Defining Global Benchmarks for Laparoscopic Liver Resections

An International Multicenter Study

Brian K.P. Goh, MBBS, MMed, MSc, FRCS,✉ Ho-Seong Han, MD, PhD,† Kuo-Hsin Chen, MD,‡ Darren W. Chua, MBBS, MMed, FRCS,* Chung-Yip Chan, MBBS, MD, MMed, FRCS,* Federica Cipriani, MD, PhD,§ Davit L. Aghayan, MD, PhD,|| Asmund A. Fretland, MD, PhD,|| Jasper Sijberden, MD,¶ Mizelle D'Silva, MD,† Tiing Foong Siow, MD,‡ Yutaro Kato, MD, PhD,# Chetana Lim, MD,** Phan Phuoc Nghia, MD,†† Paulo Herman, MD, PhD,‡‡ Marco V. Marino, MD, PhD, FACS, FEBS,§§|||| Vincenzo Mazzaferro, MD, PhD,¶¶ Adrian K.H. Chiow, MBBS, MMed, FRCS,## Iswanto Sucandy, MD, FACS,*** Arpad Ivanecz, MD, PhD,††† Sung Hoon Choi, MD,‡‡‡ Jae Hoon Lee, MD,§§§ Mikel Gastaca, MD,|||||| Marco Vivarelli, MD,¶¶¶ Felice Giuliante, MD,### Andrea Ruzzenente, MD,**** Chee-Chien Yong, MD,†††† Mengqui Yin, MD,‡‡‡‡ Zewei Chen, MD,‡‡‡‡ Constantino Fondevila, MD,§§§§|||||||| Mikhail Efanov, MD, PhD,¶¶¶¶ Fernando Rotellar, MD, PhD,####***** Gi-Hong Choi, MD,††††† Ricardo R. Campos, MD,‡‡‡‡‡ Xiaoying Wang, MD, PhD,§§§§§ Robert P. Sutcliffe, MD, FRCS,|||||||||| Johann Pratschke, MD,¶¶¶¶¶ Eric Lai, MBChB, FRACS,##### Charing C. Chong, MBChB, MSc, FRCS,****** Mathieu D'Hondt, MD, PhD,†††††† Kazuteru Monden, MD, FACS,‡‡‡‡‡‡ Santiago Lopez-Ben, MD,§§§§§§ Fabricio F. Coelho, MD, PhD,‡‡ Thomas Peter Kingham, MD,|||||||||||| Rong Liu, MD,¶¶¶¶¶¶ Tran Cong duy Long, MD,###### Alessandro Ferrero, MD,******* Giovanni B. Levi Sandri, MD,††††††† Mansour Saleh, MD,‡‡‡‡‡‡‡ Daniel Cherqui, MD,‡‡‡‡‡‡‡ Olivier Scatton, MD, PhD,** Olivier Soubrane, MD, PhD,§§§§§§§ Go Wakabayashi, MD, PhD,|||||||||||||| Roberto I. Troisi, MSc, MD, PhD,¶¶¶¶¶¶¶ Tan-To Cheung, MS, MD, FRCS,####### Atsushi Sugioka, MD, PhD,# Mohammad Abu Hilal, MD, PhD,¶******** David Fuks, MD, PhD,§§§§§§§ Bjørn Edwin, MD, PhD,|| Luca Aldrighetti, MD, PhD,§ and International Robotic and Laparoscopic Liver Resection Study Group Investigators*

From the *Department of Hepatopancreatobiliary and Transplant Surgery,, Singapore General Hospital, National Cancer Centre Singapore and Duke-National University of Singapore Medical School, Singapore, Singapore; †Department of Surgery, Seoul National University Hospital Bundang, Seoul National University College of Medicine, Seoul, Korea; ‡Division of General Surgery, Department of Surgery, Far-Eastern Memorial Hospital, New Taipei City, Taiwan; §Hepatobiliary Surgery Division, IRCCS San Raffaele Hospital, Milan, Italy; ||The Intervention Centre and Department of HPB Surgery, Oslo University Hospital, Institute of Clinical Medicine, University of Oslo, Oslo, Norway; ¶Department of Surgery, Poliambulanza Foundation Hospital, Brescia, Italy;; #Department of Surgery, Fujita Health University School of Medicine, Aichi, Japan; **Department of Digestive, HBP and Liver Transplantation, Pitie Salpetriere Hospital, APHP Paris, Sorbonne Universite, Paris, France; ††HPB Surgery Department, University Medical Center, Ho Chi Minh City, Vietnam; ‡‡Liver Surgery Unit, Department of Gastroenterology, University of Sao Paulo School of Medicine, Sao Paulo, Brazil; §§General Surgery Department, Azienda Ospedaliera Ospedali Riuniti Villa Sofia-Cervello, Palermo, Italy; ||||Oncologic Surgery Department, P. Giaccone University Hospital, Palermo, Italy; ¶¶HPB Surgery and Liver Transplantation, Fondazione IRCCS Istituto Nazionale Tumori di Milano and University of Milan, Milan, Italy; ##Hepatopancreatobiliary Unit, Department of Surgery, Changi General Hospital, Singapore; ***AdventHealth Tampa, Digestive Health Institute, Tampa, FL; †††Department of Abdominal and General Surgery, University Medical Center Maribor, Maribor, Slovenia; ‡‡‡Department of General Surgery, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, Korea; §§§Department of Surgery, Division of Hepato-Biliary and Pancreatic Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea; ||||||Hepatobiliary Surgery and Liver Transplantation Unit, Biocruces Bizkaia Health Research Institute, Cruces University Hospital, University of the Basque Country, Bilbao, Spain; ¶¶¶HPB Surgery and Transplantation Unit, United Hospital of Ancona, Department of Sperimental and Clinical Medicine Polytechnic University of Marche, Ancona, Italy; ###Hepatobiliary Surgery Unit, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Catholic University of the Sacred Heart, Rome, Italy; ****Department of Surgery, Dentistry, Gynecology, and Pediatrics, University of Verona, GB Rossi Hospital, Verona, Italy; ††††Department of Surgery, Chang Gung Memorial Hospital, Kaohsiung, Taiwan; ‡‡‡‡Department of Hepatobiliary Surgery, Affiliated Jinhua Hospital, Zhejiang University School of Medicine, Jinhua, China; §§§§General and Digestive Surgery, Hospital Universitario La Paz, IdiPAZ, Madrid, Spain; ||||||||General and Digestive Surgery, Hospital Clinic, IDIBAPS, CIBERehd, University of Barcelona, Barcelona, Spain; ¶¶¶¶Department of Hepato-Pancreato-Biliary Surgery, Moscow Clinical Scientific Center, Moscow, Russia; ####HPB and Liver Transplant Unit, Department of General Surgery, University Clinic of Navarra, University of Navarra, Pamplona, Spain; *****Institute of Health Research of Navarra (IdisNA), Pamplona, Spain; †††††Division of Hepatopancreatobiliary Surgery, Department of Surgery, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea; ‡‡‡‡‡Department of General, Visceral and Transplantation Surgery, Clinic and University Hospital Virgen de la Arrixaca, IMIB-ARRIXACA, El Palmar, Murcia, Spain; §§§§§Department of Liver Surgery and Transplantation, Liver Cancer Institute, Zhongshan Hospital, Fudan University, Shanghai, China; ||||||||||Department of Hepatopancreatobiliary and Liver Transplant Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK; ¶¶¶¶¶Department of Surgery, Campus Charité Mitte and Campus Virchow-Klinikum, Charité-Universitätsmedizin, Corporate Member of Freie Universität Berlin, and Berlin Institute of Health, Berlin, Germany; #####Department of Surgery, Pamela Youde Nethersole Eastern Hospital, Hong Kong SAR, China; ******Department of Surgery, Prince of Wales Hospital, The Chinese University of Hong Kong, New Territories, Hong Kong SAR, China; ††††††Department of Digestive and Hepatobiliary/Pancreatic Surgery, Groeninge Hospital, Kortrijk, Belgium; ‡‡‡‡‡‡Department of Surgery, Fukuyama City Hospital, Hiroshima, Japan; §§§§§§Hepatobiliary and Pancreatic Surgery Unit, Department of Surgery, Dr. Josep Trueta Hospital, IdIBGi, Girona, Spain; ||||||||||||Department of Surgery, Memorial Sloan Kettering

Objective: To establish global benchmark outcomes indicators after laparoscopic liver resections (L-LR).

Background: There is limited published data to date on the best achievable outcomes after L-LR.

Methods: This is a post hoc analysis of a multicenter database of 11,983 patients undergoing L-LR in 45 international centers in 4 continents between 2015 and 2020. Three specific procedures: left lateral sectionectomy (LLS), left hepatectomy (LH), and right hepatectomy (RH) were selected to represent the 3 difficulty levels of L-LR. Fifteen outcome indicators were selected to establish benchmark cutoffs.

Results: There were 3519 L-LR (LLS, LH, RH) of which 1258 L-LR (40.6%) cases performed in 34 benchmark expert centers qualified as low-risk benchmark cases. These included 659 LLS (52.4%), 306 LH (24.3%), and 293 RH (23.3%). The benchmark outcomes established for operation time, open conversion rate, blood loss ≥ 500 mL, blood transfusion rate, postoperative morbidity, major morbidity, and 90-day mortality after LLS, LH, and RH were 209.5, 302, and 426 minutes; 2.1%, 13.4%, and 13.0%; 3.2%, 20%, and 47.1%; 0%, 7.1%, and 10.5%; 11.1%, 20%, and 50%; 0%, 7.1%, and 20%; and 0%, 0%, and 0%, respectively.

Conclusions: This study established the first global benchmark outcomes for L-LR in a large-scale international patient cohort. It provides an up-to-date reference regarding the "best achievable" results for L-LR for which centers adopting L-LR can use as a comparison to enable an objective assessment of performance gaps and learning curves.

Keywords: laparoscopic liver resection, benchmark, global, hepatectomy, minimally invasive, quality assessment

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Benchmarking is a tool used for quality assessment and improvement in fields such as the manufacturing industry but its application in medicine and surgery remains more limited and

Cancer Center, New York, NY; ¶¶¶¶¶¶Faculty of Hepatopancreatobiliary Surgery, The First Medical Center of Chinese People's Liberation Army (PLA) General Hospital, Beijing, China; ######Department of Hepatopancreatobiliary Surgery, University Medical Center, University of Medicine and Pharmacy, Ho Chi Minh City, Vietnam; *******Department of General and Oncological Surgery, Mauriziano Hospital, Turin, Italy; †††††††Division of General Surgery and Liver Transplantation, S. Camillo Hospital, Rome, Italy; ‡‡‡‡‡‡‡Department of Hepatobiliary Surgery, Assistance Publique Hopitaux de Paris, Centre Hepato-Biliaire, Paul-Brousse Hospital, Villejuif, France; §§§§§§§Department of Digestive, Oncologic, and Metabolic Surgery, Institute Mutualiste Montsouris, Universite Paris Descartes, Paris, France; ‖‖‖‖‖‖‖Center for Advanced Treatment of Hepatobiliary and Pancreatic Diseases, Ageo Central General Hospital, Saitama, Japan; ¶¶¶¶¶¶¶ Division of HPB, Department of Clinical Medicine and Surgery, Minimally Invasive and Robotic Surgery, Federico II University Hospital Naples, Naples, Italy; #######Department of Surgery, Queen Mary Hospital, The University of Hong Kong, Hong Kong SAR, China; and ********Department of Surgery, University Hospital Southampton, Southampton, UK.

✉ bsgkp@hotmail.com, brian.goh@singhealth.com.sg.

International Robotic and Laparoscopic Liver Resection Study Group Investigators: Nicholas Syn (Department of Hepatopancreatobiliary and Transplant Surgery, Singapore General Hospital). Mikel Prieto (Hepatobiliary Surgery and Liver Transplantation Unit, Biocruces Bizkaia Health Research Institute, Cruces University Hospital, University of the Basque Country, Bilbao, Spain). Henri Schotte (Department of Digestive and Hepatobiliary/Pancreatic Surgery, Groeninge Hospital, Kortrijk, Belgium). Celine De Meyere (Department of Digestive and Hepatobiliary/Pancreatic Surgery, Groeninge Hospital, Kortrijk, Belgium) (Department of Surgery, AZ Groeninge Hospital, Kortrijk, Belgium). Felix Krenzien (Department of Surgery, Campus Charité Mitte and Campus Virchow-Klinikum, Charité-Universitätsmedizin, Corporate Member of Freie Universität Berlin, and Berlin Institute of Health, Berlin, Germany). Moritz Schmelzle (Department of Surgery, Campus Charité Mitte and Campus Virchow-Klinikum, Charité-Universitätsmedizin, Corporate Member of Freie Universität Berlin, and Berlin Institute of Health, Berlin, Germany). Kit-Fai Lee (Division of Hepatobiliary and Pancreatic Surgery, Department of Surgery, Prince of Wales Hospital, The Chinese University of Hong Kong, New Territories, Hong Kong SAR, China. Diana Salimgereeva (Department of Hepato-Pancreato-Biliary Surgery, Moscow Clinical Scientific Center, Moscow, Russia). Ruslan Alikhanov (Department of Hepato-Pancreato-Biliary Surgery, Moscow Clinical Scientific Center, Moscow, Russia). Lip-Seng Lee (Hepatopancreatobiliary Unit, Department of Surgery, Changi General Hospital, Singapore). Jae Young Jang (Department of General Surgery, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, Korea). Masayuki Kojima (Department of Surgery, Fujita Health University School of Medicine, Aichi, Japan). Jacob Ghotbi (Department of HPB Surgery, Oslo University Hospital, Oslo, Norway). Jaime Arthur Pirola Kruger (Liver Surgery Unit, Department of Gastroenterology, University of Sao Paulo School of Medicine, Sao Paulo, Brazil). Victor Lopez-Lopez (Department of Surgery, Virgen de la Arrixaca University Hospital, Murcia, Spain). Bernardo Dalla Valle (General and Hepatobiliary Surgery, Department of Surgery, Dentistry, Gynecology and Pediatrics University of Verona, GB Rossi Hospital, Verona, Italy). Margarida Casellas I Robert (Hepatobiliary and Pancreatic Surgery Unit, Department of Surgery, Dr. Josep Trueta Hospital, IdIBGi, Girona, Spain). Kohei Mishima (Center for Advanced Treatment of Hepatobiliary and Pancreatic Diseases, Ageo Central General Hospital, Saitama, Japan). Roberto Montalti (Department of Clinical Medicine and Surgery, Division of HPB, Minimally Invasive and Robotic Surgery, Federico II University Hospital Naples, Naples, Italy). Mariano Giglio (Department of Clinical Medicine and Surgery, Division of HPB, Minimally Invasive and Robotic Surgery, Federico II University Hospital Naples, Naples, Italy). Alessandro Mazzotta (Department of Digestive, Oncologic and Metabolic Surgery, Institute Mutualiste Montsouris, Universite Paris Descartes, Paris, France). Boram Lee Department of Surgery, Seoul National University Bundang Hospital, Seoul National University College of Medicine, Seoul, Korea. Hao-Ping Wang Department of Surgery, Chang Gung Memorial Hospital, Kaohsiung. Franco Pascual (Department of Hepatobiliary Surgery, Assistance Publique Hopitaux de Paris, Centre Hepato-Biliaire, Paul-Brousse Hospital, Villejuif, France). Prashant Kadam (Department of Hepatopancreatobiliary and Liver Transplant Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, United Kingdom). Chung-Ngai Tang (Department of Surgery, Pamela Youde Nethersole Eastern Hospital, Hong Kong SAR, China). Shian Yu (Department of Hepatobiliary Surgery, Affiliated Jinhua Hospital, Zhejiang University School of Medicine, Jinhua, China). Francesco Ardito (Hepatobiliary Surgery Unit, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Catholic University of the Sacred Heart, Rome, Italy). Simone Vani (Hepatobiliary Surgery Unit, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Catholic University of the Sacred Heart, Rome, Italy). Ugo Giustizieri (HPB Surgery, Hepatology and Liver Transplantation, Fondazione IRCCS Istituto Nazionale Tumori di Milano, Milan, Italy). Davide Citterio (HPB Surgery, Hepatology and Liver Transplantation, Fondazione IRCCS Istituto Nazionale Tumori di Milano, Milan, Italy). Federico Mocchegiani (HPB Surgery and Transplantation Unit, United Hospital of Ancona, Department of Sperimental and Clinical Medicine Polytechnic University of Marche). Giuseppe Maria Ettorre (Division of General Surgery and Liver Transplantation, S. Camillo Hospital, Rome, Italy). Marco Colasanti (Division of General Surgery and Liver Transplantation, S. Camillo Hospital, Rome, Italy). Yoelimar Guzmán (General & Digestive Surgery, Hospital Clínic, Barcelona, Spain).

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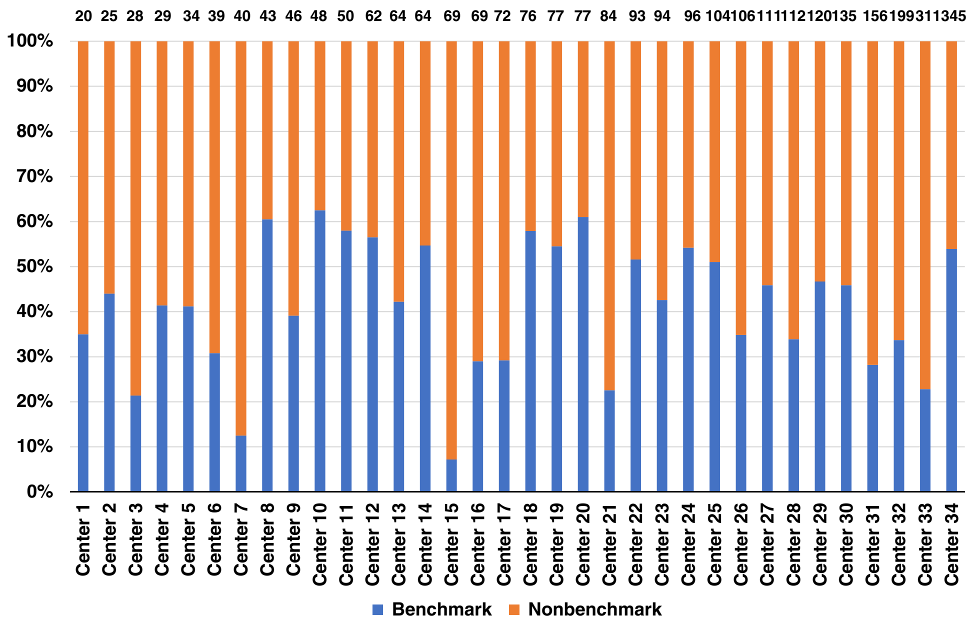

FIGURE 1. Proportion of benchmark cases performed across the 34 included benchmark centers.

ill-defined.[1,2] The objective of applying benchmarking in surgery is to assess the best possible outcome for a particular surgical procedure.[2,3] Formulation of standardized benchmarks[4] for key outcome indicators in surgery serve as important reference values for comparison when evaluating the implementation of novel surgical procedures and auditing outcomes. This has been

TABLE 1. Baseline Clinicopathological Features of the 1258 Low-risk Patients Operated in the 34 Expert Centers Selected for Benchmarking

	n (%)			
	All L-LR (N = 1258)	**LLS (n = 659)**	**LH (n = 306)**	**RH (n = 293)**
Centers (n)	34	34	34	34
Body mass index* [median (IQR)] (kg/m^2)	24.1 (21.5–26.7)	24.0 (21.5–26.6)	24.0 (21.3–26.8)	24.4 (21.7–27.1)
Age [median (IQR)] (y)	57 (49–65)	56 (47–64)	58 (48–64)	57 (47–63)
Male sex	696 (55.3)	362 (54.9)	175 (57.2)	159 (54.3)
ASA score				
I	270 (21.5)	133 (20.2)	75 (24.5)	62 (21.2)
II	988 (78.5)	526 (79.8)	231 (75.5)	231 (78.8)
Previous abdominal surgery	372/1229 (29.6)	171 (26.9)	97 (31.7)	104 (35.5)
Concomitant minor surgery	43 (3.4)	22 (3.3)	14 (4.6)	7 (2.4)
Malignancy	885 (70.3)	426 (64.6)	213 (69.6)	246 (84.0)
HCC	471 (37.4)	251 (38.1)	115 (37.6)	105 (35.8)
CRLM	263 (20.9)	110 (16.7)	54 (17.6)	99 (33.8)
ICC	69 (5.5)	24 (3.6)	28 (9.2)	17 (5.8)
Other LM	62 (4.9)	32 (4.9)	10 (3.3)	20 (6.8)
Other malignancy	20 (1.6)	9 (1.4)	6 (2.0)	5 (1.7)
Child's A cirrhosis	271 (21.5)	152 (23.1)	58 (19.0)	61 (20.8)
Neoadjuvant chemotherapy for CRLM	159 (12.6)	53 (8.0)	29 (9.5)	77 (26.3)
Multifocal tumors	258/1257 (20.5)	89 (13.5)	64 (20.9)	105 (35.8)
Multiple resections	37 (2.9)	0 (0.0)	20 (6.5)	17 (5.8)
Tumor size† [median (IQR)] (mm)	36 (18–56)	35 (20–52)	35 (20–50)	41 (25–65)
Iwate score				
Low	35 (2.8)	35 (5.3)	0 (0.0)	0 (0.0)
Intermediate	656 (52.1)	622 (94.4)	30 (9.8)	4 (1.4)
High	306 (24.3)	2 (0.3)	217 (70.9)	87 (29.8)
Expert	260 (20.7)	0 (0)	59 (19.3)	201 (68.6)

*Missing n = 42.
†Missing n = 1.
ASA indicates American Society of Anesthesiology; CRLM, colorectal liver metastases; HCC, hepatocellular carcinoma; ICC, intrahepatic cholangiocarcinoma; IQR, interquartile range; LM, liver metastases.

TABLE 2. Clinical Outcomes of the 1258 Low-risk Patients Operated in the 34 Expert Centers Selected for Benchmarking

	n (%)			
	All L-LR (N = 1258)	**LLS (n = 659)**	**LH (n = 306)**	**RH (n = 293)**
Operation time [median (IQR)] (min)	200 (113–288)	145 (91–200)	245 (180–320)	330 (265–412)
Missing data	1	0	1	0
Estimated blood loss [median (IQR)] (mL)	100 (0–225)	50 (50–150)	140 (50–300)	330 (200–500)
Missing data	90	58	19	13
Blood loss ≥ 500 mL [n/N (%)]	144/1168 (12.3)	17/601 (2.8)	39/287 (13.6)	88/280 (31.4)
Blood loss ≥ 1000 mL [n/N (%)]	23/1168 (2.0)	1/601 (0.2)	6/287 (2.1)	18/280 (6.4)
Intraoperative blood transfusion	55 (4.4)	14 (2.1)	11 (3.6)	30 (10.2)
Open conversion	60 (4.8)	10 (1.5)	23 (7.5)	27 (9.2)
Postoperative 90-d morbidity	174 (13.8)	56 (8.5)	39 (12.8)	79 (27.0)
Postoperative 90-d major morbidity [median (IQR)]	51 (4.1)	8 (1.2)	13 (4.3)	30 (10.2)
Reoperation	18 (1.4)	4 (0.6)	6 (2.0)	8 (2.7)
30-d readmission	32 (2.5)	10 (1.5)	6 (2.0)	16 (5.5)
Postoperative length of stay [median (IQR)] (d)	5 (4–7)	5 (4–6)	6 (5–7)	6.5 (5–8)
Missing data	4	0	1	3
R1 resection (< 1 mm) (malignancy only) [n/N (%)]	57/1197 (4.5)	18/424 (4.2)	11/212 (5.2)	28/245 (11.4)
Failure to rescue	3 (5.4)	1 (12.5)	0 (0.0)	2 (6.7)
30-d mortality	2 (0.2)	1 (0.2)	0 (0–0)	1 (0.3)
90-d mortality	3 (0.2)	1 (0.2)	0 (0–0)	2 (0.7)

IQR indicates interquartile range; LOS, length of stay.

recently defined for several major abdominal surgical procedures such as pancreas surgery,[5] bariatric surgery,[6] liver transplantation,[7] and open major liver surgery.[8]

The adoption of laparoscopic liver resections (L-LR) has been expanding rapidly worldwide over the past decade.[9,10] Hence, it has become critical to define benchmark values for the key outcome indicators of L-LR to promote the safe dissemination of the procedure. To date, there is limited data available in the literature on benchmarking outcomes in L-LR.[11,12] The absence of standardized benchmarks is a major shortcoming as there is a lack of reference data for which surgeons embarking on L-LR can determine if they have overcome the learning curve and achieved competency.[13,14]

In the present study, we aimed to establish various clinically relevant intraoperative and postoperative benchmark values for L-LR from low-risk patients[3,5] who underwent surgery at high-volume expert centers from around the globe. It is difficult to benchmark liver resections including L-LR as these are composed of a wide range of different procedures of varying complexities and outcomes.[15–18] Hence, to reduce the heterogeneity of the procedures and outcomes, 3 specific types of procedures: laparoscopic left lateral sectionectomy (LLS), left hepatectomy (LH), and right hepatectomy (RH) were selected to represent each of the 3 difficulty groups of L-LR as defined by Kawaguchi et al.[15]

METHODS

This is a post hoc analysis of an international multicenter database of 11,893 patients who underwent pure L-LR between January 2015 and December 2020 at 45 centers. Of note, only pure L-LR were included and other approaches such as robotic-assisted, hand-assisted, and laparoscopic-assisted (hybrid) LR were excluded in this study. Three specific L-LR procedures were selected to represent each of the 3 levels of difficulty of L-LR according to the Institute Mutualiste Montsouris (IMM) classification.[13] LLS for low difficulty, LH for intermediate difficulty, and RH for high difficulty resections.[11,13] Hence, 3519 L-LR performed at 43 centers, from 16 countries in 4 continents. The flow chart demonstrating the selection of cases is summarized in Supplementary Figure 1 (Supplemental Digital Content 1, http://links.lww.com/SLA/D884).

All institutions obtained their respective approvals according to their local requirements. Each individual center's collaborators and investigators collected and entered their deidentified data into a standard excel datasheet. This deidentified data were collated and analyzed centrally at the Singapore General Hospital. The data was stored in a password-protected computer in a locked office. All data was audited and checked for accuracy by the first author with assistance from his study team. In the event of ambiguity, the contributing center was contacted to verify the accuracy of data. The Singapore General Hospital Institution Review Board provided a waiver for this study due to its retrospective nature and the use of only deidentified data.

Study Design

High-volume Experienced Centers

A standardized methodology previously reported for procedures such as major liver resection,[8] liver transplant,[7] pancreatic surgery,[5] and bariatric surgery[6] was used as a guide to develop the benchmark outcomes in this study. Centers which met the following criteria: (1) cumulative experience of over 80 L-LR before January 2015, (2) average caseload ≥20 L-LR per annum between 2015 and 2020,[11,12,19] and (3) academic interest in L-LR as evidenced by ≥1 PubMed-indexed publication on L-LR were defined as a high-volume expert center in this study. 32 centers from 4 continents met the study criteria for the high-volume expert center. These included 17 from Europe, 13 from Asia, 1 from North America, and 1 from South America. In addition, 2 relatively new L-LR centers (1 Asia, 1 Europe) which did not meet criteria, were included as the L-LR programs in these 2 centers were initiated and the cases were performed by 2 world-renown highly experienced pioneering L-LR surgeons who had relocated to these centers. Hence, finally, 34 centers were included and the other 9 centers which did not meet the criteria formed the control group. In agreement with all centers, the identity of the centers was anonymized.

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Low-risk Procedures

To select patients with a low-preoperative risk profile for benchmarking,[2] only patients aged between 18 and 70 years old[5] and with a low American Society of Anesthesiology classification ≤2 were included.[5] Patients with very large tumors ≥10 cm,[20] Child's B liver cirrhosis or portal hypertension were excluded.[17,21] We also excluded patients who had L-LR for gallbladder cancer, donor hepatectomies, previous liver resections (repeat liver resections),[22] associating liver partition and portal vein ligation for staged hepatectomy,[11] bilioenteric anastomoses, hilar lymph node clearance, and those who underwent L-LR with concomitant major operations such as colectomies, bowel resections, and stoma reversals.[11,23,24] In addition, patients who underwent multiple minor liver resections with LLS were also excluded.[11] Notably, patients who underwent concomitant minor procedures such as cholecystectomy, hernia repair, or ablations were included. The selection criteria is summarized in Supplementary Table 1 (Supplemental Digital Content 2, http://links.lww.com/SLA/D885).

Definitions

LLS, LH, and RH were classified according to the 2000 Brisbane classification.[25] Notably, both LH and RH with caudate lobe resections were included as per the IMM classification.[15] Non-anatomical extended RH (partial segment 4) and extended LH (partial 5/8) and anatomical trisectionectomies were excluded. Postoperative complications were classified according to the Clavien-Dindo classification[26] and recorded for up to 90 days. Major complications were defined as complications > Clavien-Dindo grade 2. R1 resection was defined as a close resection margin of <1 mm. Difficulty of resections were also graded according to the Iwate score.[16,18] Failure-to-rescue 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).[27]

Outcome Indicators

Fifteen clinically relevant intraoperative and postoperative outcomes indicators were selected to establish benchmark cutoffs. The intraoperative outcomes selected were operation duration, estimated blood loss, blood loss ≥500 mL, blood loss ≥1000 mL, intraoperative blood transfusion, and open conversion. The postoperative outcomes selected were postoperative 90-day morbidity, postoperative 90-day major morbidity (> Clavien-Dindo grade 2), reoperation, postoperative 30- and 90-day mortality, postoperative length of stay, 30-day unplanned readmission rates, R1 resection (<1 mm margin for malignant tumors), and failure to rescue.

Benchmark Values and Statistical Analysis

A benchmark value was established for each of the 15 outcome indicators from patients who underwent LLS, LLH, and LRH. This was set at the 75th percentile (indicators of poor outcome) of the overall median value of the outcome indicator as previously described.[2,11] Mann-Whitney *U* test for continuous variables, while Fisher exact test and Pearson χ^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).

Comparative Cohorts

To test the benchmark values, we analyzed 2 separate cohort of patients. The first cohort was non–low-risk cases who underwent L-LR in the 34 experienced expert centers. The second cohort were low-risk L-LR meeting our study criteria for benchmark outcomes who underwent L-LR at centers which did not meet our inclusion criteria as an expert center.

RESULTS

A total of 3098 L-LR were performed in the 34 centers which met the study criteria as an expert center. Of these, there were 1543 LLS, 755 LH, and 800 RH. In all, 1258 L-LR (40.6%) cases performed in benchmark expert centers met the criteria for

TABLE 3. Fifteen Benchmark Outcome Measures After L-LR in 1258 Low-risk Cases From 34 International High-volume Centers

	LLS		LH		RH	
Variables	Across 34 Centers [Median (Range)]	Benchmark Cutoff (75th Percentile)	Across 34 Centers [Median (Range)]	Benchmark Cutoff (75th Percentile)	Across 34 Centers [Median (Range)]	Benchmark Cutoff (75th Percentile)
Operation time (min)	167 (60–412)	209.5	270 (120–703)	302	358 (180–742)	426
Estimated blood loss (mL)	50 (15–353)	100	150 (0–900)	300	350 (50–800)	400
Blood loss ≥500 mL	0 (0–18.2)	3.2	6.7 (0–58.3)	20	25 (0–100)	47.1
Blood loss ≥1000 mL	0 (0–3.2)	0	0 (0–25)	0	0 (0–30.8)	0
Intraoperative blood transfusion	0 (0–15.7)	0	0 (0–25)	7.1	0 (0–100)	10.5
Open conversion	0 (0–11.1)	2.1	0 (0–35.7)	13.4	0 (0–50)	13.0
Postoperative 90-d morbidity	6.3 (0–40)	11.1	9.1 (0–66.7)	20	23.1 (0–100)	50
Postoperative major morbidity	0 (0–16.7)	0	0 (0–33.3)	7.1	6.3 (0–50)	20
Reoperation	0 (0–16.7)	0	0 (0–33.3)	0	0 (0–50)	0
30-d readmission	0 (0–10)	0	0 (0–22.2)	0	0 (0–50)	8.3
Postoperative length of stay	4 (2–10)	5	5.5 (3–16.5)	7	6.5 (2–32)	7.5
R1 (<1 mm) resection (malignancy only)	0 (0–66.7)	7.1	0 (0–100)	10.5	0 (0–100)	18.2
Failure to rescue	0 (0–0)	0	0 (0–0)	0	0 (0–100)	0
30-d mortality	0 (0–3.3)	0	0 (0–0)	0	0 (0–5.3)	0
90-d mortality	0 (0–3.3)	0	0 (0–0)	0	0 (0–5.3)	0

low-risk benchmark cases. These included 659 LLS (52.4%), 306 LH (24.3%), and 293 RH (23.3%).

The proportion of benchmark cases in the 34 expert centers ranged from 7.2% to 62.5% (Fig. 1). The overall patient baseline clinicopathological features and outcomes are summarized in Tables 1 and 2.

Benchmark Outcomes

The 15 benchmark cutoffs derived from the 75th percentile of the medians of each outcome indicator for each center are summarized in Table 3. The benchmark outcomes established for open conversion rate, blood loss ≥ 500 mL, blood transfusion rate, postoperative morbidity, major morbidity, and 90-day mortality after LLS, LH, and RH were 2.1%, 13.4%, and 13.0%; 3.2%, 20%, and 47.1%; 0%, 7.1%, and 10.5%; 11.1%, 20%, and 50%; 0%, 7.1%, and 20%; and 0%, 0%, and 0%, respectively. Supplementary Table 2 (Supplemental Digital Content 3, http://links.lww.com/SLA/D886) summarizes the liver specific major morbidities.

Outcome Comparisons

We subsequently tested the applicability of the benchmark outcomes in 2 separate cohort of patients; non–low-risk L-LR performed in benchmark expert centers and low-risk L-LR performed in nonbenchmark centers (Table 4).

In the cohort of high-risk cases performed in benchmark centers, blood transfusion rate, blood loss ≥ 1000 mL, reoperation rate, failure to rescue, and 90-day mortality were outside the benchmark values for all 3 procedures: LLS, LH, and RH. For LLS, blood loss ≥ 500 mL, open conversion rate. Thirty-day readmission, morbidity, and major morbidity were also outside the cutoff. Furthermore, for LH, postoperative stay, morbidity, major morbidity, reoperation, and R1 resections were also beyond the benchmark cutoff. Finally, with regards to RH, open conversion rate and reoperation also exceeded the benchmark cutoff.

In the second comparison cohort of low-risk cases performed at nonbenchmark centers; for LLS, postoperative morbidity and major morbidity exceeded the cutoff. With regards to LH, postoperative stay, 90-day mortality, and failure to rescue rates exceeded the benchmark values. Finally, for RH, blood loss ≥ 1000 mL, postoperative stay, readmission rate, major morbidity rate, reoperation rate, and 90-day mortality were beyond the benchmark cutoffs.

Impact of Center Volume on Benchmark Cases

Twenty-one centers had an annual case volume of ≥ 50 L-LR/annum and 13 centers had an annual case volume of <50 cases/annum. Comparison between outcomes of L-LR stratified by annual volume is summarized in Table 5. Centers performing ≥ 50 L-LR/annum had a significantly shorter operation time for LLS, LH, and RH; lower 90-day morbidity for LH; lower major morbidity for LLS and LH; lower reoperation for LLS; lower 30-day readmission and R1 resection for RH; but increased median blood loss for LLS. Comparison between the proportion of benchmark cases in centers performing ≥ 50 L-LR/annum with centers performing <50 cases/annum demonstrated no significant difference between both groups [1008/2493 (40.4%) vs 250/605 (41.3%), $P = 0.690$]. There was no significant correlation between the proportion of benchmark cases and key outcomes such as operation time, open conversion rate, and postoperative morbidity (results not shown).

Geographical Differences in Benchmark Cases

The proportion of nonbenchmark cases performed in centers in Asia, Europe, and Americas were 765/1440 (53.1%), 1016/1543 (65.8%), and 59/115 (48.7%), respectively.

Comparison between Asian and non-Asian centers demonstrated a significantly higher proportion of benchmark cases in Asian centers ($P < 0.001$). Comparison between Asian and non-Asian centers also demonstrated a significantly higher proportion of cases performed in centers with an annual case volume ≥ 50 cases/annum in Asian centers compared with non-Asian centers [571/675 (84.6%) vs 432/583 (74.1%), $P < 0.001$].

Table 6 summarizes the 15 benchmark outcomes stratified by the geographical location of the benchmark centers. In general, a comparison between Asian versus non-Asian benchmark centers demonstrated superior outcomes in Asian centers in terms of significantly shorter operation time (LLS and LH), lower median blood loss (LLS and LH), lower open conversion rate (LH), lower 90-day morbidity, and major morbidity (LLS, LH, and RH). However, Asian centers were associated with a longer postoperative stay (LLS, LH, and RH) and increased blood loss for RH.

DISCUSSION

To our knowledge, this is the first attempt to identify global benchmark cutoffs for L-LR. In this study, we established 15 benchmark values for the short-term perioperative outcomes after L-LR based on 3 specific procedures representing each difficulty level of L-LR. The benchmark values were tested in 2 different cohorts of patients, 1 in higher risk patients who underwent L-LR at the benchmark centers and 1 in low-risk patients who were operated in nonbench centers. The results of this study demonstrate that L-LR can be performed safely today in expert centers with excellent outcomes. Low-difficulty procedures such as LLS can be performed with low morbidity, major morbidity, mortality, and open conversion rate. For procedures of intermediate and high difficulty such as LH and RH, although the mortality rate was low, these were still associated with significant morbidity, major morbidity, and open conversion rate. These findings suggest that LLS is currently an established and mature procedure in benchmark centers but procedures of intermediate and the high difficulty such as LH and RH may not have completely matured. It is also important to emphasize that these reported benchmarks values are supposed to reflect the best possible outcomes of L-LR today and were obtained from low-risk cases performed at high-volume expert centers. These values would serve as useful guide for centers and surgeons embarking on L-LR and would help to determine their progress along the learning curve.

Presently, despite the advantages, if L-LR[28,29] and its increasing adoption worldwide[9] there remains limited data on the benchmark outcomes of L-LR with only 2 recently published studies to date.[11,12] However, the 2 studies[11,12] reporting benchmark outcomes of L-LR based on the French and Italian nationwide studies have several major limitations which are worth highlighting. First, as both studies analyzed outcomes of centers limited to a single country, this limited the generalization of the results.[12] Second, the sample size of L-LR in each study was modest compared with the present analysis. Hence, these 2 studies could not implement the stringent inclusion and exclusion criteria as in the present study.

Another major limitation of the French study[11] was the long study period spanning from 2000 to 2017. Hence, a significant proportion of the benchmark cases were performed

TABLE 4. Comparison of the 15 Benchmark Outcome Measures in 2 Cohorts: Nonbenchmark Cases in the Benchmarking Centers and Benchmark Low-risk Cases in the Centers Which Did Not Meet Our Inclusion Criteria as a High-volume Expert Center

	LLS			LH			RH		
Variables	High-risk Nonbenchmark Cases (N = 884)	Benchmark Patients in Nonbenchmark Centers (N = 58)	Benchmark Cutoff	High-risk Nonbenchmark Cases (N = 449)	Benchmark Patients in Nonbenchmark Centers (N = 37)	Benchmark Cutoff	High-risk Nonbenchmark Cases (N = 507)	Benchmark Patients in Nonbenchmark Centers (N = 34)	Benchmark Cutoff
Benchmark cases (%)	NA	28	NA	NA	28.5	NA	NA	40.5	NA
Operation time [median (IQR)] (min)	169 (115)	180 (106)	209.5	275 (139)	225 (119)	302	315 (128)	345 (169)	427
Intraoperative blood transfusion	**4.2**	0	0	**13.2**	0	7.1	**15.6**	2.9	10.5
Blood loss [median (IQR)] (mL)	100 (200)	40 (100)	100	200 (300)	130 (200)	300	300 (327)	225 (250)	400
Blood loss ≥ 500 mL	**9.4**	1.7	3.2	18.2	10.8	20	30.5	20.6	47.1
Blood loss ≥ 1000 mL	**3.0**	0	0	**6.3**	0	0	**9.9**	**5.9**	0
Open conversion	**4.0**	1.7	2.1	11.1	5.4	13.4	**13.8**	8.8	13.0
Postoperative LOS [median (IQR)] (d)	5 (4)	5 (3)	5	**6 (6)**	**7 (4)**	5	7 (5)	**8 (7)**	7.5
30-d readmission	**3.2**	**1.7**	0	5.6	5.4	7	8.1	**11.8**	8.3
90-d morbidity	**16.9**	**15.5**	11.1	**23.4**	18.9	20	38.5	35.5	50
Postoperative major morbidity	**3.8**	**6.9**	0	**7.4**	5.4	7.1	17.8	**26.5**	20
Reoperation	**1.6**	**1.7**	0	**1.1**	0	0	**3.4**	**11.8**	0
30-d mortality	**0.6**	0	0	**0.9**	0	0	**1.0**	0	0
90-d mortality	**0.9**	0	0	**0.9**	**5.4**	0	**1.8**	**2.9**	0
Failure to rescue	**17.6**	0	0	**9.1**	**33.3**	0	**10.0**	0	0
R1 (< 1 mm) resection for malignancy (%)	6.7	4.3	7.1	**12**	5.6	10.5	13	8.3	18.2

Values are represented as n (%), unless otherwise specified.
IQR indicates interquartile range; LOS, length of stay; NA, not available.
Bold indicates values outside benchmark cutoffs.

TABLE 5. Comparison Between the 15 Benchmark Outcome Measures in Low-risk Cases Performed at the 34 Benchmark Centers Stratified by Center Annual Volume

	LLS			LH			RH		
Variables	**Center Volume ≤50/y (N = 144)**	**Center Volume >50/y (N = 515)**	***P***	**Center Volume ≤50/y (N = 58)**	**Center Volume >50/y (N = 248)**	***P***	**Center Volume ≤50/y (N = 53)**	**Center Volume >50/y (N = 240)**	***P***
Operation time [median (IQR)] (min)	153 (97)	144 (108)	**0.023**	290 (143)	240 (142)	**< 0.001**	365 (204)	330 (156)	**0.006**
Intraoperative blood transfusion	1 (0.7)	13 (2.5)	0.323	0	11/247 (4.5)	0.133	4 (7.5)	26 (10.8)	0.620
Blood loss [median (IQR)] (mL)	50 (80)	50 (120)	**0.010**	100 (194)	150 (250)	0.219	350 (453)	300 (300)	0.720
Blood loss ≥500 mL	0	17/494 (3.4)	0.053	4 (8.5)	35 (14.6)	0.267	15/41 (36.6)	73/239 (30.5)	0.441
Blood loss ≥1000 mL	0	1/494 (0.2)	1.000	0	4 (1.7)	1.000	1/41 (2.4)	17/239 (7.1)	0.487
Open conversion	0	10 (1.9)	0.129	1 (1.7)	22 (8.9)	0.092	7 (13.2)	20 (8.3)	0.267
Postoperative LOS [median (IQR)] (d)	4 (2)	5 (2)	0.244	6 (2)	6 (2)	0.979	7 (3)	6 (3)	0.800
30-d readmission	1 (0.7)	9 (1.7)	0.699	2 (3.4)	4 (1.6)	0.319	6 (11.3)	10 (4.2)	**0.049**
90-d morbidity	17 (11.8)	39 (7.6)	0.107	14 (24.1)	25 (10.1)	**0.004**	18 (34.0)	61 (25.4)	0.205
Postoperative major morbidity	5 (3.5)	3 (0.6)	**0.015**	6 (10.3)	7 (2.8)	**0.011**	8 (15.1)	22 (9.2)	0.212
Reoperation	3 (2.1)	1 (0.2)	**0.034**	3 (5.2)	3 (1.2)	0.084	1 (1.9)	7 (2.9)	1.000
30-d mortality	1 (0.7)	0	0.219	0	0	NC	0	1 (0.4)	1.000
90-d mortality	1 (0.7)	0	0.219	0	0	NC	0	2 (0.8)	1.000
Failure to rescue	1 (20.0)	0	0.408	0	0	NC	0	2 (9.1)	1.000
R1 (<1 mm) resection for malignancy (%)	5 (3.5)	13 (2.5)	0.564	3 (5.2)	8 (3.2)	0.443	10 (18.9)	18/239 (7.5)	**0.011**

Bold value statistically significant, $P < 0.05$.
Values are represented as n (%), unless otherwise specified.
IQR indicates interquartile range; LOS, length of stay.

during the pioneering phase of L-LR and during a center's learning curve which would unlikely be representative of the best possible outcome of L-LR today.[30] This was evident from the reportedly high benchmark values for an open conversion rate of ≤7.2% for LLS and ≤29.8% for RH reported in the study. The reported benchmark values for blood loss ≥1000 mL for L-LS and RH were also relatively high at ≤8.3% and ≤17.7%, respectively. Similarly, the benchmark blood transfusion rate was ≤3.8% and ≤14.6%. In the Italian nationwide study,[12] the authors used the Achievable Benchmark of Care (ABC) method to identify the best achievable outcomes in L-LR.[31] However, benchmark outcomes were only reported for 2 outcome indicators, that is, overall morbidity and major morbidity. These benchmark outcomes were reporting according to the difficulty of L-LR utilizing the IMM score. Hence, a notable limitation of this study was that within each difficulty group in the IMM scale, each group is heterogenous and made up of a wide range of different types of L-LR making a comparison of benchmark values difficult. For example, within the IMM III group, procedures such as RH, segmentectomy of posterosuperior segments, central hepatectomy, and extended LH are grouped together although each of these would likely be associated with very different postoperative outcomes.[15,18,32] Furthermore, the authors also included cases which underwent concomitant intestinal resection which they demonstrated had a significant impact on outcomes. Subsequently, the Italian group reported their benchmark outcomes for LLS (n = 341) and RH (n = 167), whereby the reported benchmark outcomes for morbidity, major morbidity and open conversion rate for LLS and RH were 4.5%, 0%, and 0% and 17.3%, 4.1%, and 8.3%, respectively.[33]

Interestingly, the benchmark outcomes reported in the present study compared favorably to that reported recently by Rossler et al[8] for open liver surgery. The authors reported benchmark 90-day morbidity and major morbidity values of 31.2% and 8.1%, respectively in a cohort of 5202 living donor hemihepatectomies (4206 RH, 996 LH). This was unexpected, as one would expect poorer outcomes for hepatectomies performed for liver pathology such as malignancy due to the higher risk population and underlying liver disease compared with living donors. This was evident in our study population whereby the median age was 57 years compared with 31 years in the living donor group. Furthermore, 22% of our patients had liver cirrhosis and 13% had prior chemotherapy. It is difficult to explain this observation definitively although it is plausible that the advantages of laparoscopy over open surgery accounted for these favorable results.

In this study not unexpectedly, comparison between low-risk benchmark cases performed in benchmark expert centers with the 2 control groups (high-risk nonbenchmark cases performed in benchmark expert centers and low-risk benchmark cases performed in nonbenchmark centers) demonstrated inferior outcomes in the 2 control groups. Notably, the outcomes of high-risk cases performed in benchmark expert centers tended to deviate more from the benchmark values compared with the low-risk benchmark cases performed in nonbenchmark centers. This observation suggests that patient and procedure risk level are major factors which affects the performance and achievement of predefined quality standards even in the presence of adequate expertise.

Several recent studies have demonstrated a volume-outcome relationship with regards to liver resections and specifically L-LR.[8,12,19] Although this study was not designed specifically to

TABLE 6. Summary of the 15 Benchmark Outcome Measures in Low-risk Cases Performed at the 34 Benchmark Centers Stratified by Geographical Location: Americas, Europe, and Asia and Statistical Comparison Between Asian and Non-Asian Centers

	LLS				LH				RH			
Variables	Americas (N = 29)	Europe (N = 274)	Asia (N = 356)	*P*	Americas (N = 14)	Europe (N = 106)	Asia (N = 186)	*P*	Americas (N = 13)	Europe (N = 147)	Asia (N = 133)	*P*
Operation time [median (IQR)] (min)	160 (90)	180 (100)	115 (85)	**< 0.001**	380 (131)	271 (131)	220 (136)	**< 0.001**	480 (188)	330 (130)	325 (168)	0.432
Intraoperative blood transfusion	0	4 (1.5)	10 (2.8)	0.279	0	6 (5.7)	5 (2.7)	0.349	2 (15.4)	13 (8.8)	15 (11.3)	0.593
Blood loss [median (IQR)] (mL)	50 (48)	100 (170)	50 (50)	**0.035**	150 (225)	200 (300)	100 (150)	**< 0.001**	350 (688)	300 (300)	400 (350)	**0.046**
Blood loss ≥ 500 mL	0	6 (2.8)	11 (3.1)	0.632	2 (14.3)	19 (21.8)	18 (9.7)	**0.011**	5 (41.7)	33 (24.4)	50 (37.6)	**0.035**
Blood loss ≥ 1000 mL	0	0	1 (0.3)	1.000	0	2 (2.3)	2 (1.1)	0.615	1 (8.3)	4 (3.0)	13 (9.8)	**0.048**
Open conversion	0	6 (2.2)	4 (1.1)	0.525	2 (14.3)	13 (12.3)	8 (4.3)	**0.008**	0	14 (9.5)	13 (9.8)	0.763
Postoperative LOS [median (IQR)] (d)	3 (2)	4 (2)	5 (3)	**< 0.001**	5 (2)	5 (3)	6.5 (3)	**< 0.001**	6 (2)	6 (4)	7 (4)	**< 0.001**
30-d readmission	0	3 (1.1)	7 (2.0)	0.356	0	4 (3.8)	2 (1.1)	0.215	0	10 (6.8)	6 (4.5)	0.514
90-d morbidity	1 (3.4)	32 (11.7)	23 (6.5)	**0.042**	1 (7.1)	22 (20.8)	16 (8.6)	**0.007**	4 (30.8)	50 (34.0)	25 (18.8)	**0.004**
Postoperative major morbidity	0	7 (2.6)	1 (0.3)	**0.027**	1 (7.1)	8 (7.5)	4 (2.2)	**0.038**	2 (15.4)	20 (13.6)	8 (6.0)	**0.030**
Reoperation	0	4 (1.5)	0	**0.044**	1 (7.1)	3 (2.8)	2 (1.1)	0.215	0	5 (3.4)	3 (2.3)	0.732
30-d mortality	0	1 (0.4)	0	NC	0	0	0	NC	0	1 (0.7)	0	1.00
90-d mortality	0	1 (0.4)	0	NC	0	0	0	NC	0	2 (1.4)	0	0.503
Failure to rescue	NC	1 (14.3)	0	1.000	NC	NC	NC	NC	0	2 (10.0)	0	1.000
R1 (< 1 mm) resection for malignancy	2 (6.9)	10 (3.7)	6 (1.7)	0.072	0	7 (6.7)	4 (2.2)	0.116	1 (7.7)	20 (13.7)	7 (5.3)	**0.022**

Bold value statistically significant, $P < 0.05$..
Values are represented as n (%), unless otherwise specified.
IQR indicates interquartile range; LOS, length of stay.
P-value: comparison between Asian versus non-Asian centers.

examine the impact of center volume on outcomes, we observed a significant influence of center volume on the perioperative outcomes of L-LR. When we arbitrarily stratified centers according to a cutoff of 50 L-LR cases/annum, the higher volume centers were associated with significantly superior perioperative outcomes such as lower operation time, postoperative morbidity, and readmission rate. In this study, unlike previous benchmark studies on pancreatectomy[5] and liver transplant[6] and we did not observe a correlation between the proportion of benchmark cases performed in a center and outcomes after L-LR.

Similar to the results of a previous studies on liver resections[34] and surgery for perihilar cholangiocarcinoma,[23] we observed that L-LR performed in Asian centers were associated in general with better perioperative outcomes compared with the rest of the world in terms of the significantly lower operation time, median blood loss, open conversion rate, 90-day morbidity, and major morbidity. It is difficult to determine the exact reasons accounting for the better outcomes observed with Asian centers although it must be acknowledged that there remains the potential for residual confounding factors despite the benchmark approach being utilized in this study. Notably, the higher proportion of L-LR in Asia being performed in centers with an annual case volume ≥ 50 cases/annum in this study was likely to be a major contributing factor for the better perioperative outcomes observed. The longer postoperative stay observed in Asian centers was not surprising as it is well-known that this is due to the differences in culture and health care systems including reimbursement.

There are several limitations associated with the current study which should be highlighted. First, this is a retrospective study which is associated with the usual limitations of information bias although most of the centers had a prospective database. However, this limitation can only be mitigated by performing a prospective clinical trial. Second, at present, although L-LR has been rapidly increasing worldwide,[35–37] it is possible that the procedure has not completely matured even in many of the high-volume expert centers in this study, especially for difficult resections such as RH. Hence, with the rapid evolution of L-LR, the current benchmark outcomes will need to be regularly updated in the future. Third, as this study focused on short-term perioperative outcomes; we could not report on long-term oncologic outcomes which would be an important benchmark indicator for L-LR as these are usually performed for malignancies. Fourth, unlike previous benchmark studies only age and American Society of Anesthesiology score was used in this study as information on specific comorbidities and use of anticoagulation was not collected. Finally, the comprehensive complications index which is an important indicator of cumulative morbidity was not used in this retrospective study. This index should ideally be used in future benchmark studies to emphasize the importance of reporting on multiple complications in a single patient. Nonetheless despite these limitations, this is the first global international multicenter study to provide benchmark outcomes for L-LR. Another strength of this study is the large sample size, which enabled us to focus the analysis on a relatively homogenous group of low-risk patients undergoing 3 specific L-LR procedures: LLS, LH, and RH. Furthermore, we could also apply a stringent inclusion criteria by excluding L-LR with various confounding factors such as multiple resections, concomitant major surgery, previous liver resections (redo hepatectomy), huge tumors, portal hypertension, and Child's B cirrhosis.

In conclusion, this large international multicentric study is the first to provide global benchmark values for L-LR. It provides an up-to-date reference regarding the "best achievable" results for L-LR for which centers adopting L-LR can use as a comparison to enable an objective assessment of performance gaps and learning curves. It may also allow meaningful comparison of outcomes between centers, countries, and different surgical techniques.

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