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Development of a novel educational tool to assess skills in laparoscopic liver surgery using the Delphi methodology: the laparoscopic liver skills scale (LLSS)

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Abstract

Background No specific performance assessment scales have been reported in laparoscopic liver resection. This study aimed at developing an objective scale specific for the assessment of technical skills for wedge resection in anterior segments (WRAS) and left lateral sectionectomy (LLS).

Methods A laparoscopic liver skills scale (LLSS) was developed using a hierarchical task analysis. A Delphi method obtained consensus among five international experts on relevant steps that should be included into the LLSS for assessment of operative performances. The consensus was predefined using Cronbach's alpha > 0.80.

Results A semi-structured review extracted 15 essential subtasks for full laparoscopic WRAS and LLS for evaluation in the Delphi survey. Two rounds of the survey were conducted. Three over 15 subtasks did not reach the predefined level of consensus. Based on the expert's comments, 13 subtasks were reformulated, 4 subtasks were added, and a revised skills scale was developed. After the 2nd round survey (Cronbach's alpha 0.84), 19 subtasks were adopted. The LLSS was composed of three main parts: patient positioning and intraoperative preparation (task 1 to 8), the core part of the WRAS and LLS procedure (tasks 9 to 14), and completion of procedure (task 15 to 19).

Conclusions The LLSS was developed for measuring the skill set for the education of safe and secure laparoscopic WRAS and LLS procedures in a dedicated training program. After validation, this scale could be also used as an assessment tool in the operating room and extrapolated as an operative roadmap to other complex procedures.

Keywords Educational tool · Delphi methodology · Learning curve · Laparoscopic liver resection · Training program

With the increasingly spreading of laparoscopic surgery, simulation-based surgical training has been introduced into the surgical residency curriculum [1, 2]. Many studies have demonstrated the positive impact of simulation on technical skills for basic laparoscopic procedures [3–7], shortening the learning curve (LC) of young surgeons, and reducing the number of adverse events in the operating room [8, 9].

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Laparoscopic liver resection (LLR) has been growing in terms of the number of procedures performed and their complexity [10]. However, LLR has developed very slowly due to various obstacles, which include a significant LC, especially to become familiar with liver mobilization, parenchymal transection techniques, and overall control bleeding, along with specific devices [11]. Recently, the Southampton Guidelines advocated that the laparoscopic approach should be considered as the standard practice for the lesions of the left lateral and anterior segments at the beginning of the LC [12]. Indeed, laparoscopy has become the standard surgical approach for left lateral sectionectomy (LLS) and for wedge resection of the anterior segments (WRAS), due to its anatomical accessibility [13–15].

Today, only few studies have focused on simulation-based teaching programs in laparoscopic liver surgery [16]. Most training models used for LLR were the animal model (swine liver) and the cadaver [17–21]. However, no standardized training programs have been validated for LLR, whereas specific assessment tools for training in advanced laparoscopic surgeries have recently been developed and validated [22–27]. No performance assessment scales have been reported so far in LLR. Such scales are needed to assess both the educational value of training programs and the technical skills of trainee surgeons, especially for "basic" LLR, such as WRAS and LLS. As a bridge between training and the operating room, a dedicated skills scale may be enabled to shorten the LC of young surgeons and could also be used as an operative roadmap in the operating room to improve patients' safety.

Therefore, the purpose of this study was to identify the essential steps in WRAS and LLS, and to develop an objective scale for the assessment of technical skills during these procedures. The identification of procedural steps was performed by hierarchical task analysis (HTA) and then by expert consensus, using the Delphi methodology.

Material and methods

The present study did not involve human subjects or laboratory animals. Thus, approvement by institutional review committee is not needed.

Hierarchical task analysis

HTA [28] was adopted in the present study. The purpose was to identify the successive discrete steps that are required to complete a full laparoscopic WRAS (segments 2, 3, 4b, 5, and 6), and a LLS. Literature was searched in order to identify the different laparoscopic operative techniques [29–33]. A panel of video performed by liver laparoscopic surgeons illustrating these techniques was selected from one local database and one online database (WeBsurg). The aim was to develop a scale that could assess operative performances of trainee surgeons involving in a teaching program out of the operating room. Two experienced surgeons in both laparoscopy and hepatobiliary surgery (DF and DJB) and one surgical resident (TG) reviewed independently the videos. Each reviewer listed all the consecutive discrete steps required for completion of each procedure. Then, reviewers pooled together the results and elaborated a joint list of steps. A numerical scoring scale ranging from 1 to 3 was assigned to each selected step.

Creation of the laparoscopic liver skills scale (LLSS) by Delphi

All consecutive steps generated by the HTA were submitted to a panel of 15 international experts using the Delphi methodology. In order to present a technically and educationally relevant objective skills assessment tool, surgeons who were experts in both liver and laparoscopic surgery were invited to participate in the Delphi. Moreover, the invited experts should have prior publications on LLR, be key opinion leaders in the field of laparoscopic liver surgery and have an active involvement in simulation-based surgical training programs. They were invited to participate in the project via email. Experts from different geographic zones were recruited (Europe, US) in order to develop an internationally relevant scale. All participating experts were volunteers and informed consents were obtained.

The Delphi methodology is a systematic and interactive forecasting method used to obtain consensus among a panel of experts, who are consulted over several rounds. After each round answers are collected, analyzed, and submitted back in an iterative fashion to the group. Over the successive rounds, group opinion should converge toward consensus [34, 35].

Two rounds of the Delphi survey were conducted. Experts were asked to rate, using the Likert scale ratings from 1 to 5 (1: strongly disagree, 2: disagree, 3: undecided, 4: agree, 5: strongly agree) with the guidance of the following questions: "Do you think that three levels of assessment are enough? Do you think the number of subtasks is adapted? By subtask, do you think the description of the skill levels is appropriate? Do you think that the proposed subtasks cover all the skills required to perform WRAS and LLS?" Experts were invited to comment their answers in order to modify or add steps during the second round. Mean and standard deviation obtained for each step during the first round were presented to the experts during the second round. A rate of agreement (RoA) was calculated as a measure of consensus among the experts: [(Agreement—Disagreement)/(Agreement + Disagreement + Indifferent)] × 100. Steps that reached consensus during the second round were included in the final scale.

Statistical analysis

Means and standard deviations (SD) were calculated for all the subtasks. Cronbach's alpha was calculated for internal consistency among the experts. The consensus was predefined using Cronbach's alpha > 0.8 according to a global Delphi consensus study on defining and measuring quality in surgical training [36]. The subtasks were adopted when they were rated 4 or 5 on the Likert scale by 80% or more of the experts. Data were analyzed using SPSS version 20.0 (SPSS, Chicago, Illinois, USA).

Results

A draft of the key subtasks was created using the literature, video analysis, and direct observations of WRAS and LLS cases in 2 teaching hospitals. As the videos collected recorded the intra-abdominal camera view, some aspects of the full procedure were not visualized. Therefore, the reviewers additionally listed the steps assessing patient positioning, preoperative checklist, and abdominal access. After the semi-structured review with two experienced surgeons and a surgical resident in the final process of the HTA, 15 essential subtasks for full laparoscopic WRAS and LLS were extracted for evaluation in the Delphi survey (Table 1). All subtasks were scored from 1 to 3 points. A score of 3 points considered the specific skill as acquired, whereas a score of 1 point considered it as non-acquired.

The Delphi survey was conducted between March 2019 and January 2020. Five of the 15 international experts agreed with our invitation and voluntarily participated in the Delphi survey. Participating experts (one American and four French experts) were experienced surgeons in laparoscopic liver surgery and involved in simulation-based surgical training programs. All experts completed the 1st and 2nd round survey. A total of 3 over 15 subtasks did not reach the predefined level of consensus (Table 2). Cronbach's alpha was 0.78 after the 1st round survey. The main drawback identified in the experts' comments was that the number of subtasks was insufficient and did not cover all the skills required to perform a full laparoscopic WRAS or LLS. Therefore, based on these comments, 13 subtasks were reformulated, 4 subtasks were added, and a revised skills scale was developed, including the division of the revised skills scale in three steps. This revised skills scale was submitted to the five experts who had completed the first round. Results of the second round are detailed in Table 3.

After the Delphi consensus was achieved with the results of the 2nd round survey (Cronbach's alpha 0.84), 19 subtasks were adopted. The LLSS was finally created based on the selected subtasks resulting from the Delphi 1st and 2nd round surveys (Table 4). A score of 3 points considers the specific skill as acquired. Thus, the LLSS maximum score for the full scale is 57 points. For WRAS and LLS, procedure's skills could be considered as acquired when the LLSS score is 45 and 51 points, respectively.

Discussion

The gradual introduction of simulation-based training programs using a dedicated rating scale could reduce the clinical impact of LC and improve patients' safety [37]. We used a comprehensive method, including the HTA and Delphi methods to determine the essential subtasks of full laparoscopic WRAS and LLS. With those results, we developed the LLSS for measuring the skill set for the education of safe and secure laparoscopic WRAS and LLS procedures. The LLSS is composed of three main parts: patient positioning and intraoperative preparation (task 1 to 8), the core part of the WRAS and LLS procedure (tasks 9 to 14), and completion of procedure (task 15 to 19).

In this study, we inquired about each task in the Delphi extra survey that addressed the concept of "safety" procedure. That is why 19 tasks were selected in the LLSS, including some points of safety: initial check, patient—port and aid positioning, Pringle maneuver, intraoperative ultrasonography, intraoperative bleeding and biliary leakage management, management of open conversion, and final check. In that manner, the LLSS offers the advantage of being able to assess the level of skills acquired while highlighting important safety points during training program of WRAS and LLS procedures. Moreover, the LLSS emphasizes the need to become familiar with liver mobilization and parenchymal transection techniques, along with specific devices. Indeed, the proposed rating scale may be enabled to shorten the LC of young surgeons and could also be used as an operative roadmap reducing the number of adverse events in the operating room.

The advantages of the Delphi method in order to obtain consensus among experts are well described: the anonymous nature of the process prevents a dominant member of the group from influencing the group's opinion. Furthermore, the questionnaire was completed by email and did not require for the experts to physically meet. As used in the present study, Von der Gracht et al. suggested that a RoA was an appropriate measure of consensus particularly when Likert scales were used [38]. Moreover, a two-round Delphi was conducted in order to limit the number of non-responders and to avoid forced consensus [39]. In this study, the notable limitations of the Delphi method include the fact that the selection of questions submitted to the experts were in part controlled by the Delphi facilitators and that interest of experts could diminish with consecutive rounds. Another concern of the present work is the limited number of experts who participated in the Delphi survey, that could impair the reproducibility of the study. Among the 15 international invited experts, only five agreed to participate and most of them came from French institutions. However, laparoscopy has become the standard surgical approach for WRAS and LLS, and laparoscopic LLS is a standardized step-by-step procedure. Hence, there could be a worldwide acceptance of the present LLSS. Furthermore, the usability, feasibility, and validity of this assessment scale still needs to be studied through a dedicated LLR training program. Validation of the LLSS should include comparison between experts and novices in laparoscopic liver surgery (construct validity) and comparison between operative outcomes and obtained scores in order to assess its educational value.

Recently, specific assessment tools for training in advanced laparoscopic surgeries have recently been developed [22–27] and have the advantages of identifying specific areas of the procedure that require improvement. The very

Table 1 After the semi-structured review, 15 essential subtasks for full laparoscopic wedge resection of the anterior segments and left lateral sectionectomy were extracted for evaluation in the Delphi survey

Score	1	2	3
1. Preoperative checklist and patient positioning	Unable to complete entire checklist, lack of checking surgical devices, pneumoperitoneum insufflator and energy sources, improper patient positioning	Able to complete entire checklist and to position the patient correctly with moderate prompting	Able to complete entire checklist, well positioning of surgical devices, pneumoperitoneum insufflator and energy sources, correct patient positioning in the reverse Trendelenburg position
2. Port positioning for wedge resection and left lateral sectionectomy	Improper port positioning that could lead to major conflict between devices or with the camera port, poor exposure of the operating field, need to replace one or more trocars	Able to position port correctly with moderate prompting	Able to position port properly without conflict between trocars and allowing a good exposure of the operating field
3. Operative aid positioning and exposition	Constantly changing focus of operation, overshooting target, poor coordination between hands, slow to correct	Use of both hands, some overshooting or missing plane but corrects quickly	Confident, efficient and safe conduct of operation, expertly uses both hands in a complementary manner to provide optimal working exposure
4. Autonomy	Unable to complete entire procedure, even in a straightforward case and with extensive verbal guidance	Able to complete operation safely with moderate prompting	Able to complete operation independently without prompting
5. Use of laparoscopic devices	Rough, tears tissue by excessive traction, injures liver parenchyma, poor control of coagulation and transection devices, grasper frequently slips off	Handles tissues reasonably well, with some minor trauma to liver parenchyma, coagulation of liver causes unnecessary liver bleeding, occasional slipping of grasper	Handles tissues very well with appropriate traction, uses energy sources and transection devices appropriately but not excessively
6. Pringle maneuver	Unable to complete Pringle maneuver, hepatic pedicle, inferior vena cava or adjacent organs injuries	Able to complete Pringle maneuver needing several tentative and without surrounding structures injuries	Able to use both hands in a complementary manner to provide optimal, safe and efficient Pringle maneuver, search for a left hepatic artery
7. Wedge resection of anterior segment	Excessive traction, poor coordination between hands and poor control of coagulation device leading to major hepatic parenchyma injury or liver bleeding with the need for open conversion	Non-optimized exposure of the operating field or non-selective division of intraparenchymal vessels, leading to minor hepatic parenchyma injury or liver bleeding	Very good exposure of the operating field with appropriate traction on tissues using both hands, selective division of intraparenchymal vessels, able to complete operation independently without adverse event
Operative time (min): Blood loss (mL):		Conversion: Yes/No	
8. Left lateral liver mobilization	Incomplete left lateral liver mobilization in difficult condition leading to major trauma of the liver parenchyma, the left diaphragmatic vein, left hepatic veins or to open conversion	Able to complete entire left lateral liver mobilization with moderate prompting or handles tissues leading to minor trauma of the hepatic parenchyma	Able to complete entire left lateral liver mobilization safely without verbal guidance
9. Parenchymal transection	Incomplete parenchymal transection, major trauma of the liver parenchyma leading to uncontrolled hemorrhage and to open conversion	Able to complete entire parenchymal transection with verbal guidance to improve exposure, or to control hemorrhage and biliary leakage due to a non-selective division of intraparenchymal vessels	Adequate exposure of the parenchymal transection plane throughout the whole procedure, selective division of intraparenchymal vessels, minimal bleeding

Table 1 (continued)

Score	1	2	3
10. Portal pedicle dissection of segments 3 and 2	Pedicle dissection failure with major vessel injuries leading to uncontrolled hemorrhage and to open conversion	Able to complete elective pedicle dissection with verbal guidance, minor vessel injuries leading to controlled bleeding	Efficient and safe pedicle dissection without prompting and vessel injury
11. End of procedure, left hepatic vein dissection	Dissection failure without clear identification of the left hepatic vein leading to major trauma, uncontrolled hemorrhage and to open conversion	Able to complete elective left hepatic vein dissection with verbal guidance, minor trauma of the vein leading to controlled bleeding	Efficient and safe left hepatic vein dissection without prompting and venous injury
Operative time (min): Blood loss (mL):		Conversion: Yes/No	
12. Intraoperative bleeding management	Improper exposure, forgetting to communicate, poor control of coagulation devices and fails to use pedicle clamping leading to uncontrolled hemorrhage and to open conversion	Able to complete control of bleeding with verbal guidance and prompting	Well exposure of the operating field, operative team information, confident, efficient and safe control of bleeding using pedicle clamping, coagulation devices and selective suturing
13. Intraoperative biliary leakage management	Forgot to check the parenchymal transection, lack of specific treatment, no abdominal drainage	Examination of the parenchymal transection, able to complete control of biliary leakage with verbal guidance and prompting	careful examination of the parenchymal transection, well identification of biliary leakage and selective suturing, abdominal drainage
14. Management of open conversion	Disordered, restless and unsafe open conversion with an uninformed operative team and uncontrolled bleeding	Open conversion after bleeding control requiring verbal guidance and prompting to restore confidence of the operative team	Efficient, calm and safe open conversion after operative time information and control of bleeding using primary technics as pedicle clamping and parenchymal transection packing
15. Parenchymal transection plan assessment	Fails to check the parenchymal transection, irregular parenchymal transection with significant persistent bleeding, or biliary leakage	Examination of the parenchymal transection, verbal guidance required, irregular parenchymal transection without bleeding, or biliary leakage	careful examination of the parenchymal transection, regular and linear parenchymal transection without bleeding and biliary leakage

Table 2 Results of the Delphi 1st round on the list of surgical steps generated by the hierarchical task analysis

Subtask	Mean (± SD)	RoA (%)
1. Preoperative checklist and patient positioning	3.8 (± 0.8)	60
2. Port positioning for wedge resection and left lateral sectionectomy	4.4 (± 0.9)	80
3. Operative aid positioning and exposition	4.2 (± 0.8)	80
4. Autonomy	4.6 (± 0.5)	100
5. Use of laparoscopic devices	4.6 (± 0.9)	80
6. Pringle maneuver	4.8 (± 0.4)	100
7. Wedge resection of anterior segment	3.8 (± 0.3)	60
8. Left lateral liver mobilization	4.6 (± 0.9)	80
9. Parenchymal transection	4.4 (± 0.5)	100
10. Portal pedicle dissection of segment 3 and 2	4.8 (± 0.4)	100
11. End of procedure, left hepatic vein dissection	4.6 (± 0.5)	100
12. Intraoperative bleeding management	4.4 (± 0.9)	80
13. Intraoperative biliary leakage management	3.6 (± 1.5)	60
14. Management of open conversion	4.6 (± 0.5)	100
15. Parenchymal transection plan assessment	4.6 (± 0.5)	100
Do you think that three levels of assessment are enough?	4.6 (± 0.5)	100
Do you think the number of subtasks is adapted?	3.2 (± 1.1)	60
By subtask, do you think the description of the skill levels is appropriate?	4.4 (± 0.5)	100
Do you think that the proposed subtasks cover all the skills required to perform a wedge resection in an anterior segment and a left lateral sectionectomy?	2.6 (± 0.9)	20

SD standard deviation, *RoA* rate of agreement

detailed nature of these scales makes it an interesting tool for training purposes. However, specific assessment tools did not gain worldwide acceptance compared to the OSATS scale [40]. By identifying specific areas of the procedure that require improvement, these specific assessment tools and the present LLSS should facilitate constructive feedback and thus deliberate practice. It may also be used for research in surgical education.

The Southampton Guidelines presented clinical practice guidelines designed specifically to ensure the safety of LLR setting up [12]. Indeed, a progression in skill set and competency is required to safely perform LLR [16], whereas the number of complex resections in hepatobiliary surgery performed by surgeons at the end of their residency is estimated to be less than five procedures, predominantly by open surgery [41]. Furthermore, an international survey on minimally invasive training in registered standard hepatobiliary fellowship programs revealed that fellows performed on average nine LLR yearly, which is obviously far too less to meet today's high-quality practice standards [42]. Recently, Halls et al. showed that after 46 procedures, the outcomes of the "early adopters" (*i.e.,* surgeons who received laparoscopic training and developed their practice in the stage of technical "optimization" of LLR) were comparable to those achieved by the "pioneers" (*i.e.,* surgeons who developed their practice in the earliest stage) after 150 procedures in similar cases [43]. As such, the LC in LLS could be dramatically reduced with both a specific training and an increased exposure of trainees to LLS. The Southampton consensus guidelines recommend fellowships in high-volume centers, proctored programs and courses to facilitate training [12].

The number of procedures required to gain competency in minor LLR ranged from 15 to 64 cases [16, 44, 45] through literature. This heterogeneity can be attributed to three factors that differed from one study to another: (a) the procedure itself (the LC of now standardized procedures, such as LLS seem shorter than that of a wedge resection or segmentectomy), (b) the main endpoint used to define LC, and (c) the surgeons' experience, with surgeons who did or did not receive laparoscopic training and developed their practice in the stage of technical optimization of LLR. For the specific concern of LLS, Ratti et al. collected a total of 245 LLSs performed across four centers by experienced surgeons [46]. In this study, the operative time was chosen as the marker of LC and the cut-off point for LC was determined after 15 LLSs. The present LLSS is a specific assessment tool and has the advantage of identifying specific critical points of safety of WRAS and LLS (scored from 1 to 3 points), that should be achieved by trainees in a dedicated training program to be considered competent before performing it in the operating room. Indeed, trainees could be "ready to perform independently" WRAS or LLS when they obtain a maximal score (*i.e.*, all tasks were scored 3 points); "ready to perform

Table 3 Results of the Delphi 2nd round on the list of revised surgical subtasks

Subtask	Mean (± SD)	RoA (%)
Step 1: preoperative setup and operative preparation		
1. Preoperative checklist and patient positioning	5.0 (±0.0)	100
2. Port positioning for wedge resection and left lateral sectionectomy	5.0 (±0.0)	100
3. Operative aid positioning and exposition	4.8 (±0.4)	100
4- Intraoperative fluence	5.0 (±0.0)	100
5- Use of laparoscopic devices	5.0 (±0.0)	100
6. Use of energy devices	4.8 (±0.4)	100
7. Pringle maneuver	4.8 (±0.4)	100
8. Intraoperative ultrasonography	4.4 (±0.5)	100
Step 2A: Wedge resection		
9. Exposure and parenchymal transection	4.8 (±0.4)	100
10. Tumoral margin and wedge removal	5.0 (±0.0)	100
Step 2B: Left lateral sectionectomy		
11. Left lateral liver mobilization	4.6 (±0.9)	80
12. Parenchymal transection	5.0 (±0.0)	100
13. Portal pedicle dissection of segment 3 and 2	4.8 (±0.4)	100
14. End of procedure, left hepatic vein dissection	5.0 (±0.0)	100
Step 3: Parenchymal transection plan assessment, intraoperative adverse event management and completion of procedure		
15. Parenchymal transection plan assessment	4.8 (±0.4)	100
16. Intraoperative bleeding management	4.6 (±0.9)	80
17. Intraoperative biliary leakage management	4.8 (±0.4)	100
18. Management of open conversion	5.0 (±0.0)	100
19. Liver specimen retrieval and port removal	4.8 (±0.4)	100
Do you think that three levels of assessment are enough?	4.6 (±0.5)	100
Do you think the number of subtasks is adapted?	4.6 (±0.5)	100
By subtask, do you think the description of the skill levels is appropriate?	4.8 (±0.4)	80
Do you think that the proposed items cover all the skills required to perform a wedge resection in an anterior segment and a left lateral sectionectomy?	4.8 (±0.4)	100

SD standard deviation, *RoA* rate of agreement

with supervision" when 1 to 4 tasks need guidance (*i.e.*, 1 to 4 tasks were scored 2 points); and "not ready to perform" on a real patient when more than 4 tasks were scored 2 points or when 1 task was scored 1 point. Forthcoming studies should assess the number of procedures needed in each category to achieve proficiency in a simulated setting. However, this number may depend on several factors, namely, the trainee him/herself and the simulation tool used.

Laparoscopy is now increasingly used for more complex liver resections [10, 12, 16, 37, 44]. Nevertheless, a shift in real LC compared with an ideal one shows that the increase in difficulty was attempted only after the initial LC was completed, highlighting that surgeons have a perception of their degree of training before performing more complex procedures [16, 44, 47]. The LLSS was developed to assess the level of skills acquired during training program of WRAS and LLS procedures, that represent the first steps of the LC [12]. However, such critical points as safety points, and the need to become familiar with liver mobilization and parenchymal transection techniques are emphasized by the LLSS, which can be extrapolated as an operative roadmap to other complex procedures.

Using training models to simulate complex laparoscopic liver procedures has been poorly studied so far [16]. The main training models used are the swine model and the human cadaver, including the Thiel model [16–19], which is probably the closest to reality. Swine are commonly used in training and offer tactile feedback, facilitating the acquisition of fundamental skills. More recently, the implementation of a perfused ex vivo swine liver training model has increased the fidelity of the animal model by simulating intrahepatic bleeding [18, 19]. However, the anatomy of swine liver differs from those of humans. Human cadavers have identical anatomical conditions as real patients and enable lifelike surgery. Their use as a laparoscopic training model has already been reported in several studies [48–50]. Of note, the main drawback of formalin-fixed cadavers is tissue rigidity. In contrast, Thiel bodies are soft and flexible and maintain their

Table 4 The Laparoscopic liver skills scale was finally created based on the 19 selected subtasks resulting from the Delphi 2nd round survey

Score	1	2	3
Step 1: preoperative setup and operative preparation			
1. Preoperative checklist and patient positioning	No team communication, Unable to complete entire checklist, lack of checking surgical devices, pneumoperitoneum insufflator and energy sources, improper patient positioning	Team communication, able to complete entire checklist and to position the patient correctly with moderate prompting	Team communication, able to complete entire checklist, well positioning of surgical devices, pneumoperitoneum insufflator and energy sources, correct patient positioning based on the anticipated type of resection
2. Port positioning for Wedge resection and Left Lateral Sectionectomy	Improper port positioning that could lead to major conflict between devices or with the camera port, poor exposure of the operating field, need to replace one or more trocars	Able to position port correctly with moderate prompting	Able to position port properly according to the anticipated type of resection, without conflict between trocars or with camera port, and allowing a good exposure of the operating field
3. Operative aid positioning and exposition	Lack of communication between operative aid and operator: constantly changing focus of operation, overshooting target, poor coordination between hands, slow to correct, cleaning of the camera not coordinated with the operator, leading to a constant change in exposure	Communication between operative aid and operator in order to improve the working exposure and the use of both hands, some overshooting or missing plane but corrected quickly	Confident, efficient and safe conduct of operation secondary to a close communication between operative aid and operator, expertly uses both hands in a complementary manner to provide optimal working exposure in the timing requested by the operator
4. Intraoperative fluency	Unable to complete at least one entire procedure, even in a straightforward case and with extensive verbal guidance	Able to complete the procedure safely with moderate prompting	Able to complete the procedure independently without guidance
5. Use of laparoscopic devices	Rough, tears tissue by excessive traction, injures liver parenchyma leading to major bleeding, grasper frequently slips off	Handles tissues reasonably well, with some minor trauma to liver parenchyma, occasional slipping of grasper	Handles tissues very well with appropriate traction without liver parenchyma trauma
6. Use of energy devices	Poor control of coagulation and transection devices leading to uncontrolled bleeding	Coagulation of liver causes unnecessary liver bleeding requiring additional hemostasis and increased parenchymal transection time	Uses energy sources and transection devices appropriately but not excessively leading to a safe progression in parenchymal transection plane
7. Pringle maneuver	Unable to complete Pringle maneuver, hepatic pedicle, inferior vena cava or adjacent organs injuries due to a too hasty maneuver	Able to complete Pringle maneuver needing several tentative and without surrounding structures injuries, requirement for guidance	Able to use both hands in a complementary manner or changing camera port to provide optimal, safe and efficient Pringle maneuver, search for a left hepatic artery
8. Intraoperative ultrasonography	Unable to identify all lesions located in the anterior segments and the left lobe, missing, error or confusion in the identification of the portal and suprahepatic vascular structures, lack in anticipating the parenchymal transection plan	Able to identify lesions located in the anterior segments and the left lobe as well as the portal and suprahepatic vascular structures, assessment of the proximity between lesions and vessels with prompting	Able to correctly identify lesions located in the anterior segments and the left lobe as well as the portal and suprahepatic vascular structures, high level of accuracy in assessing the proximity between lesions and vessels, anticipation of the parenchymal transection plan and vascular structures encountered without guidance

Table 4 (continued)

Score	1	2	3
Step 2A: wedge resection			
9. Exposure and parenchymal transection	Excessive traction, poor coordination between hands, and poor control of coagulation device leading to major hepatic parenchyma injury or liver bleeding with the need for open conversion	Non-optimized exposure of the operating field or non-selective division of intraparenchymal vessels, leading to minor hepatic parenchyma injury or liver bleeding	Very good exposure of the operating field with appropriate traction on tissues using both hands, selective division of intraparenchymal vessels
10. Tumoral margin and wedge removal	Hasty parenchymal transection resulting in positive margin due to wrong transection plan, inadequate in depth and laterally	Guidance required to go deep and lateral enough in order to avoid positive margin and complete the wedge removal	Able to go deep and lateral enough to avoid positive margin, complete the operation independently without adverse event
Operative time (min): Blood Loss (mL):		Conversion: Yes / No	
Step 2B: left lateral sectionectomy			
11. Left lateral liver mobilization	Incomplete left lateral liver mobilization leading to major trauma of the liver parenchyma, the left diaphragmatic vein, left hepatic veins, or need to open conversion	Able to complete entire left lateral liver mobilization with moderate prompting or handles tissues leading to minor trauma of the hepatic parenchyma	Able to complete entire left lateral liver mobilization safely and independently with controlled section of the left lateral ligament and the small omentum after identifying a left hepatic artery
12.Parenchymal transection	Incomplete or irregular parenchymal transection plan leading to major trauma of the liver parenchyma, uncontrolled hemorrhage, and need to open conversion	Able to complete entire parenchymal transection with verbal guidance to improve exposure, get a linear transection plan or to control hemorrhage due to a non-selective division of intraparenchymal vessels	Adequate exposure, regular parenchymal transection plan throughout the whole procedure, selective division of intraparenchymal vessels, minimal bleeding
13. Portal pedicle control of segments 3 and 2	Pedicle dissection failure with major vessel injuries leading to uncontrolled hemorrhage, bile in the field, and need to open conversion	Able to complete pedicle control with verbal guidance, minor vessel injuries leading to controlled bleeding	Efficient and safe pedicle control without prompting and vessel injury
14. Left hepatic vein control	Dissection failure without clear identification of the left hepatic vein leading to major trauma, uncontrolled hemorrhage, and need to open conversion	Able to complete elective left hepatic vein control with verbal guidance, minor trauma of the vein leading to controlled bleeding	Efficient and safe left hepatic vein control without prompting and venous injury
Operative time (min): Blood Loss (mL):		Conversion: Yes / No	
Step 3: Parenchymal transection plan assessment, intraoperative adverse event management and completion of procedure			
15. Parenchymal transection plan assessment	Fails to check the parenchymal transection, error or confusion in the parenchymal transection without use of intraoperative ultrasonography leading to false parenchymal transection plan	Examination of the parenchymal transection, irregular parenchymal transection, use of intraoperative ultrasonography with prompting to adjust parenchymal transection plan	Careful examination of the parenchymal transection, use of intraoperative ultrasonography without guidance leading to a regular and linear parenchymal transection plan

Table 4 (continued)

Score	1	2	3
16. Intraoperative bleeding management	Fails to check, improper exposure, forgetting to communicate about the risk of gas embolism, excessive use of suction, poor control of coagulation devices and fails to use pedicle clamping or hemostatic gauze leading to uncontrolled hemorrhage and need to open conversion	Examination of the parenchymal transection, able to complete control of bleeding with verbal guidance and prompting to use correctly suction, coagulation devices, hemostatic gauze and pedicle clamping	Careful examination of the parenchymal transection to identify bleeding, well exposure of the operating field, operative team communication about active bleeding and the risk of gas embolism, confident, efficient and safe control of bleeding using adequate suction, coagulation devices, hemostatic gauze, pedicle clamping, and selective suturing
17. Intraoperative biliary leakage management	Forgot to check the parenchymal transection, lack of specific treatment, missing abdominal drainage whenever necessary	Examination of the parenchymal transection, able to complete control of biliary leakage with verbal guidance and prompting	Careful examination of the parenchymal transection to identify biliary leakage, confident and selective suturing, abdominal drainage whenever necessary
18. Management of open conversion	Disordered, restless and unsafe open conversion with an uninformed operative team and uncontrolled bleeding	Open conversion after bleeding control requiring verbal guidance and prompting to restore confidence of the operative team	Efficient, calm and safe open conversion after operative time information and control of bleeding using primary technics as pedicle clamping and parenchymal transection packing
19. Liver specimen retrieval and port removal	Forgot to retrieve specimen	Specimen retrieval, remove trocars without port sites inspection for hemostasis, no evacuation of pneumoperitoneum gas, forgot to suture fascia for trocars $\geq$ 10 mm	Specimen retrieval, remove trocars under direct visualization and inspect port sites for hemostasis, evacuation of pneumoperitoneum gas, suture fascia for trocars $\geq$ 10 mm, close skin incision

natural color. These corpses remain more similar to in vivo conditions without releasing harmful substances into the environment [49–53]. Furthermore, vascular perfusion of Thiel-embalmed cadaveric tissues with colored solutions for endovascular procedures and flap raising education has been described [54, 55]. Recently, Rashidian et al. [17]] showed that Thiel bodies were considered significantly superior to pig models and even more useful than training under proctorship in the operating room. Unfortunately, in most of these studies, only the participants' feedback was analyzed, and the overall methodological quality was poor. Nevertheless, these studies showed encouraging results in terms of teaching technical skills and educational value. The LLSS has the advantage of being able to assess skills acquisition regardless of the teaching model used. Furthermore, this scale can also be used as an assessment tool in the operating room, on real patients.

Conclusion

An assessment scale in laparoscopic liver surgery, the LLSS, was developed for the first time, using the Delphi methodology. Its validity will be assessed through a dedicated LLR training program.

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Declarations

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