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The plow technique: An alternative method for the transection of liver parenchyma

Anatomical/embryological principles and electromedical rationale

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Background: Over the past 30 years, improvements in both technical skills and surgical equipment have been made to guarantee safe and effective liver parenchymal transection. In the present study, we propose a transection method, called "The Plow Technique" based on monopolar spray electrocoagulation in open hepatobiliary surgery.

Methods: We conducted histological analyses on a cadaveric human liver measuring the diameters of all vascular structures at increasing depths of liver parenchyma. Furthermore, we retrospectively analyzed the data of 60 consecutive patients who underwent major and minor liver resections at our Institution.

Results: The histological assessment of the distribution of vascular structures at different parenchymal depth points, failed to point out significant differences. Nevertheless, a trend toward an increased proportion of small caliber arterioles and centrilobular venules was found going from the Glissonian capsule to the deepest portion of liver parenchyma. All the hemorrhagic complications in our series were due to large caliber blood vessels spillage from the deeper parenchymal portions.

Conclusion: The Plow technique may represent a feasible and safe technique for adequate coagulation and sealing of small vessels of the first 3 cm of the anterior surface of the liver. Besides its safety and effectiveness, it may help in speeding up parenchymal transection.

Keywords: Electrosurgery; Liver embryogenesis; Liver surgery

Introduction

In liver surgery, a safe and effective parenchymal transection is of paramount importance to control intraoperative bleeding and bile leakage. Several studies have shown that intraoperative blood loss and need for transfusion (incidence 0.6%–8%)[1] are predictors of postoperative morbidity and mortality in liver surgery. Similarly, the development of a biliary fistula (incidence 0.5%-15.6%)[2] may still constitute a life-threatening complication in some cases.[3]

Over the past 30 years, improvements in both technical skills and surgical equipment have been made. As a matter of fact, the development of selective dissection tools like Cavitron Ultrasonic Surgical Aspirator (CUSA) and the jet cutter has allowed a safer dissection of vessels and transection of liver parenchyma. Among the "classical" and nonselective dissection methods that are still largely used, ultrasonic scalpel, scissors, high-frequency coagulation, laser technique, and staplers represent valid alternatives to the aforementioned selective dissection tools in experts hands.[4]

Considering liver embryogenesis and its anatomical constitution, it has been shown that both bile ducts and vessels of the first 3 cm of depth in the anterior surface of hepatic parenchyma starting from the Glisson capsule have a diameter smaller than 3 mm. We developed an easy, feasible, and effective transection method, called "The Plow Technique" using monopolar electrocautery during the initial transection of liver parenchyma in open hepatobiliary surgery. It is a safe and rapid way to initiate the transection of liver parenchyma and it may reduce the transection time without increasing the risk of bleeding and biliary leakage compared to ultrasonic surgical devices alone.[5–7]

In this study, we reviewed the embryological development of the liver and described the technique along with the anatomical evidence that supports its rationale and its efficacy, presenting our recent experience.

Methods

Principles of embryological development of the liver

Starting from the 22nd day of embryonic development, an endodermal thickening, called hepatic plate, grows in the ventral part of the duodenum and its cells proliferate, creating the hepatic

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The authors declare that they have no conflicts of interest with regard to the content of this report.

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diverticulum. It develops in the mesenchyme of the lower part of the septum transversum as hepatoblast cords, which will then differentiate into hepatocytes or biliary structures. During the growth of the hepatic diverticulum within the transverse septum, its connection with the cephalic portion of the primitive intestine narrows, to become the main bile duct. The gallbladder develops as a ventral outpouching of it, with the connection to the main bile duct persisting as the cystic duct. The gallbladder bud is solid during its early development and recanalizes later. Failure in recanalization results in extrahepatic biliary atresia.[8]

Liver stromal cells originate from the mesoderm of the septum transversum (Kupffer cells and fibroblasts), the mesoderm near the stomach, and endothelial cells, which give origin to sinusoids.

The mesenchyme that grows together with the ramifications of the portal vein creates the portal spaces, and the ramifications of the hepatic artery induce the formation of the biliary canaliculi. Biliary epithelial cells differentiate from hepatoblasts at the border with the mesenchyme of the portal spaces, forming the ductal plate after epithelial–mesenchymal interaction. The ductal plate consists of cells that duplicate and create cavitation, due to apoptosis, resulting in the ducts (Figure 1).

The maturation of the ductal plate occurs in a centrifugal direction, from the hilum to the periphery of the gland: this means, that during fetal life the hepatic hilum contains the most immature portal spaces in various stages. This observation could explain the presence of immature ectatic ducts in the central parenchyma and mature ducts smaller than 3 mm in the periphery.[9]

The development of biliary and arterial branches trace exactly the portal ones in the right hemiliver, whereas in the left hemiliver biliary and arterial structures divide into equal-size branches on both sides of the intrahepatic portion of the umbilical vein.[10–12]

Another venous plexus grows together with the rough liver, deriving from the right and left vitelline veins—located in the transverse septum—and generating the hepatic sinusoids. These vessels drain the yolk sac. Then, the vitelline veins form some anastomotic circles inside and outside the liver, organizing in a sort of vascular ring around the duodenum. Afterward, the yolk sac undergoes an involution, maintaining only the posterior vitelline veins and ring, from which the portal vein arises. The superior mesenteric vein originates from the remnant of the anterior group. The proximal portion of the vitelline veins

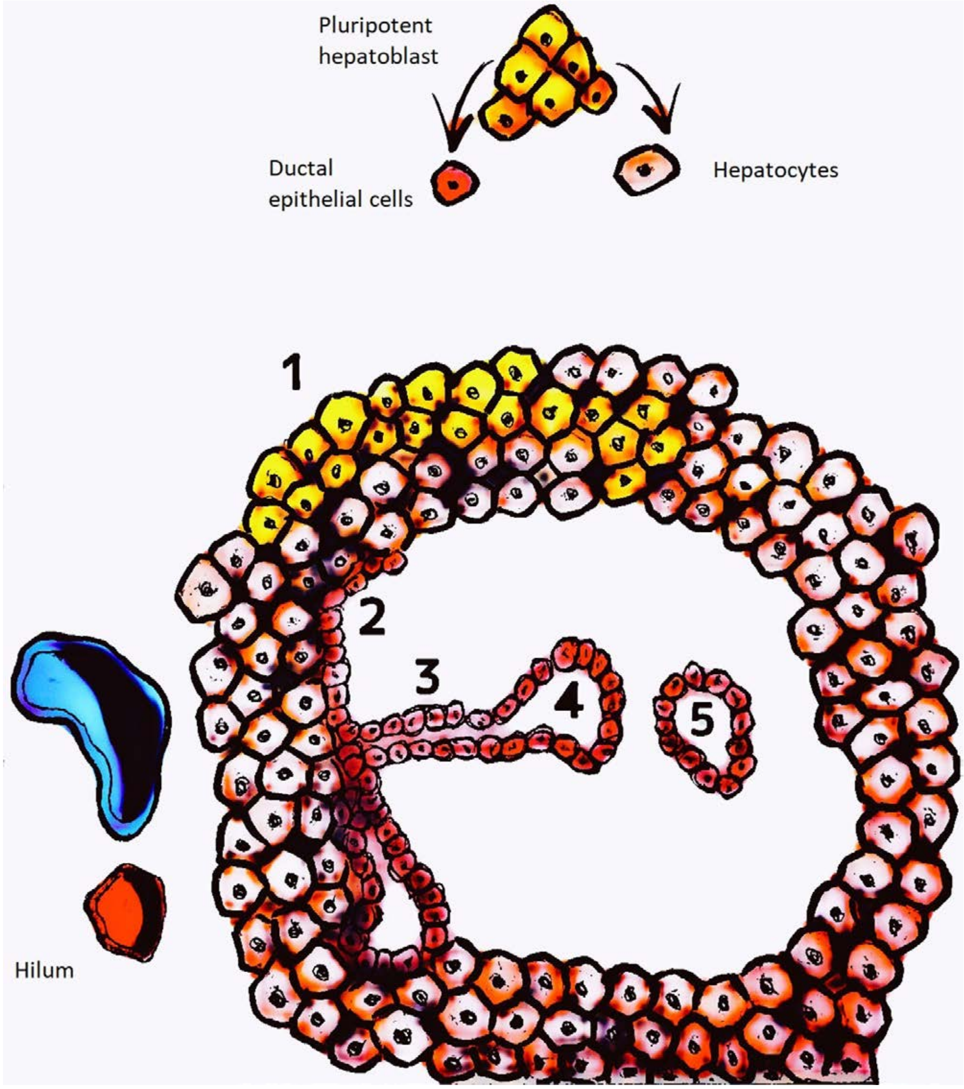

Figure 1. Development and remodeling of the ductal plate. Pluripotent hepatoblasts (1) differentiate in hepatocytes and ductal epithelial cells (2). The latter form a continuous layer at the edge of the portal space: the ductal plate, which duplicates itself (3). Appearance of the lumen (4). Development of the definitive biliary canaliculi by remodeling of the ductal plate: fragmentation by apoptosis and budding with central migration (5).

departing from the liver originates the hepatic veins. The sinusoids connect directly to the common cardinal veins, the right umbilical vein atrophies while the left umbilical vein remains to carry oxygenated blood from the placenta to the fetus. It ends into the sinus venosus, which separates from the sinusoids and directly supplies blood to the heart.[13–16]

Histological analysis

We performed a histological evaluation of the liver parenchyma examining healthy cadaveric specimens. An anteroposterior cut was conducted along S4, 2 cm from the falciform ligament and full-thickness macroscopic sections of the organ were obtained (Figure 2A, B). Four subspecimens of 2 cm length, extending from the diaphragmatic to the posterior surface of the liver, were obtained (Figure 2C). After excluding the third subspecimen (corresponding to the hilar plate), each subspecimen was then divided into four parts of around 5,000 μm, and the area of arterioles, portal, and centrilobular venules was accurately measured (Figure 2D).

Tissue sections have been processed and stained with hematoxylin and eosin using a standard technique. We used the Ventana BenchMark Ultra immunohistochemistry staining system considering CD34 and CD31 to identify vascular structures.

Electromedical high-frequency device

A Bowa HF monopolar electrocautery was used in the present study. A microprocessor controls the HF device, converting the main voltage into a high-frequency alternating current for both monopolar or bipolar applications.

The monopolar generator has four operating settings: “Cut,” “Moderate Coag,” “Forced Coag,” and “Spray Coagulation,” also known as Fulguration effect, used for contactless surface coagulation via voltaic arc. The practical application of this kind of energy is the coagulation of superficial capillaries or small vessels, allowing for hemostasis even in poorly accessible spaces (setting range 1–120 W).

The cornerstone of spray coagulation is represented by high voltages and low duty cycles, which causes a rapid rise in tissue

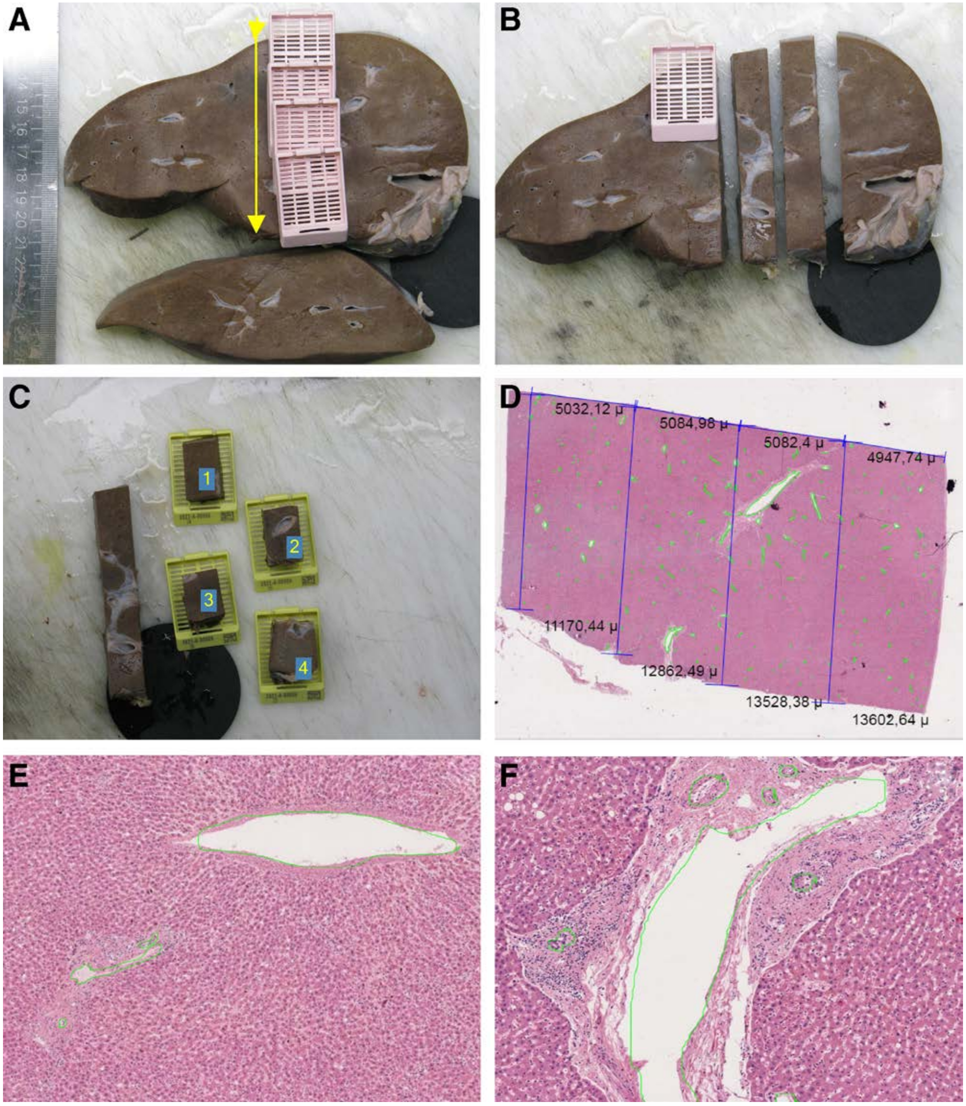

Figure 2. Histological sections of the liver parenchyma. A–C, The different phases of preparation of the liver sections, going from the diaphragmatic surface to the visceral surface and then dividing each macrosection into four microsections. D, Microscopic appearance of a section divided into 5,000 μm-subsections. E and F, Microscopic appearance of the portal triad in the first and fourth subspecimens (same magnification), respectively, after hematoxylin and eosin staining. Note the incremental diameter of the vascular structure for increasing parenchymal depth.

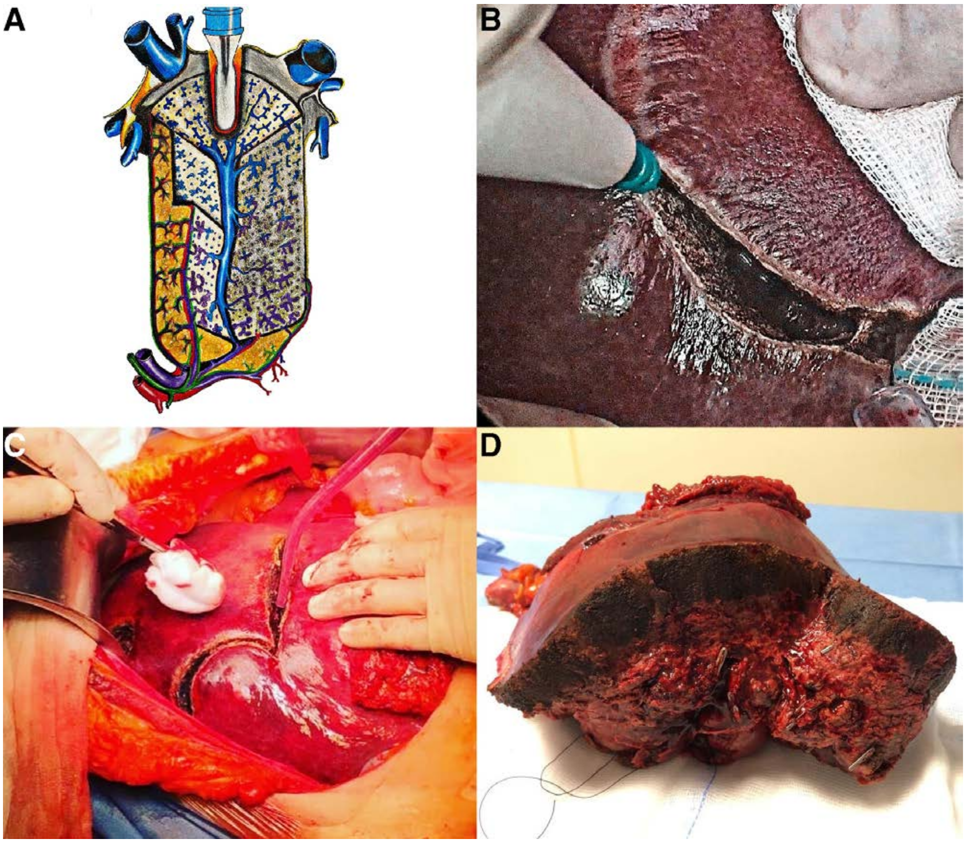

Figure 3. Surgical technique. A, Figurative representation of the Plow technique. B and C, Appearance of initial transection line using the plow technique. The blade of monopolar electrocautery is completely deepened into the liver parenchyma. D, The burn on the specimen corresponds to the depth and length of the plow line.

temperature (>200 °C) due to a fast increase in tissue impedance. This mode of energy application prevents heat transfer to the deeper layers of the parenchyma.

Surgical technique

The technique consists in using the monopolar electrocautery with the blade-type tip deepening it into the liver parenchyma for the first 3 cm (Figure 3A). The "Plow Technique" was so defined because, thanks to its constant slowness, the active blade of the high-frequency calibrated electric scalpel can create a real "furrow," just like a plow does in the ground, coagulating every small vascular structure in its course. An example of the results obtained with this technique is depicted in Figure 3B–D.

Eighty Watt power with the generator set on "Spray Coagulation" must be used. This setting allows adequate coagulation and closure of all small vessels. To achieve an adequate result, the Plow must be slow: the blade must progress through the parenchyma with a 2 cm/min (1 cm/30 s) speed. Nonetheless, it is worth underlining that the speed should be adjusted according to the depth of the blade within the parenchyma: as represented in Figure 4, the more the blade of the electric scalpel deepens into the liver, the less the transection progresses. As a rule of thumb, the pace should be halved each half cm of parenchymal depth.

Statistical analysis

To explore the potential beneficial application of the plow technique, the vascular density, expressed in terms of proportion of arterioles, portal, and centrilobular venules, was explored on both the anterior and posterior liver parenchyma. All vessels' areas and diameters were recoded in a dichotomous fashion: <100 and >100 μm for arterioles, <200 and >200 μm for portal and centrilobular venules. Eventual differences in proportions between the first two and the fourth subspecimens in terms of vessels diameters were assessed through Pearson's Chi-square test.

Furthermore, we retrospectively analyzed a prospectively collected database of consecutive patients who underwent surgery at the General Surgery Unit, Vimercate Hospital, between January and December 2020. A total of 60 patients underwent open liver

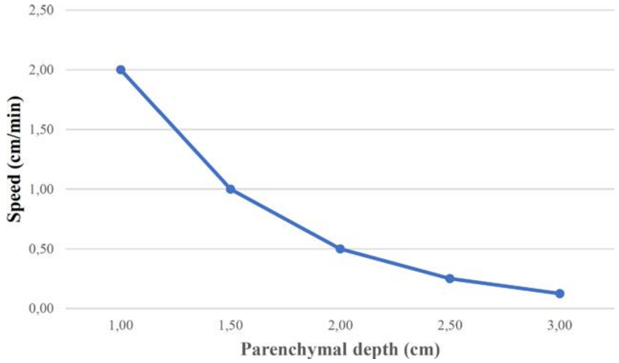

Figure 4. Graphical correlation between parenchymal depth of the electrocautery blade and speed of the transection.

Table 1

Patients' characteristics and surgical information.

Variables	Major hepatectomy (n = 21)	Minor hepatectomy (n = 39)
Age (yrs)	68 ± 10	62 ± 13
Male (%)	15 (71.4)	29 (74.4)
BMI (mean/SD)	26.5 ± 3	27 ± 5
Liver cirrhosis (%)	0 (0)	7 (17.9)
Preoperative ICG-test (mean/SD)		
PDR	19.5 ± 3.6	18.2 ± 4.4
R15	5.9 ± 3.5	7.2 ± 5.3
Surgical indication (%)		
HCC	2 (9.5)	10 (25.6)
CCC	5 (23.8)	2 (5.1)
Gallbladder cancer	1 (4.7)	0 (0)
Metastasis	9 (42.8)	21 (53.8)
Other	4 (19)	6 (15.4)
Operative time (min) (median/IQR)	208 (146–241)	123 (91–186)
Estimated blood loss (mL) (median/IQR)	300 (200–500)	100 (100–300)
Complications (%)		
Bleeding	1 (4.7)	0 (0)
Bile leakage	1 (4.7)	3 (7.7)
Clavien-Dindo ≥ 3a	10 (47.6)	5 (12.8)
Length of stay (d) (median/IQR)	15 (11–39)	7 (5–13)

BMI indicates body mass index; CCC, cholangiocarcinoma; HCC, hepatocellular carcinoma; ICG, indocyanine green; IQR, interquartile range; PDR, plasma disappearance rate; R15, retention at 15 minutes; SD, standard deviation.

resection for primary or secondary tumors and the plow technique along with CUSA were used to transect the liver (for the first 2 cm and the rest of the parenchyma respectively) in all cases. Data regarding surgery and histology were entered in a computerized spreadsheet (Microsoft Excel 2016; Microsoft Corporation, Redmond, WA) and analyzed with statistical software (IBM Corp., released 2017, IBM SPSS Statistics for Windows, Version 25.0; Armonk, NY, IBM Corp.). The results are presented as absolute values and percentages, means and standard deviation or medians, and interquartile range as appropriate.

Results

From December 2019 to May 2021, 60 liver resections were performed in our center. Fourteen (38%) patients underwent major hepatectomy, while for 23 (62%) patients, a minor liver resection was performed. Detailed information is available in Table 1. The indications for major hepatectomy were: two (9.5%) HCC, five (23.8%) CCC, nine (42.8%) metastases from colorectal cancer, one (4.7%) gallbladder cancer and four (19%) benignant disease. Ten (47.6%) patients experimented postoperative complications; one (4.7%) patient developed postoperative bleeding and one (4.7%) bile leakage. Ten (47.6%) patients experienced a ≥3a Clavien-Dindo postoperative complication. On the other hand, minor hepatectomies were performed for HCC in 10 cases (25.6%), CCC in two cases (5.1%), colorectal metastases in 21 cases (53.8%), and benignant diseases in six cases (15.4%). Three (7.7%) patients developed bile leakage and five (12.8%) patients had a ≥3a Clavien-Dindo complication.

Table 2

Distribution of parenchymal vessels among subspecimens.

Variable		Vessels' diameter	Total	*P*
Parenchymal depth		**Arterioles**		
	<100 μm	>100 μm		0.546
First two subspecimens				
Count	55	7	62	
% within first two subspecimens	88.70%	11.30%	100.00%	
% within arterioles diameter	55.00%	46.70%	53.90%	
Fourth subspecimen				
Count	45	8	53	
% within fourth subspecimen	84.90%	15.10%	100.00%	
% within arterioles diameter	45.00%	53.30%	46.10%	
		Portal venules		
	<200 μm	>200 μm		0.985
First two subspecimens				
Count	217	16	233	
% within first two subspecimens	93.1%	6.9%	100.0%	
% within portal venules diameter	51.8%	51.6%	51.8%	
Fourth subspecimen				
Count	202	15	217	
% within fourth subspecimen	93.1%	6.9%	100.0%	
% within portal venules diameter	48.2%	48.4%	48.2%	
		Centrilobular venules		
	<200 μm	>200 μm		0.431
First two subspecimens				
Count	214	17	231	
% within first two suspecimens	92.6%	7.4%	100.0%	
% within centrilobular venules diameter	62.0%	54.8%	61.4%	
Fourth subspecimen				
Count	131	14	145	
% within fourth subspecimen	90.3%	9.7%	100.0%	
% within centrilobular venules diameter	38.0%	45.2%	38.6%	

All the hemorrhagic or biliary complications were due to large caliber blood vessels/bile ducts spillage from the deeper parenchymal portions. Intraoperatively, none of the patients required bleeding control through Pringle maneuver.

The assessment of the distribution of arterioles, portal, and centrilobular venules between the first two and the fourth specimens, failed to point out significant differences. Nevertheless, a relatively greater proportion of arterioles >100 µm and centrilobular venules >200 µm was observed in the posterior portion of the liver (fourth specimen) compared to the ventral one (first two specimens).

Detailed results are reported in Table 2 and depicted in Figure 5.

Discussion

The understanding of liver embryogenesis and anatomy is fundamental for safe and effective transection of the parenchyma in hepatobiliary surgery to avoid and control both intraoperative and postoperative bleedings.

In our study, we described our "Plow" technique for initial parenchymal dissection explaining its anatomical rationale. As shown from histological analysis, the distribution of small vessels allows monopolar electrocautery to seal them safely and completely. Indeed, as shown by Oyama et al,[17] in liver surgery, the reported average depth of thermal damage created by electrocautery in soft coagulation mode using a power of 50, 60, and 70 W for 5 seconds was 3.34 ± 0.28, 3.37 ± 0.28 and 3.12 ± 0.98 mm, respectively. These values are way higher than the caliber measured in our study. Unfortunately, to the best of our knowledge, no evidence regarding the effects of spray coagulation in liver surgery is available. However, in our opinion, there is no reason to expect a weaker hemostatic effect.

It is well established how perioperative bleeding with the need for blood transfusion is detrimental for surgical patients, increasing morbidity and mortality rates and thus prolonging recovery and hospital stay.[18,19]

Surgical technique is thus of paramount importance and along with the technological devices used intraoperatively has a predominant role in the prevention of the above-mentioned complications. Suture and ligation of vascular and biliary structures may be hazardous and are time-consuming, but various methods and instruments have been developed in the last 20 years from both liver surgeons and the electromedical industry for safe dissection of vessels and liver parenchyma.

The use of Cavitron Ultrasonic Surgical Aspirator, jet cutter, ultrasonic scalpel, high-frequency coagulation, laser technique, staplers, and the old but gold clamp crushing technique are used routinely for parenchymal dissection[20–22] in all the centers that perform this type of surgery.

Some of these techniques allow a faster transection compared to others. Especially the use of staplers has proven to be effective in rapidly closing both biliary and vascular structures, sensibly diminishing the time of transection.[3,23] While all these techniques and instruments have been considered for the ligation of major vessels and biliary structures and the deepest parenchymal dissection, no one has focused on the initial phase of the transection.

In our series, monopolar electrocautery was proven safe and effective during the initial transection of liver parenchyma without the need for other tools, further accelerating the duration of the operation. Indeed, only one patient suffered from postoperative bleeding after major hepatectomy. However, it is worth underlining that the aforementioned hemorrhagic complication did not arise from the more superficial parenchymal portions. The blood vessels involved were radiologically detectable (CT scan, angiography), thus, in the order of millimeters. This reinforces our belief that the

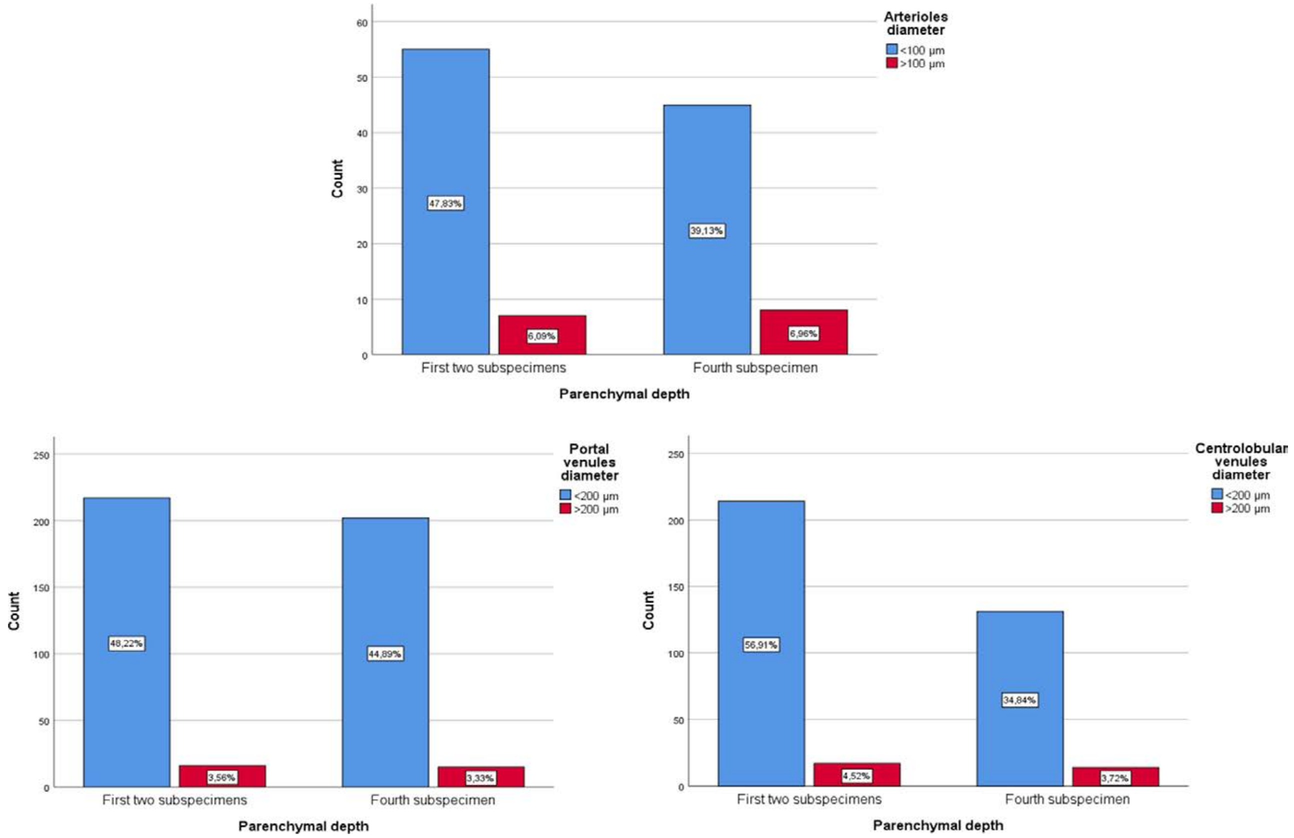

Figure 5. Bar charts summarizing the distribution of arterioles, portal, and centrilobular venules by diameter within different subspecimens.

plow technique can guarantee an effective sealing of vascular structures within the most superficial layers of liver parenchyma.

This technique can be used in both minor and major hepatectomies. In expert hands, with an adequate manual parenchymal compression and without any use of Pringle's maneuver, can lead to a rapid and safe transection of about one-third of the total surface. Nevertheless, as a rule of thumb, it should be applied only when transecting the liver parenchyma on its anterior surface. Indeed, although our analysis failed to point out any significant difference in the distribution of blood vessels among different parenchymal sections, a trend toward a higher density of arterioles >100 μm and centrilobular venules >200 μm in the deepest portions of the liver was observed.

Furthermore, even though not supported by data, in our experience the Plow technique is way more effective in fibrotic livers rather than in steatosic ones. This may be explained by the greater amount of connective tissue gathered in fibrotic parenchymas: the energy applied through the blade of the electric scalpel induces the shrinking of the tissue, contributing to a more efficient sealing of vascular structures.

To the best of our knowledge, the present study represents the first effort to demonstrate a gradient in the distribution of intrahepatic small vessels and the safety/efficacy of the plow technique. After a deep search in the published literature, we did not find any other manuscript describing our technique, which we retain as simple and reproducible.

On the other hand, it is worth mentioning some limitations of the present study, first its retrospective nature. Furthermore, although used for several years, only recently we decided to systematically collect data regarding this surgical technique. Therefore, the sample size of our study is quite limited. Moreover, an objective measure to support one of the main hypotheses of the present manuscript is lacking. Indeed, our study does not encompass a direct comparison between the plow technique and other parenchymal transection techniques in terms of operative time.

A final major drawback of the present manuscript is represented by the histological analysis conducted only on one cadaveric specimen.

In light of the aforementioned considerations, we believe our results need to be more thoroughly explored in further preclinical and clinical trials. At this regard, a study by our group exploring the potential benefits of the plow technique compared to other well-known transection techniques, in terms of hemorrhagic complications and operative time reduction, is already ongoing.

Conclusions

The Plow technique may represent a feasible and safe technique for adequate coagulation and sealing of small vessels of the first 2 cm of the anterior surface of the liver. Besides its safety and effectiveness, it may help in speeding up the parenchymal transection. Further evidence will be needed to confirm our hypothesis. The rationale of this technique is based on the anatomical and embryological principles of the maturation of the hilar plate. Such a technique may allow a substantial saving of time while ensuring hemostatic capabilities comparable to other more expensive surgical techniques reported in the literature. The Plow, which is based on an imperceptible and inexorable movement of the blade along the transection line, can also be easily reproduced and exported since it uses a tool which is always present in every operating room.

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