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International Benchmark Values for Robotic Right Hepatectomy

Multicenter Study From 22 Expert Centers

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Objective: This study aimed to identify benchmark values for robotic right hepatectomy (RH) based on a low-risk cohort treated at expert centers.

Background: Robotic liver surgery is emerging as a preferred minimally invasive approach to the liver. To enable conclusive comparisons with the standard open or laparoscopic approaches, reference values are needed.

Methods: Outcomes from consecutive patients undergoing robotic RH for malignant or benign indications at 22 international expert centers between 2018 and 2024 were analyzed. Low-risk, benchmark patients were without significant comorbidities such as portal hypertension, Child B cirrhosis, cardiac disease, chronic pulmonary disease, and renal failure. Patients undergoing robotic RH for donor hepatectomy were excluded. Fifteen reference values were derived from the 75th or the 25th percentile of the median values of all centers. Reference values were compared with a laparoscopic cohort from 4 centers and published benchmark values for laparoscopic and open RH.

Results: Of 357 patients, 172 (48%) qualified as the benchmark cohort. The main indications were hepatocellular carcinoma (31%) and colorectal liver metastases (27%). Reference values included: operative time (≤476 min), conversion rate (≤8.2%), bile leak (≤15.4%), major complications (≤23.1%), and comprehensive complication index at 90 days (≤15.6). Robotic RH compared favorably to a multinational cohort series of laparoscopic RH with lower conversion (10.0% vs ≤8.2%) and R1 rate (10.9% vs ≤0%). Compared to open robotic hepatectomy, cutoffs for major complications (≤50.0% vs ≤23.1%) and liver failure (≤22.0% vs ≤2.7%) were lower for robotic right hepatectomies.

Conclusion: This international benchmark study on robotic right hepatectomy (RRH) demonstrates that the robotic approach provides advantages compared with laparoscopic and open RH. RRH can be expected to become the minimally invasive approach of choice for tumors in the right liver.

Keywords: outcome research, robotic liver surgery, robotic right hepatectomy

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INTRODUCTION

The introduction of robotic liver surgery (RLS) has been one of the key technological advancements in hepato-biliary surgery over the last decade.[1–4] Compared to laparoscopic liver surgery (LLS), RLS provides a magnified three-dimensional view and a stable platform to perform complex surgical tasks such as biliary/vascular reconstructions. RLS has been rapidly adopted by centers experienced in open and LLS,[5,6] and for many indications, RLS has become the preferred minimally invasive approach.[7,8] However, even in high-volume expert centers, formal major hepatectomies are being less frequently performed nowadays, mostly due to the advancement of parenchyma-sparing techniques in combination with local thermal ablation.[9–12] However, in patients not amenable to parenchyma-sparing surgery, right hepatectomy (RH) is the preferred treatment for pathologies in the right hemiliver.

With modern surgical practice's growing complexity and costs, convincing and unbiased quality assessment becomes mandatory. The notion of quality assessment is widely recognized and used in the world of business. One possible tool for quality assessment is benchmarking.[13] Benchmarking is a process of measuring performance to enable outcome comparison and improvement within a specific domain.[13] Rössler et al[14] have successfully demonstrated how the concept of benchmarking can be adapted in the field of surgery. In the surgical community, however, such standard outcome measures have been rarely developed, and benchmarking of best possible results is in its early phase,[15–17] especially in RLS. Nonetheless, reference values from benchmarking can add considerable value to the quality control of procedures by making outcomes comparable between different surgeons, centers, or countries through creating a standard of care.[18]

Worldwide reference values for robotic right hepatectomy (RRH) can be derived by summarizing the data of a clearly defined low-risk patient cohort, which may serve as a quality measurement tool for both centers experienced or starting with RLS. Furthermore, reference values in RLS are needed to enable conclusive comparisons with the standard open or laparoscopic approaches.

The aim of this study was to identify the best possible outcomes (ie, benchmarking) of RRH in an international low-risk cohort. Therefore, data from consecutive patients were analyzed to serve as "controls" for comparison with any future analyses of RRH.

METHODS

Study Design

This retrospective multicenter cohort study analyzed outcomes from low-risk patients undergoing RRH for benign or malignant disease in international expert centers. The final collaborative group consisted of 22 centers from 3 continents and 13 countries, from which 15 benchmark values were identified to define best practice for RRH.

The participating centers were selected based on experience, their publication history, and the availability of a prospectively maintained database. The selected centers needed to have a case load of at least 50 liver resections per year, with a cumulative experience of over 100 RLS and a minimum of 5 RRH.

Benchmark values were derived from the 75th or 25th percentile of the median values of all benchmark centers, as previously applied and reported for other complex procedures in pancreatic and hepato-biliary surgery.[15–17] The 75th percentile was used for adverse outcomes, while the 25th percentile was applied for favorable outcomes. The anonymized data were collected and stored in an encrypted data registry provided by the University Hospital Basel. Ethical approval was granted by the Ethics Committee of Basel, Switzerland (BASEC ID 2024-01863). This study is structured according to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.[19]

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Study Population

Adult patients undergoing RRH for malignant or benign liver lesions were included between 1, 2018 and 12, 2024, while RRH performed for donor hepatectomy or extended RRH were excluded. From the collected data, patients with a low-risk profile were selected as the "benchmark cohort." Low-risk patients were defined as those without significant comorbidities such as American Society of Anesthesiologists (ASA) classification ≥3, portal hypertension (>10 mm Hg), Child B cirrhosis, cardiac disease, chronic renal failure Modification of Diet in Renal Disease (MDRD) stage ≥3, chronic obstructive pulmonary disease (COPD), and the use of anticoagulants. To ensure comparability among benchmark cohorts, the criteria were aligned with 2 previously published benchmark analyses for open and LLS.[20,21]

Indicators for Outcome

Fifteen relevant perioperative values were identified that served as reference values. Those were calculated at discharge and 90 days after surgery for each patient. Outcome measures included procedure-related morbidity and mortality as well as liver-specific morbidity such as biliary leakage (BL),[22] posthepatectomy liver failure (PHLF),[23] postoperative hemorrhage,[24] readmission, and failure to rescue rate. The severity of complications was assessed with the Clavien-Dindo classification (CD)[25,26] and the comprehensive complication index.[27] The failure-to-rescue rate was calculated according to the previously established methodology: number of deaths in patients with a CD complication graded >II (numerator) to the total number of patients with a complication graded CD >II (denominator).[28]

Textbook outcome (TBO) reflects optimal surgical results after liver surgery and was defined by the absence of intraoperative incidents (Oslo classification grade ≥2),[29] postoperative BL (B/C), severe postoperative complications (CD >II), reintervention, readmission within 30 days, in-hospital mortality, and the presence of R0 resection margin.[30]

Similar to the TBO, the Composite Endpoint of Liver Surgery (CELS) has recently been developed as a composite measure to assess outcomes following liver surgery. The CELS is considered positive if one of the following adverse events is present: BL, PHLF, posthepatectomy hemorrhage, or intraoperative blood loss of ≥2000 mL.[31]

Outcomes Along the Implementation of RRH

To depict the outcomes along the international implementation of RRH, the evolution of operative time, major complications, and conversion rate was evaluated for the overall low-risk cohort from 2018 to 2024.

Comparison With Open and Laparoscopic Right Hepatectomy

The reference values were compared to the previously published multinational benchmark values for patients undergoing open (ORH) and laparoscopic RH (LRH) as well as technically major laparoscopic hepatectomy.[20,21,32] The ORH control group consisted of 1476 benchmark patients from 44 international centers.[20] The LRH control group included 293 benchmark patients from an international multicenter database from 45 centers. The technically major laparoscopic control group consisted of 461 benchmark patients with segment 7 or 8 resections from 19 expert centers.

In addition, a fourth control group consisted of real-world data (benchmark and nonbenchmark patients) undergoing LRH for benign or malignant diseases from 4 international high-volume centers from 1, 2012 to 12, 2024: Hannover Medical School (Germany), Beaujon Hospital Clichy, (France), Poliambulanza Foundation Hospital Brescia (Italy) Oslo University Hospital (Norway).

Statistical Analysis

Qualitative variables were expressed as frequencies and percentages, and quantitative variables as means and standard deviation if normally distributed and as medians and interquartile range (IQR) otherwise. Missing at random values were imputed using multiple imputation by chained equations with 5 multiply imputed datasets with 10 iterations each being created using predictive mean matching for categorical variables and classification and regression trees for continuous variables.

Benchmark cutoffs were established according distribution of median values across centers: the 75th percentile was used for adverse outcomes, while the 25th percentile was applied for favorable outcomes. For further comparison, the median from the entire cohort was used.

Statistics were performed using R Statistical Software (version 4.2.3, 2023; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Twenty-two centers contributed 357 cases, of which 172 (48%) were low-risk patients. The proportion of benchmark cases varied between 24% and 100% per center. The median age was 63 years (IQR 50–70), with a median BMI of 25.6 kg/m^2 (IQR 22.9–29.4), and 56% were male. The main indication for surgery was liver malignancy (82%) and, more specifically, hepatocellular carcinoma (31%), colorectal liver metastases (27%), and cholangiocarcinoma (14%). 34% had an underlying Child A cirrhosis. Only 12% had a previous liver resection with a robotic (6%), laparoscopic (4%), or open approach (2%). Participating centers had an annual case load of 110 (55–450) liver resections and thereof 60 (30–154) robotic liver resections. Most centers had previous experience in LLS (21 of 22).

Outcomes Along the Learning Curve

Among the low-risk cohort, operative time remained relatively stable along the implementation phase of RRH from 2018 with a median operative time of 370 to 420 minutes in 2024. Likewise, no significant changes were observed for the rate of major complications (8% in 2018 and 18% in 2024). However, a decrease in the conversion rate was observed along the international implementation from 13% 2018 to 1% 2024 (Fig. 1).

Reference Values

The benchmark values defined as the 75th or the 25th percentile of the median outcome parameters are reported in Table 1. Benchmark values for operative time, conversion rate, comprehensive complication index at 90 days, BL, and major complications were ≤476 minutes, ≤8.2%, ≤15.6, ≤15.4%, and ≤23.1%.

Comparison of Outcomes

The novel RRH benchmark values were applied to 5 independent cohorts of patients (Table 2). First, patients undergoing RRH from the same 22 centers classified as higher-risk cases due to relevant comorbidities were identified. In this cohort, most values were within benchmark criteria, except for an increased overall complication rate (64.3% vs ≤46.1%), PHLF rate (9.2% vs ≤2.7%), and higher 90-day mortality rate (3.3% vs 0%).

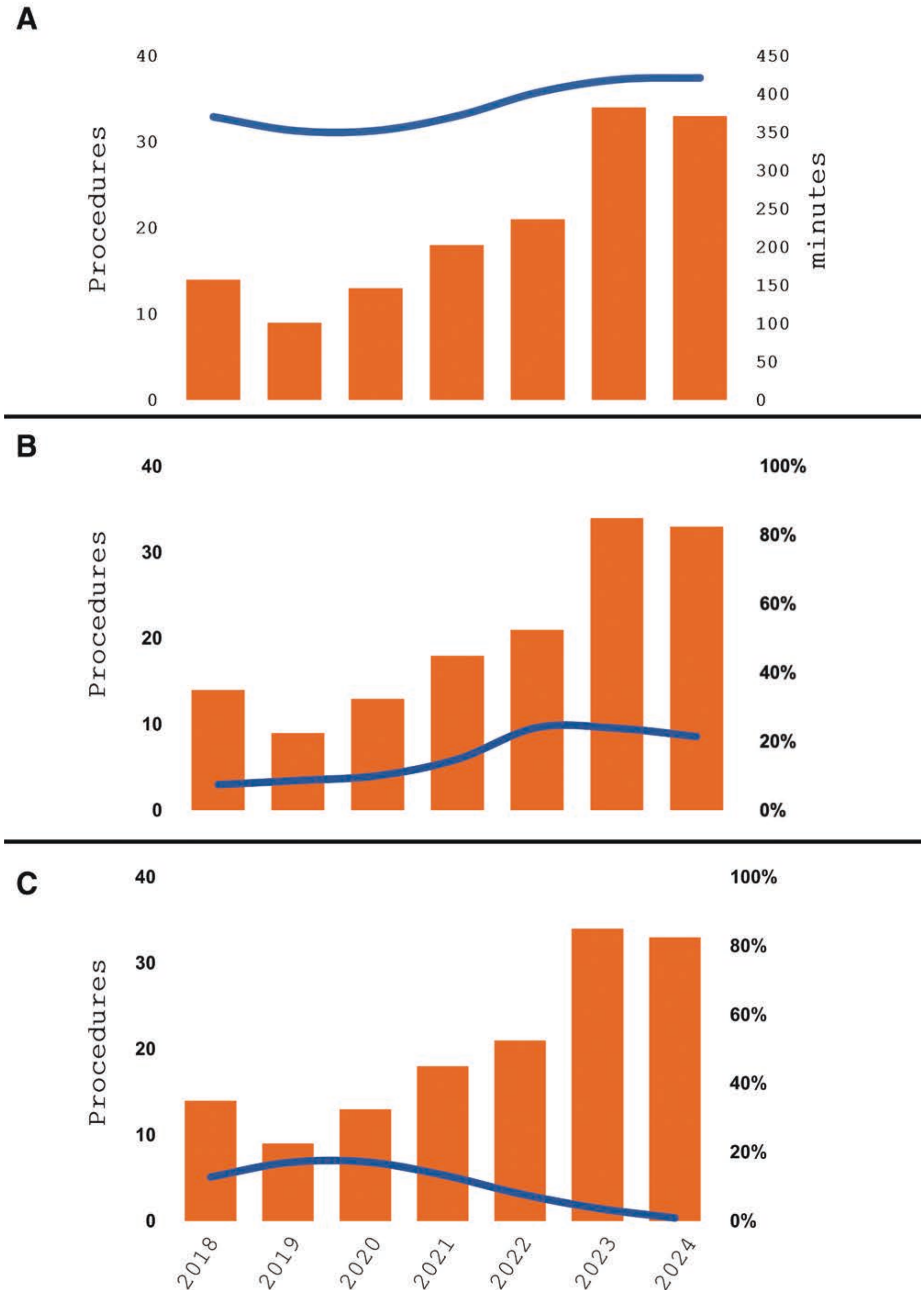

FIGURE 1. Evolution of surgical outcomes among low-risk, benchmark patients. A, Operative time. B, Major complications. C, Conversion rate.

Second, in a multinational cohort series of LRH, RRH compared favorably, especially with a lower conversion rate (10.0% vs ≤8.2%), R1 rate (11.3% vs 0%), and patients achieving TBO (35.2% vs ≥50%).

In a third step, the different reference cutoffs of laparoscopic major hepatectomy, LRH, and ORH were compared. While the benchmark cutoffs for laparoscopic technically major hepatectomy were well within the benchmark cutoffs of RRH, relevant differences were found comparing the international benchmarks of LRH and RRH. While cutoffs for operative time (RRH: ≤476 min vs LRH: ≤426 min), overall morbidity (RRH: ≤46.1% vs LRH: ≤50.0%), and mortality (both: 0%) were comparable between RRH and LRH, benchmark values for conversion (RRH: ≤8.2% vs LRH: ≤13.0) and R1 rate (RRH: 0% vs LRH: ≤18.2) were in favor of the robotic approach. Compared to the benchmark values of ORH, the cutoff for operation time was 2 hours longer for the robotic approach (RRH: ≤476 min vs ORH: ≤342 min); however, values for major complications (RRH: ≤23.1% vs ORH: ≤50.0%) and PHLF (RRH: ≤2.7% vs ORH: ≤22.0%) show distinct advantages of the robotic approach.

Volume Outcome Relationship

Centers were divided according to the annual volume of RLS, with a cutoff of 50 RLS/year.[21] The annual robotic liver volume did neither influence the conversion rate (0% vs 3%, P = 0.367), nor the proportion of major complications (20% vs 13%; P = 0.314), patients achieving TBO (75% vs 60%, P = 0.195) or CELS (10% vs 13%, P = 0.232) (Fig. 2).

TABLE 1.

Reference Values of 172 Low-Risk Patients Undergoing Robotic Right Hepatectomy

	Median (Range)	Reference Value
Operative time, min	405 (310–496)	≤476
Estimated blood loss, mL	200 (100–500)	≤794
Conversion, %	9 (5.8)	≤8.2
Postoperative 90-day morbidity		
Overall complications, %	43 (27.6)	≤46.1
Major complications, %	24 (15.4)	≤23.1
Bile leak, %	15 (9.6)	≤15.4
Bleeding, %	5 (3.2)	0
Posthepatectomy liver failure, %	10 (6.4)	≤2.7
Reoperation rate, %	7 (4.5)	0
Reintervention rate, %	14 (9.0)	≤16.6
Length of stay, days	7 (5–10)	≤11
Comprehensive complication index	8.7 (0–20.9)	≤15.6
Readmission rate, %	10 (6.5)	0
Mortality rate, %	2 (1.4)	0
Failure to rescue rate, %	2 (1.4)	0
R1 rate, %	5 (4.6)	0
Textbook outcome*, %	105 (69.5)	≥50
Composite Endpoint of Liver Surgery†, %	22 (15.4)	≤25

Data are given as n (%) and median (IQR).*Data from Görgec et al.[30]†Data from Kawashima et al.[31]

TABLE 2.

Reference Values for Robotic Right Hepatectomy in Comparison With Benchmark Values for Laparoscopic and Open Right Hepatectomy

	Higher-Risk RRH (n = 185)	Laparoscopic RH (n = 200)	Laparoscopic Technically Major (n = 461)	Laparoscopic RH* Benchmark (n = 293)	Open RH† Benchmark (n = 1476)	Reference Value
Operative time, min	373 (306–477)	295 (229–360)	373	≤426	≤342	≤476
Blood loss, mL	400 (200–725)	500 (200–750)	250	≤400	≤800	≤794
Conversion, %	16 (8.6)	20 (10.0)	4.4	≤13.0	NA	≤8.2
Overall complications, %	119 (64.3)	61 (30.5)	31	≤50.0	≤57.1	≤46.1
Major complications, %	42 (22.7)	34 (17.0)	7.4	≤20.0	≤50.0	≤23.1
Bile leak, %	19 (10.3)	6 (3.0)	3.1	NA	≤21.0	≤15.4
Bleeding, %	13 (7.0)	5 (2.5)	1.5	0	NA	0
Posthepatectomy liver failure, %	17 (9.2)	8 (4.0)	NA	0	≤22.0	≤2.7
Reoperation rate, %	11 (5.9)	4 (2.1)	1.3	0	≤5.7	0
Reintervention rate, %	23 (12.4)	28 (14.0)	7.8	NA	NA	≤16.6
Length of stay, days	7 (5–10)	6 (4–8)	6	≤7.5	≤11.0	≤11
Comprehensive complication index	8.7 (0.0–26.1)	0.0 (0.0–8.7)	NA	NA	≤9.6	≤15.6
Readmission rate, %	20 (10.9)	15 (7.5)	8.3	≤8.3	≤16.0	0
Mortality rate, %	6 (3.3)	4 (2.0)	3.5	0	≤3.6	0
R1 rate, %	21 (13.8)	17 (11.3)	NA	≤18.2	≤16.8	0
Textbook outcome*, %	99 (55.6)	70 (35.2)	NA	NA	NA	≥50
Composite Endpoint of Liver Surgery†, %	40 (22.9)	23 (12.5)	NA	NA	NA	≤25

Note: Data are given as n (%) and median (IQR).*Data from Goh et al.[21]†Data from Sousa et al.[20]

DISCUSSION

This international multicenter study identified 15 reference values for short-term outcomes of RRH. In specialized centers with experience in RLS, the study showed excellent results for RRH that were largely comparable to the benchmark values of LRH; however, with the main advantage of a reduced risk for conversion and a lower R1 resection rate with the robotic approach. Apart from the LRH benchmark cohort, these findings were further confirmed in a multicenter real-world LRH cohort.[21] Compared to the open approach, RRH entails clinically relevant advantages, such as a halved major complication rate and lower PHLF rate; however, with a 2-hour longer operative time. Interestingly, the previously described volume-outcome relationship for LLS did not apply to RRH, as the results were mainly independent of the RLS volume.[21,33–35] Furthermore, the cutoffs for RRH were mostly met for higher-risk, nonbenchmark patients, except for an increased overall complication rate, while the major complication (19%) and 90-day mortality rate (3.3%) were comparably low. This finding suggests that the minimally invasive, robotic approach remains a safe and viable option even in sicker patients with more complex comorbidities.

A comparison of the novel RRH reference values with previously established cutoffs for ORH and LRH revealed several improvements, supporting the global transition to RLS.[36–38] Important advantages of the robotic approach include a lower PHLF rate and less major complications, both findings that are supported by large multicenter studies.[39,40] A recent comparison of more than 10,000 patients undergoing robotic and laparoscopic liver resections found distinct advantages for the robotic approach; for example, a higher proportion of patients reaching TBO, a lower conversion rate, and a higher R0 rate – differences that were seen in the current study as well.[41] While those studies were retrospective analyses, the first randomized controlled trial comparing robotic with LLS mainly included minor hepatectomies and found comparable postoperative outcomes except for a higher reintervention rate in the laparoscopic group.[7] The

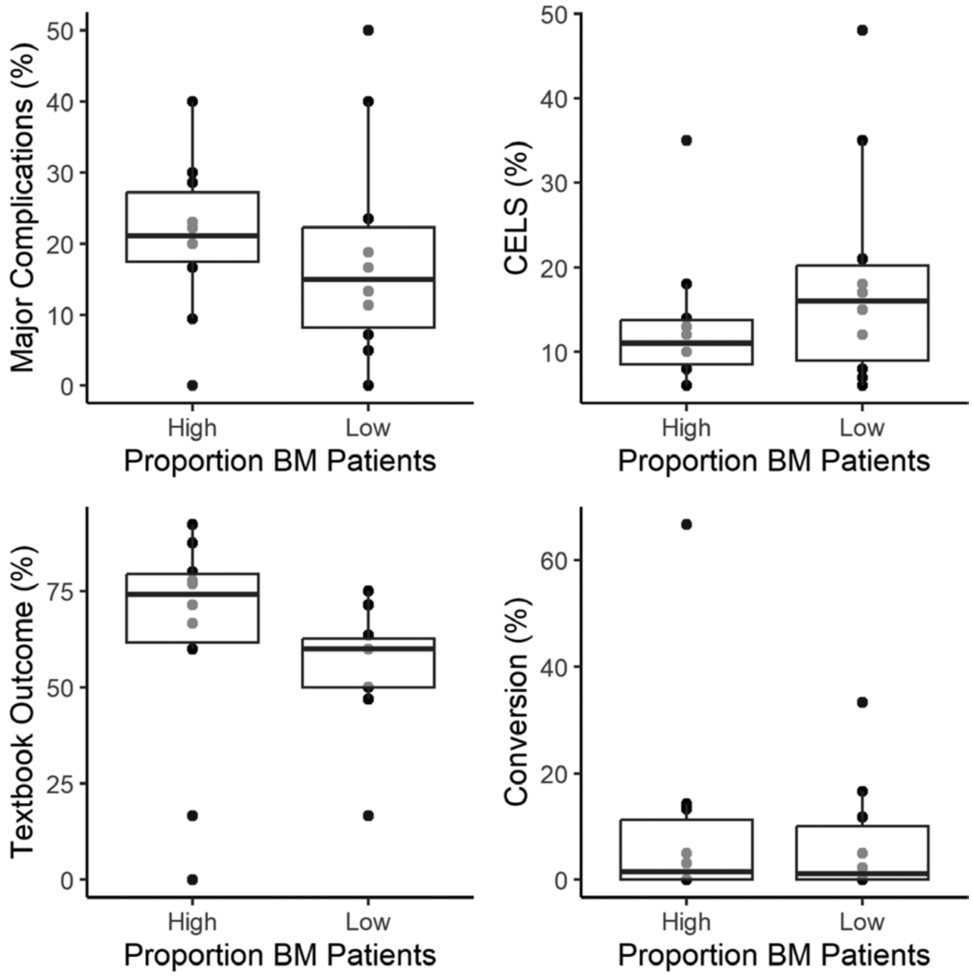

FIGURE 2. Volume-related outcomes of centers with high (>50 cases/year) and low volume of robotic liver surgery. BM indicates Benchmark; CELS, Composite Endpoint of Liver Surgery.

transition to RLS is supported by the cost-effectiveness of RLS. The procedural cost is highest for RLS compared to LLS and open liver surgery; however, this is overcompensated with a reduction of major complications, resulting in a decreased hospital stay.[38,42]

Excellent clinical outcomes were achieved for RRH in this international multicenter study; however, a certain selection bias of less advanced tumors in favor of robotic surgery seems inevitable. Especially difficult to resect tumors, such as perihilar tumors, large tumors (eg, >10 cm), or resections with the need to reconstruct vasculo-biliary structures, are even in expert centers rarely approached with the robotic platform, and are still mostly being performed open.[43–45] Therefore, the oncological surrogate parameters, and especially the low rate of R1 resections, need to be interpreted with caution, and long-term oncological outcomes from RLS in comparison to the open approach are needed from well-matched or randomized patient cohorts, taking into account tumor entity, tumor stage, and size as well as proximity to major vascular structures.

Compared to the previous benchmark study on RLS by Li et al,[4] 2 major differences need to be considered. First, half of the resections performed in the previous benchmark study were living donor hepatectomies and second, 80% of the remaining procedures were minor liver resections. Living donor hepatectomy and oncologic liver resections serve fundamentally different purposes and are performed in distinctly different patient populations.[46] In the setting of living donor hepatectomy, a healthy individual with a healthy liver donates a portion of their liver. The primary surgical objective in this context is the preservation of critical vascular inflow and outflow structures, ensuring both donor safety and optimal postoperative liver function. Conversely, in oncologic hepatectomy, the patient typically has underlying hepatic pathology—such as cirrhosis or chemotherapy-associated liver injury—and requires resection of a liver tumor. This procedure adheres to different surgical principles, prioritizing complete oncologic clearance while balancing functional hepatic reserve. As such, it is not directly comparable to the scenario of living donor surgery. Like in open liver surgery,[14,20] we strongly advocate for the application of distinct reference values for robotic living donor hepatectomy and oncologic robotic liver resection.

In contrast to in the Italian LLS benchmark study by Russolillo et al, we decided against a stratification of patients according to certain difficulty scores (eg, IWATE or Institut Mutualiste Montsouris Classification system). First of all, RRH is classified as a technically advanced procedure in all available difficulty grading systems,[47–49] and only slightly different scores would be expected according to tumor size or proximity to major vessels. Second, a stratification of patients according to the difficulty scores and not according to surgical procedure may lead to heterogeneous groups that include different procedures within a specific difficulty group. This would limit the applicability of benchmark cutoffs for further comparisons.[34]

With the clinically relevant reduction of major morbidity in modern liver surgery, composite endpoints that summarize multiple adverse outcomes and depict ideal recovery after major abdominal surgery gain importance.[30,31,50–52] For example, TBO or CELS stress favorable postoperative outcomes and patient recovery of successfully completed RRH, revealing significant differences between LRH and RRH in the current study. While previous benchmark studies did not include composite endpoints in their analysis, we strongly recommend assessing them for further reference cutoff calculations as they summarize ideal outcomes within a single parameter.

For the interpretation of the RRH results achieved in this benchmark study, a learning curve for RLS must be mastered. While 1 may argue that the presented reference values were gathered during the international implementation of RRH, our findings suggest stable outcomes without a trend to declining operative times and major complications (Fig. 1). Overcoming the learning curve of RLS is multifactorial and complex and should take the previous open and LLS experience into account.[53,54] Furthermore, a gradual adoption of RLS from minor towards major hepatectomies must be considered. Most surgeons and centers have extensive experience in open and LLS as well as minor RLS before embarking towards major robotic hepatectomies. Therefore, to only report the learning curve of major robotic resections neglects the fact that surgeons pass the initial learning curve mainly with minor resections. For a holistic learning curve assessment, a standardized 3-phase reporting of the learning curves in minimally invasive liver surgery was proposed. The 3 phases of competency, proficiency, and mastery were reached after 34, 50, and 58 procedures,[55] demonstrating the significant amount of procedures needed to master minimally invasive liver surgery. However, the influence of the learning process on short- and long-term oncologic outcomes (eg, R1 rate) is currently not well documented. This finding is further supported by a large single-center study that evaluated the 3 phases for RLS and showed that 15, 25, and 52 patients were necessary to overcome the different phases of the learning curve.[56] Similarly, consensus guidelines on complex RLS recommend 15 cases of minor and 25 of major RLS for an experienced surgeon to overcome the learning curve for major liver resections.[57]

There are some limitations that should be mentioned. First, the study included a limited number of patients, and it is possible that the procedure has not completely matured even in these experienced high-volume centers. Therefore, reference cutoffs might be different if the study is repeated at a later implementation phase. However, the limited amount of RH is rather due to the fact that formal hepatectomies are nowadays being performed rarely with the advancement of parenchyma-sparing techniques. Overall, the 22 included centers perform approximately 2980 annual liver resections, of which 44% are being performed robotically, demonstrating the extensive experience in RLS. Furthermore, the results of this study might not be generalizable to every surgeon or center, as only high-volume centers with extensive experience in RLS were included to define the benchmark values. However, as RRH is a complex and advanced major liver resection, it is mainly performed at highly specialized centers around the world. Third, the reference values were calculated based on a highly selected low-risk cohort with only 48% qualifying as benchmark patients. However, this selection is wanted and in line with other benchmark studies, where usually 30–60% of all cases qualify as low-risk, benchmark cases.[4,14,15,16,17]

In conclusion, this international multicentric analysis sets novel reference values for RRH, indicating favorable outcomes compared to ORH and LRH. In contrast to laparoscopic hepatectomy, the outcomes of RRH were largely independent of institutional case volume and only minimally affected by the surgical learning curve, underscoring the reproducibility and robustness of the robotic technique. These reference values provide an essential framework for quality assurance during the implementation of RLS and may serve as objective standards for performance comparison and continuous improvement across surgeons, institutions, and healthcare systems. Given the favorable clinical results, RRH is anticipated to emerge as the preferred minimally invasive approach for RH in the future.

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