

Liver resection by Ultrasonic Dissection and Intraoperative Ultrasonography

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Ultrasonic dissection (USD) and intraoperative ultrasonography (IOUS) have shown encouraging results in a retrospective analysis of 109 patients with benign or malignant liver disease. Of 109 patients assessed between 1980 and 1993, 84 were resected: 27 by finger fracture technique (FFT) and 57 by USD. Hospital mortality was 4.8% (4/84) and 30-day mortality was 6.0% (5/84). Overall morbidity was 48.8% (41/84) and liver related morbidity (hepatic bleeding, sepsis, and bile leak) was 34.5% (29/84); of the 29 patients, 5 required re-operation. Liver complications occurred in 12/27 (44.4%) in the FFT group as opposed to 17/57 (29.8%) in the USD group. The incidence of postoperative hepatic bleeding was significantly less by USD than by FFT ($p=0.03$). As well, intraoperative blood loss ($p=0.01$) number of intraoperative blood units used ($p=0.002$), and postoperative length of stay ($p=0.009$) have been significantly reduced by USD. IOUS was used on 64 patients. Not only has it improved the sensitivity (99%) and specificity (98%) for detection of hepatic neoplasms, it has also helped increase the precision and accuracy of anatomical tumour localization. As a result, 11/64 patients (17.2%) had their preoperative plans changed: 8 were abandoned and 3 were revised. In summary, USD has significantly reduced intraoperative blood loss and hence reduced the number of intraoperative transfusions, incidence of postoperative complications and postoperative length of stay. IOUS should be routinely employed in patients undergoing liver resection since it provides critical information that could obviate oncologically useless resections.

KEY WORDS: Liver resection ultrasonic dissection intraoperative ultrasonography

INTRODUCTION

Since the first successful liver resections performed in the late 1800's, the evolution in surgical technique for hepatic resection has focused mainly on maximizing hemostasis.¹ Recently, ultrasonic dissection has been given considerable attention partly because of its widespread surgical applications^{2,3,4}. As well, intraoperative ultrasonography has been able to give higher resolution images for better tumour localization and anatomical definition over any other preoperative radiological device⁵. By directly examining the liver with an ultrasound probe, it has allowed the surgeon to clearly map out each individuals' anatomical and pathological variations for precise and accurate resections.

The purpose of this study is to retrospectively assess how the ultrasonic dissector compares to the standard finger fracture technique with respect to hepatic re-

lated morbidity both intra- and postoperatively in major and minor liver resections. The influence of intraoperative ultrasonography on the decisions made during laparotomy is also examined.

MATERIALS AND METHOD

Between 1980 and 1993, 109 patients were assessed for liver surgery by the primary author (S.S.H) at the Division of General Surgery, Sunnybrook Health Science Centre - University of Toronto (Toronto, Canada). Twenty and 89 patients presented with benign and malignant disease, respectively (Table 1). Their ages ranged from 21 to 78 years with a mean age of 56.2 fifty-one were female and 58 were male. Preoperative work-up included ultrasonography (US), computed tomography (CT) scan, and a serum

Table 1 Patient distribution of presenting liver neoplasms

Malignant Disease (n=89)		No.
Metastases from:	colorectal cancer	49
	biliary/panc. ca.	14
	genitourinary ca.	9
	other ca.	17
Hepatocellular carcinoma		8
Benign Disease (n=20)		
Focal Nodular Hyperplasia		8
Hemangioma		4
Other		8

biochemical liver profile in all patients. Where warranted, angiography, radionuclide scanning and percutaneous biopsies were also done to aid in the diagnosis. CT portography (CTP) was performed on 30 patients since its advent in 1990 and magnetic resonance imaging (MRI) was incorporated as a diagnostic test since 1991

All 109 patients were surgically explored. The final decision as to whether or not to proceed with resection was made during laparotomy. All explorations consisted of general inspection and palpation of the abdomen including careful examination of the liver and, since October 1989⁶, intraoperative ultrasound (IOUS) of the liver. Patients with malignant disease were considered unresectable if there was diffuse hepatic disease, if there was extensive extrahepatic disease, or if the patient had advanced cirrhosis. Of the 109 patients explored, 84 were amenable to resection. The finger fracture technique (FFT) was used on 27 patients and the ultrasonic dissector (Cavitron Ultrasonic Surgical Aspirator, CUSA^R, Valleylab, Pfizer Co) was used on 57 patients; since 1988, the CUSA was routinely used on almost every patient thereafter. Fifty-one patients underwent major liver resections (lobectomies and trisegmentectomies) and 33 underwent minor resections (removal of 3 or fewer separate segments as defined by Couinaud) (Table 2). All resections performed by the primary author were intended for cure.

Since its introduction to the author's practice in October 1989, IOUS was used on 64 of the 109 patients analyzed. From the 27 patients in the FFT group, 3 had IOUS; from the 57 patients in the CUSA group, 31 had IOUS. Twenty of the 25 patients that were not resected also had IOUS. IOUS of the liver was done with an Aloka SSD-630 (Omnium Medical Devices, Ontario) sonographic unit with both linear 7.5 MHz (556T-75) and 5 MHz (587T-5) transducers. Liver surfaces were exposed for optimal imaging and were systematically examined in perpendicular planes. Neoplasms were carefully localized in accordance with

Table 2 Types of resections performed (n=84)

Major Resections (n=51)		
	USD	FFT
left lobectomies	7	5
right lobectomies	10	8
step left lobectomies*	1	0
step right lobectomies**	7	0
left trisegmentectomies	0	1
right trisegmentectomies	6	5
resection of 4 segments	1	0
	32	19
Minor Resections (n=33)		
resection of ≤ 2 segments	24	7
resection of 3 segments	2	0
	26	7

* left lobectomy + resection of segment 5

** right lobectomy + resection of segment 4A or 4B

Couinaud's segmental anatomy and in relation to key vascular structures such as the vena cava, the portal vein and the hepatic vein.

All patient records were maintained on a computer database (Smart and Smart II Database Systems, Informix Software, Inc.) for retrospective analysis. Statistical comparisons were made between the FFT group and the CUSA group. To make the comparisons more statistically uniform, separate comparisons were made with patients only undergoing major resections (lobectomies and trisegmentectomies) in the two groups. Estimated blood loss, the number of perioperative blood units used, and the postoperative length of stay were compared using Wilcoxon Rank Sum Tests. The rates of postoperative hepatic complications in the two groups were compared using Fisher's Exact Test. Postoperative hepatic complications included bile leak, sepsis and hepatic bleeding.

The influence of IOUS was measured by how many operative plans it altered and by how many neoplastic lesions it detected. This number was compared to the actual number determined by pathology in those patients who were resected. All patients would proceed to surgery from pre-operative assessment and then would have IOUS. Its result would influence outcome in one of three ways: proceed with resection plan; alter resection plan; or abandon the resection. If surgery was abandoned because of unforeseen tumour burden, it would be confirmed either by tissue biopsy examined by frozen section or by obvious gross and palpable intraoperative assessment. A true positive was gauged by histological examination of each specimen. Five to 10 millimetre slices (depending on the size of the specimen) would be histologically examined for malignant cells after gross inspection. A true negative per se could not be measured since each specimen contained tumour.

The presence of false positives, however, which could be found from histological examination of all pre-operative worked-up and IOUS detected lesions, requires some definition of a true negative to measure specificity. Thus, a true negative will be arbitrarily defined as the number of specimens in which the number of lesions found from either preoperative work-up or IOUS was equal to the number of lesions found by pathology.

RESULTS

Mortality and Morbidity

Overall hospital mortality (i.e. death within the same hospital admission) was 4.8% (4/84) and 30-day mortality was 6.0% (5/84). These included patients with advanced cirrhosis, severe jaundice and other premorbid factors (Table 3).

Overall morbidity was 48.8% (41/84) and hepatic related morbidity (hepatic bleeding, sepsis and bile leak) was 34.5% (29/84); 5/29 required re-operation (Table 4, Figure 1). All patients (7) who experienced hepatic bleeding alone underwent major resection; no patient experienced postoperative hepatic bleeding from minor resections. The patients that underwent major resections showed a hepatic related complication rate of 31.2% (10/32) in the USD group and 50.0% (9/18, 19th patient was intraoperative death) in the FFT group.

Operative Technique

Table 5 and Figures 2–4 summarize the comparison between the USD and FFT group with respect to estimated blood loss (EBL), number of blood units (NBU) required and postoperative length of stay (PLOS).

Table 3 Mortality analysis of resected patients

Patient	Day of Death	Diagnosis	Complicating Features	Cause & Place of Death
1 FFT	intraop	carcinoid syndrome	tricuspid regurgitation ventricular septal defect	hemorrhage in hosp.
2 FFT	5 POD*	renal cell ca.	–	MI**, PE+ in hosp
3 FFT	20 POD	bile duct ca.	severe jaundice	MI in hosp.
4 USD	25 POD	colorectal metastases	severe cardiac disease	MI at home
5 USD	30 POD	hepatoma	cirrhosis PBC**	bleeding varices on re-adm.
6 FFT	36 POD	carcinoid syndrome	FFT-excessive IO hemorrhage	hemorrhage liver failure in hosp.

- * postoperative day
- ** myocardial infarction
- + pulmonary embolus
- ** primary biliary cirrhosis

Table 4 Morbidity analysis of resected patients

Postoperative complication	Frequency	
	USD (N=57)	FFT (n=27)
non-hepatic related alone (wound infection, chest comp., jaundice, etc)	14.0%	14.8%
hepatic related alone (hepatic bleeding, bile leak, sepsis)	14.0%	22.2%
hepatic bleeding alone	3.5%	19.2%
hepatic and non-hepatic related in combination	15.7%	22.2%
either hepatic alone or with non-hepatic comb.	29.8%	44.4%

p=0.03

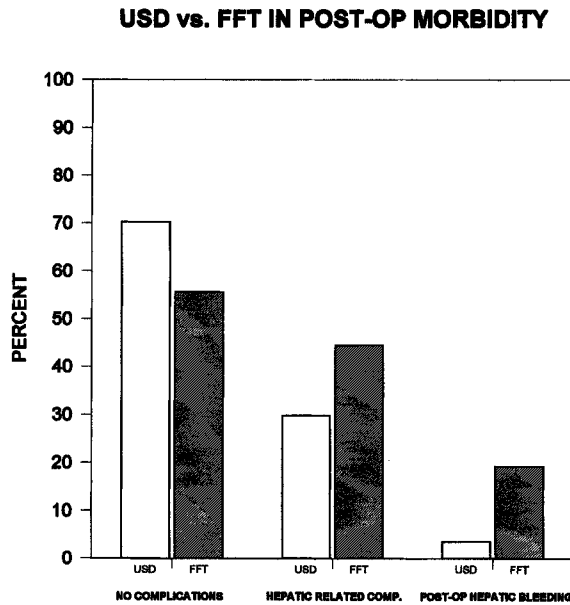


Figure 1 Postoperative morbidity comparisons between ultrasonic dissection (USD) and finger fracture (FFT).

Of the 64 patients that underwent IOUS, 11 plans were altered (17.2%). Eight plans for resections were abandoned and 3 plans were amended. IOUS revealed 2 patients with diffuse unresectable hepatic metastases from colorectal cancer (Figure 5); 3 patients with lesions adherent to vascular structures (vena cava, the portal and hepatic veins) in which their nature made it technically unfeasible for resection (Figure 6); 1 with a tumour thrombus in the right portal vein from a hepatoma; 1 with a benign lesion from focal nodular hyperplasia that was left alone; and the eighth patient with a hepatoma and extensive cirrhosis whose resection was abandoned because IOUS detected more nodules which would have required an extended right lobectomy. Of the three remaining patients who had altered resections, IOUS revealed that one patient planned for a right lobectomy from metastases from a Klatskin tumour had only segments 4B and 5 involved and therefore only those segments were removed. In

Table 5 Comparison of USD and FFT in estimated blood loss (EBL), number of blood units used (NBU), and postoperative length of stay (PLOS)

All Resections			
	USD (n=57)	FFT (n=27)	p-value
mean EBL	3765 mL	9478 mL	0.01
range EBL	350-24000 mL	500-34000 mL	
mean NBU	5.6 units	16.4 units	0.002
range NBU	0-35 units	0-51 units	
mean PLOS	18.6 days	27.8 days	0.009
range PLOS	5-76 days	7-78 days	
Major Resections			
	USD (n=32)	FFT (n=19)	p-value
mean EBL	4369 mL	11641 mL	0.0005
range EBL	350-21500 mL	550-34000 mL	
mean NBU	6.9 units	20.4 units	0.0002
range NBU	0-28 units	0-51 units	
mean PLOS	19.6 days	35.4 days	0.003
range PLOS	6-70 days	12-78 days	

Intraoperative Assessment

Forty patients within the database had IOUS and records available revealing number of hepatic neoplasms found by pathology; a total of 68 liver nodules were found. Sensitivity and specificity rates are compared in Table 6. The single false positive from IOUS was a hemangioma lesion detected in the caudate lobe that could not be confirmed by pathology.

another patient planned for a right lobectomy from colorectal metastases, IOUS showed that the tumour extended into segment 4A and thus a step resection of 4A with the right lobectomy was performed. In the third patient planned for left lateral sectorectomy (segments 2 and 3) from colorectal metastases, IOUS revealed that the tumour involved portions of the left medial lobe and therefore an anatomic left lobectomy was performed.

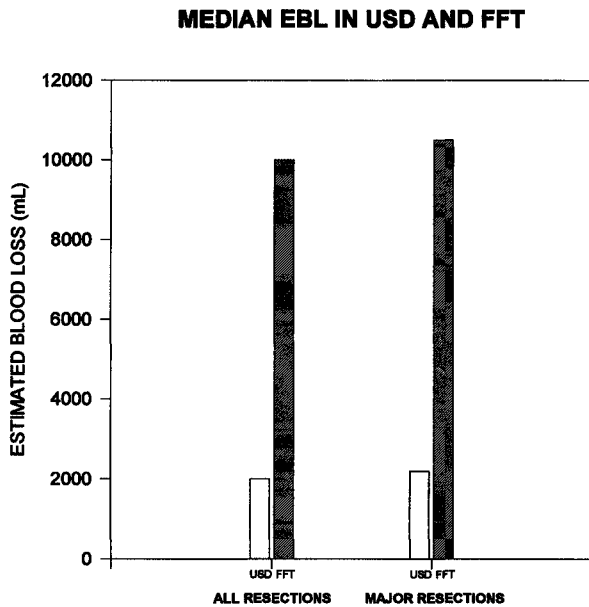


Figure 2 Comparison of the median estimated blood loss (EBL) between ultrasonic dissection (USD) and finger fracture (FFT)

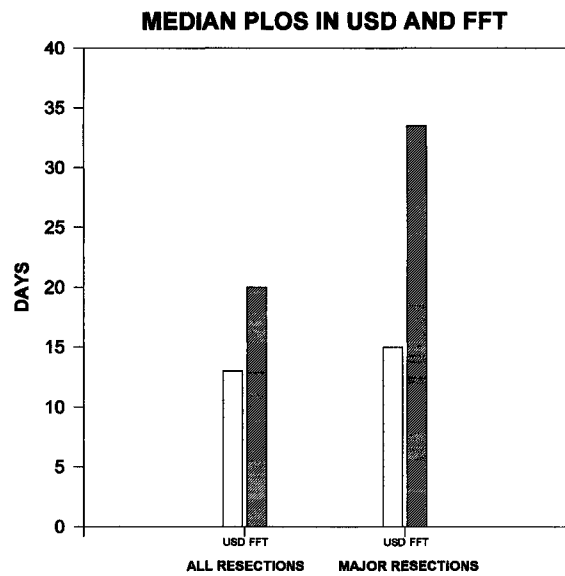


Figure 4 Comparison of the median hospital postoperative length of stay (PLOS) between ultrasonic dissection (USD) and finger fracture (FFT).

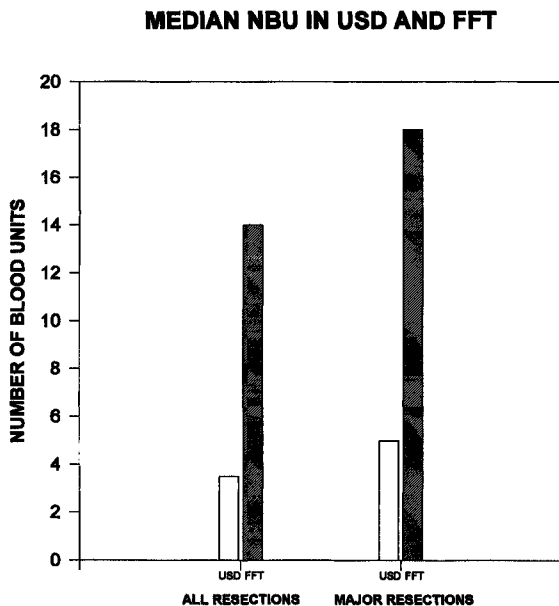


Figure 3 Comparison of the median number of blood units used intraoperatively (NBU) between ultrasonic dissection (USD) and finger fracture (FFT).

DISCUSSION

Ultrasonic Dissection

The principle behind ultrasonic dissection (USD) is based on the premise that different tissues have different water content in proportion to collagen and elastin density. Hepatic tissue with high water content can

Table 6 IOUS assessment. TP = true positive; TN = true negative; FP = false positive, FN = false negative

	TP	TN	FP	FN
Preoperative work-up*	68	36	4	9
IOUS assessment	68	39	1	1
	Sensitivity+		specificity++	
Preoperative work-up*	88%		90%	
IOUS assessment	99%		98%	

* includes pre-op ultrasonography, CT scan ±portography, ±MRI scan, ±radionuclide scanning.
 + sensitivity = TP/(TP+FN)
 ++ specificity = TN/(TN+FP)

therefore be selectively fragmented at a given frequency leaving numerous collagen rich blood vessels and bile ducts intact for safe ligation.⁷ Thus, blood loss is minimized and a cleaner resection line is obtained.

Hemorrhage is the most important intraoperative and postoperative complication in liver surgery.⁸⁻¹¹ Little *et al.* found that USD significantly reduced perioperative blood loss and the number of transfusions required.¹² Reports have shown that the higher the blood loss, the greater the incidence of postoperative complications.^{8,10} Although the determinants for postoperative length of stay (PLOS) is multifactorial, the degree of intraoperative and postoperative blood loss plays a major role. Indeed, PLOS was, on average, approximately 10 days shorter in the USD group which reduced health care costs by 30% in our series.

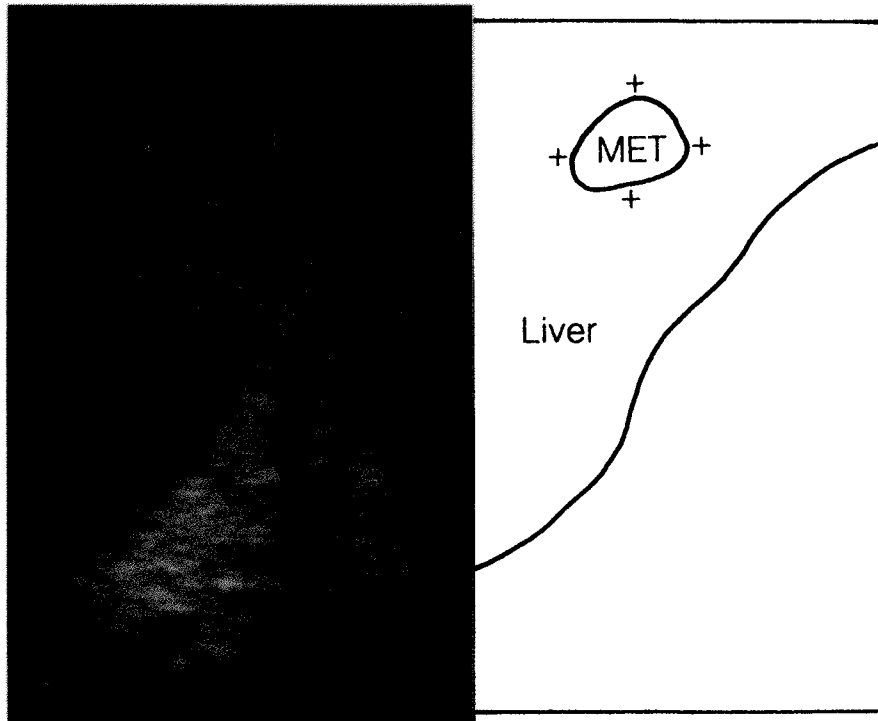


Figure 5 IOUS detection of extra lesion (MET) that was not detected by preoperative computed tomography. Similar lesions were found elsewhere in the liver and resection was subsequently abandoned.

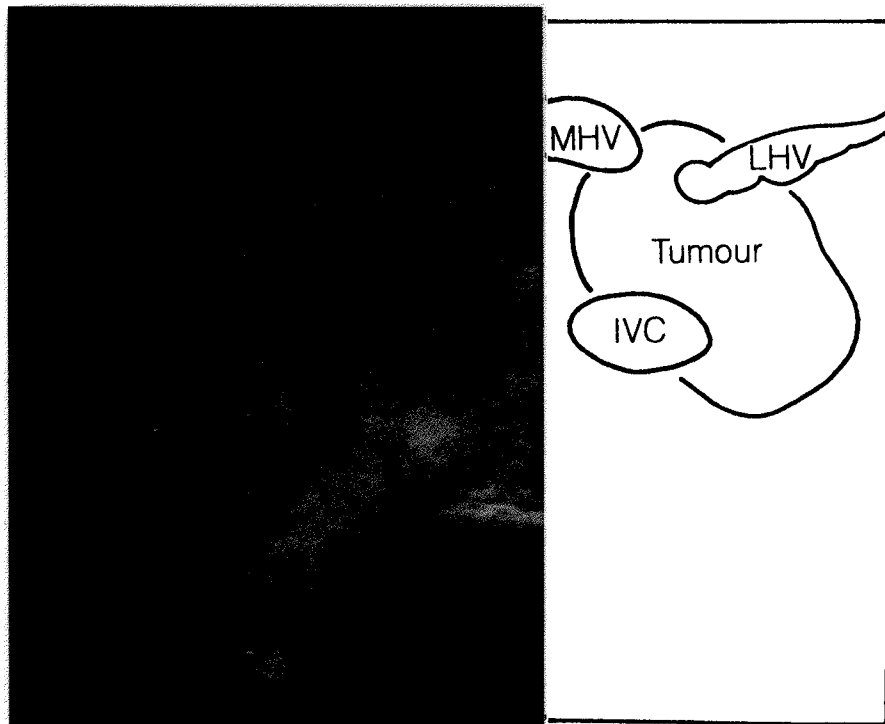


Figure 6 IOUS detection of extra tumour involvement with the middle hepatic vein (MHV), left hepatic vein (LHV) and inferior vena cava (IVC) which were not discernable by preoperative computed tomography. Resection was subsequently abandoned.

Table 7 Literature report of IOUS sensitivity and specificity

	patients	sensitivity	specificity
Castaing <i>et al.</i> ²⁵	42	78.5%	100.0%
Gozzetti <i>et al.</i> ²⁸	37	97.8%	–
Haider <i>et al.</i> ³⁰	22	91.8%	100.0%
Igawa <i>et al.</i> ³¹	83	90.9%	96.0%
Machi <i>et al.</i> ³²	84	97.8%	94.0%
Machi <i>et al.</i> ⁵	227	93.3%	94.7%
Makuuchi <i>et al.</i> ³³	152	99.0%	–
Nagasue <i>et al.</i> ²⁷	113	98.0%	–
Parker <i>et al.</i> ³⁴	42	98.0%	–
Rifkin <i>et al.</i> ³⁵	49	100.0%	100.0%
Sheu <i>et al.</i> ²⁶	47	96.5%	–
Hanna <i>et al.</i> [*]	64	99.0%	98.0%

* values apply only in detecting intrahepatic metastases.

** present report.

It has been further suggested that high perioperative blood loss requiring numerous blood transfusions may have an unfavourable prognostic influence on long-term survival in colorectal metastatic disease since blood loss may adversely influence immunocompetence.¹³⁻¹⁵ Although the exact mechanism is unclear, experiments performed on tumour bearing mice and rats have clearly shown increased tumour growth as a result of blood transfusions possibly by affecting lymphocyte and macrophage activity.¹⁶⁻¹⁹

USD also decreases the amount of ischemic tissue at the resection margin in controlled animal experiments.^{20,21} This may explain why the USD group experienced less morbidity since the degree of devitalized tissue after the resection may be directly related to the severity of sepsis which is a major contributor towards postoperative morbidity.²²⁻²⁴

It should be mentioned that subjectively, USD increased the time required for the liver transection phase compared to finger fracture, but once the liver transection was complete hemostasis was superior to finger fracture and this most likely resulted in no difference in overall operative time.

Intraoperative Ultrasonography

The advantage of scanning with an ultrasound probe directly across the liver surface has allowed for more accurate anatomic localization of neoplasms. Because there is no need to penetrate the abdominal wall, high frequency transducers (7.5 MHz) can be used to generate high resolution images that cannot be obtained preoperatively.²⁵ As a result, IOUS saved 8 patients from unnecessary resections that would have otherwise resulted in considerable morbidity and possible mortality. It altered the plans of 3 patients by changing the amount of resected liver to allow for

greater tumour free resection margins. IOUS revealed vital information specifically entailing the location of tumours in relation to major vessel structures and segmental anatomy (Figure 5, 6).

As well, IOUS is particularly important in patients with hepatocellular carcinoma and underlying cirrhosis. Not only has IOUS been effective in detecting small hepatomas that could not be palpated during laparotomy or detected preoperatively,²⁶⁻²⁸ but it has also been able to map out more conservative resections, and thereby maintain adequate hepatic reserve in cirrhotic livers.

Conversely, by detecting extra smaller nodules of hepatocellular carcinoma, IOUS may also avoid any unwarranted resections (as it did with one patient with cirrhosis in our series).

Despite careful preoperative imaging with CT-portography, ultrasound, and MRI, the sensitivity and specificity of IOUS have been higher. Other authors show similar results as summarized in Table 7. Despite some concerns such as increasing operative time and intra-interpretor variability²⁹, the overwhelming consensus in the high sensitivity and specificity rates reported internationally (Table 7) indicate the invaluable information that can be obtained from IOUS. It should therefore be regularly incorporated as the final diagnostic test prior to proceeding with liver resection.

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