

Validation of the Institute Mutualiste Montsouris system for the stratification of laparoscopic liver resections: an international multicenter study

Alessandro Mazzotta¹, David Fuks¹, Olivier Soubrane¹, Hwee-Leong Tan², Nicholas L. Syn³, Safi Dokmak⁴, Salvatore Gruttadauria^{5,6}, Federica Cipriani⁷, Giuseppe Zimmiti⁸, Mohammad Alzoubi⁹, Atsushi Sugioka¹⁰, Olivier Scatton¹¹, Paulo Herman¹², Yufu Peng¹³, Marco V. Marino^{14,15}, Roland S. Croner¹⁶, Vincenzo Mazzaferro¹⁷, Adrian K. H. Chiow¹⁸, Iswanto Sucandy¹⁹, Arpad Ivanecz²⁰, Sung-Hoon Choi²¹, Jae Hoon Lee²², Mikel Gastaca²³, Marco Vivarelli²⁴, Felice Giuliani²⁵, Andrea Ruzzenente²⁶, Chee-Chien Yong²⁷, Mengqiu Yin²⁸, Constantino Fondevila^{29,30}, Mikhail Efanov³¹, Zenichi Morise³², Fabrizio Di Benedetto³³, Raffaele Brustia³⁴, Raffaele Dalla Valle³⁵, Ugo Boggi³⁶, David Geller³⁷, Andrea Belli³⁸, Riccardo Memeo^{39,40}, Alejandro Mejia⁴¹, James O. Park⁴², Fernando Rotellar^{43,44}, Gi-Hong Choi⁴⁵, Ricardo Robles-Campos⁴⁶, Kiyoshi Hasegawa⁴⁷, Yoshikuni Kawaguchi⁴⁷, Xiaoying Wang⁴⁸, Robert P. Sutcliffe⁴⁹, Johann Pratschke⁵⁰, Eric C. H. Lai⁵¹, Charing C. N. Chong⁵², Mathieu D'Hondt⁵³, Kazuteru Monden⁵⁴, Santiago Lopez-Ben⁵⁵, T. Peter Kingham⁵⁶, Rong Liu⁵⁷, Alessandro Ferrero⁵⁸, Giuseppe Maria Ettorre⁵⁹, Daniel Cherqui⁶⁰, Xiao Liang⁶¹, Go Wakabayashi⁶², Roberto I. Troisi⁶³, Tan-To Cheung⁶⁴, Motokazu Sugimoto⁶⁵, Ho-Seong Han⁶⁶, Tran Cong duy Long⁶⁷, Wanguang Zhang⁶⁸, Yonggang Wei¹³, Davit L. Aghayan⁶⁹, Bjorn Edwin⁶⁹, Kuo-Hsin Chen⁷⁰, Mohammad Abu Hilal^{9,71}, Luca Aldrighetti⁷, Brian K. P. Goh^{2,72}^; International Robotic and Laparoscopic Liver Resection Study Group Investigators*

¹Department of Digestive, Oncologic and Metabolic Surgery, Institute Mutualiste Montsouris, Universite Paris Descartes, Paris, France; ²Department of Hepatopancreatobiliary and Transplant Surgery, Singapore General Hospital and National Cancer Centre Singapore, Singapore; ³Yong Loo Lin School of Medicine, National University of Singapore, Singapore and Ministry of Health Holdings Singapore, Singapore; ⁴Department of HPB Surgery and Liver Transplantation, Beaujon Hospital, University Paris Cite, Clichy, France; ⁵Department for the Treatment and Study of Abdominal Diseases and Abdominal Transplantation, IRCCS-ISMETT, University of Pittsburgh Medical Center, Palermo, Italy; ⁶Department of Surgery and Medical and Surgical Specialties, University of Catania, Catania, Italy; ⁷Hepatobiliary Surgery Division, IRCCS San Raffaele Hospital, Milan, Italy; ⁸Department of Surgery, Fondazione Poliambulanza, Brescia, Italy; ⁹Department of General Surgery, School of Medicine, The University of Jordan, Amman, Jordan; ¹⁰Department of Surgery, Fujita Health University School of Medicine, Aichi, Japan; ¹¹Department of Digestive, HBP and Liver Transplantation, Hopital Pitie-Salpetriere, Sorbonne Universite, Paris, France; ¹²Liver Surgery Unit, Department of Gastroenterology, University of Sao Paulo School of Medicine, Sao Paulo, Brazil; ¹³Division of Liver Surgery, Department of General Surgery, West China Hospital, Sichuan University, Chengdu, China; ¹⁴General Surgery Department, Azienda Ospedaliera Ospedali Riuniti Villa Sofia-Cervello, Palermo, Italy; ¹⁵Oncologic Surgery Department, P. Giaccone University Hospital, Palermo, Italy; ¹⁶Department of General, Visceral, Vascular and Transplant Surgery, University Hospital Magdeburg, Magdeburg, Germany; ¹⁷HPB Surgery and Liver Transplantation, Fondazione IRCCS Istituto Nazionale Tumori di Milano and University of Milan, Milan, Italy; ¹⁸Hepatopancreatobiliary Unit, Department of Surgery, Changi General Hospital, Singapore, Singapore; ¹⁹AdventHealth Tampa, Digestive Health Institute, Tampa, FL, USA; ²⁰Department of Abdominal and General Surgery, University Medical Center Maribor, Maribor, Slovenia; ²¹Department of General Surgery, CHA Bundang Medical Center, CHA University School of Medicine, Seongnam, Korea; ²²Division of Hepato-Biliary and Pancreatic Surgery, Department of Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea; ²³Hepatobiliary Surgery and Liver Transplantation Unit, Biocruces Bizkaia Health Research Institute, Cruces University Hospital, University of the Basque Country, Bilbao, Spain; ²⁴HPB Surgery and Transplantation Unit, Department of Experimental and Clinical Medicine, United Hospital of Ancona, Polytechnic University of Marche, Ancona, Italy; ²⁵Hepatobiliary Surgery Unit, Fondazione Policlinico Universitario A. Gemelli, IRCCS, Catholic University of the Sacred Heart, Rome, Italy; ²⁶General and Hepatobiliary Surgery, Department of Surgery, Dentistry, Gynecology and Pediatrics University of Verona, GB Rossi Hospital, Verona, Italy; ²⁷Department of Surgery, Chang Gung Memorial Hospital, Kaohsiung; ²⁸Department of Hepatobiliary Surgery, Affiliated Jinhua Hospital, Zhejiang

^ ORCID: 0000-0001-8218-4576.

* See Appendix 1.

University School of Medicine, Jinhua, China; ²⁹General and Digestive Surgery, Hospital Universitario La Paz, IdiPAZ, Madrid, Spain; ³⁰General and Digestive Surgery, Hospital Clinic, IDIBAPS, CIBERehd, University of Barcelona, Barcelona, Spain; ³¹Department of Hepato-Pancreato-Biliary Surgery, Moscow Clinical Scientific Center, Moscow, Russia; ³²Department of Surgery, Okazaki Medical Center, Fujita Health University School of Medicine, Okazaki, Japan; ³³Hepatopancreatobiliary Surgery and Liver Transplant Unit, University of Modena and Reggio Emilia, Modena, Italy; ³⁴Department of Digestive and Hepatobiliary and Pancreatic Surgery, AP-HP, Henri-Mondor Hospital, Creteil, France; ³⁵Hepatobiliary Surgery Unit, Department of Medicine and Surgery, University of Parma, Parma, Italy; ³⁶Division of General and Transplant Surgery, University of Pisa, Pisa, Italy; ³⁷Division of Hepatobiliary and Pancreatic Surgery, Department of Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA, USA; ³⁸Division of Hepatopancreatobiliary Surgical Oncology, Department of Abdominal Oncology, National Cancer Center-IRCCS-G. Pascale, Naples, Italy; ³⁹Unit of Hepato-Biliary and Pancreatic Surgery, "F. Miulli" General Hospital, Acquaviva delle Fonti, 70021 Bari, Italy; ⁴⁰Department of Medicine and Surgery, LUM University, Casamassima, 70010 Bari, Italy; ⁴¹The Liver Institute, Methodist Dallas Medical Center, Dallas, TX, USA; ⁴²Department of Surgery, University of Washington Medical Center, Seattle, WA, USA; ⁴³HPB and Liver Transplant Unit, Department of General Surgery, Clinica Universidad de Navarra, Universidad de Navarra, Pamplona, Spain; ⁴⁴Institute of Health Research of Navarra (IdisNA), Pamplona, Spain; ⁴⁵Division of Hepatopancreatobiliary Surgery, Department of Surgery, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea; ⁴⁶Department of Surgery, Virgen de la Arrixaca University Hospital, IMIB-Pascual Parrilla, Murcia, Spain; ⁴⁷Hepato-Biliary-Pancreatic Surgery Division, Department of Surgery, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan; ⁴⁸Department of Liver Surgery and Transplantation, Liver Cancer Institute, Zhongshan Hospital, Fudan University, Shanghai, China; ⁴⁹Department of Hepatopancreatobiliary and Liver Transplant Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK; ⁵⁰Department of Surgery, Campus Charité Mitte and Campus Virchow-Klinikum, Charité-Universitätsmedizin, Corporate Member of Freie Universität Berlin, and Berlin Institute of Health, Berlin, Germany; ⁵¹Department of Surgery, Pamela Youde Nethersole Eastern Hospital, Hong Kong SAR, China; ⁵²Department of Surgery, Prince of Wales Hospital, The Chinese University of Hong Kong, New Territories, Hong Kong SAR, China; ⁵³Department of Digestive and Hepatobiliary/Pancreatic Surgery, Groeninge Hospital, Kortrijk, Belgium; ⁵⁴Department of Surgery, Fukuyama City Hospital, Hiroshima, Japan; ⁵⁵Hepatobiliary and Pancreatic Surgery Unit, Department of Surgery, Dr. Josep Trueta Hospital, IdIBGi, Girona, Spain; ⁵⁶Department of Surgery, Memorial Sloan Kettering Cancer Center, New York, NY, USA; ⁵⁷Faculty of Hepatopancreatobiliary Surgery, The First Medical Center of Chinese People's Liberation Army (PLA) General Hospital, Beijing, China; ⁵⁸Department of General and Oncological Surgery, Mauriziano Hospital, Turin, Italy; ⁵⁹Division of General Surgery and Liver Transplantation, San Camillo Forlanini Hospital, Rome, Italy; ⁶⁰Department of Hepatobiliary Surgery, Assistance Publique Hopitaux de Paris, Centre Hepato-Biliaire, Paul-Brousse Hospital, Villejuif, France; ⁶¹Department of General Surgery, Sir Run-Run Shaw Hospital, Zhejiang University School of Medicine, Hangzhou, China; ⁶²Center for Advanced Treatment of Hepatobiliary and Pancreatic Diseases, Ageo Central General Hospital, Saitama, Japan; ⁶³Division of HPB, Minimally Invasive and Robotic Surgery, Department of Clinical Medicine and Surgery, Federico II University Hospital Naples, Naples, Italy; ⁶⁴Department of Surgery, Queen Mary Hospital, The University of Hong Kong, Hong Kong SAR, China; ⁶⁵Department of Hepatobiliary and Pancreatic Surgery, National Cancer Hospital East, Kashiwa, Japan; ⁶⁶Department of Surgery, Seoul National University Hospital Bundang, Seoul National University College of Medicine, Seoul, Korea; ⁶⁷Department of Hepatopancreatobiliary Surgery, University Medical Center, University of Medicine and Pharmacy, Ho Chi Minh City, Vietnam; ⁶⁸Hepatic Surgery Center and Hubei Key Laboratory of Hepato-Biliary-Pancreatic Diseases, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China; ⁶⁹The Intervention Centre and Department of HPB Surgery, Oslo University Hospital, Institute of Clinical Medicine, University of Oslo, Oslo, Norway; ⁷⁰Division of General Surgery, Far Eastern Memorial Hospital, New Taipei City; ⁷¹Department of Surgery, University Hospital Southampton, Southampton, UK; ⁷²Surgery Academic Clinical Programme, Duke-National University of Singapore Medical School, Singapore, Singapore

Contributions: (I) Conception and design: BKP Goh, D Fuks, O Soubrane, A Mazzotta; (II) Administrative support: BKP Goh, D Fuks, O Soubrane; (III) Provision of study materials or patients: All authors; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: BKP Goh, D Fuks, A Mazzotta, NL Syn, HL Tan; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Brian K. P. Goh, MBBS, MMed, MSc, FRCSEd. Department of Hepatopancreatobiliary and Transplant Surgery, Singapore General Hospital and National Cancer Centre Singapore, Level 5, 20 College Road, Academia, Singapore 169856, Singapore; Surgery Academic Clinical Programme, Duke-National University of Singapore Medical School, Singapore, Singapore. Email: bsgkp@hotmail.com.

Background: The Institut Mutualiste Montsouris (IMM) 3-level complexity classification has been validated for laparoscopic liver resection (LLR) in several studies with small sample size. However, it has not been well-validated in large studies down to the individual procedure type. Hence, in order to address current limitations in the studies validating the IMM complexity classification, we performed an international multicenter study to validate the IMM complexity classification across its three complexity levels and the

categorization of the 11 distinct procedure types.

Methods: A retrospective cohort study of 22,252 patients undergoing LLR across 64 centers worldwide between 2005 and 2021 was performed. Baseline characteristics and perioperative outcomes were analyzed across the three difficulty levels and 11 procedure types of the IMM complexity classification.

Results: A total of 14,765 patients were included in our final analysis. The main indications for LLR in our study was hepatocellular carcinoma or intrahepatic cholangiocarcinoma (n=7,781, 52.7%) followed by liver metastasectomy (n=3,911, 26.5%). In terms of underlying liver pathology, 5,127 (34.7%) cases had cirrhosis, and 1,214 (8.3%) had portal hypertension. Perioperative outcomes including operative time, open conversion rate, intraoperative blood loss, need for intraoperative blood transfusion, need for Pringle's application, length of stay, postoperative morbidity, major postoperative morbidity and 90-day mortality all demonstrated a significant increasing trend with increasing IMM complexity grades ($P<0.001$). These trends remained significant following adjustment for baseline characteristics ($P<0.001$). Notably, when examining the 11 LLR procedure types, all procedures within each IMM complexity grade were individually higher than all procedures in the preceding complexity grade for operative time, blood loss, length of stay, postoperative morbidity and major postoperative morbidity.

Conclusions: The three IMM complexity grades were well associated with LLR complexity as determined by key surrogate perioperative measures. Our findings also supported the categorization of the 11 distinct LLR procedures into the three complexity levels.

Keywords: Laparoscopic liver resection (LLR); Iwate criteria; validation; international multicenter study; perioperative outcomes

Submitted Jun 03, 2024. Accepted for publication Feb 26, 2025. Published online Jan 22, 2026.

doi: 10.21037/hbsn-24-304

View this article at: <https://dx.doi.org/10.21037/hbsn-24-304>

Introduction

Laparoscopic liver resection (LLR) has become increasingly adopted across the world over the past two decades (1-4). The traction gained by LLR is largely attributable to

the compelling amount of evidence to date that LLR is associated with improved perioperative outcomes compared with traditional open liver resections (OLRs) (3,5,6). The improved outcomes associated with LLR are however contingent upon the safe and proficient performance of LLR, which requires mounting a significant learning curve (7). To this end, several difficulty scoring systems (DSS) for LLR have been developed over the years which serve two key purposes (8-14). The first is to allow for risk stratification of liver resection cases to guide decision making on the choice of operative approach (open versus laparoscopic) for an individual surgeon depending on how far along he/she is along the LLR learning curve (7,8). The second is to provide an objective metric by which LLR cases can be assessed for inherent difficulty so as to facilitate evaluation of perioperative outcomes which is essential for auditing LLR programs and benchmarking against international standards (8).

The Institut Mutualiste Montsouris (IMM) 3-level complexity classification (*Table 1*) was developed in 2018 based on a single institutional retrospective review of 452 consecutive LLR performed over a 20-year period

Highlight box

Key findings

- This study successfully validated the three Institut Mutualiste Montsouris (IMM) complexity grades including the 11 individual procedures within each grade.

What is known and what is new?

- Previous studies had only validated the three IMM complexity grades but not the individual procedures within each grade.
- This study is the first to validate the categorization of each of the 11 distinct procedure types.

What is the implication, and what should change now?

- This study supports the use of the IMM complexity classification system.
- Further studies are needed to determine if the IMM system can be further improved and optimized.

Table 1 IMM 3-level complexity classification

Grade of complexity	Procedures
Low	
I	Wedge AL Sg
II	Wedge PS Sg
III	Lt lateral Sect
Intermediate	
IV	Sgm AL Sg
V	Lt Hep
High	
VI	Sgm PS Sg
VII	Rt Hep
VIII	Ext Rt Hep
IX	Rt Post Sect
X	Central Hep/Rt Ant Sect
XI	Ext Lt Hep

AL, anterolateral (II, III, IVb, V, VI); Ant, anterior; Ext, extended; Hep, hepatectomy; IMM, Institut Mutualiste Montsouris; Lt, left; Post, posterior; PS, posterosuperior (I, IVa, VII, VIII); Rt, right; Sect, sectionectomy; Sg, segment; Sgm, segmentectomy.

(1995 to 2015) (14). Using the pre-existing Brisbane 2000 nomenclature and definitions of anterolateral (segments 2, 3, 4b, 5 and 6) and posterosuperior (segments 1, 4a, 7 and 8) segments put forth in preceding position statements, this DSS divided LLR into 11 distinct procedures (1,2,14,15). These 11 procedures were in turn grouped into three levels of complexity (grades I, II and III) based on a composite score derived from determining if each procedure was at or above the median value of the entire cohort for three perioperative variables (operative time, intraoperative blood loss and conversion rate), which served as a surrogate measure of technical complexity (14).

Since its conception, the IMM has been extensively validated by several studies and shown to be a significant discriminator for operative time, blood loss, need for transfusion, need for Pringle's maneuver and Pringle's time, conversion rate, postoperative complication rate, length of stay, liver failure rate and mortality for LLR (9,16-22). These studies however, including the initial study by Kawaguchi *et al.* which developed the complexity classification, had limited sample sizes which only permitted evaluation of the IMM DSS across its three difficulty

levels and not down to the granularity of the 11 distinct procedures. Additionally, they are predominantly single institutional cohorts which limit the generalizability of the validation as key clinicopathologic variables such as the prevalence of cirrhosis and proportions of different indications for liver resection may differ internationally (9,13,23).

As such, this study was conducted as the first international multicenter study to validate the IMM complexity classification across its three complexity levels and to evaluate if the categorization of the 11 distinct procedure types into the 3 complexity levels was appropriate. We present this study in accordance with the STROBE reporting checklist (available at <https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-304/rc>).

Methods

Study design

This is an international multicenter post hoc study of 22,252 patients who underwent pure LLR at 64 centers between 2005 and 2021. All institutions obtained their respective approvals according to their local center's requirements. The study was performed in accordance with the Declaration of Helsinki and its subsequent amendments. This study was approved by the Singapore General Hospital Institution Review Board (2020/2802) and the need for patient consent was waived. The deidentified data were collected in the individual centers. These were collated and analyzed centrally at the Singapore General Hospital.

Patients who underwent donor hepatectomy for transplant or associating liver partition and portal vein ligation for staged hepatectomy (ALPPS) (n=70), had multiple simultaneous liver resections (n=2,308), previous liver resections (n=2,042) or concomitant major operations (n=1,958), were excluded. Notably, patients with concomitant minor operations such as hernia repair or ablations were included. Following the aforementioned exclusions, 14,765 cases of LLR with complete data were included in this study for analysis.

Definitions and outcomes

The types of LLR were defined in accordance with the original IMM complexity classification which utilised the pre-existing Brisbane 2000 nomenclature and definitions of anterolateral (segments 2, 3, 4b, 5 and 6) and

posterosuperior (segments 1, 4a, 7 and 8) segments put forth in preceding position statements (1,2,14,15). The LLR procedures were ordered from 1 to 11 as originally presented in the IMM complexity classification as follows: (I) anterolateral wedge resection; (II) posterosuperior wedge resection; (III) left lateral sectionectomy; (IV) anterolateral segmentectomy; (V) left hepatectomy; (VI) posterosuperior segmentectomy; (VII) right hepatectomy; (VIII) extended right hepatectomy; (IX) right posterior sectionectomy; (X) central hepatectomy/right anterior sectionectomy; (XI) extended left hepatectomy (14). These 11 procedures were in turn grouped into three complexity levels as per the IMM system, with grade I (low difficulty) encompassing procedures 1 to 3, grade II (intermediate difficulty) encompassing procedures 4 and 5, and grade III (high difficulty) encompassing procedures 6 to 11 (14).

The baseline clinicopathological characteristics of patients were recorded and analyzed, including age, sex, year of resection, ASA score, previous abdominal surgery history, concomitant minor surgery, proportion of malignant pathology, pathology type, liver cirrhosis, Child-Pugh grade, portal hypertension, median tumor diameter, tumor number, and the difficulty index of the Iwate DSS. The diameter of the largest lesion was used in cases of multiple tumors. Cirrhosis was defined based on pathological examination (METAVIR F4) and portal hypertension was defined based on, as the presence of ascites, varices or splenomegaly with a platelet count of less than $100 \times 10^9/L$.

Postoperative complications were classified according to the Clavien-Dindo classification and recorded for up to 30 days or during the same hospitalization and included 30-day readmissions (24). Thirty-day and 90-day mortalities were recorded. To mitigate confounding factors from historical bias and center experience, the resections were classified into three periods: 2005–2010, 2011–2016 and 2017–2021.

Perioperative variables (both intraoperative characteristics and postoperative outcomes after LLR) were analyzed and evaluated according to both the three difficulty levels (low, intermediate, high) and across the 11 distinct LLR procedures delineated in the IMM complexity classification (14).

Statistical analysis

Continuous variables were summarized as medians and their interquartile ranges, while factor variables were

summarised as percentages. The Cochran-Armitage and Jonckheere-Terpstra trend tests to assess presence of a monotonic association between the Iwate DSS and perioperative outcomes. To control for differences in baseline characteristics and enable comparability across strata, adjusted outcomes for each strata were obtained by conditioning the predictive margins on the baseline characteristics of the overall population. Bootstrapped quantile and Firth penalized-likelihood logistic regressions were employed for continuous and binary dependent variables respectively, and covariates included all baseline characteristics shown in *Table 2*. Statistical analyses were conducted in R version 4.2.1.

Results

A total of 14,765 LLR were performed across 64 international centers, comprising 3,890 anterolateral wedge resections, 2,020 posterosuperior wedge resections, 2,394 left lateral sectionectomies, 1,989 anterolateral segmentectomies, 1,029 left hepatectomies, 1,094 posterosuperior segmentectomies, 1,174 right hepatectomies, 75 extended right hepatectomies, 640 right posterior sectionectomies, 358 central hepatectomies/right anterior sectionectomies and 102 extended left hepatectomies. There was an increase in the number of LLR performed across the three pre-defined time periods, with 1,297 (8.8%), 5,486 (37.2%) and 7,982 (54.1%) LLR performed in 2005–2010, 2011–2016 and 2017–2021 respectively. The main indications for LLR in our study was hepatocellular carcinoma or intrahepatic cholangiocarcinoma ($n=7,781$, 52.7%) followed by liver metastasectomy ($n=3,911$, 26.5%). In terms of underlying liver pathology, 5,127 (34.7%) cases had cirrhosis, and 1,214 (8.3%) had portal hypertension. The overall and comparative baseline clinicopathologic characteristics across the three IMM DSS difficulty levels and 11 LLR procedure types are summarized in *Table 2*.

The overall and raw unadjusted comparative perioperative outcomes across the three IMM complexity levels and 11 LLR procedure types are summarized in *Table 3* and *Figures 1–3*, while the adjusted comparative outcomes are summarized in *Table 4* and *Figures 1–3*. Key perioperative outcomes including operative time, open conversion rate, intraoperative blood loss, need for intraoperative blood transfusion, need for Pringle's application, length of stay, postoperative morbidity, major postoperative morbidity and 90-day mortality all demonstrated a significant increasing trend with increasing

Table 2 Comparison between baseline clinicopathological characteristics stratified by IMM procedure type

Variable	Overall (N=14,765)	IMM I (low)			IMM II (intermediate)		IMM III (high)					
		1: Wedge AL Sg (N=3,890)	2: Wedge PS Sg (N=2,020)	3: Lt lateral Sect (N=2,394)	4: Segment AL (N=1,989)	5: Lt Hep (N=1,029)	6: Segment PS Sg (N=1,094)	7: Rt Hep (N=1,174)	8: Ext Rt Hep (N=75)	9: Rt Post Sect (N=640)	10: Central Hep/Rt Ant Sect (N=358)	11: Ext Lt Hep (N=102)
Median age, years [IQR]	62 [52–71]	63 [53–71]	63 [53–71]	61 [50–70]	62 [52–71]	63 [52–70]	64 [54–73]	62 [52–71]	64 [55–71]	62 [52–71]	62 [53–71]	63 [55–71]
Male sex	9,052 (61.3)	2,294 (58.9)	1,261 (62.4)	1,371 (57.2)	1,291 (64.9)	586 (56.9)	745 (68.1)	692 (58.9)	51 (68.0)	422 (65.9)	268 (74.8)	71 (69.6)
Year of resection												
2005–2010	1,297 (8.8)	462 (11.8)	127 (6.2)	309 (12.9)	136 (6.8)	76 (7.3)	31 (2.8)	100 (8.5)	5 (6.6%)	38 (5.9%)	5 (1.4%)	8 (7.8)
2011–2016	5,486 (37.2)	1,430 (36.7)	701 (34.7)	949 (39.6)	853 (42.8)	355 (34.5)	323 (29.5)	488 (41.5)	32 (42.6%)	221 (34.5%)	96 (26.8%)	38 (37.2)
2017–2021	7,982 (54.1)	1,998 (51.3)	1,192 (59.0)	1,136 (47.4)	1,000 (50.2)	598 (58.1)	740 (67.6)	586 (49.9)	38 (50.6%)	381 (59.5%)	257 (71.7%)	56 (54.9)
ASA score												
I/II	10,999 (74.5)	2,847 (73.2)	1,472 (72.9)	1,857 (77.6)	1,448 (72.9)	794 (77.2)	802 (73.3)	897 (76.4)	51 (68.0)	492 (76.9)	272 (76.0)	67 (65.7)
III/IV	3,758 (25.5)	1,040 (26.8)	546 (27.1)	536 (22.4%)	539 (27.1)	235 (22.8)	292 (26.7)	277 (23.6)	24 (32.0)	148 (23.1)	86 (24.0)	35 (34.3)
Previous abdominal surgery	4,691/14,409 (32.5)	1,305/3,756 (34.7)	745/1,967 (37.8)	661/2,315 (28.5)	578/1,933 (29.9)	326/1,022 (31.9)	357/1,082 (32.9)	405/1,164 (34.7)	18/75 (24.0)	184/635 (28.9)	80/358 (22.3)	32/102 (31.4)
Concomitant minor surgery	643/11,656 (5.5)	197/2,984 (6.6)	63/1,575 (4.0)	77/1,840 (4.1)	82/1,642 (4.9)	48/790 (6.0)	35/916 (3.8)	67/886 (7.5)	3/57 (5.2)	39/552 (7.0)	23/334 (6.8)	9/80 (11.3)
Malignant pathology	11,844/14,748 (80.3)	3,028/3,886 (77.9)	1,683/2,019 (83.4)	1,703/2,388 (71.3)	1,705/1,985 (85.9)	699/1,028 (68.0)	980/1,093 (89.7)	994/1,174 (84.7)	72/75 (96.0)	562/640 (87.8)	332/358 (92.7)	86/102 (84.3)
Pathology type												
Benign pathology	2,904 (19.7)	858 (22.1)	336 (16.6)	658 (28.7)	280 (14.1)	329 (32.0)	113 (10.4)	180 (15.3)	3 (4.0)	78 (12.2)	26 (7.26)	16 (15.7)
HCC/ICC	7,781 (52.7)	1,854 (47.7)	987 (48.8)	1,159 (48.4)	1,287 (64.8)	484 (47.0)	684 (62.6)	575 (48.98)	47 (62.7)	382 (59.7)	266 (74.3)	56 (54.9)
CRLM/LM	3,911 (26.5)	1,122 (28.9)	685 (33.9)	530 (22.2)	390 (19.6)	202 (19.6)	292 (26.7)	401 (34.2)	24 (32.0)	176 (27.5)	60 (16.7)	29 (28.4)
Other malignancies	152 (1.0)	52 (1.3)	11 (0.5)	14 (0.6)	28 (1.4)	13 (1.3)	4 (0.4)	18 (1.5)	1 (1.3)	4 (0.6)	6 (1.7)	1 (1.0)
Cirrhosis	5,127/14,760 (34.7)	1,375/3,889 (35.3)	754/2,020 (37.3)	739/2,393 (30.8)	835/1,987 (42.0)	256/1,029 (24.8)	462/1,094 (42.2)	290/1,173 (24.7)	24/75 (32.0)	206/640 (32.1)	165/358 (46.0)	21/102 (20.5)
Childs-Pugh score												
No cirrhosis	9,633/14,753 (65.3)	2,514/3,885 (64.7)	1,266/2,019 (62.7)	1,654/2,393 (69.1)	1,152/1,987 (57.9)	773/1,029 (75.1)	632/1,094 (57.7)	883/1,172 (75.3)	51/74 (68.9)	434/640 (67.8)	193/358 (53.9)	81/102 (79.4)
A	4,639/14,753 (31.4)	1,268/3,885 (32.6)	681/2,019 (33.7)	680/2,393 (28.4)	734/1,987 (36.9)	224/1,029 (21.7)	411/1,094 (37.5)	256/1,172 (21.8)	18/74 (34.3)	189/640 (29.5)	157/358 (43.8)	21/102 (20.6)
B	481/14,753 (3.3)	103/3,885 (2.7)	72/2,019 (3.6)	59/2,393 (2.5)	101/1,987 (5.1)	32/1,029 (3.1)	51/1,094 (4.7)	33/1,172 (2.8)	5/74 (6.8)	17/640 (2.7)	8/358 (2.23)	0/102 (0.0)
Portal hypertension	1,214/14,687 (8.3)	401/3,862 (10.4)	192/2,015 (9.5)	163/2,384 (6.8)	215/1,974 (10.8)	41/1,026 (4.0)	107/1,086 (9.8)	40/1,169 (3.42)	4/75 (5.3)	24/638 (3.7)	24/358 (6.7)	3/100 (3.0)
Median tumor size, mm [IQR]	30 [20–50]	25 [16–35]	25 [16–35]	37 [24–60]	31 [22–47]	45 [30–70]	30 [21–45]	50 [30–80]	58 [31–93]	40 [29–69]	35 [27–55]	48 [35–78]
Multiple tumors	1,989/14,759 (13.5)	324/3,890 (8.3)	175/2,019 (8.6)	353/2,392 (14.7)	199/1,989 (10.0)	170/1,027 (16.5)	123/1,094 (11.2)	391/1,173 (33.3)	37/75 (49.3)	126/640 (19.6)	62/358 (17.3)	26/102 (25.5)

Data are presented as n (%) unless otherwise specified. AL, anterolateral (II, III, IVb, V, VI); Ant, anterior; ASA, American Society of Anesthesiologists; CRLM, colorectal liver metastasis; Ext, extended; Hep, hepatectomy; HCC, hepatocellular carcinoma; Hep, hepatectomy; ICC, intrahepatic cholangiocarcinoma; IMM, Institut Mutualiste Montsouris; IQR, interquartile range; LM, liver metastasis; Lt, left; Post, posterior; PS, posterosuperior (I, IVa, VII, VIII); Rt, right; Sect, sectionectomy; Sg, segment.

Table 3 Raw unadjusted perioperative outcomes of LLR stratified by IMM procedure type

Variable	Overall (N=14,765)	IMM I (low)			IMM II (intermediate)		IMM III (high)					
		1: Wedge AL Sg (N=3,890)	2: Wedge PS Sg (N=2,020)	3: Lt lateral Sect (N=2,394)	4: Segment AL Sg (N=1,989)	5: Lt Hep (N=1,029)	6: Segment PS Sg (N=1,094)	7: Rt Hep (N=1,174)	8: Ext Rt Hep (N=75)	9: Rt Post Sect (N=640)	10: Central Hep/Rt Ant Sect (N=358)	11: Ext Lt Hep (N=102)
Median operating time, min [IQR]	204 [140–285]	150 [100–210]	186 [130–250]	165 [120–220]	219 [162–283]	252 [190–322]	270 [200–360]	320 [265–407]	360 [300–410]	310 [240–390]	304 [240–400]	348 [280–435]
Median blood loss, mL [IQR]	150 [50–300]	100 [30–200]	100 [50–300]	100 [50–200]	200 [100–350]	200 [80–350]	200 [100–500]	300 [200–550]	500 [225–1,000]	400 [200–700]	300 [200–600]	400 [200–800]
Blood loss (categories)												
<500 mL	11,609 (83.6)	3,298 (91.4)	1,675 (87.3)	2,045 (93.0)	1,553 (82.3)	829 (84.8)	766 (73.6)	765 (68.0)	34 (47.2)	359 (59.1)	228 (64.6)	57 (56.4)
≥500 mL	2,281 (16.4)	311 (8.6)	244 (12.7)	153 (6.9)	334 (17.7)	148 (15.2)	275 (26.4)	360 (32.0)	38 (52.8)	249 (40.9)	125 (35.4)	44 (43.6)
Intraoperative blood transfusion	1,163/14,774 (7.9)	130/3,880 (3.3)	153/2,017 (7.6)	78/2,391 (3.3)	172/1,986 (8.6)	72/1,028 (7.0)	145/1,094 (13.2)	187/1,173 (15.9)	24/75 (32.0)	127/640 (19.8)	53/358 (14.8)	22/102 (21.6)
Pringle maneuver applied	6,269/14,264 (43.9)	1,248/3,783 (32.9)	911/1,958 (46.5)	455/2,314 (19.6)	1,047/1,941 (53.9)	507/963 (52.6)	684/1,060 (64.5)	642/1,133 (56.6)	34/67 (50.7)	430/608 (70.7)	253/344 (73.5)	58/93 (62.3)
Open conversion	906/14,765 (6.1)	153/3,890 (3.9)	113/2,020 (5.6)	88/2,394 (3.6)	131/1,989 (6.5)	75/1,029 (7.2)	68/1,094 (6.2)	168/1,174 (14.3)	9/75 (12.0)	62/640 (9.6)	24/358 (6.7)	15/102 (14.7)
Median postoperative stay, days [IQR]	8 [5–11]	4 [3–6]	5 [3–7]	5 [3–7]	5 [4–8]	6 [5–8]	6 [4–9]	7 [5–10]	8 [6–16]	7 [5–9]	8 [6–11]	8 [5–11]
30-day readmission	390/14,700 (2.6)	71/3,878 (1.8)	48/2,019 (2.3)	44/2,383 (1.8)	47/1,980 (2.3)	38/1,024 (3.7)	38/1,093 (3.4)	58/1,150 (5.0)	2/75 (2.6)	16/640 (2.5)	23/356 (6.4)	5/102 (4.9)
Postoperative morbidity	2,586/14,746 (17.5)	471/3,881 (12.1)	291/2,020 (14.4)	302/2,392 (12.6)	374/1,987 (18.8)	181/1,028 (17.6)	260/1,092 (23.8)	411/1,173 (35.0)	28/75 (37.3)	139/640 (21.7)	102/356 (28.6)	27/102 (26.4)
Major morbidity (Clavien-Dindo grade >2)	805/14,747 (5.5)	118/3,881 (3.0)	74/2,019 (3.7)	68/2,392 (2.8)	112/1,987 (5.6)	61/1,028 (5.9)	86/1,092 (7.9)	164/1,174 (14.0)	18/75 (24.0)	51/640 (8.0)	37/357 (10.4)	16/102 (15.7)
Reoperation	175/14,764 (1.2)	25/3,890 (0.6)	10/2,020 (0.5)	25/2,394 (1.0)	14/1,989 (0.7)	18/1,028 (1.7)	16/1,094 (1.5)	44/1,174 (3.7)	6/75 (8.0)	10/640 (1.5)	3/358 (0.8)	4/102 (3.9)
30-day mortality	45/14,764 (0.3)	2/3,889 (0.05)	4/2,020 (0.2)	6/2,394 (0.2)	6/1,989 (0.3)	8/1,029 (0.8)	3/1,094 (0.3)	10/1,174 (0.8)	1/75 (1.3)	2/640 (0.3)	3/358 (0.8)	0/102 (0.0)
In-hospital mortality	70/14,765 (0.5)	5/3,890 (0.1)	8/2,020 (0.4)	7/2,394 (0.3)	10/1,989 (0.5)	5/1,029 (0.5)	5/1,094 (0.5)	17/1,174 (1.4)	4/75 (5.3)	6/640 (0.9)	3/358 (0.8)	0/102 (0.0)
90-day mortality	91/14,764 (0.5)	6/3,890 (0.1)	7/2,020 (0.3)	13/2,394 (0.5)	12/1,989 (0.6)	9/1,029 (0.8)	5/1,094 (0.4)	23/1,173 (1.9)	3/75 (4.0)	8/640 (1.2)	4/358 (1.1)	1/102 (0.9)
Close/involved margins (≤1 mm)	1,998/14,648 (13.6)	492/3,842 (12.8)	323/2,001 (16.1)	162/2,381 (6.8)	317/1,981 (16.0)	101/1,018 (9.9)	220/1,089 (20.2)	150/1,168 (12.8)	15/74 (20.3)	118/638 (18.5)	69/355 (19.4)	31/101 (30.7)

Data are presented as n (%) unless otherwise specified. AL, anterolateral (II, III, IVb, V, VI); Ant, anterior; Ext, extended; Hep, hepatectomy; IMM, Institut Mutualiste Montsouris; IQR, interquartile range; LLR, laparoscopic liver resection; Lt, left; Post, posterior; PS, posterosuperior (I, IVa, VII, VIII); Rt, right; Sect, sectionectomy; Sg, segment.

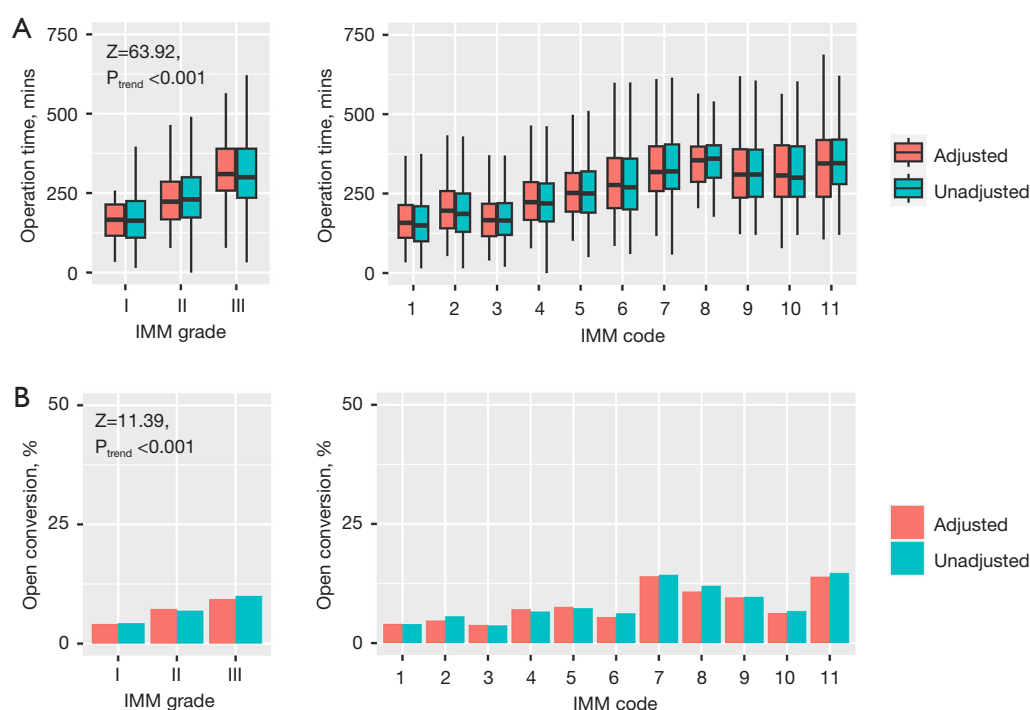


Figure 1 Unadjusted and adjusted comparative perioperative outcomes across the three IMM complexity levels and 11 LLR procedure types. (A) Operation time; (B) open conversion rate. IMM, Institut Mutualiste Montsouris; LLR, laparoscopic liver resection.

IMM DSS complexity grade ($P<0.001$). These trends remained significant following adjustment for baseline characteristics ($P<0.001$). Notably, when examining the 11 LLR procedure types, all procedures within each IMM complexity level were individually higher than all procedures in the preceding difficulty level for operative time, blood loss, length of stay, postoperative morbidity and major postoperative morbidity. Comparison between adjusted perioperative outcomes of procedures stratified by IMM difficulty level are summarized in *Table 5* which showed statistical significance for most outcome comparisons.

Missing data was generally inconsiderable and these are summarized in *Table S1*. The variables with the most missing data were blood loss ($n=875$) and tumor size ($n=664$). The pattern of missingness evaluated with Little's tests indicated the data was missing completely-at-random, $P>0.99$.

Discussion

Our current study demonstrates the increasingly widespread adoption of LLR for progressively more complex resections over the past two decades, with more than half the LLR

cases performed in most recent five years from 2016 to 2021. This trend has been borne out of a growing body of evidence of the multitude of perioperative benefits afforded by a minimally-invasive approach not unprecedented in various other surgical subspecialties (1-3). Great caution is however advised when adopting LLR due to its steep inherent learning curve, an approach echoed consistently throughout the various international consensus statements (1-3,25). A well validated complexity classification system for LLR is essential for risk stratification of liver resection cases to influence the choice of operative approach (open versus laparoscopic) based on the expected difficulty in relation to a surgeon's LLR learning curve, as well as to facilitate audits of individual surgeons' and centers' LLR outcomes benchmarked against international standards (7,8). While the IMM 3-level complexity classification has been validated by several studies to date, they have been primarily limited to single center experiences, and validated only across its three difficulty levels. These studies however did not evaluate the categorization of the 11 distinct LLR procedural types (9,16-22). This limits the ability to generalize the IMM classification as a well validated system for predicting LLR difficulty across an international

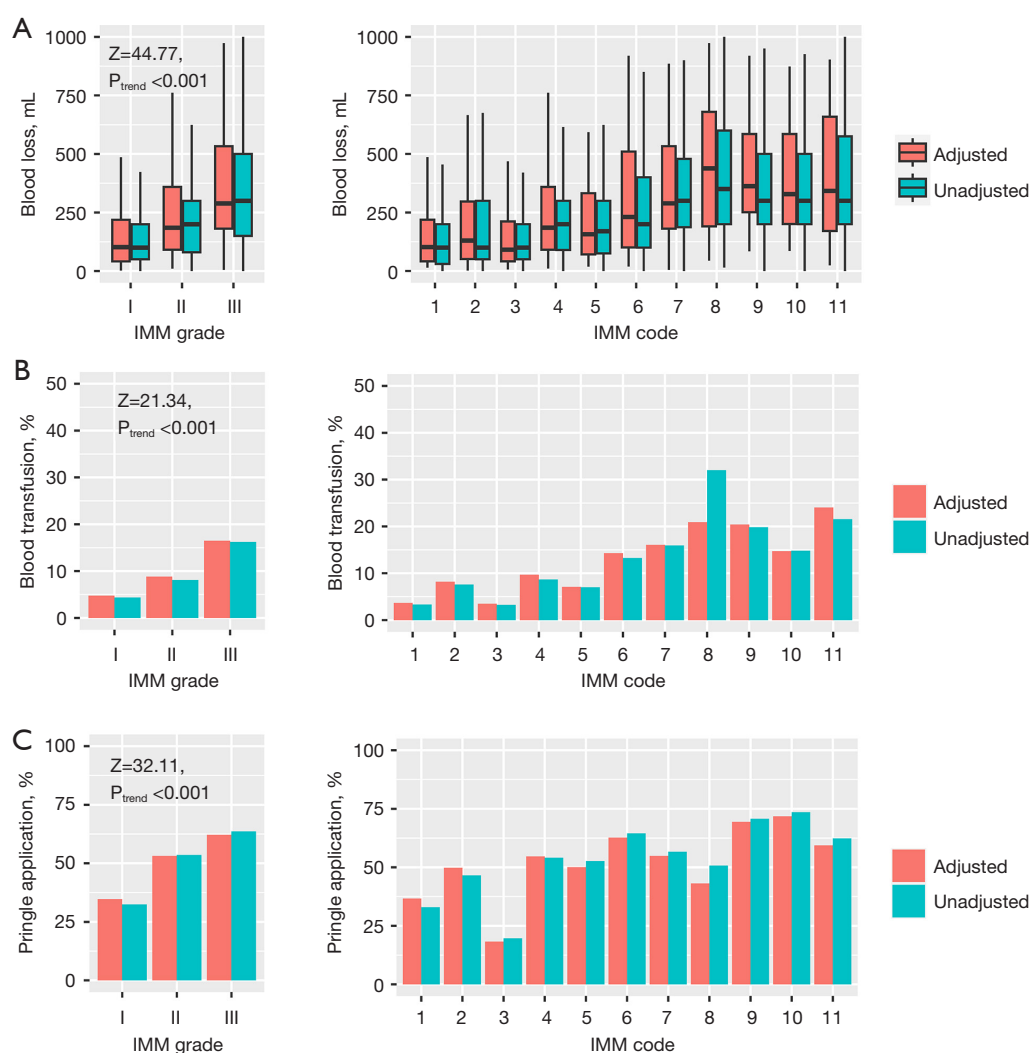


Figure 2 Unadjusted and adjusted comparative perioperative outcomes across the three IMM complexity levels and 11 LLR procedure types. (A) Estimated blood loss; (B) blood transfusion rate; (C) application of Pringle's maneuver. IMM, Institut Mutualiste Montsouris; LLR, laparoscopic liver resection.

platform.

This present study addresses this gap through featuring the largest multicenter cohort of LLR to date, which provided a sample size large enough to evaluate the IMM system down to the granularity of its 11 LLR procedure types. Across the three complexity levels of the classification, a significant corresponding trend in key intraoperative (operative time, conversion rate, blood loss, need for transfusion and need for Pringle's application) and postoperative (length of stay, postoperative morbidity, major postoperative morbidity and 90-day mortality) outcomes was observed, with a higher difficulty level associated

with worse outcomes. When examining the 11 LLR procedure types, we noted that every procedure within each difficulty level was individually higher than the preceding difficulty level for operative time, blood loss, length of stay, postoperative morbidity and major postoperative morbidity. These findings confirmed that the categorization of the 11 distinct procedures into the three difficulty levels was appropriate.

Within each difficulty level however, there were differing trends between the procedure types. Amongst the low complexity level (grade I) procedures, procedure 2 (posterolateral wedge resections) had worse intraoperative

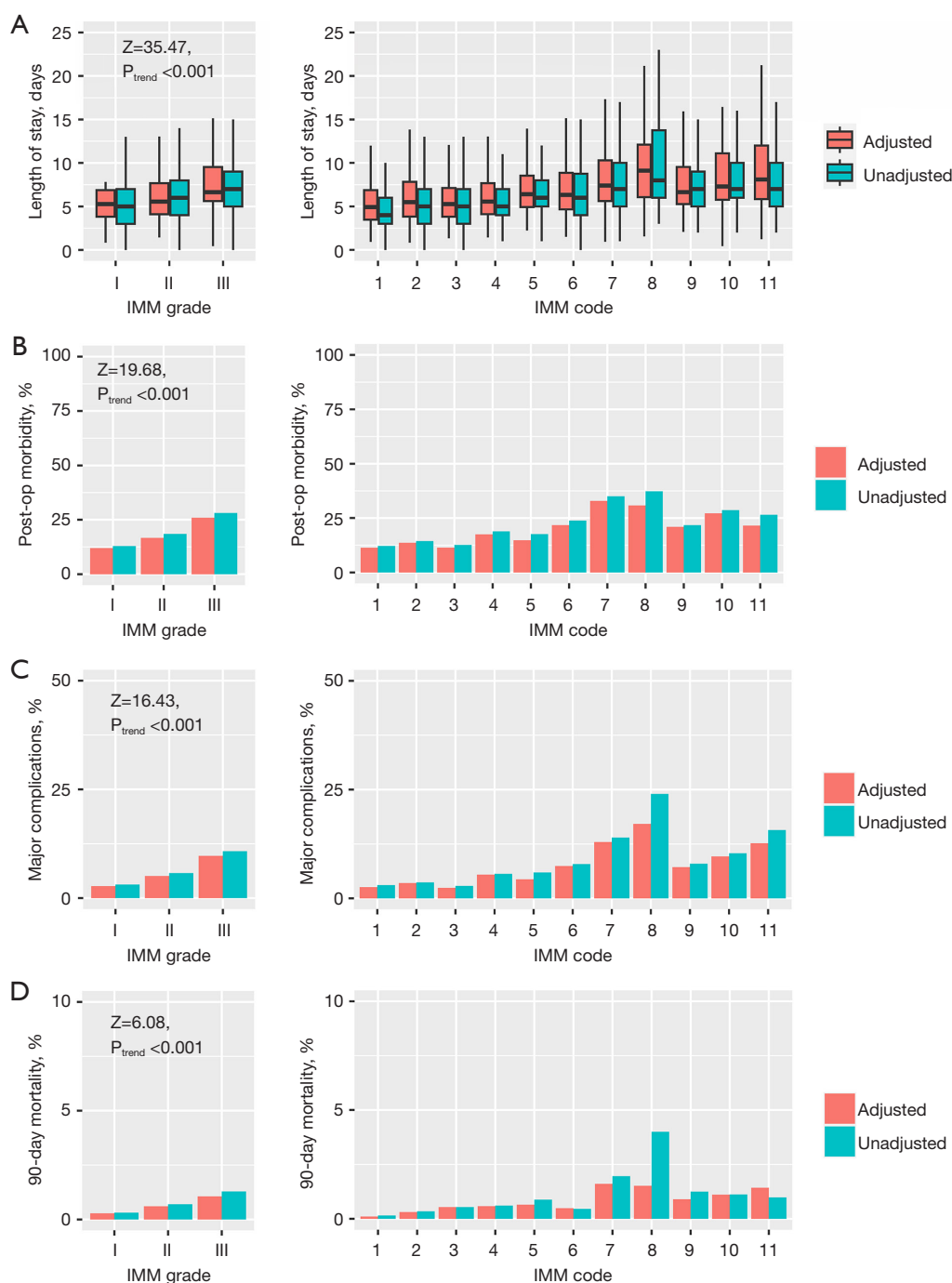


Figure 3 Unadjusted and adjusted comparative perioperative outcomes across the three IMM complexity levels and 11 LLR procedure types. (A) Postoperative length of stay; (B) postoperative morbidity; (C) Major complications; (D) 90-day mortality. IMM, Institut Mutualiste Montsouris; LLR, laparoscopic liver resection.

Table 4 Adjusted predictive margins[†] of perioperative outcomes of LLR stratified by IMM procedure type

Variable	IMM I (low)			IMM II (intermediate)		IMM III (high)					
	1: Wedge AL Sg (N=3,890)	2: Wedge PS Sg (N=2,020)	3: Lt lateral Sect (N=2,394)	4: Segment AL Sg (N=1,989)	5: Lt Hep (N=1,029)	6: Segment PS Sg (N=1,094)	7: Rt Hep (N=1,174)	8: Ext Rt Hep (N=75)	9: Rt Post Sect (N=640)	10: Central Hep/Rt Ant Sect (N=358)	11: Ext Lt Hep (N=102)
Median operating time [IQR], min	158 [111–214]	197 [142–259]	166 [117–219]	223 [168–286]	253 [193–315]	277 [204–362]	318 [259–400]	356 [287–398]	310 [238–390]	307 [240–402]	345 [238–420]
Median blood loss [IQR], mL	102 [41–219]	130 [51–298]	91 [41–213]	186 [91–359]	158 [71–332]	231 [101–511]	289 [181–533]	439 [191–680]	362 [251–585]	328 [201–585]	342 [171–659]
Blood loss (categories)											
<500 mL	7.5 (6.5–8.5)	11.7 (10.1–13.4)	6.8 (5.6–8.0)	15.7 (13.9–17.5)	12.8 (10.4–15.3)	25.3 (22.3–28.3)	28.7 (25.5–31.9)	45.3 (31.6–59.0)	39.6 (35.3–43.9)	34.2 (28.9–39.5)	37.7 (26.8–48.6)
≥500 mL	92.5 (91.5–93.5)	88.3 (86.6–89.9)	93.2 (92.0–94.4)	84.3 (82.5–86.1)	87.2 (84.7–89.6)	74.7 (71.7–77.7)	71.3 (68.1–74.5)	54.7 (41.0–68.4)	60.4 (56.1–64.7)	65.8 (60.5–71.1)	62.3 (51.4–73.2)
Intraoperative blood transfusion	3.2 (25.9–38.4)	7.6 (6.3–8.9)	31.4 (23.5–3.9)	8.3 (6.9–9.6)	71.8 (5.3–9.0)	13.4 (11.1–15.6)	15.6 (13.1–18.1)	20.9 (10.1–31.7)	20.2 (16.8–23.7)	14.3 (10.4–18.1)	24.4 (14.7–34.1)
Pringle maneuver applied	36.0 (34.2–37.9)	47.3 (44.7–49.8)	17.0 (15.2–18.8)	53.5 (50.9–56.1)	47.1 (43.4–50.7)	58.8 (55.4–62.2)	53.1 (49.6–56.7)	43.1 (28.6–57.5)	67.5 (63.3–71.7)	67.3 (61.8–72.9)	57.4 (45.6–69.4)
Open conversion	3.6 (3.0–4.37)	4.5 (3.52–5.63)	3.6 (2.76–4.51)	6.6 (5.39–7.84)	7.8 (5.90–0.09)	5.3 (0.03–9.78)	13.9 (11.5–16.3)	10.8 (2.52–19.0)	9.7 (7.1–12.2)	6.4 (3.7–9.1)	13.2 (5.8–20.6)
Median postoperative stay, days [IQR]	4.9 [4.8–5.1]	5.49 [5.3–5.6]	5.2 [5.1–5.4]	5.56 [5.4–5.7]	6.4 [6.1–6.6]	6.3 [6.1–6.5]	7.4 [7.1–7.6]	9.1 [8.2–10]	6.6 [6.3–6.9]	7.3 [6.9–7.6]	8.1 [7.3–8.8]
30-day readmission	1.6 (1.17–2.11)	20.9 (1.3–28.2)	2.0 (1.3–2.7)	2.0 (1.3–2.7)	1.8 (0.9–2.8)	2.6 (1.5–3.6)	4.1 (0.2–5.5)	0.8 (1.4–3.0)	2.3 (1.0–3.5)	6.6 (3.9–9.1)	4 (0.01–0.08)
Postoperative morbidity	10.5 (9.4–11.6)	12.8 (11.1–14.5)	11.1 (9.7–12.7)	16.2 (14.4–18.0)	15.1 (12.5–17.7)	20.6 (18.0–23.3)	32.2 (29.0–35.5)	30.8 (18.6–43.0)	21.2 (17.7–24.8)	27.0 (22.1–32.0)	20.7 (11.7–29.7)
Major morbidity (Clavien-Dindo grade >2)	2.4 (1.8–2.9)	3.3 (2.4–4.3)	2.3 (1.6–3.0)	5.1 (4.0–6.1)	4.3 (2.9–5.8)	7.1 (5.4–8.8)	12.1 (9.9–14.4)	17.1 (7.4–26.7)	7.2 (5.0–9.4)	9.7 (6.4–12)	11.8 (4.8–18.9)
Reoperation	0.4 (0.2–0.7)	0.3 (0.01–0.6)	0.9 (0.4–1.3)	0.6 (0.2–1.0)	1.1 (0.3–1.8)	1.3 (0.5–2.1)	3.1 (1.8–4.3)	9.4 (1.5–17.3)	1.2 (0.2–2.1)	0.8 (0.2–1.9)	2.9 (0.6–6.5)
30-day mortality	0.05 (0.03–0.13)	0.2 (0.01–0.4)	0.3 (0.06–0.6)	0.3 (0.06–0.6)	0.6 (0.09–1.2)	0.3 (0.02–0.06)	0.5 (0.09–1.0)	1.5 (1.0–4.2)	0.4 (0.1–0.9)	0.8 (0.08–1.7)	0.4 (0.8–1.7)
In-hospital mortality	0.1 (0.07–0.2)	0.3 (0.06–0.59)	0.3 (0.9–0.6)	0.4 (0.1–0.7)	0.2 (0.06–0.5)	0.4 (0.04–0.7)	0.9 (0.3–1.6)	1.2 (0.8–3.2)	0.6 (0.0–1.3)	0.7 (0.06–1.5)	0.4 (0.7–1.5)
90-day mortality	0.1 (0.006–0.2)	0.3 (0.04–0.5)	0.5 (0.2–0.8)	0.5 (0.2–0.9)	0.6 (0.09–1.1)	0.4 (0.06–0.9)	1.6 (0.7–2.4)	1.5 (0.9–4.01)	0.8 (0.13–1.6)	1.1 (0.05–2.1)	1.4 (0.8–3.7)
Close/involved margins (≤1 mm)	6.8 (5.2–8.0)	7.6 (5.9–9.4)	3.8 (2.8–4.8)	8.4 (6.6–10.3)	9.4 (7.2–11.6)	4.6 (33–6.0)	4.6 (3.3–6.0)	7.0 (2.2–11.8)	8.3 (6.0–10.6)	9.3 (6.4–12.2)	15.3 (8.0–22.6)

Data are presented as % (95% CI) unless otherwise specified. [†], to control for differences in baseline characteristics and enable comparability across strata, adjusted outcomes for each strata were obtained by conditioning the predictive margins on the baseline characteristics of the overall population. I.e., the adjusted median operating time of 141 and 148 minutes for patients with IMM procedure 1 and IMM procedure 2 respectively represent the predicted OT time in a *hypothetical scenario* where 34.7% of patients in both strata had cirrhosis (as opposed to the actual cirrhosis rates of 35.4% and 37.3%) and 13.5% of patients in both strata had multifocal tumors (as opposed to the actual rate of 8.3% and 8.6% respectively), and so on. AL, anterolateral (II, III, IVb, V, VI); Ant, anterior; CI, confidence interval; Ext, extended; Hep, hepatectomy; IMM, Institut Mutualiste Montsouris; IQR, interquartile range; LLR, laparoscopic liver resection; Lt, left; Post, posterior; PS, posterosuperior (I, IVa, VII, VIII); OT time, operating time; Rt, right; Sect, sectionectomy; Sg, segment.

Table 5 Statistical comparisons between adjusted IMM difficulty groups

Variable	P value			
	IMM II vs. IMM I [†]	IMM III vs. IMM II [†]	IMM III vs. IMM I [†]	Monotonic trend [‡]
Median operating time	<0.001	<0.001	<0.001	<0.001
Median blood loss (continuous variable)	<0.001	<0.001	<0.001	<0.001
Blood loss (categorical variable: <500 vs. ≥500 mL)	<0.001	<0.001	<0.001	<0.001
Intraoperative blood transfusion	<0.001	<0.001	<0.001	<0.001
Pringle maneuver applied	<0.001	<0.001	<0.001	<0.001
Open conversion	<0.001	<0.001	<0.001	<0.001
Median postoperative stay	<0.001	<0.001	<0.001	<0.001
30-day readmission	<0.001	<0.001	<0.001	<0.001
Postoperative morbidity	<0.001	<0.001	<0.001	<0.001
Major morbidity (Clavien-Dindo grade >2)	<0.001	<0.001	<0.001	<0.001
Reoperation	0.10	<0.001	<0.001	<0.001
30-day mortality	0.003	0.73	<0.001	0.001
In-hospital mortality	0.04	0.02	<0.001	<0.001
90-day mortality	0.008	0.02	<0.001	<0.001
Close/involved margins (≤1 mm)	0.004	<0.001	<0.001	<0.001

[†], pairwise comparisons were performed using Fisher's exact test and Mann-Whitney *U* test respectively for factor and continuous outcomes; [‡], two-sided Cochran-Armitage or Jonckheere-Terpstra trend tests were used to evaluate the presence of a monotonic increasing or decreasing gradation over the three IMM difficulty categories, which was treated as an ordinal variable. IMM, Institut Mutualiste Montsouris.

outcomes (operative time, conversion rate, blood loss, need for transfusion and need for Pringle's application) than procedure 3 (left lateral sectionectomy), which was in turn much more comparable to procedure 1 (anterolateral wedge resections). This is unsurprising in view of the significant technical challenges associated with accessing the posterosuperior segments as compared to a left lateral sectionectomy which has long been used as a landmark operation for surgeons at the earlier part of their LLR learning curve (1,10,26,27).

Amongst the intermediate complexity level (grade II) procedures, procedure 4 (anterolateral segmentectomy) and procedure 5 (left hepatectomy) were largely comparable for all key intraoperative and postoperative outcomes. This is likely attributable to similarities in the operative techniques required for both LLR procedure types, including ease of access to the transection lines and minimal requirement for right lobe mobilization and securing of short hepatic veins.

Amongst the high complexity level (grade III) procedures, a considerable amount of discordance in

perioperative outcome trends was observed. As the biggest group in the IMM classification with six procedures included, the original IMM development cohort study also delved into a subgroup analysis comparing between the procedure types of this group, and found that when taken together, procedures 9 to 11 (right posterior sectionectomy, central hepatectomy, extended left hepatectomy) had worse perioperative outcomes in terms of operative time, blood loss, conversion rate, bile leak rate and fluid collection rate than procedures 6 to 8 (posterosuperior segmentectomy, right hepatectomy, extended right hepatectomy) (14). In our current study, with sufficient numbers of LLR performed to allow for a more granular evaluation of these six procedures, we found that procedure 8 (extended right hepatectomy) was associated with the worst perioperative outcomes in terms of operation time, blood loss, need for blood transfusion, length of stay, postoperative morbidity, major postoperative morbidity and 90-day mortality. This is likely due to an interplay of technical factors (need for extensive liver mobilization including complete mobilization off the

inferior vena cava), disease factors (large central tumors or cholangiocarcinomas requiring extended resections for oncologic margins) and higher rates of postoperative liver failure with the amount of parenchymal loss associated with this procedure. Conversely, procedure 6 (posterosuperior segmentectomy) was associated with the best perioperative outcomes in terms of operation time, conversion rate, blood loss, need for blood transfusion, length of stay and 90-day mortality. This is reflective of the more limited liver mobilization required, lack of need for hilar dissection and lower parenchymal loss associated with this procedure within grade III procedures. Interestingly, procedure 7 (right hepatectomy) is associated with the highest conversion rate, and has operation time similar to procedures 9 and 10 (right posterior sectionectomy and central hepatectomy/right anterior sectionectomy) in spite of a technically more challenging parenchymal transection plane in the latter two (28,29). This could be attributable to the fact that a conventional resection such as procedure 7 (right hepatectomy) is likely to be undertaken laparoscopically by a larger pool of surgeons with considerable inter-individual variation in technical expertise and procedural experience, while resections involving the right intersectional plane such as procedures 9 and 10 (right posterior sectionectomy and central hepatectomy/right anterior sectionectomy) are more likely to be undertaken laparoscopically by a smaller pool of experienced surgeons.

A common criticism of the IMM complexity classification compared to several other established DSS lies in its unidimensional nature as it only takes into account the type of resection, and not various other variables such as tumor size, proximity to major vessels, parenchymal quality such as presence of cirrhosis, body mass index and previous liver resections which have been found to correlate with perioperative outcomes (10-13). This however is advantageous in rendering the IMM classification as arguably the simplest system for daily usage when assessing individual cases of liver resections (9,17). Furthermore, the use of additional variables to predict LLR difficulty may not always be clinically relevant as the decision on the type of resection to undertake often already takes into account many of these factors. For instance, a segment 7 lesion that is close to the right hepatic vein would be relevant when considering a limited segmentectomy, but largely irrelevant when considering a right hepatectomy. Notably, in this analysis, the IMM classification was useful in stratifying LLR according to its complexity in both the raw and

adjusted analyses suggesting that other factors played a more minor role in the complexity of LLR compared to the type and extent of liver resection. Hence, further studies are needed to determine if these other factors such as tumor size, liver cirrhosis and body mass index should be added on to the IMM system to improve its ability to stratify LLR according to its complexity level.

The IMM complexity classification is unique because it was originally devised for stratifying the surgical complexity of LLR procedures (14) and subsequently validated for OLR (30). As such, IMM complexity classification may be useful for adjusting intergroup differences of the surgical complexity (31) and developing risk-stratified posthepatectomy pathways in patients undergoing LLR and OLR (32-35). Furthermore, with the increasing adoption of robotic liver resections today, the utility of this system should also be validated for robotic procedures.

We recognize several limitations of our current study. Firstly, its retrospective nature lends itself to potential selection bias and missing data. Nonetheless, evaluation of *Tables 1,2* showed that the raw rate of missing data was relatively consistent between the variables and not proportional to the size of category nor the nature variable. Furthermore, Little's test indicated the data was missing in a random pattern. The heterogeneity in individual center and surgeon technical expertise, caseload, surgical technique and perioperative care may also confound our findings. However, our study remains the largest validation cohort by far of the IMM complexity system, with highly generalizable findings having been derived from an international multicenter collaboration, and offers the first evaluation of the 11 LLR procedure types dimension of the IMM system.

Conclusions

The three difficulty levels of IMM complexity classification correlate well with LLR complexity as determined by key surrogate perioperative measures. Our findings also supported the categorization of the 11 distinct LLR procedures into the 3 complexity levels. Hence, the IMM classification would serve as a robust tool in stratifying LLR for auditing and benchmarking purposes.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at <https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-304/rc>

Data Sharing Statement: Available at <https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-304/dss>

Peer Review File: Available at <https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-304/prf>

Funding: This work was funded by the US National Cancer Institute MSKCC Core Grant number P30 CA008747 for this study (to T.P.K.), the Research Project of Zhejiang Provincial Public Welfare Fund Project in the Field of Social Development (LGF20H160028 to M.Y.), and by a grant from the Intuitive Foundation (to B.K.P.G.). Any research findings, conclusions, or recommendations expressed in this work are those of the authors and not of the Intuitive Foundation.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at <https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-304/coif>). O.S., K.H., H.S.H., M.A.H., and L.A. serve as the unpaid editorial board members of *HepatoBiliary Surgery and Nutrition*. J.P. serves as an unpaid editorial board member of *HepatoBiliary Surgery and Nutrition* and reports a research grant from Intuitive Surgical Deutschland GmbH and personal fees or non-financial support from Johnson & Johnson, Medtronic, AFS Medical, Astellas, CHG Meridian, Chiesi, Falk Foundation, La Fource Group, Merck, Neovii, NOGGO, pharma-consult Peterson, and Promedice. R.I.T. reports speaker fees and support outside the submitted work from Integra, Stryker, Medtronic, Medistim, and MSD. B.K.P.G. has received grant from Intuitive Foundation; and travel grants, honorarium and research grants from Johnson and Johnson, Olympus, Intuitive Surgery, Roche and Boston Scientific. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was performed in accordance with the Declaration of Helsinki and its subsequent amendments. This retrospective study

on anonymized patient data was approved by the Singapore General Hospital Institution Review Board (2020/2802) and the need for any further board review and patient consent was waived.

Open Access Statement: This is an Open Access article distributed in accordance with the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 International License (CC BY-NC-ND 4.0), which permits the non-commercial replication and distribution of the article with the strict proviso that no changes or edits are made and the original work is properly cited (including links to both the formal publication through the relevant DOI and the license). See: <https://creativecommons.org/licenses/by-nc-nd/4.0/>.

References

1. Buell JF, Cherqui D, Geller DA, et al. The international position on laparoscopic liver surgery: The Louisville Statement, 2008. *Ann Surg* 2009;250:825-30.
2. Wakabayashi G, Cherqui D, Geller DA, et al. Recommendations for laparoscopic liver resection: a report from the second international consensus conference held in Morioka. *Ann Surg* 2015;261:619-29.
3. Abu Hilal M, Aldrighetti L, Dagher I, et al. The Southampton Consensus Guidelines for Laparoscopic Liver Surgery: From Indication to Implementation. *Ann Surg* 2018;268:11-8.
4. Gotohda N, Cherqui D, Geller DA, et al. Expert Consensus Guidelines: How to safely perform minimally invasive anatomic liver resection. *J Hepatobiliary Pancreat Sci* 2022;29:16-32.
5. Franken C, Lau B, Putchakayala K, et al. Comparison of short-term outcomes in laparoscopic vs open hepatectomy. *JAMA Surg* 2014;149:941-6.
6. Witowski J, Rubinkiewicz M, Mizera M, et al. Meta-analysis of short- and long-term outcomes after pure laparoscopic versus open liver surgery in hepatocellular carcinoma patients. *Surg Endosc* 2019;33:1491-507.
7. Chua D, Syn N, Koh YX, et al. Learning curves in minimally invasive hepatectomy: systematic review and meta-regression analysis. *Br J Surg* 2021;108:351-8.
8. Goh BKP, Han HS, Chen KH, et al. Defining Global Benchmarks for Laparoscopic Liver Resections: An International Multicenter Study. *Ann Surg* 2023;277:e839-48.
9. Linn YL, Wu AG, Han HS, et al. Systematic review and

- meta-analysis of difficulty scoring systems for laparoscopic and robotic liver resections. *J Hepatobiliary Pancreat Sci* 2023;30:36-59.
10. Ban D, Tanabe M, Ito H, et al. A novel difficulty scoring system for laparoscopic liver resection. *J Hepatobiliary Pancreat Sci* 2014;21:745-53.
 11. Wakabayashi G. What has changed after the Morioka consensus conference 2014 on laparoscopic liver resection? *Hepatobiliary Surg Nutr* 2016;5:281-9.
 12. Hasegawa Y, Wakabayashi G, Nitta H, et al. A novel model for prediction of pure laparoscopic liver resection surgical difficulty. *Surg Endosc* 2017;31:5356-63.
 13. Halls MC, Berardi G, Cipriani F, et al. Development and validation of a difficulty score to predict intraoperative complications during laparoscopic liver resection. *Br J Surg* 2018;105:1182-91.
 14. Kawaguchi Y, Fuks D, Kokudo N, et al. Difficulty of Laparoscopic Liver Resection: Proposal for a New Classification. *Ann Surg* 2018;267:13-7.
 15. Strasberg SM. Nomenclature of hepatic anatomy and resections: a review of the Brisbane 2000 system. *J Hepatobiliary Pancreat Surg* 2005;12:351-5.
 16. Aldrighetti L, Cipriani F, Fiorentini G, et al. A stepwise learning curve to define the standard for technical improvement in laparoscopic liver resections: complexity-based analysis in 1032 procedures. *Updates Surg* 2019;71:273-83.
 17. Goh BKP, Prieto M, Syn N, et al. Validation and comparison of the Iwate, IMM, Southampton and Hasegawa difficulty scoring systems for primary laparoscopic hepatectomies. *HPB (Oxford)* 2021;23:770-6.
 18. Hobeika C, Tribillon E, Marchese U, et al. Validation of the IMM classification in laparoscopic repeat liver resections for colorectal liver metastases. *Surgery* 2021;170:1448-56.
 19. Hołowko W, Triantafyllidis I, Neuberg M, et al. Does the difficulty grade of laparoscopic liver resection for colorectal liver metastases correlate with long-term outcomes? *Eur J Surg Oncol* 2020;46:1620-7.
 20. Lin H, Bai Y, Yin M, et al. External validation of different difficulty scoring systems of laparoscopic liver resection for hepatocellular carcinoma. *Surg Endosc* 2022;36:3732-49.
 21. Russolillo N, Maina C, Fleres F, et al. Comparison and validation of three difficulty scoring systems in laparoscopic liver surgery: a retrospective analysis on 300 cases. *Surg Endosc* 2020;34:5484-94.
 22. Yang J, Yang Z, Jia G, et al. Clinical Practicality Study of the Difficulty Scoring Systems DSS-B and DSS-ER in Laparoscopic Liver Resection. *J Laparoendosc Adv Surg Tech A* 2019;29:12-8.
 23. Kawaguchi Y, Tanaka S, Fuks D, et al. Validation and performance of three-level procedure-based classification for laparoscopic liver resection. *Surg Endosc* 2020;34:2056-66.
 24. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg* 2004;240:205-13.
 25. Goh BK, Wang Z, Koh YX, et al. Evolution and trends in the adoption of laparoscopic liver resection in Singapore: Analysis of 300 cases. *Ann Acad Med Singap* 2021;50:742-50.
 26. Lee W, Han HS, Yoon YS, et al. Comparison of laparoscopic liver resection for hepatocellular carcinoma located in the posterosuperior segments or anterolateral segments: A case-matched analysis. *Surgery* 2016;160:1219-26.
 27. D'Silva M, Han HS, Liu R, et al. Limited liver resections in the posterosuperior segments: international multicentre propensity score-matched and coarsened exact-matched analysis comparing the laparoscopic and robotic approaches. *Br J Surg* 2022;109:1140-9.
 28. Willems E, D'Hondt M, Kingham TP, et al. Comparison Between Minimally Invasive Right Anterior and Right Posterior Sectionectomy vs Right Hepatectomy: An International Multicenter Propensity Score-Matched and Coarsened-Exact-Matched Analysis of 1,100 Patients. *J Am Coll Surg* 2022;235:859-68.
 29. Yang HY, Choi GH, Chin KM, et al. Robotic and laparoscopic right anterior sectionectomy and central hepatectomy: multicentre propensity score-matched analysis. *Br J Surg* 2022;109:311-4.
 30. Kawaguchi Y, Hasegawa K, Tzeng CD, et al. Performance of a modified three-level classification in stratifying open liver resection procedures in terms of complexity and postoperative morbidity. *Br J Surg* 2020;107:258-67.
 31. Hobeika C, Nault JC, Barbier L, et al. Influence of surgical approach and quality of resection on the probability of cure for early-stage HCC occurring in cirrhosis. *JHEP Rep* 2020;2:100153.
 32. Mazzotta AD, Kawaguchi Y, Pantel L, et al. Conditional cumulative incidence of postoperative complications stratified by complexity classification for laparoscopic liver resection: Optimization of in-hospital observation. *Surgery*

- 2023;173:422-7.
33. Kim BJ, Arvide EM, Gaskill C, et al. Risk-stratified posthepatectomy pathways based upon the Kawaguchi-Gayet complexity classification and impact on length of stay. *Surg Open Sci* 2022;9:109-16.
 34. Martin AN, Concors SJ, Kim BJ, et al. Individual components of post-hepatectomy care pathways have differential impacts on length of stay. *Am J Surg* 2023;225:53-7.
 35. Watanabe G, Kawaguchi Y, Ichida A, et al. Understanding conditional cumulative incidence of complications following liver resection to optimize hospital stay. *HPB (Oxford)* 2022;24:226-33.

Cite this article as: Mazzotta A, Fuks D, Soubrane O, Tan HL, Syn NL, Dokmak S, Gruttadauria S, Cipriani F, Zimmitti G, Alzoubi M, Sugioka A, Scatton O, Herman P, Peng Y, Marino MV, Croner RS, Mazzaferro V, Chiow AKH, Sucandy I, Ivanecz A, Choi SH, Lee JH, Gastaca M, Vivarelli M, Giulianti F, Ruzzenente A, Yong CC, Yin M, Fondevila C, Efanov M, Morise Z, Di Benedetto F, Brustia R, Dalla Valle R, Boggi U, Geller D, Belli A, Memeo R, Mejia A, Park JO, Rotellar F, Choi GH, Robles-Campos R, Hasegawa K, Kawaguchi Y, Wang X, Sutcliffe RP, Pratschke J, Lai ECH, Chong CCN, D'Hondt M, Monden K, Lopez-Ben S, Kingham TP, Liu R, Ferrero A, Ettore GM, Cherqui D, Liang X, Wakabayashi G, Troisi RI, Cheung TT, Sugimoto M, Han HS, Long TCD, Zhang W, Wei Y, Aghayan DL, Edwin B, Chen KH, Abu Hilal M, Aldrighetti L, Goh BKP; International Robotic and Laparoscopic Liver Resection Study Group Investigators. Validation of the Institute Mutualiste Montsouris system for the stratification of laparoscopic liver resections: an international multicenter study. *HepatoBiliary Surg Nutr* 2026;15(1):5. doi: 10.21037/hbsn-24-304