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Laparoscopic liver resection difficulty score- a validation study

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Abstract

OBJECTIVE(S): The technical complexity of laparoscopic liver resection (LLR) poses unique challenges distinct from open surgery. An objective scoring system was developed that preoperatively quantifies the difficulty of LRR to help guide surgeon decision-making regarding the feasibility and safety of minimally-invasive approaches. The aim of this multi-institutional study was to externally validate this scoring system.

METHODS: Patients who underwent LLR at 2 institutions were reviewed. LLR difficulty score (LDS) was calculated based on patient, tumor, and anatomic characteristics by 2 independent, blinded hepatobiliary surgeons. Surrogates of case complexity (e.g. conversion rate, operative time) were used for validation of this index.

RESULTS: From 2006-2016, 444 LLR were scored as low (n=94), intermediate (n=98), and high difficulty (n=152) with respective conversion rates of 5.3%, 15.7%, and 25%. Cases of higher LDS correlated with larger mean blood loss (203 ml vs. 331 ml vs. 635 ml). Mean operative and Pringle

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Author Contributions

All the authors have made substantial contributions to the conception or design of the work. They have all contributed substantially to the acquisition, analysis, or interpretation of data for the work. This included drafting the manuscript and/or revising it critically for important intellectual content.

All authors have read and given the final approval of the version to be published and agree to be 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.

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maneuver used were associated with increasing LDS (155 min vs. 202 min vs. 315 min and 14.4% vs. 29.7% vs. 45.1% respectively). These operative surrogates of difficulty correlated significantly with the LDS. (all p<0.0001).

CONCLUSIONS: This comprehensive external validation of the LDS is robust and applicable in diverse patient populations. This LDS serves as a useful objective predictor of technical difficulty for LLR to help surgeons in selecting patients according to their individual operative experience and is valuable for preoperative risk estimation and stratification in randomized trials.

Keywords

Laparoscopic liver resection; Difficulty score

Introduction

In the past decade, minimally invasive liver surgery is becoming more common, since its first report in 1992.(1) Laparoscopic liver resection (LLR) was initially limited to small lesions in accessible locations. With time and experience, however, major and complex LLR have become more common, especially in expert and high volume tertiary centers.(2-5) Surgical competency and expertise is built on the cumulative experience through procedures of increasing difficulty and complexity over time.(2, 6) The learning curve in LLR is significant and well documented, new techniques and approaches have been developed to tackle various aspects of the procedure.(7, 8) These pose new challenges as the difficulty of a LLR is often different from the challenges of an open approach.(9) Moreover, the difficulty of various LLR procedures can be quite subjective and may be under-appreciated by less experienced surgeons early in their learning curve.(6, 10)

Traditionally, the learning curve has been navigated cautiously with the mentor/mentee model through apprenticeship such as residency, fellowships, proctorships and courses.(6) Therein lies a fine balance between pushing the technical envelope without comprising patient's safety and outcomes. Optimally the mentee seeks advice and guidance from the mentor as part of pre-surgical planning to decide if a particular LLR procedure is appropriate for his/her current progress on the learning curve. This judgment from an experienced LLR surgeon/team is invaluable but not easily quantifiable or well- defined.

Recently, a group of LLR experts have devised a novel LLR difficulty score (LDS) based on a study population of 86 patients from 3 centers in Japan who had a pure LLR. The degree of difficulty was assessed by the operator using a score of 1–10 and the score is then translated to 3 levels of difficulty (low, intermediate and high). Inter-rater agreement (weighted kappa statistic) was used to calculate the concordance between the operators' and reviewers' (expert LLR surgeons) assessments of difficulty. A 10-level difficulty score by linear modeling based on clinical information revealed a weighted kappa statistic of 0.72. Several factors such as extent of the planned procedure, extent of liver cirrhosis, tumor's size, location and its proximity to major vessels were identified as significant factors; these were weighted and incorporated into a scoring system to predict difficulty of various LLRs preoperatively. (Figure 1) This LDS reflected well with surrogates of difficulty as such operative time, and blood loss (weighted kappa statistic of 0.68). (11) The primary aim of this study is to externally validate this LLR difficulty score with our combined experience and secondly, to correlate it with short-term clinical outcome.(11)

Methods

A retrospective review of consecutive patients who underwent LLR from 2006 to 2016 in Singapore General Hospital (SGH) and Memorial Sloan Kettering Cancer Center (MSKCC) was performed from the respective prospectively maintained Hepato-pancreato-biliary (HPB) surgery databases. Patient demographics, clinicopathologic variables, operative data and clinical outcomes were reviewed from the databases, and verified and supplemented with additional chart and electronic medical record review when necessary. Clinical parameters examined included age, gender, American Society of Anesthesiologists (ASA) score, body mass index (BMI), Child-Pugh score/grade, tumor location, size and number. Surgical parameters such as type of resection, reasons for conversion, operative time, estimated blood loss (EBL) and perioperative blood transfusion requirements were recorded. Pathological data such as margin status, resection margin, presence of cirrhosis and tumor type were reviewed. Postoperative outcomes including 90-day morbidity and its grade, 90-day mortality and readmission rate, and the length of post-operative hospital stay (LOS) were also included in the analysis. Diagnoses were based on final pathology. All pathological specimens were reviewed and confirmed by gastrointestinal pathologists. Approval for the study was obtained from the respective institutional review boards.

Preoperative Assessment and Surgery

Prior to treatment, the diagnosis was confirmed by clinical evaluation (history and physical examination), radiological assessment [Computed tomography (CT) or Magnetic resonance imaging (MRI)], percutaneous liver biopsy and/ or combined with relevant investigations e.g. alpha-fetoprotein and hepatitis status. The SGH and MSKCC multidisciplinary HPB tumor boards are both composed of medical oncologists, radiologists, interventional radiologists, radiation oncologists, pathologists, gastroenterologists/hepatologists, surgical oncologists (MSKCC) or HPB and liver transplant surgeons (SGH). Consensus decisions were made concerning optimal management, resectability and appropriateness of liver resection and a laparoscopic approach. Decisions were made on a case-by-case basis after an informed discussion with the patient and taking into account the patients’ fitness for surgery, and their preferences. All LLR liver resections were performed using techniques as reported previously by both institutions.(2, 12-16) Major resections were defined as those consisting of 3 or more Couinaud liver segments.(17) Postoperative morbidity, mortality and readmissions were defined as complications, deaths or readmissions within 90 days after surgery, respectively. Events were recorded prospectively into a departmental database during the department weekly morbidity and mortality conferences and graded as per the Clavien-Dindo classification (SGH) or a similar MSKCC complications grading system (MSKCC Surgical Secondary Events Program).(18, 19)

Difficulty score

The LLR difficulty score by Ban et al. was used. Its various parameters (tumor location, extent of liver resection, tumor size, liver function and proximity to major vessels) were captured from both institutions' databases. Each LLR was retrospectively scored from 1-12 and then classified to low, intermediate and high difficulty levels by 2 independent HPB surgeons at the respective institution who were blinded to the patients' outcomes (Figure 1).(11) Tumor location was defined based on pre-operative high resolution cross-sectional imaging (CT and/or MRI) where the tumor was located in or where a major portion of it resides; if there was a doubt e.g. tumor straddles several segments, the segment chosen as the tumor location is where the epicenter or the majority of the tumor is located; if it is equidistant between 2 segments, the segment with the higher score was used. Proximity to major vessels is defined as being within 1cm of any part of the tumor to the inferior vena cava or the first and second orders of the portal pedicle or the major hepatic veins based on axial, sagittal or coronal sections of the pre-operative scans (CT/MRI). If there was a doubt, a joint decision was made with a third reviewer where it is deemed most appropriate. The minimum score is 1; the maximal score is 12; Low, intermediate and high levels of difficulty was defined as scores of 1-3, 4-6, and ≥7 respectively. Cystic lesions, gallbladder carcinomas and procedures with concomitant additional organ resection(excluding cholecystectomy), such as a combined single-stage colorectal resection, were excluded as the LDS was designed on a basis of solid liver tumors and did not take in account of additional procedures such as hilar lymphadenectomy. There was a proposed modification of this score (IWATE criteria) named after the 2nd LLR consensus meeting in Iwate, Japan 2014, it incorporated hand-assisted laparoscopic surgery(HALS)/ Hybrid as another factor (subtracting 1 point), added Segment 1(4 points) and distinguished S4a and 4b(4 and 3 points respectively). We decided to use the original score as it has been previously validated in other studies and none of the LLR in this study were hybrid or HALS.(20-22)

Established surrogates of technical operative difficulty such as operative time, intra-operative blood loss, the need for the Pringle's maneuver and its duration, blood transfusion requirements and conversion rate were used as primary validators.(23) Short term perioperative outcomes such as post-operative hospital stay, 90-day readmissions, mortality and morbidity were used as secondary validators.

Statistical Analysis

Comparisons of continuous variables for two independent samples employed the Student t test or Wilcoxon rank-sum test as appropriate, depending on whether a variable was normally distributed or not. Categorical variables were compared using Fisher exact test. The Jonckheere-Terpstra test was used to test for a monotonic increasing response in operative time, blood loss and duration of Pringle's maneuver (if applied) and other operative outcomes variables (conversion rate, blood transfusion, 90-day mortality and morbidity, hospital stay and readmission rates) versus LDS range (1 – 12) and difficulty level (Low, Intermediate, High). Univariate and multiple stepwise multiple logistic regression analysis (significance level to enter, $p = 0.20$) was used to identify variables predictive of conversion. Statistical significance was set at $p \leq 0.05$. All analyses were performed using SAS software (SAS Inc., Cary, NC, USA).

Results

Clinicopathologic characteristics and indications for laparoscopic liver resection

The demographics and clinicopathologic characteristics of the patients in each institution and as a whole population are summarized in Table 1. The most common indications for the resection were HCC (39%) followed by colorectal cancer liver metastasis (CRLM) (32.1%) (Based on final pathology). The mean operative time of the whole population was 231.1 mins (±124.3). The mean tumor size and number were 32.5mm ((±20.5) and 1.3 (±0.8) respectively. The overall conversion rate was 16.7%. A R0 resection of 96% for the malignant tumors with a mean closest resection margins of 8.9mm (±9.5) was achieved. Mean post-operative hospital stay was 5 days (±4.2) and 90-day major morbidity (≥ grade 3), mortality rate and readmission rate were 2%, 0.7% and 4.3% respectively.

Validation of the LLR difficulty score with surrogates of operative difficulty and outcomes

Operative time correlated well with the LDS as well as the difficulty level. Operative time increased when comparing low to high scores and from low to intermediate to high scores ($p<0.0001$) (Figure 2A). Similarly, intraoperative EBL increased from low to higher scores and from low to intermediate to high level of difficulty ($p<0.0001$). (Figure 2B) Conversion rates were also associated with the LDS levels- low vs. intermediate vs. high: 5.3 vs. 15.7 vs. 25 % respectively ($p<0.0001$). The number of patients who required Pringle's maneuver ($p<0.0001$) and the duration ($p=0.029$) when it was used both trended with difficulty level as well. (Figure 2C). These are summarized in Table 2 as well. The results were consistent and similar when each center was analyzed individually as well. (Supplementary data)

As illustrated in Figure 3A, there was a clear clustering of easy LLR with lower blood loss and operative time, the intermediate cases with more blood loss and operative time and the high difficulty cases tended to require the most operative time and resulted in the most blood loss. Based on the operative time and blood loss scatter plot, the grouping of the low difficulty cases is also tighter than the intermediates cases, with the difficult cases being the most widespread. This signifies that operative time and blood loss were more consistent and predictable when cases were classified by the LDS as easy and less predictable in difficult cases. In this series, some of the cases were performed during the surgeons' earlier experience, this may in part account for the large spread of the scatter plot, especially evident in the high difficulty cases. (Figure 3A) In cases which were converted to open procedures, the grouping and clustering were not clearly evident in any of the low, intermediate or high difficulty cases. (Figure 3B) This is likely due to the fact that once a procedure is converted to the open approach, the operative time and blood loss becomes more variable and much less predictable by the LDS.

Difficulty scores and levels also correlated well with secondary validators such as LOS ($p<0.0001$) and 90-day- mortality rate ($p=0.034$) and there was a trend with 90-day morbidity (although not statistically significant, likely due to small numbers). These are summarized in Table 2.

Factors, outcomes and predictors of conversion

Patients who are male, have a higher ASA, higher BMI, larger tumor size, previous abdominal surgery, higher LDS and difficulty levels were significantly more prevalent in the converted group. The converted group also has significantly higher EBL, more requiring blood transfusions and a longer post-operative stay. These factors and outcomes associated with conversions are summarized in Table 3.

Patient demographics (Age, gender, ASA, BMI, previous abdominal surgery), preoperative factors (major/minor resection, cirrhosis, tumor size and number), the LDS and its difficulty levels were entered into a multivariate regression analysis. Previous abdominal surgery, male gender and the difficulty level were found to be independent predictors of conversions. (Table 4)

Additional factors evaluated to improve the difficulty score

Preoperative factors - BMI and previous abdominal surgery were assessed if they correlated with the various surrogates of difficulty such as operative time, EBL and conversion rates. Body mass index did not correlate significantly with operative time [Pearson correlation coefficient (PCC) = 0.044. p=0.37] or EBL (PCC=0.061. p=0.16). Body mass index had a significant association with conversion albeit a poor predictor [Area under curve (AUC) = 0.58, p=0.007). Previous abdominal surgery did not correlate significantly with operative time (p=0.15) or EBL (p=0.13) but correlated with conversion rate (12.7 vs 23.5%. p =0.005).

Discussion

Perception of the difficulty of a procedure or surgical techniques can often be quite subjective. It can be influenced by a multitude of variables. These range from patient factors such as BMI, previous surgical and medical history, disease factors such as the type of tumor or its nature (e.g. cystic vs solid tumors), surgeon factors such as aptitude, experience, learning curve and type of training, and team or institutional factors such as nursing support or assistant’s expertise and familiarity with the procedure and equipment.

Since the Louisville LLR consensus in 2008, minor LLR has become standard practice in many institutions.(4, 24) After the Morioka LLR consensus in 2014, based on IDEAL (Idea, Development, Exploration, Assessment, Long-term study) framework, minor LLR was judged to be at the assessment phase while major LLR was at the exploration phase. (3, 25) The traditional Brisbane definition of major and minor liver resections was based on open liver surgery and is less applicable to LLR. As an example, posterosuperior tumor resections via the laparoscopic approaches such as posterior sectionectomy and non-anatomic LLR of segments 7 and 8 tumors are technically difficult because these transection planes can be in several planes that are awkward to access laparoscopically, the view can be angled and viewed with flexible laparoscopes, especially if the lesions are deep and not easily accessible. These LLR procedures are increasingly performed and accepted as major and complex hepatectomies due to the technical complexity via the laparoscopic approach, despite not fulfilling the Brisbane definition of major hepatectomy.(5, 26-28) To further illustrate this point, Lee and Strasberg et al. recently published a perceived Complexity score for open liver resection based on a survey of 66 experts across the world- in this open liver resection complexity score, an open right posterior sectionectomy is perceived to be between 5-6 on a score of 1-10 (10 being the most complex). In contrast, a laparoscopic right posterior sectionectomy will be at least a 9 on the LDS. (29, 30)

Scoring systems in medicine are not novel. They have often been developed and designed with the intent to guide clinical decision making.(31) This concept in its various forms has gained popularity in many aspects of medicine from estimating oncologic prognosis to surgical outcomes.(32, 33) Many different scoring systems for surgical procedures have been proposed in the past for HPB surgery, including the various difficulty scores for laparoscopic cholecystectomy and a complexity score for open liver resection.(29, 34-36) These are valuable in that they provided an easy way for clinicians to turn difficult qualitative judgments into semi- or quantitative assessments. The novel LDS comprised of components such as tumor location, extent of resection, tumor size, proximity to major vessel; and liver function (Child-Pugh); these are all available preoperative information surgeons routinely study as part of their preoperative planning. (Figure 1) (11) (11, 30)

The learning curve of every surgeon differs. Given that LLR is a relatively new procedure, there are many surgeons worldwide at varying stages of their learning curve with different exposure to LLR training and access to experienced LLR surgeon/team who can guide them in their assessment of the difficulty of each procedure preoperatively. Moreover the assessment in the difficulty of a particular procedure can be subjective and inconsistent even among different experts, even in open liver surgery.(29)

Selection is key. Appropriate case selection in LLR with respect to where an individual or a team lies on their learning curve is paramount to patient care and central to improving outcomes. Preoperative scoring systems to assess technical surgical difficulty can allow appropriate selection of cases for trainees and less experienced surgeons. This guides the allocation of less difficult procedures to less experienced surgeons or experienced open liver surgeons early in their LLR learning curve. Such approaches may also provide a graduated training framework for surgeons learning LLR surgery. These scoring systems could also be used for unbiased comparisons among surgeons for cases of various difficulties. This score has been partially validated recently by Im et al. for patients who underwent laparoscopic left lateral sectionectomy and demonstrated that the median blood loss and complication grade correlated with the different difficulty score subgroups.(21) Uchida and colleagues also reported in a single center series of 78 LLR patients that the LDS correlated well with operative time and was an independent predictor of operative time. (22) Most recently, Tanaka et al. published the largest study to-date validating this LDS in a Japanese population; they reported that the difficulty level correlated well with conversion rate, operative time, blood loss, post-operative complications as well as hospital stay. Notably, they also noted that the incidence of post-operative liver failure and in-hospital mortality was significantly higher in the higher difficulty group when compared to the lower difficulty group.(20) Similarly, our study validated the LDS/difficulty levels with blood loss and operative time, in addition with the other various established surrogates of difficulty e.g. the usage and duration of the Pringle's maneuver, conversion rate. It also correlated well with early outcomes such as post-operative stay and 90-day mortality (Table 2, 3). The difficulty levels (high vs. low) were also found be the most significant independent predictor of conversion (p=0.0005) (Table 4). In our cohort, the morbidity and readmissions rate were similar between the converted and converted groups. The converted group did have a longer length of post-operative stay and higher mortality rate. It remains debatable whether conversion could offset advantages of laparoscopic techniques. Cauchy et al. studied this issue in a French multi-center study of 223 patients undergoing major LLR, after propensity score matching, the morbidity rate in patients who had conversion was higher than in patients who did not but this was not significantly different from patients treated by planned laparotomy.(37) We also noticed that there is a pattern of clustering - the easy cases tended to have more predictable lower blood loss and shorter operative time, the intermediate group with more blood loss and longer operative time and difficulty group tend to have the most blood loss, the longest operative time and least predictable (Figure 3A). Albeit there was significant overlap in the scatter plots of these 3 groups, we attributed these overlaps to a variety of factors inherent to the nature of surgery, such as an imperfect score, uniqueness and diverse nature of the procedures, patients' and surgeons' factors. Nonetheless, this pattern of clustering disappears when the converted cases are analyzed. (Figure 3B) In another words, when a case is converted to open surgery, the LDS becomes less predictive and relevant.

The enthusiasm and the drive to push the technical envelope in surgery must be secondary to patients' safety at all times. As custodians of our patients' health, we must adopt a slow, steady and cautious approach especially when it comes to complex and new surgical procedures that have significant morbidity/mortality coupled with low margins of errors. A well validated scoring system may help surgeons better select their cases and to provide patients with appropriate pre-operative information and counselling regarding the predicted risk of the proposed procedure when compared to an open procedure, permitting a well-informed discussion of the risk and benefits of a LLR.(23)

The study is unique as it is a large and comprehensive external validation of a novel LLR difficult score for all types of LLR, consisting of patients from both East and West tertiary centers with adequate follow-up. This study validated the LDS with the various surrogates of operative complexity such as operative time, Pringle's maneuver usage and duration, intraoperative blood loss, blood transfusions as well as early surgical outcomes such as hospital stay, and mortality. These findings hold true when each institution (SGH or MSKCC) was analyzed independently- this signifies that this score is robust and applicable even in centers with different patient population, diverse disease patterns and varying institution practice (Supplementary Data). This strengthens it as a good selection tool for surgeons as well as a valuable source of preoperative information for counselling patients about the risks of a particular LLR procedure.

Limitations of the study include the surgical techniques, disease pattern and patients' characteristics may differ between the countries and institutions e.g. in MSKCC cohort, patients have higher BMI, but fewer had cirrhosis when compared to the SGH cohort. The surgeries are performed also by different surgeons in each center with varying experience and techniques in LLR. The surgeons are at different stages of their learning curves, e.g. a junior surgeon performing an easy case may have higher blood loss and/or longer operative time, and this can skew the results. Nonetheless, based the literature and our experience, the LLR learning curve is about 20-60 cases for both minor and major LLR, the majority of the cases in this series were performed by surgeons beyond their initial learning curve. (2, 8, 38) Other factors such as BMI and previous abdominal surgery what might strengthen the accuracy of LDS can be considered as shown. Larger prospective studies will need to be performed in the future to validate our findings, improve the score as well as to validate the proposed IWATE criteria.

Conclusion

This is a comprehensive external validation of a novel LLR difficulty score and based on our combined East-West experience, it serves as an accurate preoperative guide. This is useful for selecting patients according to the individual surgeon’s phase in his/her learning curve and can be helpful for preoperative surgical planning and counselling.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

References

1. Gagner M, Rheault M, Dubuc J. Laparoscopic partial hepatectomy for liver tumor. [abstract]. Surg Endosc. 1992;6(99).
2. Goh BK, Chan CY, Wong JS, Lee SY, Lee VT, Cheow PC, et al. Factors associated with and outcomes of open conversion after laparoscopic minor hepatectomy: initial experience at a single institution. Surg Endosc. 2014 11. PubMed PMID: 25427418. ENG.
3. Wakabayashi G, Cherqui D, Geller DA, Buell JF, Kaneko H, Han HS, et al. Recommendations for laparoscopic liver resection: a report from the second international consensus conference held in Morioka. Ann Surg. 2015 4;261(4):619–29. PubMed PMID: 25742461. eng. [PubMed: 25742461]
4. Buell JF, Cherqui D, Geller DA, O'Rourke N, Iannitti D, Dagher I, et al. The international position on laparoscopic liver surgery: The Louisville Statement, 2008. Ann Surg. 2009 11;250(5):825–30. PubMed PMID: 19916210. eng. [PubMed: 19916210]
5. Dagher I, O'Rourke N, Geller DA, Cherqui D, Belli G, Gamblin TC, et al. Laparoscopic major hepatectomy: an evolution in standard of care. Ann Surg. 2009 11;250(5):856–60. PubMed PMID: 19806057. eng. [PubMed: 19806057]
6. Chiow AK, Lee SY, Chan CY, Tan SS. Learning curve in laparoscopic liver surgery: a fellow's perspective. Hepatobiliary Surg Nutr. 2015 12;4(6):411–6. PubMed PMID: 26734626. PMCID: PMC4689688. eng. [PubMed: 26734626]
7. Robinson SM, Hui KY, Amer A, Manas DM, White SA. Laparoscopic liver resection: is there a learning curve? Dig Surg. 2012;29(1):62–9. PubMed PMID: 22441622. eng. [PubMed: 22441622]
8. Vigano L, Laurent A, Tayar C, Tomatis M, Ponti A, Cherqui D. The learning curve in laparoscopic liver resection: improved feasibility and reproducibility. Ann Surg. 2009 11;250(5):772–82. PubMed PMID: 19801926. eng. [PubMed: 19801926]
9. Tomishige H, Morise Z, Kawabe N, Nagata H, Ohshima H, Kawase J, et al. Caudal approach to pure laparoscopic posterior sectionectomy under the laparoscopy-specific view. World J Gastrointest Surg. 2013 6;5(6):173–7. PubMed PMID: 23977419. PMCID: PMC3750128. eng. [PubMed: 23977419]
10. Kluger MD, Vigano L, Barroso R, Cherqui D. The learning curve in laparoscopic major liver resection. J Hepatobiliary Pancreat Sci. 2013 2;20(2):131–6. PubMed PMID: 23064988. Epub 2012/10/16. eng. [PubMed: 23064988]

11. Ban D, Tanabe M, Ito H, Otsuka Y, Nitta H, Abe Y, et al. A novel difficulty scoring system for laparoscopic liver resection. J Hepatobiliary Pancreat Sci. 2014 10;21(10):745–53. PubMed PMID: 25242563. eng. [PubMed: 25242563]
12. Teo JY, Kam JH, Chan CY, Goh BK, Wong JS, Lee VT, et al. Laparoscopic liver resection for posterosuperior and anterolateral lesions-a comparison experience in an Asian centre. Hepatobiliary Surg Nutr. 2015 12;4(6):379–90. PubMed PMID: 26734622. PMCID: PMC4689685. eng. [PubMed: 26734622]
13. Ito K, Ito H, Are C, Allen PJ, Fong Y, DeMatteo RP, et al. Laparoscopic versus open liver resection: a matched-pair case control study. J Gastrointest Surg. 2009 12;13(12):2276–83. PubMed PMID: 19727974. eng. [PubMed: 19727974]
14. Fong Y, Jarnagin W, Conlon KC, DeMatteo R, Dougherty E, Blumgart LH. Hand-assisted laparoscopic liver resection: lessons from an initial experience. Arch Surg. 2000 7;135(7):854–9. PubMed PMID: 10896382. eng. [PubMed: 10896382]
15. Goh BK, Chan CY, Lee SY, Lee VT, Cheow PC, Chow PK, et al. Laparoscopic Liver Resection for Tumors in the Left Lateral Liver Section. JSLS. 2016 2016 Jan-Mar;20(1). PubMed PMID: 26877627. PMCID: PMC4744999. eng.
16. Goh BK, Teo JY, Chan CY, Lee SY, Cheow PC, Chung AY. Laparoscopic repeat liver resection for recurrent hepatocellular carcinoma. ANZ J Surg. 2016 4. PubMed PMID: 27117542. ENG.
17. Strasberg SM, Phillips C. Use and dissemination of the brisbane 2000 nomenclature of liver anatomy and resections. Ann Surg. 2013 3;257(3):377–82. PubMed PMID: 22895397. Epub 2012/08/17. eng. [PubMed: 22895397]
18. 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 8;240(2):205–13. PubMed PMID: 15273542. PMCID: Pmc1360123. Epub 2004/07/27. eng. [PubMed: 15273542]
19. Lee SY, Allen PJ, Sadot E, D'Angelica MI, DeMatteo RP, Fong Y et al. Distal pancreatectomy: A single institution's experience in open, laparoscopic and robotic approaches. J Am Coll Surg. 2015 1;220(1):18–27. doi: 10.1016/j.jamcollsurg.2014.10.004. Epub 2014 Oct 15. PubMed PMID: 25456783. [PubMed: 25456783]
20. Tanaka S, Kubo S, Kanazawa A, Takeda Y, Hirokawa F, Nitta H, et al. Validation of a Difficulty Scoring System for Laparoscopic Liver Resection: A Multicenter Analysis by the Endoscopic Liver Surgery Study Group in Japan. J Am Coll Surg. 2017 4. PubMed PMID: 28408311. Epub 2017/04/10. eng.
21. Im C, Cho JY, Han HS, Yoon YS, Choi Y, Jang JY, et al. Validation of difficulty scoring system for laparoscopic liver resection in patients who underwent laparoscopic left lateral sectionectomy. Surg Endosc. 2016 6. PubMed PMID: 27287898. ENG.
22. Uchida H, Iwashita Y, Saga K, Takayama H, Watanabe K, Endo Y, et al. Clinical Utility of the Difficulty Scoring System for Predicting Surgical Time of Laparoscopic Liver Resection. J Laparoendosc Adv Surg Tech A. 2016 6. PubMed PMID: 27352010. ENG.
23. Muangkaew P, Cho JY, Han HS, Yoon YS, Choi Y, Jang JY, et al. Defining Surgical Difficulty According to the Perceived Complexity of Liver Resection: Validation of a Complexity Classification in Patients with Hepatocellular Carcinoma. Ann Surg Oncol. 2016 1. PubMed PMID: 26727918. ENG.
24. Dagher I, Gayet B, Tzanis D, Tranchart H, Fuks D, Soubrane O, et al. International experience for laparoscopic major liver resection. J Hepatobiliary Pancreat Sci. 2014 10;21(10):732–6. PubMed PMID: 25098667. eng. [PubMed: 25098667]
25. McCulloch P, Altman DG, Campbell WB, Flum DR, Glasziou P, Marshall JC, et al. No surgical innovation without evaluation: the IDEAL recommendations. Lancet. 2009 9;374(9695):1105–12. PubMed PMID: 19782876. eng. [PubMed: 19782876]
26. Cho JY, Han HS, Yoon YS, Shin SH. Experiences of laparoscopic liver resection including lesions in the posterosuperior segments of the liver. Surg Endosc. 2008 11;22(11):2344–9. PubMed PMID: 18528623. Epub 2008/06/06. eng. [PubMed: 18528623]
27. Di Fabio F, Samim M, Di Gioia P, Godeseth R, Pearce NW, Abu Hilal M. Laparoscopic major hepatectomies: clinical outcomes and classification. World J Surg. 2014 12;38(12):3169–74. PubMed PMID: 25159116. Epub 2014/08/28. eng. [PubMed: 25159116]

28. Xiang L, Xiao L, Li J, Chen J, Fan Y, Zheng S. Safety and Feasibility of Laparoscopic Hepatectomy for Hepatocellular Carcinoma in the Posterosuperior Liver Segments. World J Surg. 2015 1 14. PubMed PMID: 25585525. Epub 2015/01/15. Eng.
29. Lee MK, Gao F, Strasberg SM. Perceived complexity of various liver resections: results of a survey of experts with development of a complexity score and classification. J Am Coll Surg. 2015 1;220(1):64–9. PubMed PMID: 25451665. eng. [PubMed: 25451665]
30. Ban D, Kudo A, Ito H, Mitsunori Y, Matsumura S, Aihara A, et al. The difficulty of laparoscopic liver resection. Updates Surg. 2015 6;67(2):123–8. PubMed PMID: 26160064. eng. [PubMed: 26160064]
31. Barbini P, Cevenini G, Furini S, Barbini E. A naïve approach for deriving scoring systems to support clinical decision making. J Eval Clin Pract. 2014 2;20(1):1–6. PubMed PMID: 23648123. eng. [PubMed: 23648123]
32. Bilimoria KY, Liu Y, Paruch JL, Zhou L, Kmiecik TE, Ko CY, et al. Development and evaluation of the universal ACS NSQIP surgical risk calculator: a decision aid and informed consent tool for patients and surgeons. J Am Coll Surg. 2013 11;217(5):833–42.e1-3. PubMed PMID: 24055383. PMCID: PMC3805776. eng. [PubMed: 24055383]
33. Lee SY, Konstantinidis IT, Eaton AA, Gönen M, Kingham TP, D'Angelica MI, et al. Predicting recurrence patterns after resection of hepatocellular cancer. HPB (Oxford). 2014 10;16(10):943–53. PubMed PMID: 25041404. PMCID: PMC4238862. eng. [PubMed: 25041404]
34. Randhawa JS, Pujahari AK. Preoperative prediction of difficult lap chole: a scoring method. Indian J Surg. 2009 8;71(4):198–201. PubMed PMID: 23133154. PMCID: PMC3452633. eng. [PubMed: 23133154]
35. Vivek MA, Augustine AJ, Rao R. A comprehensive predictive scoring method for difficult laparoscopic cholecystectomy. J Minim Access Surg. 2014 4;10(2):62–7. PubMed PMID: 24761077. PMCID: PMC3996733. eng. [PubMed: 24761077]
36. Gupta N, Ranjan G, Arora MP, Goswami B, Chaudhary P, Kapur A, et al. Validation of a scoring system to predict difficult laparoscopic cholecystectomy. Int J Surg. 2013;11(9):1002–6. PubMed PMID: 23751733. eng. [PubMed: 23751733]
37. Cauchy F, Fuks D, Nomi T, Schwarz L, Barbier L, Dokmak S, et al. Risk factors and consequences of conversion in laparoscopic major liver resection. Br J Surg. 2015 6;102(7):785–95. PubMed PMID: 25846843. Epub 2015/04/02. eng. [PubMed: 25846843]
38. Brown KM, Geller DA. What is the Learning Curve for Laparoscopic Major Hepatectomy? J Gastrointest Surg. 2016 5;20(5):1065–71. [PubMed: 26956007]

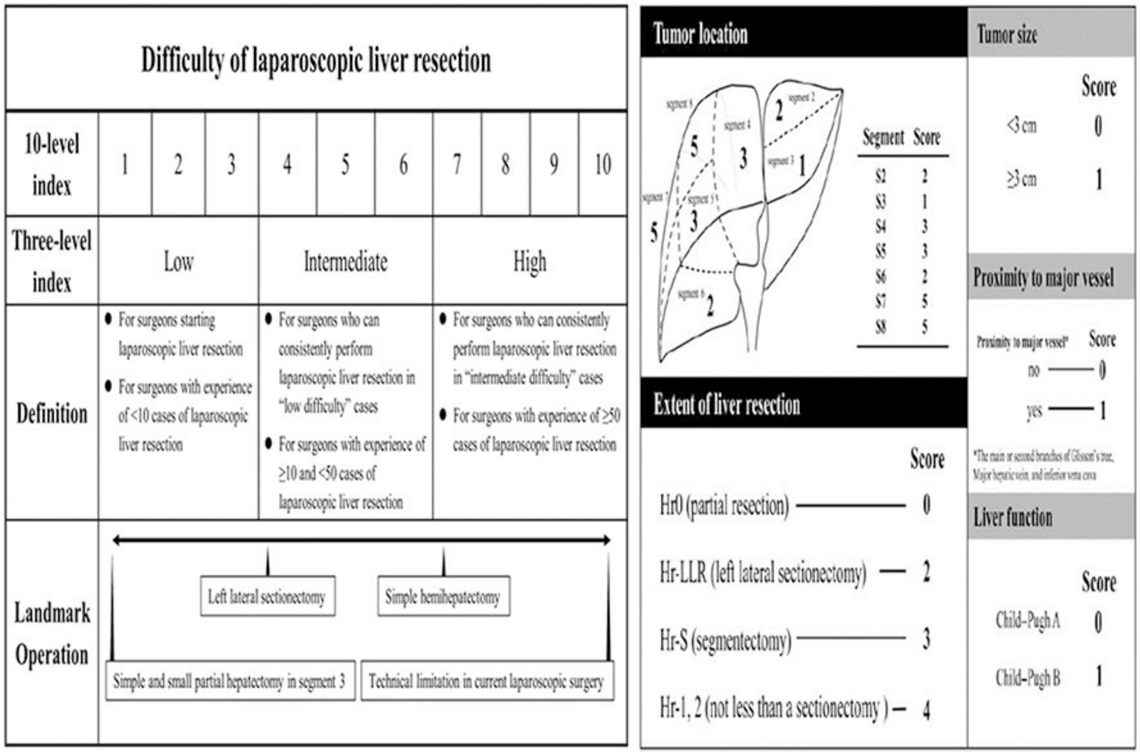

Figure 1:

The laparoscopic liver resection difficulty score and difficulty levels.

Adapted with permission. Ban D, Tanabe M, Ito H, et al. A novel difficulty scoring system for laparoscopic liver resection. J Hepatobiliary Pancreat Sci 2014; 21(10):745-53.

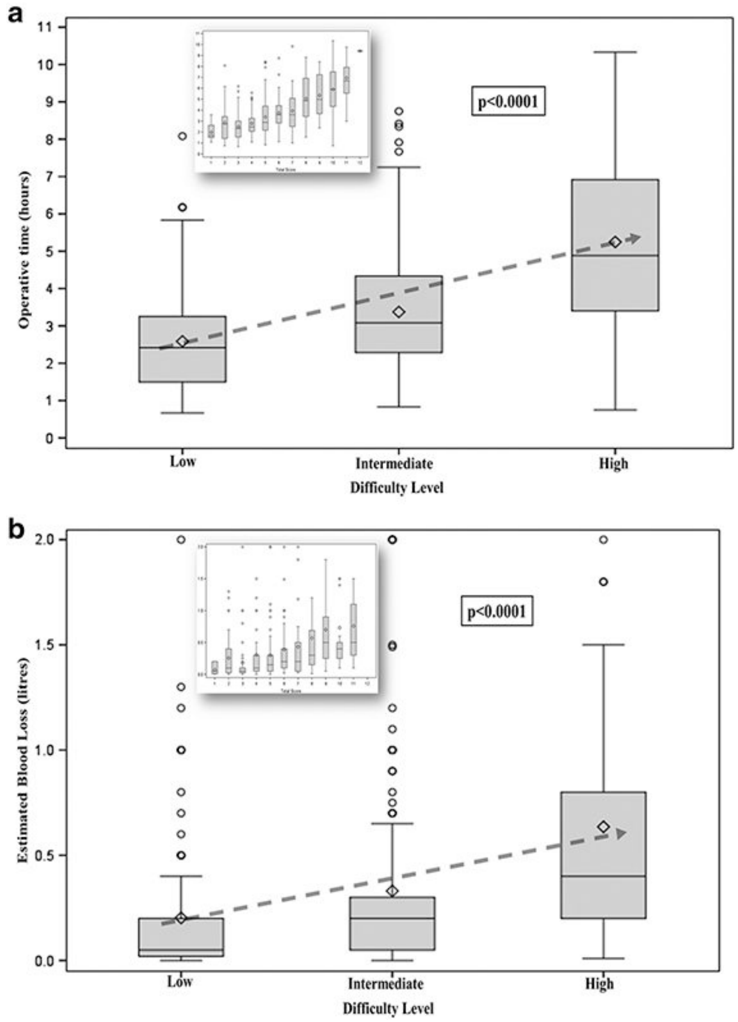

Figure 2.

A: Operative time vs. Difficult Level

(Inset: Operative time vs. Difficulty scores)

B: Estimated blood loss vs. Difficulty level

(Inset: Estimated blood loss vs Difficulty scores)

C: Duration of Pringle's maneuver (if applied) vs. Difficulty level

(Inset: Duration of Pringle's maneuver (if applied) vs Difficulty scores)

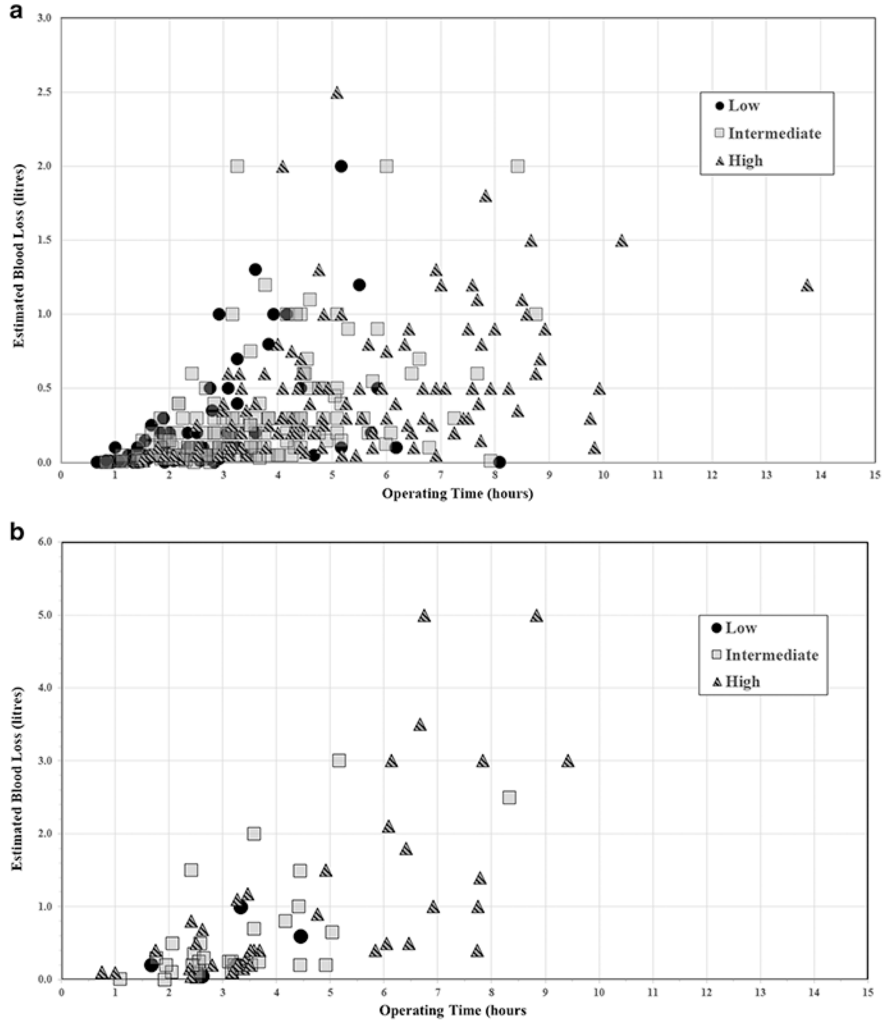

Figure 3.

A: Scatter plot of estimated blood loss and operative time- laparoscopic cases

B: Scatter plot of estimated blood loss and operative time- converted cases

Table 1.

Clinicopathologic and perioperative data of patients undergoing laparoscopic liver resection

	Whole study population, n (%)	**SGH n (%)**	**MSKCC n (%)**	**p***
Demographics				
Number of patients	444	267	177	-
Females (%)	46.0%	36.5%	60.1%	**<.0001**
Age (years), mean (range)	59.1 (22-86)	60.4 (27-86)	57.1 (22-82)	**0.008**
Median ASA (IQR)	2 (2,3)	2 (2,2)	3 (2,3)	**<.0001**
Underlying Liver disease - Cirrhosis (Child-Pugh A/B)	94 (21.2%)	90 (34%)	4 (2.3%)	**<.0001**
BMI, median (IQR)	25.1 (21.9-28.8)	23.9 (21.3-26.7)	27.7 (23.7-32.5)	**<.0001**
Previous abdominal surgery (%)	39.6%	23.2%	63.0%	**<.0001**
Histopathology n (%)(Based on final pathology)				
Hepatocellular carcinoma	173 (39.0)	144 (54.1)	29 (16.4)	**<.0001**
Colorectal Liver Metastasis	142 (32.1)	52 (19.6)	90 (50.9)	
Other non-colorectal liver metastases	23 (5.2)	22 (8.3)	1 (0.6)	
Hepatic adenoma	34 (7.7)	25 (9.4)	9 (5.1)	
Other Benign lesions	71 (16.0)	23 (8.7)	48 (27.1)	
Malignant lesions, (%)	76.3%	82.0%	67.9%	**<.0001**
Laparoscopic Difficulty score				
Difficulty score (mean, ± SD)	5.8 ±2.6	5.8 ±2.8	5.7 ±2.3	0.54
Difficulty score (median, IQR)	5.0 (4,8)	5.0 (4,8)	5.0 (4,7)	
Difficulty level				
- Low	94 (21.2)	60 (22.6)	34 (19.1)	0.68
- Intermediate	198 (44.6)	117 (44)	81 (45.5)	
- High	152 (34.2)	89 (33.5)	63(35.4)	
Operative parameters				
Major resections (≥3 segments), n (%)	42 (9.5)	24 (9)	18(10.2)	0.74
Operative time (mins), mean ±SD	231.1 ±124.3	252.6 ±136	199.0 ±96.2)	**<.0001**
Pringle’s Maneuver, n (%)	135 (31.7)	77 (28.1)	58 (35.4)	0.20
Total Pringle’s time (mins), mean ±SD	43.9 ±28.3	52.8 ±32.1	32.2 ±16.4	**<.0001**
Estimated Blood Loss (ml), mean ±SD	408.6 ±626.1	513.4 ±737	249.8 ±349.9	**<.0001**
Blood transfusion, no. of patients, n (%)	49(11)	49 (18.6)	1(0.6)	**<.0001**
Conversion to open, n (%)	74 (16.7)	29 (10.9)	45(25.4)	**<.0001**
Tumor size (mm), mean ±SD	32.5 ±20.5	31.0 ±19.2	35 ±22	0.091
No. of tumors, mean ±SD	1.3 ±0.8	1.3 ±0.9	1.3 ±0.8	0.67
Surgical Margin (mm), mean ±SD	8.9 ±9.5	9.5 ±10.3	7.5 ±7.1	0.03
Outcomes				
R0 resection, n (%)	416 (96.3)	253 (95.1)	162 (97.6)	0.31
90 days Major morbidity (Grade ≥3), n (%)	25 (2.0)	4 (1.5)	5 (2.8)	0.16

	Whole study population, n (%)	SGH n (%)	MSKCC n (%)	p*
90 days Mortality, n (%)	3 (0.68)	3(1.1)	0	
LOS, (days), mean ±SD	5.0 ±4.2	5.2 ±5	4.8 ±2.7	0.26
90 days Re-admissions rate, n (%)	19 (4.3)	14(5.3)	5(2.8)	0.21

ASA: American Society of Anesthesiologists; Body Mass Index: BMI; IQR: Interquartile range; SD: Standard deviation; EBL: estimated blood loss; LOS: Length of stay; post-operative.

*Analysis comparing the SGH and MSKCC cohorts. B: excludes gallbladder as an addition organ as cholecystectomy is considered as part of the liver resection; FNH: Focal Nodular Hyperplasia.

Table 2.

Difficulty levels vs. operative surrogates of difficulty and early outcomes (whole population)

Difficulty Level vs. Operatives parameters / Outcome measures	**Low n= 94**	**Intermediate n= 198**	**High n= 152**	**p**
Operative parameters				
Operative time (mins), mean ±SD	155.2 ±85.2	202.5 ±89.9	314.8 ±136.2	**<.0001**
Conversion rate (%)	5.3%	15.7%	25.0%	**<.0001**
Estimated blood loss (mls), mean ±SD	202.5 ±346.0	330.5 ±510.5	635.2 ±804.3	**<.0001**
Blood transfusion, n (%)	6.6%	6.7%	20.8	**0.0001**
Pringle's maneuver utilized (%)	14.4%	29.7%	45.1%	**<.0001**
Duration of Pringle's maneuver (mins), mean ±SD	36.8 ±22	39.4 ±23.7	50 ±32.6	**0.029**
Outcome measures				
90-day Morbidity Grade ≥3 (%)	0	2%	4.5%	0.123
90-day Mortality (%)	0	0	2%	**0.034**
Postoperative hospital stay (days), mean ±SD	3.8 ±2.9	4.5 ±2.5	6.4 ±6.0	**<.0001**
90-day Readmission rate (%)	3.2%	6.6%	2.0%	0.358

SD: Standard deviation

Table 3.

Factors and outcomes associated with Conversions

	Non-converted n=370	**Converted n=74**	**p**
Demographics			
Females (%)	48.7%	32.4%	**0.011**
Age (years), mean ±SD	59.2 ±12.4	58.4 ±12.5	0.60
ASA, median (IQR), mean ±SD	2 (2,3)	2 (2,3)	**0.003** [1]
	2.2 ±0.6	2.4 ±0.5	**0.003**
Cirrhosis (Child-Pugh A/B) (%)	21.4%	18.9%	0.75
BMI, mean ±SD	25.7 ±5.7	27.8 ±6.7	**0.007**
Previous abdominal surgery (%)	36.5%	54.9%	**0.005**
Operative parameters			
Major resections (≥3 segments) (%)	8.7%	13.5%	0.19
Operative time (min), mean ±SD	229.4 ±125.1	239.8 ±120.4	0.51
Estimated blood loss (mls), mean ±SD	320.8 ±433	847.9 ±1094	**0.0001**
Blood transfusion (%)	9.7%	20.3%	**0.0015**
Pringle's Maneuver (%)	30.1%	40%	0.12
Total Pringle's duration (mins), mean ±SD	44.5 ±28.4	41.5 ±28.3	0.62
Tumor size (mm), mean ±SD	31.3 ±19.9	38.1 ±22.4	**0.01**
No. of tumors, mean ±SD	1.3 ±0.9	1.4 ±0.7	0.39
Laparoscopic Difficulty score			
Mean Score ±SD	5.6 ±2.6	6.7 ±2.5	**0.0005**
- Low	24.1%	6.8%	**0.0003**
- Intermediate	45.1%	41.9%	
- High	30.8%	51.4%	
Outcomes			
Post-operative hospital stay (days), mean ±SD	4.6 ±3.8	7.4 ±5.4	**<.0001**
90-day Major Morbidity (Grade ≥3) (%)	2.3%	3.9%	0.62
90-day Mortality (%)	0.27%	2.7%	**0.07**
90-day readmission rates (%)	4.1%	5.5%	0.53

[1] P-value reflects a significant difference in dispersion between groups not reflected by the median (IQR).

SD: Standard deviation; ASA: American Society of Anesthesiologists; Body Mass Index: BMI.

Table 4.

Logistic regression analysis: Predictive factors of Conversions

	Univariate analysis, OR (95% CI)	p	Stepwise multivariate analysis, OR (95% CI)	p
Demographics				
Males vs. Females	1.95 (1.16 - 3.30)	0.01	2.30 (1.26 – 4.18)	**0.0064**
Age	0.99 (0.98 – 1.01)	0.59	-	-
ASA			-	-
- 2 vs. 1	5.38 (1.00 – 28.9)	0.05		
- 3,4 vs. 1	8.49 (1.56 – 46.17)	0.013		
Cirrhosis (Child Pugh A/B only)	0.88 (0.47 – 1.64)	0.68	-	-
BMI	1.06 (1.02 – 1.10)	0.007	-	-
Previous abdominal surgery	2.11 (1.26 – 3.53)	0.004	2.30 (1.30 – 4.06)	**0.004**
Preoperative variables				
Major resections (≥3 segments)	1.70 (0.80 – 3.60)	0.68	-	-
Tumor size	1.01 (1.00 -1.03)	0.01	-	-
No. of tumors	1.12 (0.86 – 1.47)	0.40	-	-
Laparoscopic Difficulty score				
Mean Score	1.18 (1.07 – 1.30)	0.0007	-	-
Difficulty level				
- Intermediate vs. Low	3.06 (1.19 – 7.88)	0.021	7.37 (1.70 – 32.04)	**0.008**
- High vs. Low	5.47 (2.14 – 14.01)	0.0004	13.67 (3.15 – 59.39)	**0.0005**

CI: Confidence interval; ASA: American Society of Anesthesiologists; Body Mass Index: BMI