Title: Navigating complexity in liver resection: A narrative review of factors influencing intra-operative difficulty

Short Title: Operative difficulty in liver resection

Authors:

1. Meet Patel BMedSt., MD, MS[1] – meet.patel@sydney.edu.au – ORCID: 0000-0003-1039-902X
2. Anthony R Glover MBBS, PhD, FRACS[1] – anthony.glover@sydney.edu.au – ORCID: 0000-0003-0762-0977
3. Thomas J. Hugh MD, FRACS[2,3] - tom.hugh@sydney.edu.au – ORCID: 0000-0001-6690-342X

Affiliations:
1. Faculty of Medicine and Health, University of Sydney, NSW, Australia
2. Upper Gastrointestinal Surgical Unit, Royal North Shore Hospital, St Leonards, NSW, Australia
3. Northern Clinical School, University of Sydney, NSW, Australia

Corresponding Author:

Name: Dr Meet Patel

Address: The University of Sydney, Science Rd, Camperdown NSW 2050

Email: meet.patel@sydney.edu.au

Key terms:

- Liver malignancy
- Operative difficulty
- Liver resection
- Minimally invasive surgery

This is the accepted version of the following article: Patel M, Glover AR, Hugh TJ. Navigating Complexity in Liver Resection: A Narrative Review of Factors Influencing Intraoperative Difficulty. Journal of Laparoendoscopic & Advanced Surgical Techniques. 2025 May; 35(7): 519-530 which has now been formally published in final form at Journal of Laparoendoscopic & Advanced Surgical Techniques at 10.1089/lap.2025.0041. This original submission version of the article may be used for non-commercial purposes in accordance with the Mary Ann Liebert, Inc., publishers' self-archiving terms and conditions.

Abstract:

Background: Liver resection remains the cornerstone for curative management in primary liver malignancies. Liver surgery ranges from simple wedge resections to complex hepatectomies involving vascular or biliary reconstructions. The anatomical complexity of the liver and these varied surgical approaches create challenges in assessing operative difficulty. This literature review explores the key factors influencing operative difficulty in liver resection for primary liver malignancy across surgical techniques.

Methods: A broad literature review was conducted to determine the factors that were associated with increased operative difficulty in liver resection using Embase, PubMed and Cochrane databases for studies published between 2000-2025.

Results: This review identifies several patient, tumour, and surgical factors that influence operative difficulty in liver resection. Numerous difficult scoring systems were identified, yet their applicability across different operative approaches remains uncertain. Across open and minimally invasive techniques, tumour size and location are commonly used to determine complexity. However, debate remains regarding the optimal cut-off for tumour diameter. Other identified factors include extent of resection, patient-specific variables (e.g., cirrhosis, body mass index, previous surgeries), and surgical technique. Additionally, liver resection procedures classified based off the 2000 Brisbane terminology have been stratified into three groups of increasing difficulty.

Conclusion: The ability to predict operative difficulty is useful for case selection, surgical planning, and risk stratification for meaningful shared decision making. Future research should focus on refining predictive models by integrating composite measures, including patient-reported outcomes and long-term survival. A unified, validated scoring system applicable across surgical techniques could enhance consistency in clinical practice and research to improve outcomes.

Main Text (5877 words)

Introduction:

The treatment of primary liver cancer is nuanced and depends on the subtype or location of the tumour, but surgery remains the mainstay for curative intent. "Liver resection" is a broad term that encompasses heterogenous procedures ranging from simple wedge resections to complex hepatectomies involving vascular or biliary reconstructions. Partly due to the complexity and variability of liver anatomy, there have been inconsistencies in resection nomenclature in the past.

In 1979, Tung described "minor" and "major" liver resections, with "minor" being defined as the resection of two or fewer Couinaud segments and "major" as three or more Couinaud segments.[1] At the meeting of the International Hepato-Pancreato-Biliary Association in Brisbane, Australia, in 2000 there was an attempt to rationalise and standardise the numerous and often confusing nomenclature of hepatic anatomy and resections.[2] This led to the Brisbane 2000 Nomenclature of hepatic anatomy and resection based on eight attributes: (1) it is anatomically correct; (2) anatomical and surgical terms are in agreement; (3) consistency; (4) self-explanatory; (5) linguistically correct; (6) precise; (7) concise; and (8) translatable.[2] Although the Brisbane classification has improved communication amongst hepatic surgeons, its limitations include the use of multiple terms for the same resection and its failure to adequately describe non-anatomical resections, multiple resections, or combined bilio-vascular reconstructions. Since then, further classification systems have been proposed, including the "New World" terminology by Nagino et al. (2021) and the updated Brisbane classification by Wakabayashi et al. (2022). Regardless of the nomenclatures or system used, classification of the relative difficulty of a resection is not standardised and remains at the discretion of the surgeon.[3, 4]

There is a spectrum of technical difficulty encompassing the broad range of liver resection operations. The terms "minor" and "major" resections can be misleading as they do not stratify the complexities of the procedure despite having the same name. For example, a left lateral sectionectomy (segments 2 and 3) and a right anterior sectionectomy (segments 5 and 8) would be both classified as a minor resection, although they vary greatly in complexity. Certainly, within laparoscopic liver resection, there is agreement that complexity varies significantly based on the location. For example, accessing posterior segments is much more challenging laparoscopically than it is during an open approach.[5]

The differentiation of surgical complexity or the technical difficulty of an operation is challenging because it is a subjective measure and varies depending on the experience and training of the surgeon. Surrogate markers for technical or operative difficulty have been proposed including operative time, duration of inflow occlusion, estimated blood loss, number of units of blood transfused, and whether a minimally invasive approach was converted to an open approach. In a range of general surgical procedures, operative time and conversion to open approach has been used as a surrogate for operative difficulty.[6-9] Furthermore, increased operative time has been shown to be associated with an increased risk of post-operative complications across open, laparoscopic, and robotic liver resections.[10] Understanding the difficulty of a procedure is beneficial because surgeons can accumulate experience in easier cases during their operative learning curve, and then progress to more challenging cases as they progress. Furthermore, understanding the difficulty of an operation would aid with planning of the approach, which is particularly important for minimally invasive approaches.

There is still much to understand about predicting the difficulty of a liver resection and understanding the factors that impact the intra-operative complexity. Addressing these issues would be useful for justifying a specific operative technique, for improving patient counselling and to assist with comparative clinical outcomes research. This narrative review aims to investigate the factors associated with predicting operative difficulty in liver resection for malignant tumours.

Methods:
A thorough literature review of existing literature was completed using Embase, PubMed and Cochrane databases to complete this narrative review. The following search terms were applied between 10th December 2025 to 26th December 2024:

1. ("liver resection" OR hepatectomy) AND operative AND difficulty AND (malignan* OR cancer)
2. ("liver resection" OR hepatectomy) AND (difficult* OR complex*) AND (malignan* OR cancer)
3. "Hepatectomy"[Mesh] AND (difficult* OR complex*) AND (malignan* OR cancer)

Results between 2000 and 2025 were screened. After duplicate results were removed, relevant articles were screened through title and abstract review (Figure 1). Further relevant articles were reviewed through a full-text review. Inclusion criteria were all study types including systematic reviews, meta-analyses, randomised control trials and cohort studies that assessed factors that impacted intra-operative difficulty in liver resection for malignancy. This study included liver resection operations including open, laparoscopic and robotic techniques.

Results:
After evaluating the existing literature, numerous operative difficulty scoring systems were identified that were developed based on expert opinion or retrospective review of existing databases. However, these scoring systems were validated across a single operative technique e.g. open, laparoscopic, or robotic. A summary of the various difficulty scoring systems have been summarised in Table 1. There have been attempts to rationalise the difficulty of different types of liver resections based on the anatomical location of the resection. A summary of the identified classifications based on the procedure have been summarised in Table 2. Additionally, patient factors have been assessed to determine which parameters influence intra-operative difficulty.

<u>Open liver resection</u>
The development of a difficulty scoring system in open liver resection was completed by Pothet et al. (2021), where operative difficulty was defined based on the operative time, the liver transection time, the estimated blood loss, and the number of vascular inflow (Pringle) manoeuvres.[11] Operations were stratified into two categories: “standard liver resection” and “difficult liver resection” through a multicentre prospective cohort study known as the DIFF-sCOR study.[11] To calculate the probability of a difficult liver resection, the tool assess the patient’s body weight, the number of tumour nodules, the maximum tumour size (>10cm), the type of hepatectomy (anatomical vs non-anatomical), whether transection planes were used in the resection, the site of a non-anatomical resection, whether vena caval reconstruction is required, whether a bilio-enteric anastomosis is required and whether there will be more than one liver specimen to calculate the probability of a difficult liver resection. Although this scoring system was useful in predicting intra-operative outcomes, its use may

be limited by the complexity of the formula to predict difficulty and it was not able to accurately predict post-operative outcomes.[11]

Prior to this, Pulitanò et al. in 2007 attempted to identify pre-operative factors associated with peri-operative blood transfusion in liver surgery.[12] Using a forward-step regression model, they demonstrated that a pre-operative haemoglobin of ≤12.5g/dL, exposure of the vena cava, the presence of cirrhosis, having an associated surgical procedures, and the largest tumour > 4cm were associated with increased incidence of perioperative blood loss.[12] These five clinical variables were then used to develop a transfusion risk score, demonstrating good discrimination in the validation set.[12] The number of blood units transfused has been used as a surrogate marker of operative difficulty, hence, these factors may be useful in determining the operative difficulty. Furthermore, a retrospective assessment of patient factors that might affect the difficulty of a colorectal metastasis liver resection was undertaken by Inoue et al. (2020), who showed that overall body mass index (BMI) did not impact operative times or estimated blood loss.[13] However, in relation to the operative technique, a further subgroup analysis of patients with BMI >25 showed that an open resection took 87 minutes longer than a minimally invasive approach, highlighting that there may be a benefit in using a minimally invasive approach in obese patients.[13]

<u>Laparoscopic liver resection</u>:
Various operative difficulty scoring systems have been developed to estimate the difficulty of laparoscopic liver resections.

Ban et al. (2015) proposed a 10-level index that reflected the variable difficulty of laparoscopic liver resection after completing a three-centre retrospective study examining 90 cases.[14] The study used subjective assessment by the surgeon in relation to the degree of difficulty, and determined that the culmination of five factors including, tumour location, the extent of liver resection, tumour size (<3cm or ≥3cm), proximity to major vessels and the Child Pugh status, aligned with difficulty assessment completed by the surgeon.[14] Furthermore, when the 10-index score was converted into a three-level assessment (low, intermediate and high) system, the scoring system also showed 95% agreement.[14] Subsequently, this become known as the IWATE difficulty scoring system and has since been validated by other studies.[15-19] Expanding on this work, a successive novel difficulty scoring system was proposed by Xi et al. (2022), that used a 14 point scoring system.[20] It differs from the original scoring system by including additional factors such as the including the caudate lobe as a location of the tumour, a diagnosis of either a benign or malignant condition and whether there was a history of hepatobiliary surgery.

The Hasegawa scoring system (2017) proposed for Japanese patients was developed through a retrospective review of a prospectively collected database. These authors examined a range of pre-operative factors, determining that obesity, low platelet count, and the extent of resection were correlated with increased operative time.[21] However, this scoring system excluded patients with resection involving segment 1, tumours ≥10 cm, patients with ≥four lesions, patients with visceral metastatic disease, or those who underwent concomitant vascular or bile duct reconstructions. In contrast to the IWATE score, this study found that proximity to a major vessel was not associated with increased operative time; however, this may be due to the exclusion of certain patients as described above.[21] From the initial multivariate analysis, they proposed a three-level difficulty tier with the extent of resection, the location of the tumour, the presence of obesity (BMI >30) and the pre-operative platelet count (≤100 x 10^9/L) showing statistically significant differences between the three tiers in terms of surgical time, blood loss, and length of stay in the hospital.

Furthermore, the Institut Mutualiste Montsouris (IMM) score was developed by Kawaguchi et al. (2018) in French patients who underwent laparoscopic liver resection.[22] This was completed through a retrospective review of prospectively collected patient data, stratifying procedures based on the Brisbane classification across three levels based on operative time < or ≥190 minutes), blood loss (< or ≥100mL), duration of the Pringle manoeuvre, and rates of conversion to an open operation (< or ≥4.2%).[22] Similar to the other groups, the study cohort excluded patients who underwent biliary or vascular reconstruction, multiple liver resections (>four), repeat laparoscopic liver resection and concomitant extra-hepatic procedures (except cholecystectomy).[22] These authors classified wedge resection of the anterolateral segment, wedge resection of the posterolateral segment, or left lateral resection as group I; anterolateral segmentectomy and left hepatectomy as group II; and posterosuperior segmentectomy, right hepatectomy, extended right hepatectomy, right posterior hepatectomy, central hepatectomy (segment 5 and 8 or segments 4, 5, and 8) and extended left hepatectomy as group III.

The Southampton difficulty scoring system, developed by Halls et al. (2018), used operative time as an objective marker of operative difficulty.[23] Following a survey of 80 surgeons through the European-African Hepato-Pancreato-Biliary Association, as well as a literature review, they identified variables that increased operative difficulty. Through a retrospective review, they determined that a previous open liver resection, a diagnosis of benign or malignant condition, the tumour size (<3 cm, 3-5 cm, >5 cm) and the classification of the resection (minor, technically major or anatomically major) would be included in their scoring system. With a higher score, this group demonstrated an increased likelihood of intra-operative complications, as well as predicting 90-day mortality.[23] Subsequently, an external validation of the Southampton score was shown to be a good effective predictor of intra-operative outcomes and post-operative outcomes.[17, 24]

Additional difficulty scoring systems have been proposed for repeat laparoscopic liver resection. Okamuru et al. (2019) proposed a system derived from the IWATE score for repeat laparoscopic liver resection by adding a parameter to include whether the tumour was on the cranial or dorsal side of the previous surgical site.[25] However, only limited conclusions can be drawn from this study, as it was based on only 40 patients, with an inclusion criteria restricted to patients who underwent partial hepatectomy or left lateral sectionectomy without thoracotomy, consequently limiting generalisability.[25] Furthermore, in patients with recurrent hepatocellular carcinoma, Kinoshita et al. (2019) demonstrated that two or more previous liver resections and procedures more radical than a sectionectomy were associated with increased operative times, while the operative approach in the previous resection (open or laparoscopic), a history of cholecystectomy at the time of the previous resection or a history of non-surgical treatment before the operation was not associated with operative difficulty.[26] These studies highlight the need for further research to assess which variables most effectively determine operative difficulty in repeat laparoscopic liver resection.

There have been attempts to rationalise the optimal cut-offs for tumour size to stratify the operative difficulty in laparoscopic liver resection. Ivanecz et al. (2021) proposed using 3.8cm as the cut-off size for tumour diameter after a retrospective review to assess how the IWATE score affects intra-operative and post-operative complications.[14, 27] Further, Kabir et al. (2022) found that larger tumour size in laparoscopic liver resections was associated with increased operative time as well as prolonged post-operative hospital stay.[28] They suggested using a trichotomy of <3 cm, 3-6.9 cm, ≥7 cm as tumour size cut-offs and that this would be a better predictor than using the dichotomy in the IWATE scoring system. However, this study excluded patients who underwent concomitant operations.[28] Further, Aizza et al. (2022) argued that in relation to laparoscopic lateral sectionectomy, cut-offs should be 0-3.9 cm, 4-6.9 cm, 7-9.9 cm and ≥10 cm as they determined that these sizes consistently discriminated between open conversion rates, operative time, estimated blood loss, transfusion rates and Pringle manoeuvre use, as well as correlating with major post-operative complication rates.[29] A subsequent retrospective review by Kato et al. (2023), involving 1396 patients who underwent laparoscopic major hepatectomies, showed that tumour cut-offs of 5cm and 10cm impacted the rates of conversion to open surgery, operative times, estimated blood loss, application of the Pringle manoeuvre, and requirement for an intra-operative blood transfusion.[30] However, these factors did not affect major post-operative complications or length of stay in hospital.[30] Therefore, although a tumour diameter of 3cm was used as the cut-off in the IWATE score, given the heterogeneity in liver resection, a single or unifying tumour cut-off size may not be appropriate as further studies have suggested that this may not be the optimal diameter to effectively stratify operative difficulty.

Patient and radiological factors
As well as the above-mentioned difficulty scoring systems in laparoscopic resection, other studies have assessed patient and radiological factors that might impact operative difficulty. A multicentre retrospective review of 1034 patients undergoing minimally invasive liver resection for colorectal metastasis by Ghotbi et al. (2023) showed that neoadjuvant chemotherapy did not impact open conversion rates, mean operating time, or intra-operative transfusion rates.[31] Indirectly, this suggests that these factors have no impact on the difficulty of the operation, despite being used in the Southampton difficulty scoring system.[32] Montalti et al.'s (2023) multicentre retrospective review of patients undergoing minimally invasive (laparoscopic or robotic) major liver resection showed that males, previous abdominal surgery, ASA score ≥3, median tumour size, IMM score class III, and portal hypertension were independently associated with an increased risk of conversion to open surgery.[31] Interestingly, the leading cause of conversion to open surgery in this study was bleeding.[31]

Although, liver cirrhosis and tumour size have previously been shown to increase the difficulty of the operation due to distorting anatomy, it was suggested that ASA ≥ 3 was associated with high conversion rates because of a lower threshold for conversion in the presence of comorbidities. Also, it was suggested that male patients had an increased risk of converting to open surgery because of higher BMIs, larger liver size and a higher incidence of cirrhosis compared to female patients as opposed to other technical challenges of the procedure.[31, 33] The findings of liver cirrhosis increasing operative difficulty have been replicated in patients with Child Pugh A liver cirrhosis undergoing minimally invasive liver resection of the anterolateral segments, laparoscopic left sectionectomy and major laparoscopic liver resection, with studies also showing an increase in post-operative hospital stay and morbidity.[34-36] Interestingly, sub-group analysis comparing Child Pugh A and B patients showed no difference in intra-operative outcomes and additionally, there was no difference in intra-operative outcomes in sub-group analysis of cirrhotic patients with or without portal hypertension.[35, 36] This highlights the relative increase in difficulty of laparoscopic liver resection for patients with cirrhosis due to stiffened parenchyma and the loss of tactile feedback, along with a lowered threshold for accepting bleeding in these patients.

Furthermore, Chen et al. (2023) showed increasing BMI is associated with longer operative times, increased blood loss, higher blood transfusion rates, greater use of the Pringle manoeuvre and higher conversion to open rates in laparoscopic left lateral sectionectomy.[37] Additionally, Guilbaud et al. (2020) estimated the technical difficulty of the resection by estimating the total transection surface area using pre-operative triple phase liver protocol CT with 3D reconstruction.[38] They identified that the transacted area would increase with increasing IMM grade, and that is not an unexpected finding as IMM grades are based on the type of resection. This study demonstrated that an estimated parenchyma transection surface area ≥ 100cm^2 was associated with increased operative time, higher blood loss and increased conversion to open surgery rates as well as worse post-operative outcomes including higher overall morbidity, higher biliary leakage rates, increased rates of fluid collections and increased rates of pulmonary complications when compared to estimated parenchyma transection surface area <100cm^2.[38] Therefore, in laparoscopic liver resection it is suggested that previous abdominal surgery, increasing BMI, cirrhosis and estimated transection surface area are important factors associated with increasing technical difficulty of the operation.

Robotic surgery

While the widespread uptake of robotic approaches has been limited worldwide due to a lack of a dedicated robotic parenchymal transection tool, the development of a difficulty scoring system in robotic liver surgery is still of interest. The Tampa difficulty scoring system was developed by Sucandy et al. (2024) to predict the difficulty of robotic liver resection using the following parameters: whether neoadjuvant chemotherapy was used, the tumour location (segments 7 and 8 scoring the highest), the tumour size (<3cm or ≥3cm), the extent of the parenchymal resection, the need for a portal lymphadenectomy and the need for extrahepatic biliary reconstruction.[39] Operative time and estimated blood loss were used as a surrogate marker for operative difficulty in this study.[39] Subsequently, an internal validation of the Tampa difficulty scoring system was conducted through a prospective cohort study showing that operative difficulty progressively increased with increasing grades. However, interestingly there was increased estimated blood loss in the advanced group compared to the expert group. Additionally, there was a progressive increase in length of hospital stay with increasing difficulty. Although, there was no analysis of whether this was associated with long-term overall survival.[40] In summary, similar variables are used in laparoscopic procedures impact operative difficulty in robotic liver resection. Further studies are needed for external validation of the Tampa difficulty scoring system.

Anatomical Classifications:

The difficulty of liver resection has been assessed based on the anatomical location of the tumour and the resection site.

Through a survey study of international liver surgeons by Lee et al. (2015), classified open liver resections into three categories of complexity based on those expert opinions, placing operations into low complexity (peripheral wedge resection and left lateral sectionectomy), medium complexity (left hepatectomy without caudate resection, right hepatectomy, right posterior sectionectomy, left hepatectomy with caudate resection, right trisectionectomy), and high complexity categories (right anterior sectionectomy, middle hepatectomy, left trisectionectomy without caudate resection, left trisectionectomy with caudate resection).[41] Subsequently, retrospective reviews of patients undergoing open liver resection for hepatocellular carcinoma showed that this classification system was effective in differentiating operative times, blood transfusion rates and estimated blood loss from the low to the high complexity groups as well in predicting post-operative outcome, including morbidity and major complication rates. [42, 43] Furthermore, the system outperformed the traditional minor/major classification.[42, 43] Lee et al. (2016) then conducted a further survey of experts and amended right hepatectomy to account for whether it was performed with or without caudate resection as well as taking into consideration considered vascular or biliary reconstructions.[44] As a result, the medium difficulty procedures included a right hepatectomy without caudate resection and isolated caudate resection, and the high complexity group included right hepatectomy with caudate resection, right hepatectomy with hepaticojejunostomy, anatomic middle hepatectomy and right hepatectomy with portal vein reconstruction or inferior vena cava reconstruction.[44]

Kawaguchi et al. (2020) completed a retrospective review of patients across two sites to determine whether the IMM score initially designed for laparoscopic liver resection, would be applicable to open liver resection.[45] They demonstrated that operative time, estimated blood loss and complication rates increased in a stepwise manner from grade I-III, indicating that this system could potentially also be used in open procedures.[45] Therefore, open resection of the posterosuperior segment (Couinaud segments 1, 4a, 7, and 8) was associated with worse surgical and post-operative outcomes compared to anterolateral segments (Couinaud segments 2, 3, 4b, 5, and 6).[45, 46] Interestingly, this trend has already been observed in laparoscopic liver resection.[45, 46]

A multicentre retrospective review by Efanov et al. (2022) comparing the difficulty of laparoscopic limited liver resection in segment 7 compared to segment 8 showed that segmentectomies in segment 7 had longer operative times and subsequent lengths of stay compared to segment 8.[47] This contrasted with their findings that atypical resections in segment 7 had greater estimated blood loss, higher transfusion rates, longer operative times and higher conversion rates compared to an atypical resections of segment 8.[47] These findings are attributed to segment 7 being in a more anatomically difficulty location to access because of its posterior location, where the ribs extending caudally restricting access in this region. However, these findings are significant given that in the IWATE difficulty scoring system, the IMM scoring system, the Southampton difficulty scoring system and the Hasegawa scoring system did not differentiate between segment 7 and 8 in terms of points rating or difficulty grade.

Furthermore, a retrospective review of prospectively collected data by Azoulay et al. (2022) to determine if open liver resection in the "central column" of the liver, defined accurately in their paper, was associated with increased operative difficulty for colorectal metastasis.[48] They showed that resection of this area was associated with longer operative time and higher number of units of blood transfused suggesting increased operative difficulty. However, they also demonstrated that liver resection in the central column was associated with higher rates of severe post-operative complications.[48] These findings contrast with a prior meta-analysis comparing central liver resection and extended hepatectomy for malignant resections by Chan et al. (2018) which showed that central liver resections had fewer overall post-operative complications than extended hepatectomy, with similar mortality rates. However, this meta-analysis considered a wide range of surgical approaches, and its definition of central liver resection differed slightly from that used by Azoulay et al. (2022).[48, 49]

Discussion:
The results of this review show several patient, tumour, and surgical factors that are associated with increased operative difficulty in liver resection. Across open and minimally

invasive techniques, tumour size and location are commonly used to determine the difficulty of the operation; however, there is still debate regarding the optimal cut-off for tumour diameter. Patient factors that impact operative difficulty include body habitus (BMI or weight), anaemia, cirrhosis, thrombocytopenia and whether there were previous abdominal operations. Of these, the only pre-operative modifiable factors are body habitus and anaemia status that could potentially help to decrease the technical difficulty of a procedure. Increasing BMI has been shown to increase the risk of steatohepatitis and cirrhosis due to the association with metabolic associated fatty liver disease.[50, 51] This would not only increase the difficulty of the operation due to ensuring appropriate exposure of the patient but also due to concerns from steatosis or liver cirrhosis. Liver cirrhosis was shown to increase the difficulty of both open and minimally invasive techniques which can be attributed to the fibrosed parenchyma, the frequent presence of portal hypertension, and coagulation deficits, distortion of the liver anatomy and difficult intra-operative ultrasound visualisation for assessment of tumour margins and localisations.[5, 33-36] Further, steatohepatitis which can be considered a pre-cursor to liver cirrhosis, was shown to be one of the most common liver abnormalities in patients undergoing liver resection.[51] Patients with higher BMI have shown greater degree of fibrosis likely secondary to increasing rates of steatosis, but, steatosis has independently been shown to increase the blood loss in patients undergoing resection, suggesting steatosis could be a risk factor for increasing operative difficulty.[52, 53] Ultimately, understanding these factors contributing to the technical difficulty of procedures will assists the surgeon with pre-operative planning in relation to the expected operation length, use of experienced operating room staff, and identifying patients who may require a senior and more experienced assistance. Further research is needed to identify modifiable patient factors that can improve intra-operative and post-operative events.

Operative difficulty scoring systems in liver surgery are helpful, and are more accurate than the surgeons' subjective expectation regarding post-operative outcomes which generally have low sensitivity, specificity, accuracy and performance, even when controlled for surgical experience, highlighting the need for an objective measure.[54] The scoring systems are superior because they use objective measures. The variables included in the multiple operative difficulty scoring systems identified in this review are summarised in Table 1, showing significant overlap, despite different operative approaches. The most common factors were the extent of the liver resection, the tumour location and the tumour diameter. Table 2 highlights the anatomical classification of the liver resection based on the three-tiered difficulty systems in the IMM classification and by Lee et al. (2016). There are similarities in the classification for both laparoscopic and open procedures within these systems, highlighting that the relative difficulties of each procedure can translate across operative techniques. Although numerous operative difficulty scoring systems have been proposed to date, inconsistencies remain between them, possibly explaining why no single system has been universally adopted. Further work is required to determine the most effective system and for which surgical approach it is best suited.

Currently, the IWATE scoring system has been evaluated in open and robotic procedures, despite initially being developed for laparoscopic procedures only. For robotic liver resection, Chong et al. (2019) applied the IWATE scoring system in a prospective cohort study demonstrating a good correlation across the different grades for operative time, blood loss, morbidity rate, and post-operative hospital stay.[15] Further, Luberice et al. (2020) highlighted increased operative time with increasing scores in robotic liver resection, however, interestingly, there was no statistically significant difference was found between expert and advanced difficulty levels in terms of post-operative outcomes, as compared to laparoscopic liver resection.[55] This suggests the most benefit with robotic surgery is in difficult procedures, where the utility of stereopsis and increased articulation in tight anatomical areas assist with challenging dissection with a trade-off in simpler cases where the benefit may be marginal or non-existent. However, these advanced techniques place a larger economic burden which can strain healthcare resources due to increased upfront costs for equipment, requirement for specialised teams in robotic surgery and training in robotic surgery. While robotic surgery may offer benefits for a small subset of very advanced or difficult cases, the larger proportion of patients may receive minimal benefit, raising concerns about cost-effectiveness. This highlights the need for future research to include economic evaluations through cost-benefit studies to fully assess the impact on resource allocation and sustainability of the procedure. Subsequent retrospective cohort studies have shown similar results with increasing IWATE difficulty scores correlating with increased operative time, estimated intra-operative blood loss, post-operative hospital stay, increased overall 90-day mortality and liver failure rates, highlighting that the adoption of the IWATE score in robotic liver resection could be appropriate.[56-58] The IWATE difficulty scoring system was used to stratify patients into uncomplicated and complex liver surgery by Xie et al. (2022) to identify differences between perioperative outcomes in liver resection between open, laparoscopic and robotic techniques.[59] They demonstrated that in more straightforward liver resection, robotic and laparoscopic liver resection took longer to complete than open with no difference in post-operative complications, however, in technically challenging liver resection, open and laparoscopic techniques were quicker than robotic liver resection but the robotic technique was associated with fewer post-operative compilations and shorter length of stay in hospital. Given the findings of these studies and the degree of overlap of factors in the operative difficulty systems, it highlights the potential utility of using the IWATE scoring system in robotic or open surgery, where a unified scoring system across operative techniques would increase ease of use amongst clinicians and assist with standardising research when comparing operative techniques.

The laparoscopic difficulty scoring systems have been compared through several studies. Goh et al. (2021) completed a retrospective review to compare these scoring systems in terms of intra-operative and post-operative outcomes, assessing the IWATE, IMM, Southampton and Hasegawa difficulty scoring systems. There was no difference in the calibration of the four systems in terms of blood loss and post-operative stay, however, the Southampton scoring system performed worse in predicting operative time compared to the other three systems in this study. All four scoring systems showed poor discrimination with respect to blood transfusion rates, conversion to open rate and post-operative morbidity.[17] Similar comparison for patients with hepatocellular carcinoma undergoing laparoscopic liver resection by Linn et al. (2022) showed that all four difficulty scoring systems performed well in predicting operative time, estimating blood loss, post-operative complications but the IWATE score was the only one able to predict conversion to open rates in their cohort.[60] Further, Ruzzenente et al. (2022) conducted a machine learning analysis of these four scoring systems through retrospective review of patients undergoing laparoscopic liver resection for both benign and malignant liver lesions, showing that all difficulty scoring systems had good discrimination for operative times and estimated blood loss.[58] The utility of the difficulty scoring systems in laparoscopic liver resection has also been assessed in patients undergoing non-malignant resections, where Yang et al. (2019) showed that in the intergroup analysis both the Iwate and IMM difficulty scoring system were able accurately classify the degree of difficulty with respect to operative time, estimated blood loss and conversion to open rates.[56]

Moreover, increasing operative difficulty has been shown to impact post-operative patient outcomes. It has been established that increasing difficulty can lead to higher short-term morbidity, with studies revealing that higher IMM classifications and increasing IWATE scores being associated with higher complication rates.[22, 43] Although surgical risks calculators such as The National Surgical Quality Improvement Program (NSQIP) can predict the risk of post-operative complications based on patient's clinical factors and can be used for liver resection, studies have suggested that it underestimates the risk in complex procedures, particularly liver resection.[61, 62] Additionally, there is conflicting data regarding oncological outcomes with Holowoko et al. (2020) showing that increasing IMM grades have worsened overall survival despite similar positive resection rates in laparoscopic liver resection for colorectal metastases and Hobeika et al. (2021) demonstrated worsening textbook outcome rates with increasing difficulty in repeat laparoscopic liver resection for liver metastases.[63, 64] Interestingly, from a long-term perspective increasing IWATE scores were inversely associated with 5-year survival and the 5-year disease free survival in hepatocellular carcinoma.[65] There is a dearth in the literature assessing the impact of operative difficulty on patient-reported outcome measures and quality-of-life measures, including complications such as prolonged recovery, chronic pain and reduced functional capacity. Further research in this area would help to rationalise whether technically challenging procedures, although feasible, provide any meaningful benefit to the patient and could provide a better understanding of the trade-offs associated with complex resections. Here, a better understanding of the trade-offs associated with complex resections could enhance shared decision-making, allowing for more informed discussions between surgeons and patients regarding the risks and benefits of these procedures.

The operative difficulty scoring systems identified in this review, used operative time as a marker for operative difficulty which can vary significantly based on surgical experience. In the original studies, it was noted that the procedures were not controlled for operative experience. [11, 20, 21, 23] However, in the Southampton score, the authors stated that due to using numerous surgeons across multiple sites meant that the study incorporated surgeons at various points along the surgical learning curve.[23] Lee at al (2016) found that in their initial study surgeons with less experience were more likely to rate the same procedure as harder than experienced surgeons and in their second study more experience surgeons had a lower overall total difficulty rating compared to less experienced surgeons.[44] This highlights that difficulty levels are inversely correlated with surgical skill and that the assessment of surgical difficulty should require a multivariate approach. In previous literature, there has been an over-reliance on using operative time as a surrogate marker for technical difficulty, but this does not always reflect technical challenges, especially in centres with skilled surgeons, advanced robotic systems, or where cases might be slowed by surgical trainees. Hence, to counteract the limitations of using operative time as a universal metric for operative difficulty, composite measures such as textbook oncological outcomes to assess surgical performance would be of utility and is of interest as it assesses outcomes that are more clinically important. Textbook oncological outcomes are defined across seven variables as the absence of intra-operative incidents ≥2 as defined by the Oslo grade, grade ≥B post-operative bile leak, grade ≥B post-operative liver failure, post-operative complication ≥ 3a as according to the Clavien-Dindo classification, readmission within 90 days of surgery with Clavien-Dindo ≥3 complications, 90 day or in hospital mortality and R1/R2 margin and has been shown to be associated with improved long-term outcomes.[66] When comparing the various laparoscopic difficulty scoring systems, studies revealed higher difficulty was associated with increased failure of textbook outcomes, with the Southampton score being the most accurate in predicting textbook outcome.[58] Although the Southampton score does not include obesity in their difficulty scoring system, obesity has been associated with poorer rates of achieving textbook outcomes. Interestingly, of the identified difficulty scoring systems, the type of malignant disease was not an included variable for operative difficulty, however, it is known that the diagnosis impacts post-operative outcomes in liver resection, this would need to be taken into consideration when using composite measures as an overall endpoint. Hence, the use of composite measures may be a better suited method to assess the overall success of the operation considering both intra-operative and post-operative outcomes, providing better insight for shared decision making. Further studies should assess if difficulty of the operation is associated with achieving textbook outcomes and the performance of the various difficulty scoring systems in predicting textbook outcomes and long-term outcomes.

Conclusion

Numerous difficulty scoring systems exist for open, laparoscopic, and robotic procedures to predict intra-operative difficulty based on patient, tumour, and surgical factors. However, there are very few modifiable predictors of intra-operative difficulty in liver resection procedures. Current operative difficulty scoring systems provide essential tools for technical planning, and their predictive value for long-term outcomes is burgeoning. Integrating futility metrics, such as tumour biology and systemic health, could enhance decision-making by identifying patients who are unlikely to benefit from surgery. Future research should focus on developing and validating composite models that balance technical feasibility with meaningful clinical outcomes.

Disclosure Statement: Nil conflict of interests to declare.

Funding Statement: Nil funding has been sought for the production of this manuscript.

Authorship Confirmation: This manuscript has been approved by all authors and has not been submitted for publication elsewhere.

Author Contributions:
Dr Meet Patel: Methodology (equal); writing – original draft (lead); conceptualization (supporting); investigation (equal); writing – review & editing (supporting)
A/ Prof Anthony R Glover: Methodology (supporting); visualisation (equal); writing – review & editing (equal); validation (equal); supervision (supporting)
Professor Thomas J. Hugh: Methodology (equal); writing – original draft (supporting); conceptualization (lead); investigation (equal); writing – review & editing (lead); supervision (lead)

References:

1. Tung TT. Les résections majeures et mineures du foie. Paris: Masson; 1979.
2. Terminology Committee of the International Hepato-Pancreato-Biliary Association. The Brisbane 2000 Terminology of Liver Anatomy and Resections. *HPB*. 2000;2(3):333-339. doi: 10.1016/S1365-182X(17)30755-4.
3. Nagino M, DeMatteo R, Lang H, et al. Proposal of a New Comprehensive Notation for Hepatectomy: The "New World" Terminology. *Ann Surg*. 2021;274(1):1-3. doi: 10.1097/SLA.0000000000004808.
4. Wakabayashi G, Cherqui D, Geller DA, et al. The Tokyo 2020 terminology of liver anatomy and resections: Updates of the Brisbane 2000 system. *J Hepatobiliary Pancreat Sci*. 2022;29(1):6-15. doi: 10.1002/jhbp.1091.

5. Buell JF, Cherqui D, Geller DA, et al. The international position on laparoscopic liver surgery: The Louisville Statement, 2008. *Ann Surg*. 2009;250(5):825-830. doi: 10.1097/sla.0b013e3181b3b2d8.
6. Yuval JB, Thompson HM, Fiasconaro M, et al. Predictors of operative difficulty in robotic low anterior resection for rectal cancer. *Colorectal Dis*. 2022;24(11):1318-1324. doi: 10.1111/codi.16212.
7. Azoulay D, Salloum C, Llado L, et al. Defining Surgical Difficulty of Liver Transplantation. *Ann Surg*. 2023;277(1):144-150. doi: 10.1097/SLA.0000000000005017.
8. Bell SW, Kong JCH, Clark DA, et al. The National Aeronautics and Space Administration-task load index: NASA-TLX: evaluation of its use in surgery. *ANZ J Surg*. 2022;92(11):3022-3028. doi: 10.1111/ans.17830.
9. Vannucci M, Laracca GG, Mercantini P, et al. Statistical models to preoperatively predict operative difficulty in laparoscopic cholecystectomy: A systematic review. *Surgery*. 2022;171(5):1158-1167. doi: 10.1016/j.surg.2021.10.001.
10. Kuemmerli C, Sijberden JP, Cipriani F, et al. Is prolonged operative time associated with postoperative complications in liver surgery? An international multicentre cohort study of 5424 patients. *Surg Endosc*. 2024;38(12):7118-7130. doi: 10.1007/s00464-024-11276-x.
11. Pothet C, Drumez E, Joosten A, et al. Predicting Intraoperative Difficulty of Open Liver Resections: The DIFF-scOR Study, An Analysis of 1393 Consecutive Hepatectomies From a French Multicenter Cohort. *Ann Surg*. 2021;274(5):805-813. doi: 10.1097/SLA.0000000000005133.
12. Pulitano C, Arru M, Bellio L, Rossini S, Ferla G, Aldrighetti L. A risk score for predicting perioperative blood transfusion in liver surgery. *Br J Surg*. 2007;94(7):860-865. doi: 10.1002/bjs.5731.
13. Inoue Y, Ishii M, Fujii K, et al. Safety and Efficacy of Laparoscopic Liver Resection for Colorectal Liver Metastasis With Obesity. *Am Surg*. 2021;87(6):919-926. doi: 10.1177/0003134820952448.
14. Ban D, Kudo A, Ito H, et al. The difficulty of laparoscopic liver resection. *Updates Surg*. 2015;67(2):123-128. doi: 10.1007/s13304-015-0302-7.
15. Chong CCN, Lok HT, Fung AKY, et al. Robotic versus laparoscopic hepatectomy: application of the difficulty scoring system. *Surg Endosc*. 2020;34(5):2000-2006. doi: 10.1007/s00464-019-06976-8.
16. Lee SY, Goh BKP, Sepideh G, et al. Laparoscopic Liver Resection Difficulty Score-a Validation Study. *J Gastrointest Surg*. 2019;23(3):545-555. doi: 10.1007/s11605-018-4036-y.
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(5):770-776. doi: 10.1016/j.hpb.2020.09.015.
18. Uchida H, Iwashita Y, Saga K, et al. Clinical Utility of the Difficulty Scoring System for Predicting Surgical Time of Laparoscopic Liver Resection. *J Laparoendosc Adv Surg Tech A*. 2016;26(9):702-706. doi: 10.1089/lap.2016.0135.
19. Barron JO, Orabi D, Moro A, et al. Validation of the IWATE criteria as a laparoscopic liver resection difficulty score in a single North American cohort. *Surg Endosc*. 2022;36(5):3601-3609. doi: 10.1007/s00464-021-08561-4.
20. Xi C, Zhu M, Ji T, et al. A novel difficulty scoring system of laparoscopic liver resection for liver tumor. *Front Oncol*. 2022;12:1019763. doi: 10.3389/fonc.2022.1019763.
21. Hasegawa Y, Wakabayashi G, Nitta H, et al. A novel model for prediction of pure laparoscopic liver resection surgical difficulty. *Surg Endosc*. 2017;31(12):5356-5363. doi: 10.1007/s00464-017-5616-8.

22. Kawaguchi Y, Fuks D, Kokudo N, Gayet B. Difficulty of Laparoscopic Liver Resection: Proposal for a New Classification. *Ann Surg*. 2018;267(1):13-17. doi: 10.1097/SLA.0000000000002176.
23. 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(9):1182-1191. doi: 10.1002/bjs.10821.
24. Ivanecz A, Plahuta I, Magdalenic T, et al. The external validation of a difficulty scoring system for predicting the risk of intraoperative complications during laparoscopic liver resection. *BMC Surg*. 2019;19(1):179. doi: 10.1186/s12893-019-0645-y.
25. Okamura Y, Yamamoto Y, Sugiura T, et al. Novel patient risk factors and validation of a difficulty scoring system in laparoscopic repeat hepatectomy. *Sci Rep*. 2019;9(1):17653. doi: 10.1038/s41598-019-54099-w.
26. Kinoshita M, Kanazawa A, Kodai S, et al. Difficulty classifications of laparoscopic repeated liver resection in patients with recurrent hepatocellular carcinoma. *Asian J Endosc Surg*. 2020;13(3):366-374. doi: 10.1111/ases.12746.
27. Ivanecz A, Plahuta I, Magdalenic T, et al. Evaluation of the Iwate Model for Predicting the Difficulty of Laparoscopic Liver Resection: Does Tumor Size Matter? *J Gastrointest Surg*. 2021;25(6):1451-1460. doi: 10.1007/s11605-020-04657-9.
28. Kabir T, Syn N, Koh YX, et al. Impact of tumor size on the difficulty of minimally invasive liver resection. *Eur J Surg Oncol*. 2022;48(1):169-176. doi: 10.1016/j.ejso.2021.08.019.
29. Aizza G, Russolillo N, Ferrero A, et al. Impact of tumor size on the difficulty of laparoscopic left lateral sectionectomies. *J Hepatobiliary Pancreat Sci*. 2023;30(5):558-569. doi: 10.1002/jhbp.1279.
30. Kato Y, Sugioka A, Kojima M, et al. Impact of Tumor Size on the Difficulty of Laparoscopic Major Hepatectomies: An International Multicenter Study. *Ann Surg Oncol*. 2023;30(11):6628-6636. doi: 10.1245/s10434-023-13863-z.
31. Montalti R, Giglio MC, Wu AGR, et al. Risk Factors and Outcomes of Open Conversion During Minimally Invasive Major Hepatectomies: An International Multicenter Study on 3880 Procedures Comparing the Laparoscopic and Robotic Approaches. *Ann Surg Oncol*. 2023;30(8):4783-4796. doi: 10.1245/s10434-023-13525-0.
32. Ghotbi J, Aghayan D, Fretland A, et al. Impact of neoadjuvant chemotherapy on the difficulty and outcomes of laparoscopic and robotic major liver resections for colorectal liver metastases: A propensity-score and coarsened exact-matched controlled study. *Eur J Surg Oncol*. 2023;49(7):1209-1216. doi: 10.1016/j.ejso.2023.01.014.
33. Goh BKP, Syn N, Lee SY, et al. Impact of liver cirrhosis on the difficulty of minimally-invasive liver resections: a 1:1 coarsened exact-matched controlled study. *Surg Endosc*. 2021;35(9):5231-5238. doi: 10.1007/s00464-020-08018-0.
34. Zheng J, Liang X, Wu AGR, et al. Impact of liver cirrhosis, severity of cirrhosis and portal hypertension on the difficulty of laparoscopic and robotic minor liver resections for primary liver malignancies in the anterolateral segments. *Eur J Surg Oncol*. 2024;50(1):107252. doi: 10.1016/j.ejso.2023.107252.
35. Coelho FF, Herman P, Kruger JAP, et al. Impact of liver cirrhosis, the severity of cirrhosis, and portal hypertension on the outcomes of minimally invasive left lateral sectionectomies for primary liver malignancies. *Surgery*. 2023;174(3):581-592. doi: 10.1016/j.surg.2023.04.057.
36. Cipriani F, Aldrighetti L, Ratti F, et al. Impact of Liver Cirrhosis, Severity of Cirrhosis, and Portal Hypertension on the Difficulty and Outcomes of Laparoscopic and Robotic Major Liver Resections for Primary Liver Malignancies. *Ann Surg Oncol*. 2024;31(1):97-114. doi: 10.1245/s10434-023-14376-5.

37. Chen Z, Yin M, Fu J, et al. Impact of body mass index on the difficulty and outcomes of laparoscopic left lateral sectionectomy. *Eur J Surg Oncol*. 2023;49(8):1466-1473. doi: 10.1016/j.ejso.2023.03.235.
38. Guilbaud T, Scemama U, Sarran A, et al. Predictive ability of preoperative CT scan for the intraoperative difficulty and postoperative outcomes of laparoscopic liver resection. *Surg Endosc*. 2021;35(6):2942-2952. doi: 10.1007/s00464-020-07734-x.
39. Sucandy I, Dugan MM, Ross SB, et al. Tampa Difficulty Score: a novel scoring system for difficulty of robotic hepatectomy. *J Gastrointest Surg*. 2024;28(5):685-693. doi: 10.1016/j.gassur.2024.02.022.
40. Pattilachan TM, Christodoulou M, Ross SB, Lingamaneni G, Rosemurgy A, Sucandy I. Internal validation of the Tampa Robotic Difficulty Scoring System: real-time assessment of the novel robotic scoring system in predicting clinical outcomes after hepatectomy. *Surg Endosc*. 2024;38(12):7131-7138. doi: 10.1007/s00464-024-11291-y.
41. Lee MKt, 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;220(1):64-69. doi: 10.1016/j.jamcollsurg.2014.09.017.
42. Muangkaew P, Cho JY, Han HS, 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;23(8):2602-2609. doi: 10.1245/s10434-015-5058-2.
43. Periyasamy M, Cho JY, Ahn S, et al. Prediction of surgical outcomes of laparoscopic liver resections for hepatocellular carcinoma by defining surgical difficulty. *Surg Endosc*. 2017;31(12):5209-5218. doi: 10.1007/s00464-017-5589-7.
44. Lee MKt, Gao F, Strasberg SM. Completion of a Liver Surgery Complexity Score and Classification Based on an International Survey of Experts. *J Am Coll Surg*. 2016;223(2):332-342. doi: 10.1016/j.jamcollsurg.2016.03.039.
45. 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(3):258-267. doi: 10.1002/bjs.11351.
46. Kazaryan AM, Rosok BI, Marangos IP, Rosseland AR, Edwin B. Comparative evaluation of laparoscopic liver resection for posterosuperior and anterolateral segments. *Surg Endosc*. 2011;25(12):3881-3889. doi: 10.1007/s00464-011-1815-x.
47. Efanov M, Salimgereeva D, Alikhanov R, et al. Comparison between the difficulty of laparoscopic limited liver resections of tumors located in segment 7 versus segment 8: An international multicenter propensity-score matched study. *J Hepatobiliary Pancreat Sci*. 2023;30(2):177-191. doi: 10.1002/jhbp.1210.
48. Azoulay D, Desterke C, Bhangui P, et al. Tumors located in the central column of the liver are associated with increased surgical difficulty and postoperative complications following open liver resection for colorectal metastases. *HPB (Oxford)*. 2022;24(8):1376-1386. doi: 10.1016/j.hpb.2022.03.006.
49. Chan J, Perini M, Fink M, Nikfarjam M. The outcomes of central hepatectomy versus extended hepatectomy: a systematic review and meta-analysis. *HPB (Oxford)*. 2018;20(6):487-496. doi: 10.1016/j.hpb.2017.12.008.
50. Jarnagin WR, Gonen M, Fong Y, et al. Improvement in perioperative outcome after hepatic resection: analysis of 1,803 consecutive cases over the past decade. *Ann Surg*. 2002;236(4):397-406; discussion 406-397. doi: 10.1097/01.SLA.0000029003.66466.B3.
51. McCormack L, Capitanich P, Quinonez E. Liver surgery in the presence of cirrhosis or steatosis: Is morbidity increased? *Patient Saf Surg*. 2008;2:8. doi: 10.1186/1754-9493-2-8.

52. Kampf S, Sponder M, Fitschek F, et al. Obesity and its influence on liver dysfunction, morbidity and mortality after liver resection. *Hepatobiliary Surg Nutr*. 2023;12(5):704-714. doi: 10.21037/hbsn-22-291.
53. Koh YX, Tan HJ, Liew YX, et al. Liver Resection for Nonalcoholic Fatty Liver Disease-Associated Hepatocellular Carcinoma. *J Am Coll Surg*. 2019;229(5):467-478 e461. doi: 10.1016/j.jamcollsurg.2019.07.012.
54. Farges O, Vibert E, Cosse C, et al. "Surgeons' intuition" versus "prognostic models": predicting the risk of liver resections. *Ann Surg*. 2014;260(5):923-928; discussion 928-930. doi: 10.1097/SLA.0000000000000961.
55. Luberice K, Sucandy I, Modasi A, et al. Applying IWATE criteria to robotic hepatectomy: is there a "robotic effect"? *HPB (Oxford)*. 2021;23(6):899-906. doi: 10.1016/j.hpb.2020.10.008.
56. 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(1):12-18. doi: 10.1089/lap.2018.0150.
57. Steinkraus KC, Traub B, Heger P, et al. Results of robotic liver surgery in association with IWATE criteria - the first 100 cases. *Langenbecks Arch Surg*. 2024;409(1):50. doi: 10.1007/s00423-024-03239-6.
58. Ruzzenente A, Bagante F, Poletto E, et al. A machine learning analysis of difficulty scoring systems for laparoscopic liver surgery. *Surg Endosc*. 2022;36(12):8869-8880. doi: 10.1007/s00464-022-09322-7.
59. Xie F, Ge J, Sheng W, et al. Based on the IWATE criteria: to investigate the influence of different surgical approaches on the perioperative outcomes of hepatectomy. *Surg Endosc*. 2023;37(2):1044-1052. doi: 10.1007/s00464-022-09563-6.
60. 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(1):36-59. doi: 10.1002/jhbp.1211.
61. Campagnaro T, Poletto E, Tarchi P, et al. Evaluation of the ACS-NSQIP Surgical Risk Calculator in Patients with Hepatic Metastases from Colorectal Cancer Undergoing Liver Resection. *J Gastrointest Surg*. 2023;27(10):2114-2125. doi: 10.1007/s11605-023-05784-9.
62. van der Hulst HC, Dekker JWT, Bastiaannet E, et al. Validation of the ACS NSQIP surgical risk calculator in older patients with colorectal cancer undergoing elective surgery. *J Geriatr Oncol*. 2022;13(6):788-795. doi: 10.1016/j.jgo.2022.04.004.
63. 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(5):1448-1456. doi: 10.1016/j.surg.2021.05.034.
64. Holowko 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(9):1620-1627. doi: 10.1016/j.ejso.2020.05.019.
65. Lv X, Zhang L, Yu X, Yu H. The difficulty grade of laparoscopic hepatectomy for hepatocellular carcinoma correlates with long-term outcomes. *Updates Surg*. 2023;75(4):881-888. doi: 10.1007/s13304-023-01452-4.
66. Gorgec B, Benedetti Cacciaguerra A, Pawlik TM, et al. An International Expert Delphi Consensus on Defining Textbook Outcome in Liver Surgery (TOLS). *Ann Surg*. 2023;277(5):821-828. doi: 10.1097/SLA.0000000000005668.
67. Ricker AB, Davis JM, Motz BM, et al. External validation of the Japanese difficulty score for laparoscopic hepatectomy in patients undergoing robotic-assisted hepatectomy. *Surg Endosc*. 2023;37(9):7288-7294. doi: 10.1007/s00464-023-10330-4.

Table 1 - Comparison of factors included in operative difficulty assessment tools for liver resection

	Operative difficulty scoring system	Extent of resection	Tumour resection location	Tumour diameter	Diagnosis (malignant vs benign)	Patient's body habitus	Concomitant procedures with liver resection	Vascular or biliary reconstruction/ anastomosis	Liver function (Child Pugh A vs B)	Previous abdominal surgery	Neoadjuvant chemotherapy	Pre-operative platelet count ($<100 \times 10^9$/L vs $\geq 100 \times 10^9$/L)
Open liver resection	DIFF-scOR (Pothet et al. 2021)	X	X	X		X	X	X				
Laparoscopic liver resection	IWATE score (Ban et al. 2015)	X	X	X					X			
	Xi et al. (2022)	X	X	X	X				X	X		
	Hasegawa scoring system (Hasegawa et al. 2017)	X	X			X						X
	Southampton difficulty scoring system (Halls et al. 2018)	X		X	X					X	X	
Robotic liver resection	Tampa difficulty score (Sucandy et al. 2024)	X	X	X	X		X	X			X	

Table 2 – Comparison of classification tools of liver resection procedures by difficulty

Anatomical classification	Low complexity (Group 1)	Medium complexity (Group 2)	High complexity (Group 3)
Lee et al. (2016) for open procedures[44]	• Peripheral wedge resection, <3cm • Left lateral sectionectomy	• Left hepatectomy without caudate resection • Right hepatectomy without caudate resection • Right posterior sectionectomy • Left hepatectomy with caudate resection • Isolated caudate resection • Right trisectionectomy	• Right anterior sectionectomy • Right hepatectomy with caudate resection • Right hepatectomy with hepaticojejunostomy • Anatomic middle hepatectomy • Right trisectionectomy with caudate resection • Left trisectionectomy without caudate resection • Right trisectionectomy with hepaticojejunostomy • Left trisectionectomy with caudate resection • Right hepatectomy with portal vein reconstruction (main to left) • Right trisectionectomy with portal vein reconstruction (main to left) • Right hepatectomy with IVC reconstruction
IMM score (Kawaguchi et al. 2018) for laparoscopic procedures[22]	• Wedge resection of the anterolateral segment • Wedge resection of the posterolateral segment • Left lateral resection	• Anterolateral segmentectomy • Left hepatectomy	• Posterosuperior segmentectomy • Right hepatectomy • Extended right hepatectomy • Right posterior hepatectomy • Central hepatectomy (segment 5 and 8 or segments 4, 5 and 8) • Extended left hepatectomy

Figure Legend:
Figure 1 – Search strategy
Table 1 - Comparison of factors included in operative difficulty assessment tools for liver resection
Table 2 - Comparison of classification tools of liver resection procedures by difficulty