated at expert centers, hence reflecting the best possible outcomes of R-LR. The present results provide an up-to-date reference of the best achievable outcomes after R-LR and would be valuable for the evaluation of surgical performance after R-LR allowing meaningful comparison between individual surgeons and institutions.

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Declarations

We confirm all the authors are accountable for all aspects of the work

i) Dr Goh BK has received travel grants and honorarium from Johnson and Johnson and Olympus.

ii) Dr Marino MV is a consultant for CAVA robotics LLC.

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Figure 1. Selection of study cohort

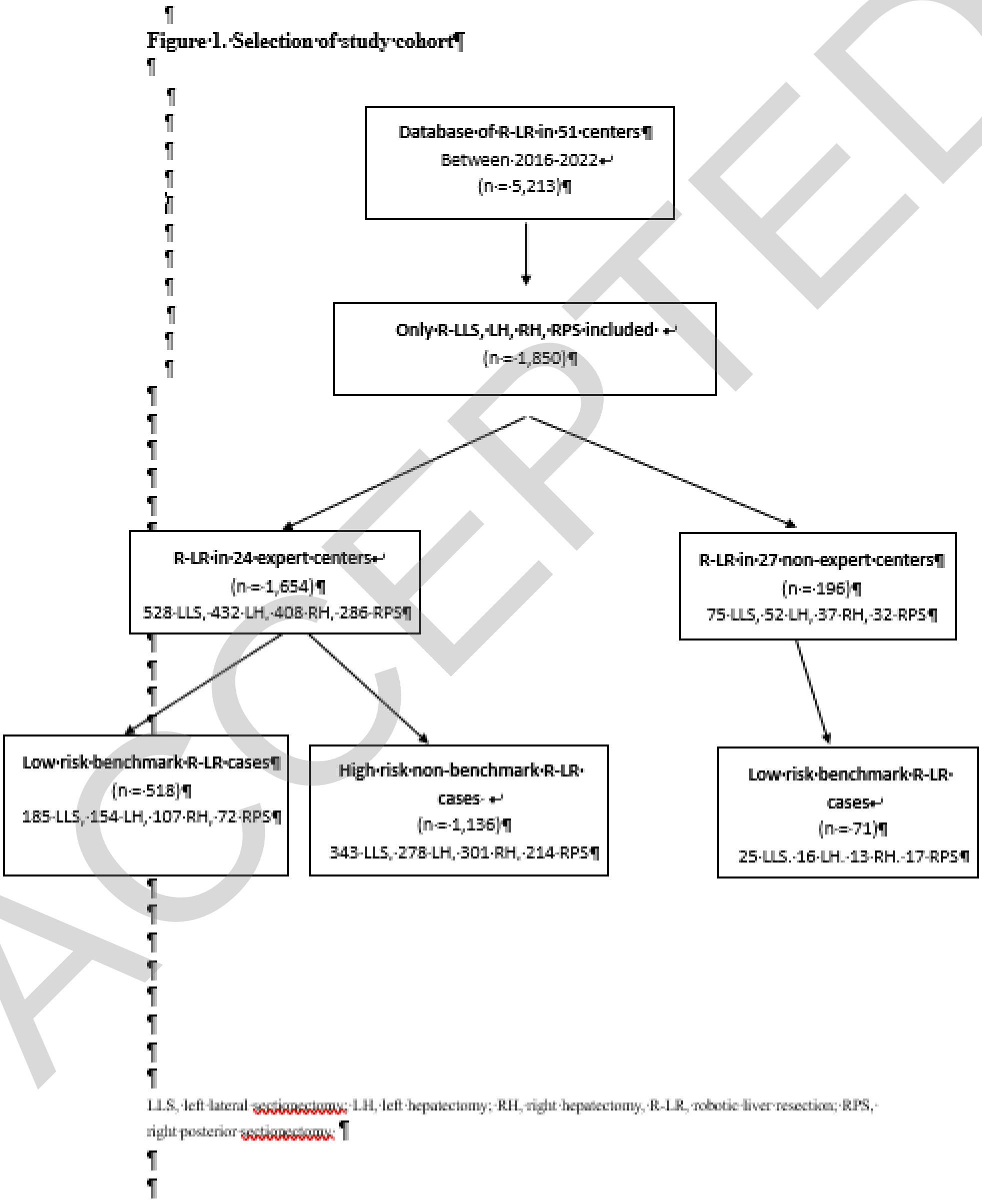

Figure 2. Proportion of benchmark cases performed across the 25 benchmark centers.

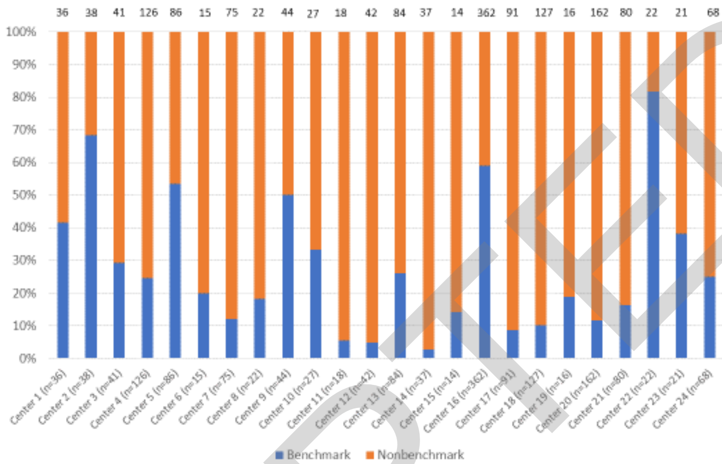

Table 1. Sixteen benchmark outcome measures after R-LLS/H23 and R-LH/H234 in low-risk cases from 24 expert centers

Variables	**R-LLS/ H23**		**L-LLS/ H23**	**R-LH/ H234±1**		**L-LH/H234±1**
	Median of medians across centers (range)	**Benchmark cutoff (75th percentile)**	**Benchmark cutoff (75th percentile)**	**Median of medians across centers (range)**	**Benchmark cutoff (75th percentile)**	**Benchmark cutoff (75th percentile)**
Operation time, min	171 (90-265)	≤190	≤209.5	265 (169-588)	≤323	≤302
Estimated blood loss, cc	50 (0-275)	≤100	≤100	100 (0-1479)	≤250	≤300
Blood loss ≥ 500 mls, %	0.0 (0.0-20.0)	0.0	≤3.2	0.0 (0.0-100.0)	≤ 27.1	≤20
Blood loss ≥ 1000 mls, %	0.0 (0.0-9.1)	0.0	0	0.0 (0.0-100.0)	≤0.4	0
Intraoperative blood transfusion, %	0.0 (0.0-9.1)	0.0	0	0.0 (0.0-33.3)	0.0	≤7.1
Open conversion, %	0.0 (0.0-16.7)	0.0	≤2.1	0.0 (0.0-4.8)	0.0	≤13.4
Postoperative 90-day morbidity, %	0.0 (0.0-100.0)	≤33.3	≤11.1	0.0 (0.0-50.0)	≤22.9	≤20
Postoperative major morbidity, %	0.0 (0.0-33.3)	0.0	0	0.0 (0.0-22.2)	0.0	≤7.1
Reoperation, %	0.0 (0.0-33.3)	0.0	0	0.0 (0.0-0.0)	0.0	0

30-day readmission, %	0.0 (0.0-33.3)	≤5.2	0	0.0 (0.0-33.3)	≤1.2	0
Postoperative length of stay, day	4 (2-9)	≤6	≤5	5 (2-12)	≤7	≤7
R1 (<1 mm) resection (malignancy only), %	0.0 (0.0-20.0)	0.0	≤7.1	0.0 (0.0-33.3)	≤18.3	≤10.5
Failure to rescue, %	0.0 (0.0-1.3)	0.0	0	0.0 (0.0-0.0)	0.0	0
30-day mortality, %	0.0 (0.0-0.0)	0.0	0	0.0 (0.0-0.0)	0.0	0
90-day mortality, %	0.0 (0.0-1.3)	0.0	0	0.0 (0.0-0.0)	0.0	0
Textbook outcome, %	62.5 (0.0-100.0)	≥12.5	NA	48.8 (0.0-100.0)	≥24.3	NA

L-LH, laparoscopic left hepatectomy; R, robotic; LLS, left lateral sectionectomy

Benchmark cutoffs for L-RH from Goh BKP, et al. Defining Global Benchmarks for Laparoscopic Liver Resections: An International Multicenter Study. *Ann Surg 2023;277:e839-48.*

Table 2. Sixteen benchmark outcome measures after R-RH/H5678 and R-RPS/H67 in low-risk cases from 24 expert centers

Variables	R-RH/ H5678±1		L-RH/ H5678±1	R-RPS/ H67		L-RPS/H67
	Median of medians across centers (range)	Benchmark cutoff (75th percentile)	Benchmark cutoff (75th percentile)	Median of medians across centers (range)	Benchmark cutoff (75th percentile)	Benchmark cutoff (75th percentile)
Operation time, min	390 (160-894)	≤474	≤ 426	310 (177-851)	≤413	≤ 350.8
Estimated blood loss, cc	249 (100-1077)	≤600	≤ 400	200 (0-1850)	≤550	≤ 450
Blood loss ≥ 500 mls, %	0.0 (0.0-100.0)	≤57.8	≤ 47.1	0.0 (0.0-100.0)	≤100.0	≤ 53.8
Blood loss ≥ 1000 mls, %	0.0 (0.0-100.0)	≤17.5	0.0	0.0 (0.0-100.0)	≤36.7	≤ 32.0
Intraoperative blood transfusion, %	0.0 (0.0-50.0)	≤20.0	≤ 10.5	0.0 (0.0-100.0)	≤29.2	≤ 22.9
Open conversion, %	0.0 (0.0-20.0)	≤1.3	≤ 13.0	0.0 (0.0-50.0)	0.0	≤ 12.5
Postoperative 90-day morbidity, %	0.0 (0.0-100.0)	≤50.0	≤50.0	0.0 (0.0-100.0)	≤58.4	≤ 23.8
Postoperative major morbidity, %	0.0 (0.0-100.0)	≤20.9	≤ 20.0	0.0 (0.0-100.0)	≤16.7	≤ 2.8
Reoperation, %	0.0 (0.0-33.3)	0.0	0.0	0.0 (0.0-33.3)	0.0	0.0
30-day readmission,	0.0 (0.0-16.7	≤1.3	≤ 8.3	0.0 (0.0-100.	≤1.5	0.0

%	)			0)		
Postoperative length of stay, day	8 (3-14)	≤10	≤ 8	6 (3-29)	≤7	≤ 7
R1 (<1 mm) resection (malignancy only), %	0.0 (0.0-16.7)	0.0	≤ 18.2	0.0 (0.0-50.0)	0.0	0.0
Failure to rescue, %	0.0 (0.0-6.7)	0.0	0.0	0.0 (0.0-0.0)	0.0	0.0
30-day mortality, %	0.0 (0.0-0.0)	0.0	0.0	0.0 (0.0-0.0)	0.0	0.0
90-day mortality, %	0.0 (0.0-6.7)	0.0	0.0	0.0 (0.0-0.0)	0.0	0.0
Textbook outcome, %	31.0 (0.0-100.0)	≥0.0	NA	33.3 (0.0-100.0)	≥0.0	≥33

L-RH, laparoscopic right hepatectomy; R, robotic; RPS, right posterior sectionectomy

Benchmark cutoffs for L-RH from Goh BKP, et al. Defining Global Benchmarks for Laparoscopic Liver Resections: An International Multicenter Study. *Ann Surg 2023;277:e839-48.*

Table 3. Comparison of the 16 benchmark outcome measures in 2 cohorts: non-bench mark cases in the expert centers and benchmark low risk cases in the nonexpert centers,

Variables	High risk non-benchmark R-LLS/H23 cases in expert centers N = 343	Benchmark R-LLS/H23 in non-expert centers N = 25	Benchmark cutoff	High risk non-benchmark R-LH/H234±1 cases in expert centers N =278	Benchmark R-LH/H234±1 in non-expert centers N =16	Benchmark cutoff
% benchmark cases						
Operation time, min (IQR)	180 (30-235)	275 (218-332)	≤190	270 (210-339)	375 (286-426)	≤323
Intraop blood transfusion, n (%)	10 (2.9)	0 (0.0)	0.0	29 (10.4)	1 (6.3)	0.0
Median blood loss, mls	100 (30-200)	100 (50-200)	≤100	110 (50-258)	275 (88-375)	≤250
Blood loss ≥ 500 mls, n (%)	20 (5.8)	0 (0.0)	0.0	21 (7.6)	1 (6.3)	≤ 27.1
Blood loss ≥ 1000 mls, n (%)	2 (0.6)	0 (0.0)	0.0	11 (4.0)	1 (6.3)	≤0.4
Open conversion, n (%)	5 (1.5)	0 (0.0)	0.0	18 (6.5)	0 (0.0)	0.0
Postoperative LOS, days (IQR)	4 (3-6)	4 (3-6)	≤6	5 (4-8)	6 (5-11)	≤7
30-day readmission, n (%)	16 (4.7)	2 (8.0)	≤5.2	21 (7.6)	0 (0.0)	≤1.2

90-day morbidity, n (%)	49 (14.3)	2 (8.0)	≤33.3	74 (26.6)	5 (31.3)	≤22.9
Postoperative major morbidity, n (%)	14 (4.1)	0 (0.0)	0.0	25 (9.0)	2 (12.5)	0.0
Reoperation, n (%)	4 (1.2)	0 (0.0)	0.0	5 (1.8)	0 (0.0)	0.0
30-day mortality, n (%)	2 (0.6)	0 (0.0)	0.0	2 (0.7)	0 (0.0)	0.0
90-day mortality, n (%)	4 (1.2)	0 (0.0)	0.0	2 (0.7)	0 (0.0)	0.0
Failure to rescue, n (%)	4 (1.2)	0 (0.0)	0.0	2 (0.7)	0 (0.0)	0.0
R1 (<1 mm) resection for malignancy (%)	12 (3.5)	1 (4.0)	0.0	15 (5.4)	0 (0.0)	≤18.3
Textbook outcome, n (%)	173 (50.4)	13 (52.0)	≥12.5	134 (48.2)	6 (37.5)	≥24.3

LOS, length of stay; R-LLS, Robotic left lateral sectionectomy; R-LH, robotic left hepatectomy

Table 4. Comparison of the 16 benchmark outcome measures in 2 cohorts: non-benchmark cases in the expert centers and benchmark low risk cases in the nonexpert centers,

Variables	High risk non-benchmark R-RH/ H5678±1 cases in expert centers N = 301	Benchmark R-RH/ H5678±1 in non-expert centers N = 13	Benchmark cutoff	High risk non-benchmark R-RPS/ H67cases in expert centers N = 214	Benchmark R-RPS/ H67 in non-expert centers N = 17	Benchmark cutoff
% benchmark cases						
Operation time, min (IQR)	300 (250-389)	455 (345-503)	≤474	288 (220-390)	360 (315-676)	≤413
Intraop blood transfusion, n (%)	51 (16.9)	3 (23.1)	≤20.0	34 (15.9)	6 (35.3)	≤29.2
Median blood loss, mls	300 (150-600)	500 (300-650)	≤600	290 (100-500)	500 (200-1100)	≤550
Blood loss ≥ 500 mls, n (%)	68 (22.6)	5 (38.5)	≤57.8	48 (22.4)	8 (47.1)	≤100.0
Blood loss ≥ 1000 mls, n (%)	27 (9.0)	0 (0.0)	≤17.5	21 (9.8)	4 (23.5)	≤36.7
Open conversion, n (%)	23 (7.6)	2 (15.4)	≤1.3	9 (4.2)	0 (0.0)	0.0
Postoperative LOS, days (IQR)	6 (4-9)	9 (6-15)	≤10	5 (3-7)	6 (4-7)	≤7
30-day readmission, n (%)	37 (12.3)	0 (0.0)	≤1.3	15 (7.0)	0 (0.0)	≤1.5
90-day	118 (39.2)	3 (23.1)	≤50.0	60 (28.0)	2 (11.8)	≤58.4

morbidity, n (%)						
Postoperative major morbidity, n (%)	44 (14.6)	2 (15.4)	≤20.9	16 (7.5)	0 (0.0)	≤16.7
Reoperation, n (%)	9 (3.0)	2 (15.4)	0.0	4 (1.9)	0 (0.0)	0.0
30-day mortality, n (%)	4 (1.3)	0 (0.0)	0.0	1 (0.5)	0 (0.0)	0.0
90-day mortality, n (%)	5 (1.7)	0 (0.0)	0.0	2 (0.9)	0 (0.0)	0.0
Failure to rescue, n (%)	5 (1.7)	0 (0.0)	0.0	1 (0.5)	0 (0.0)	0.0
R1 (<1 mm) resection for malignancy (%)	23 (7.6)	1 (7.7)	0.0	12 (5.6)	2 (11.8)	0.0
Textbook outcome, n (%)	95 (31.6)	4 (30.8)	≥0.0	99 (46.3)	6 (35.3)	≥0.0

LOS, length of stay; R-RH, Robotic right hepatectomy; R-RPS, Robotic right posterior sectionectomy