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ORIGINAL ARTICLE – HEPATOBILIARY TUMORS

Theory of Relativity for Posterosuperior Segments of the Liver

G. Fiorentini, MD, F. Ratti, MD, F. Cipriani, MD, L. Cinelli, MD, M. Catena, MD, PhD, M. Paganelli, MD, and L. Aldrighetti, MD, PhD

Hepatobiliary Surgery Division, IRCCS San Raffaele Hospital, Milan, Italy

ABSTRACT

Background. The accessibility to posterosuperior segments of the liver has traditionally constituted a restrain to adopt the laparoscopic approach in this setting. To overcome this challenge, multiple approaches have been reported in literature. Total transabdominal approach has been previously described for this purpose, even though the rationale to standardly adopt it and a technical depiction of *how* to achieve an optimal mobilization has never been specifically addressed.

Methods. Total transabdominal purely laparoscopic approach to posterosuperior segments of the liver is presented, with detailed emphasis to the rotational motions targeted in laparoscopy. A literature review is presented to summarize all other possible accesses to posterosuperior area of the liver. The institutional series for the laparoscopic approach to Sg 7, Sg 6+7, and Sg8 is retrospectively described.

Results. Three rotational motions of the liver are specifically addressed in a video presentation and described for the laparoscopic total-transabdominal approach; the local institutional series using this approach is presented. Other miscellaneous approaches identified from literature encompassing variations in operative position, transabdominal, transthoracic, and combined approaches are described.

Conclusions. Complete mobilization of the ligaments of the liver leads to a rotation of the transection line in front of the operator's view, allowing to achieve a safe total transabdominal laparoscopic approach to the posterosuperior ligaments of the liver, without compromising the vascular inflow control, the possibility to convert to open approach, nor requiring potentially harmful decubitus.

Technical feasibility, clinical benefits, and oncological adequacy of laparoscopic liver resection have been documented with high level of evidence in recent years. Initially developing the approach to the "laparoscopic" segments (2, 3, 4b, 5), the wide-spreading to "nonlaparoscopic" segments (4a, 7, 8) has been quick.

The approaches to posterosuperior (Segment 7) and superior segments (4a and 8) have been multiple and variegates, seeing different patient positioning and operative set-up, increasing potentially unfavourable variables related to lack of standardization.[1–23] Potentially, surgeons dealing with posterosuperior segments find themselves having to operate in uncomfortable or unusual settings, such as lateral or semiprone decubitus, with lack of an easy inflow control and an incomplete domain of all the sectors of the liver. Furthermore, the use of intercostal ports might be harbinger of increased morbidity.

Throughout the development and improvements of technique and technology,[24] total transabdominal approaches have been proposed, without sacrificing the supine position, therefore, maintaining access to the hepatic pedicle and avoiding the use of transthoracic ports. For this purpose, it is necessary to perform a complete rotation of the liver in laparoscopy to move the target area to a favorable anterior position, more suitable for resection.

The present work has been conceived with the goal of showing in an analytic, step-by-step fashion the rotational motions of the liver in laparoscopy, a topic still poorly tackled in literature, for a total transabdominal approach without any intercostal ports. An educational video is presented with this purpose, and a review of the recent literature has been conducted.

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G. Fiorentini, MD
e-mail: fiorentini.guido@hsr.it

METHODS

Case Description

Two cases of single metastatic lesions in Segment 7 are shown to introduce the topic of rotational motions of the liver. In the first, a laparoscopic sub-segmentectomy of segment 7 for a superficial lesion is planned to describe the "up to down" and the "counterclockwise" mobilizations.

In the second case, a deeper lesion in Sg 7 is approached, requiring further mobilization through the "flipping over rotation"; the presence of accessory right inferior hepatic veins from Sg6 allow its sparing, taking Sg7 and harvesting the right hepatic vein at the hepatocaval confluence.

Operative Setup

The operative setup is shown, and the surgical technique is described. (See video, Supplemental Digital Content 1, "Theory of relativity for posterosuperior segments of the liver.")

The patient is placed in a "modified" French position (Fig. 1). Both inferior and superior limbs are abducted; slight flexion of ankles and knees confers more stability in case of extreme tilting. During surgery, the operative table is tilted to the left, and reverse Trendelenburg is achieved. Trocars position: a standardized set up of five 12-mm trocars adopted for any kind of liver resection is shown. No intercostal ports are ever used.

The first Hasson cannula is placed on the right midclavicular line along a line parallel and above the transverse umbilical line; thus, the camera will always result in line with the inferior vena cava. Four more operative ports are inserted under direct vision: two on the same transverse line, on each side of the first trocar, becoming the first operator's accesses. Two additional ports in epigastric region and in left hypochondrium allow the second operator to assist by using both hands.

Mobilization of the Liver

Particular emphasis is given to the mobilization of the liver, being a flagship for the feasibility of this approach. The final goal of an adequate liver mobilization is "commuting" a posterosuperior segment (Sg7) into an anteroinferior position. For this purpose, two rotational motions are described.

1. Up-to-down mobilization (Fig. 2): the round ligament together with the falciform, the right triangular, and the superior coronary ligaments, which physiologically keep the liver in place and counteract its craniocaudal rotation, are sectioned.
2. Counterclockwise mobilization (Fig. 3): the inferior coronary ligament along the peritoneal reflection opposes to the counterclockwise mobilization of the

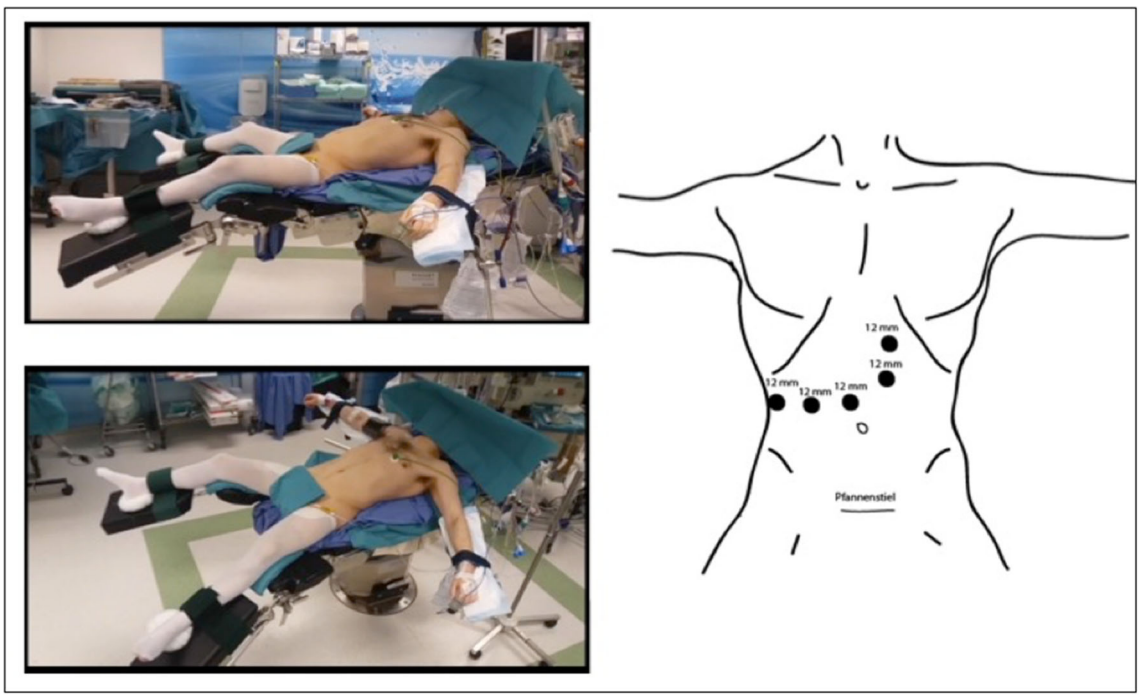

FIG. 1 Operative setup

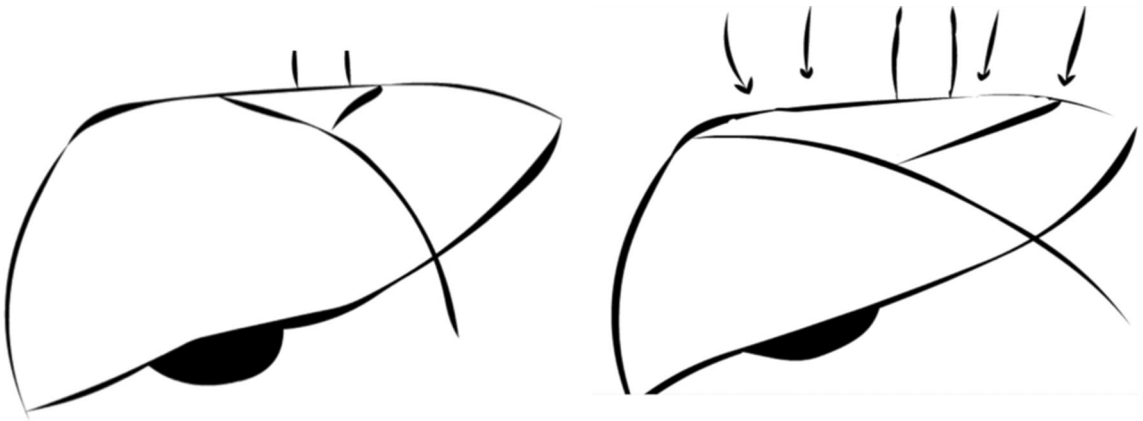

FIG. 2 Up-to-down rotational motion of the liver

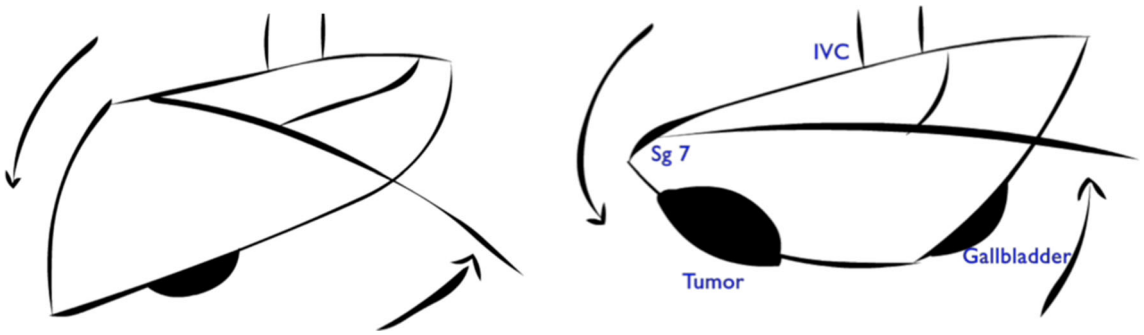

FIG. 3 Counterclockwise mobilization and rotation

liver. A full exposition of the bare area of the liver associated to the previous maneuvers allow a satisfactory exposure of Segment 7 area, achieving a comfortable angle of work for the straight laparoscopic instruments.

The final result is a tension-free totally rotated right hemi-liver, without need for a permanent retraction by the assistant. Therefore, both the operators will be able to use all their four hands for the resective phase at the same time.

Another maneuver is represented by the flipping-over rotation of the liver: once the right hemiliver is completely mobilized, a lifting rotational motion around the longitudinal axis of the inferior vena cava (IVC) is used to expose the posterosuperior area of the liver. Usually this motion is more pronounced during open surgery, whereas the posterosuperior area of the liver becomes partially "extracted" from the abdomen (Fig. 4). Similarly, in laparoscopy this maneuver can be reproduced for lesions which are deeper in the liver parenchyma of Sg7, although it is less pronounced in comparison with open surgery.

Parenchymal Transection

Once inflow control is achieved through an extra-corporeal Pringle maneuver, which is used for intermittent pedicle clamping, the resective time begins. An energy device based on ultrasonic and radiofrequency energies, and an ultrasonic aspirator for parenchymal fragmentation, are used for the transection. Vascular structures are sealed by wet bipolar forceps or clips, according to dimension. At the end of transection, the specimen is extracted through a retrieval bag; haemostasis and biliostasis are optimized and verified, and the liver is returned to its anatomic position. In accordance to the local ERAS protocol, an abdominal drain is left in place when liver resection is performed in areas not easily accessible by an eventual subsequent percutaneous drainage.

Institutional Experience

The local series at San Raffaele hospital of laparoscopic approach to Sg 7, Sg 6+7, and Sg8 resection is analytically described since the introduction of minimally invasive program in 2005.

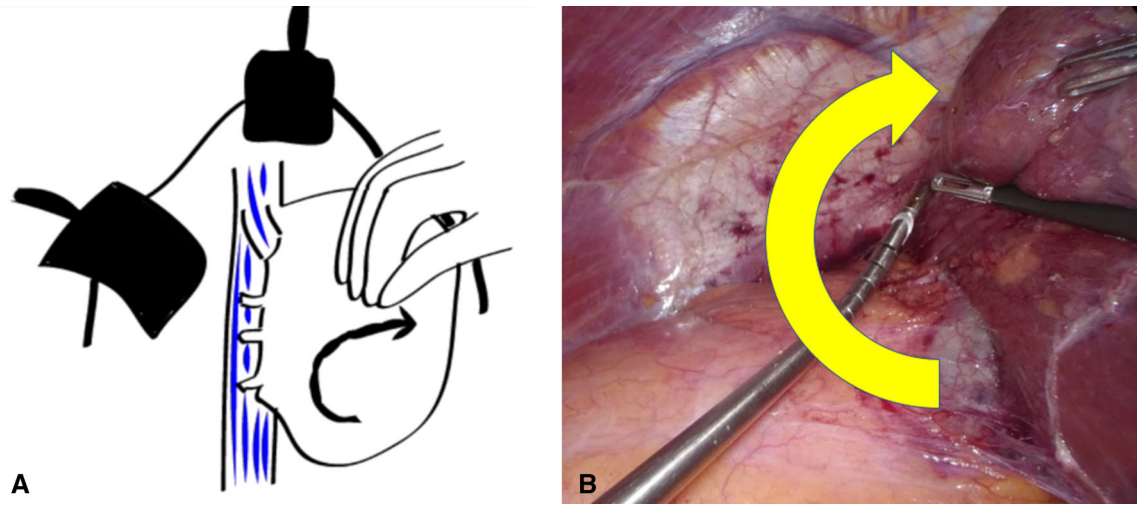

FIG. 4 Flipping-over rotation of the right hemiliver in open surgery (**a**) and a laparoscopic procedure (**b**)

RESULTS

San Raffaele Hospital Experience

Since the introduction of minimally invasive liver resection program at San Raffaele hospital in 2005, 59, 26, and 78 laparoscopic resections of Sg 7, Sg 6+7, and Sg8 cases have been performed. Demographic characteristics and clinicopathological outcomes are reported in Table 1. Median OR time was 190, 210, and 200 min for Sg 7, Sg 6+7, and Sg8, respectively; EBL was 250, 300, and 300 mL; postoperative complications were 16.9%, 15.4%, and 16.7%; median length of stay was 5, 6, and 6 days. Conversion to open occurred in 10.2%, 11.5%, and 10.3% of cases.

DISCUSSION

A step-by-step guide to the complete liver mobilization for a total transabdominal laparoscopic approach to the posterosuperior area of the liver has been presented. The two cases shown in the video are representative of the stepwise approach to more and more difficult locations, reflecting the increasing level of difficulty encountered in the climbing of the learning curve. While more superficial resections, requiring sub-segmentectomy of Sg7, can be achieved through the first two rotational motions only, an adjunctive rotation is required to complete Sg 7 and to approach the right hepatic vein.

The application of laparoscopy to minimally invasive treatment of the liver has quickly spread from the so called "laparoscopic" segments (2, 3, 4b, 5) to "nonlaparoscopic" segments (4a, 7, 8). Nevertheless, the approach to posterosuperior segments of the liver presents challenges in terms of exposition and the use of laparoscopic straight instruments, putting these procedures to the highest level of the difficulty score according to Ban et al.[25] Since then, many different approaches have been depicted through years, encompassing transthoracic access, retroperitoneal, transabdominal with adjunctive thoracic ports, or totally transabdominal with liver mobilization, using pure laparoscopic, hand-assisted, or hybrid techniques. An analysis of the recent literature on this topic identified 23 studies, which encompassed case reports, single-institution, and multicentric case series (Table 2), performing minimally invasive, monosegmentectomies on superior and posterosuperior segments (Sg 4a, 6, 7, 8), bisegmetectomies (Sg 5+8, 6+7), or trisegmentectomies (5+6+7).

Manifolds positions were adopted for laparoscopic approach: left-lateral decubitus (5 studies), left-lateral jackknife (1 study), left semilateral (8 studies), Lloyd-Davies (1 study), lithotomy (5 studies), supine with or without right-side elevation (5 study), semiprone (2 studies).

Techniques of choice primarily consisted of pure laparoscopy in 20 studies, laparoscopy-assisted liver mobilization only (hybrid, 2 studies), and hand-assisted (2 studies). The approaches were totally transabdominal (without any transthoracic ports, 10 studies), transabdominal with adjuvant transthoracic ports (9 studies). Three studies illustrated a complete transthoracic approach, and one study showed a retroperitoneal approach.

Whereas adjunctive intercostal ports were placed, between one and three ports had been used. An inflow control of some type is described in 14 studies. Among the eight studies where a Pringle maneuver was not used, in six studies of them the patient was in a partial or complete lateral decubitus, whereas in another study the patient was

TABLE 1 Demographic characteristics and clinicopathological outcomes of patients operated at San Raffaele Hospital for resections of Sg7, Sg6+7, and Sg8

	Sg7 (n = 59)	Sg 6+7 (n = 26)	Sg8 (n = 78)
Demographic characteristics			
Male, n (%)	27 (45.8)	14 (53.8)	39 (50)
Age, median (IQR), year	63 (37–81)	61 (44–79)	64 (28–85)
BMI, median (IQR), kg/m^2	23.5 (19.9–25.9)	24.1 (20.7–27.2)	23.6 (19.8–28.3)
ASA score, n (%)			
1	7 (11.9)	4 (15.4)	6 (7.7)
2	36 (61.0)	16 (61.5)	45 (57.7)
3	16 (27.1)	6 (23.1)	26 (33.3)
4	0 (0)	0 (0)	1 (1.3)
Child A cirrhosis, n (%)	12 (20.3)	3 (11.5)	19 (24.4)
Tumor type, n (%)			
Malignant	51 (86.4)	21 (80.8)	65 (83.3)
HCC	23 (39.0)	8 (30.8)	26 (33.3)
CRC	18 (30.5)	7 (26.9)	25 (32.1)
ICC	10 (16.9)	6 (23.1)	14 (17.9)
Benign	8 (13.6)	5 (19.2)	13 (16.7)
Clinicopathological outcomes			
N. lesions, median (IQR)	1 (1–3)	1 (1–3)	1 (1–2)
Largest tumor size, median (IQR), cm	41 (22–140)	50 (41–178)	39 (23–78)
R0 resection, n (%)	58 (98.3)	25 (96.2)	76 (97.4)
OR time min, median (IQR)	190 (165–245)	210 (188–310)	200 (155–290)
Conversion to open, n (%)	6 (10.2)	3 (11.5)	8 (10.3)
EBL mL, median (IQR)	250 (50–800)	300 (100–1000)	300 (50–1000)
Pringle maneuver, n (%)	58 (98.3)	25 (96.2)	78 (100)
Transfusion rate, n (%)	7 (11.9)	3 (11.5)	9 (11.5)
ICU stay, n (%)	1 (1.7)	1 (3.8)	1 (1.3)
Post operative morbidity, n (%)	10 (16.9)	4 (15.4)	13 (16.7)
Clavien Dindo II–III	8 (13.6)	3 (11.5)	9 (11.5)
Clavien Dindo IV–V	2 (3.4)	1 (3.8)	4 (5.1)
Liver specific complicances			
Bile leakage	4 (6.8)	2 (7.7)	5 (6.4)
Ascitis	5 (8.5)	3 (11.5)	4 (5.1)
Transient partial liver failure	4 (6.8)	2 (7.7)	4 (5.1)
LOS day, median (IQR)	5 (3–7)	6 (4–8)	6 (4–12)
30-day mortality	0 (0)	0 (0)	0 (0)
90-day mortality	0 (0)	0 (0)	1 (1.3)

placed in semiprone position, likely expression of how an inflow control was more difficultly achieved in these positions.

This multitude of possible approaches has been associated to multiple variations on the theme, focusing the discussion mainly on which operative position should be adopted and how many intercostal ports should be used. It is worthy to discuss singularly the possible limitations of these added variables.

Adopting different patient positioning reflects the idea of changing the operative approach to the liver. Although even if the left-lateral or the prone decubitus offer a front view of the target site, it can be identified pre- and intra-operative disadvantages. Actually, left lateral decubitus positioning requires particular carefulness to avoid nervous injuries of the brachial plexus, as the right superior limb comes fixed over the head, doubly flexed at shoulder and elbow, and might be subject to incidental displacement during table tilting, with possible damage. Intraoperatively,

TABLE 2 Review of the recent literature on the minimally invasive approach to posterosuperior liver segments

Author	Year	Single/multicentric	# of cases	Position	Region of the liver[a]	Approach	Transthoracic ports	Pringle	OR time (min)[b]	EBL (mL)[b]	LOS[b]
Aikawa M. et al.	2014	Single institution	1	Left lateral decubitus	8	Total trans-thoracic	3	No			
Chen J. et al.	2017	Single institution	10	Left lateral jack-knife	6, 7, 8	Trans abdominal + trans thoracic	1	No	166 ± 38	220 ± 135	4 (2–7)
Cheng K.C. et al.	2011	Single institution	1	Lloyd-Davies	7	Total trans-abdominal	0	No	510	800	6
Young Cho J. et al.	2009	Single institution	7	Supine or semi-lateral decubitus	6+7	Total trans-abdominal	0	No	423 ± 121	600 ± 245	11 (5–38)
Coles S.R. et al.	2015	Single institution	20	Supine, right-side elevation	7; 6+7	Total trans-abdominal	0	Yes	252/271	400/625	4.6–6.9
D'Hondt M. et al.	2017	Single institution	30	Semi-prone	6, 7, 8; 5+8; 6+7; 5+6+7	Total trans-abdominal	NR	No	140	150 (30–1500)	6
Fuks D. et al.	2015	Single institution on a literature review	NR	Left lateral decubitus; semiprone	6, 7	Trans-thoracic; trans-abdominal; hybrid; hand-assisted	1–3	Yes	NR	NR	NR
Giuliani A. et al.	2017	Single institution	1	Right lateral decubitus (total situs inversus)	7	Total trans-abdominal	0	Yes	240	220	5
Giuliani A. et al.	2015	Multicentric	84	Left semi-lateral; semi-prone	6, 7, 8; 5+8; 6+7	Total trans-abdominal	0	Yes	204 ± 66	206.2 ± 164.6	4 (3–10)
Hu M. et al.	2011	Single institution	1	Left lateral decubitus	7	Retroperitoneal	0	No	120	150	9
Inoue Y et al.	2017	Single institution	91	Left semi-lateral decubitus	6, 7, 8	Trans-abdominal	2	Yes	192	70/100	10/11
Ishizawa et al.	2012	Single institution	31	Left lateral decubitus	6, 7, 8; 6+7	Trans-abdominal	2	Yes	90/390	50/1300	7 (4–25)
Yang J.Y. et al.	2017	Single institution	1	Lithotomy and left semi-lateral decubitus	8	Trans-abdominal	1	Yes	420	600	6
Jin H. et al.	2017	Single institution	19	Lithotomy and left semi-lateral decubitus	6+7	Trans-abdominal; hybrid	0	Yes	254 ± 79	477 ± 756	7.5 ± 2.7
Kruger J.A.P. et al.	2014	Single institution	1	Left semi-lateral decubitus	8	Trans-abdominal	2	No	75	20	2

TABLE 2 continued

Author	Year	Single/multicentric	# of cases	Position	Region of the liver[a]	Approach	Transthoracic ports	Pringle	OR time (min)[b]	EBL (mL)[b]	LOS[b]
Lee W et al. (150–14.300) 8.5	2016	Single institution	75	Lithotomy	6, 7, 8	Trans-abdominal	1	Yes	358	(160–930)	550
Lee W et al.	2014	Single institution	5	Lithotomy	7, 8	Trans-abdominal	2	Yes	197 ± 68	161 ± 138	7 ± 3.5
Machado M.A.C. et al. 5 (3–8)	2008	Single institution	3	Left semi-lateral	6+7	Total trans-abdominal	0	No	460	(300–630)	NR
Machado M.A.C. et al.	2011	Single institution	1	Left semi-lateral	7+8	Total trans-abdominal	0	Yes	240	NR	5
Martínez-Cecilia D. et al.	2017	Single institution	30	Supine	6, 7, 8	Total trans-abdominal	0	Yes	200/210	250/191	4 (3–7)
Okuno M et al.	2017	Single institution	29	NR	4a, 7, 8	Trans-abdominal, hand-assisted	1	NR	217 (62–586)	100 (10–800)	4 (1–12)
Scuderi V. et al.	2017	Multicentric	76	Supine or lithotomy	4a, 7, 8	Trans-abdominal	1 or 2	Yes	200 (0–2000)	215 (52–540)	4 (1–11)
Xiao L et al.	2015	Single institution	40	Supine	4a, 7, 8	Total trans-abdominal	0	Yes	242 ± 74	272 ± 170	9.4 ± 2.7

NR not reported

[a]Region of the liver are expressed as mono-segmentectomy (e.g., 7), bi-segmentectomy (e.g., 6+7) or trisegmentectomy (e.g., 5+6+7)

[b]Results are reported as mean ± SD, median (IQR), or compared ranges within the same study

the whole liver becomes less visible both in its entirety and by ultrasound assessment. The hepatic pedicle becomes itself less accessible due to lateral positioning, resulting in a missing inflow control, with potential impairment of the safety level in laparoscopy. Furthermore, in presence of multiple aloof lesions, elsewhere in the liver, for instance on the left lateral sector, complete clearance of the liver may result challenging with patient placed on a lateral decubitus. Currently, the minimally invasive approach to the liver is widespread even for multiple liver metastases, with better short-term outcomes proved. Therefore, the need for treating bilobar disease is becoming more frequent.

The second topic is about the use of intercostal ports to access the abdominal cavity, in a combined transthoracic-assisted abdominal laparoscopy. Concerns regarding not just the access itself can be raised, for the possible onset of intercostal bleeding and increased pain for injury to the subcostal neurovascular bundle but also concerns which are liver-related, for the possible risk of developing pleural effusion (especially in the eventuality of cirrhotic livers) and the potential risk of a bilio-pleural fistula. The option of a thoracic port might be a good choice in selected cases, as for adhesions due to previous surgery of right liver or previous combined thoracic and hepatic procedures. Nevertheless, it requires advanced expertise and should therefore be discouraged for teams first approaching posterosuperior segments laparoscopically. In the end, the eventuality of a conversion to open would result in a suboptimal operative field with an incision on the flank during a lateral positioning.

The technique has evolved through the timeline of laparoscopic liver surgery.[26] Other authors have proposed transabdominal supine approaches. Among the studies evaluated, the two largest Western series are reported by Scuderi et al. and Coles et al.

Scuderi et al.[7] identified 170 laparoscopic cases from seven tertiary referral European hepatobiliary surgical units' databases. Among these, 124 were laparoscopic resections of segments 4a, 7, and 8. Seventy-six cases of those were propensity-score matched to open cases. Even though in this multicentric study still one or two intercostal trocars were adopted according to different cases and different centers, they concluded that laparoscopic liver surgery of tumours in posterosuperior segments were associated with fewer complications without compromising survival compared with open procedures.

Coles et al.[11] detain one of the largest single-center series of totally transabdominal pure laparoscopic resection of posterosuperior segments without using any transthoracic ports in a supine position, keeping access to the inflow control. In this series, authors presented 7 laparoscopic resections of Sg7 and 13 right-posterior sectionectomies (Sg 6+7), remarking on the safe feasibility of this approach.

Nevertheless, to our knowledge, a step-by-step description of the rotational motions of the liver is still lacking for educational purposes. Anatomic structures that counteract the three potential rotations of the liver have been described. The proper ligaments of liver, in particular, act limiting the up-to-down, the counterclockwise, and the flipping-over rotations of the liver. However, only the first two motions are required for the laparoscopic theory of relativity of the liver, whereas the flipping-over rotation is required only for deeper lesions.

Eventually, this mobilization is tension-free. Actually, if properly performed, the liver will keep the position itself, offering a favourable position during the transection, keeping both first operator and its assistant working at the same time with both hands.

This technique is suitable for approaching the superior segments (7, 8) to perform bisegmentectomy 6+7, trisegmentectomy 5+6+7, and as preliminary step for the laparoscopic right hepatectomy, when the classic approach is chosen. Therefore, the theory of relativity for liver segments contemplates posterosuperior area would be posterosuperior only in a relative way, so that Segment 7 could be commuted to a Segment 5, taking it to a more favourable condition for a laparoscopic liver resection.

CONCLUSIONS

For the minimally invasive approach of posterosuperior segment 7 of the liver, a total transabdominal mobilization allows its resection, without the use of any trans-thoracic ports nor the sacrifice of the required standard of safety for laparoscopic liver surgery.

AUTHORS' CONTRIBUTIONS LA, GF: conception and design; FC, FR, GF, LC: acquisition of data; FR: data analysis and interpretation; GF, FR: manuscript writing; LA, MP, MC: critical review for intellectual content; GF, FR, FC, LC, MC, MP, LA: final approval. All authors are accountable for all aspects of the work and ensure proper investigation and resolution on any question related to the accuracy or the integrity of the manuscript.

DISCLOSURES The material has not been previously published or submitted elsewhere for publication and will not be sent to another journal until a decision is made concerning publication. All listed authors have participated in the study and have approved the final manuscript. There is no personal conflicts of interest or financial disclosure for any of the authors. The present study is not based on any previous communication to a society or a meeting.

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