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Water-jet dissection for parenchymal division during hepatectomy

CHARLES M. VOLLMER, ELIJAH DIXON, AJAY SAHAJPAL, MARK S. CATTRAL, DAVID R. GRANT, STEVEN GALLINGER, BRYCE R. TAYLOR & PAUL D. GREIG

University of Toronto, Toronto, Ontario, Canada

Abstract

Background. High-pressure water-jet dissection was originally developed for industry where ultra-precise cutting and engraving were desirable. This technology has been adapted for medical applications with favorable results, but little is understood about its performance in hepatic resections. Blood loss may be limited by the thin laminar liquid-jet effect that provides precise, controllable, tissue-selective dissection with excellent visualization of, and minimal trauma to, surrounding fibrous structures. *Patients and methods.* The efficacy of the Water-jet system for hepatic parenchymal dissection was examined in a consecutive case series of 101 hepatic resections (including 22 living donor transplantation resections) performed over 11 months. Perioperative outcomes, including blood loss, transfusion requirements, complications, and length of stay (LOS), were assessed. *Results.* Three-quarters of the cases were major hepatectomies and 22% were cirrhotic. Malignancy was the most common indication (77%). Median operative time was 289 min. Median estimated blood loss (EBL) was 900 ml for all cases, and only 14% of patients had >2000 ml EBL. Furthermore, EBL was 1000 ml for major resections, 775 ml for living donor resections, 600 ml in cirrhotic patients and 1950 ml for steatotic livers. In all, 14% of patients received heterologous packed red blood cell (PRBC) transfusions for an average of 0.59 units per case. Median LOS was 7 days. EBL, transfusion requirements, and LOS were slightly increased in the major resection cohort. There was one mortality (1%) overall. These results are equivalent to, or better than, those from our contemporary series of resections performed with ultrasonic dissection. *Conclusion.* Water-jet dissection minimizes large blood volume loss, requirements for transfusion, and complications. This initial experience suggests that this precision tool is safe and effective for hepatic division, and compares favorably to other established methods for hepatic parenchymal transection.

Key Words: *hepatic parenchymal dissection, Water-jet, blood loss, transfusion, living donor transplantation*

Introduction

Major improvements in outcomes for major hepatic surgery have occurred over the last two decades [1–6]. Advances in patient selection, intraoperative anesthesiology, and postoperative critical care have made significant contributions. Along with the improved understanding of hepatic surgical anatomy, the development of new technologies for hepatic parenchymal transection has contributed greatly to the limitation of blood loss during these procedures. A variety of instruments have been designed that allow for better identification and control of intrahepatic vascular and biliary anatomy. These include ultrasonic dissection, Argon beam coagulation, the bipolar vascular sealing device, the harmonic scalpel, the floating ball instrument, radiofrequency coagulation, biological glues, and stapling techniques [7–21]. These new methods compare favorably with the more traditional, less precise ‘finger fracture’ or ‘crush clamp’ techniques by reducing blood loss, transfusion requirements, and biliary leaks.

High-pressure Water-jet dissection technology was originally developed for applications in the steel and glass industries, where ultra-precise cutting and engraving were desirable. This technology has recently been adapted for medical applications with favorable results (Hydro-Jet®; ERBE, Tuebingen, Germany). The advantages of this thin, laminar liquid-jet effect include precise, controllable, tissue-selective dissection with excellent visualization of, and minimal trauma to, surrounding fibrous structures. To date,

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Correspondence: Charles M. Vollmer Jr, MD, Harvard Medical School, Beth Israel Deaconess Medical Center, Division of General Surgery, 330 Brookline Avenue–St 9, Boston, MA 02215, USA. Tel: +1 617 667 2633. Fax: +1 617 667 7756. E-mail: cvollmer@bidmc.harvard.edu

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the Water-jet has been successfully employed in procedures performed on such diverse organs as the kidney, prostate, synovium, gallbladder, and parotid gland [22–24]. Another emerging application is for total mesorectal excision in colorectal surgery [25]. Although the application of this novel technology to liver surgery has thus far been limited [26–28], it appears to have ideal characteristics for improving precision in parenchymal dissection, and has even been adapted for use in laparoscopic hepatic resections [29].

This report presents an initial experience with Water-jet dissection for major hepatic resections performed at a high-volume, North American hepatobiliary surgery unit. The safety profile and efficacy of the Water-jet were determined in a prospective case study of 101 liver resections performed over 11 months, representing the largest contemporary experience in the literature with this device.

Patients and methods

Over the 11-month period spanning March 2002 to January 2003, 131 consecutive liver resections, including 27 living donor hepatectomies for transplantation, were performed by 5 attending surgeons in the Hepatobiliary and Transplantation divisions at the Toronto General and Mount Sinai Hospitals in Toronto. Preoperative demographics and comorbidities, intraoperative factors, and short-term postoperative outcomes were retrieved from a prospectively collected database of hepatic surgery performed at the institutions during that time period.

Cases were segregated by method of hepatic parenchymal dissection employed during this time period. The focus of this analysis is the 101 cases, starting in March 2002, where the Water-jet was employed. In 30 other cases, an alternative method of parenchymal dissection was chosen at the discretion of the attending surgeon. The cavitron ultrasonic suction aspirator (CUSA) had previously been the preferred dissection method used at this institution. Following the introduction of the Water-jet device, the CUSA was employed only 18 more times and was soon abandoned (within 3 months) once all the surgeons became familiar with the Water-jet. Furthermore, two additional cases consisted of rapid conversions from the Water-jet to crush-clamp; one due to a technical unfamiliarity of the machine, and another from perceived inefficiency of dissection in a fibrotic liver. Both of these were early in the learning curve with the Water-jet. In 10 other instances stapling, monopolar cautery, 'crush-clamp', or a combination of these techniques, were employed – usually on minor resections and in the setting of exposing trainees to the broad array of alternative techniques available for transection. Due to the heterogeneity and small sample size of any one of these techniques, these cases cannot be adequately compared directly to the cohort of Water-jet cases that comprises the focus of this review and they have been eliminated from further consideration.

Nomenclature for hepatic resections is presented according to the Brisbane 2000 terminology of the International Hepato-Pancreato-Biliary Association [30]. Analysis of outcomes is divided into major resections (three segments or greater) and minor resections (two segments or fewer, including non-anatomic resections).

Although the operative conduct of each resection varied, we consistently adhered to the following general principles. Patients were regularly placed in the Trendelenburg position and central venous pressure (CVP) was maintained below 5 mm Hg during the parenchymal transection. For all cases involving more than a single segmental resection, 'selective' inflow occlusion was regularly performed, whereby the hepatic arterial and portal venous structures supplying only the segments to be resected were isolated and divided. The corresponding hepatic venous drainage was also routinely ligated (most frequently using an Endo-GIA stapler with a vascular setting) just before parenchymal dissection. An exception to this general technique was the living donor hepatectomy operation, where parenchymal dissection was performed before any vascular division to minimize warm ischemic time to the graft. Cell saver technology was only employed during these live donor cases. Generalized inflow occlusion via the Pringle maneuver was not performed as a standard maneuver, but rather only when significant bleeding was encountered during parenchymal dissection (nine cases, 7%). Likewise, total vascular exclusion (TVE) was never required in this series.

Parenchymal dissection with the Water-jet was performed using the following method. Glisson's capsule is scored 2–3 mm deep along the demarcated plane of transection with a monopolar cautery. Then, 2-0 prolene sutures are placed on each inferior liver margin to provide adequate tissue distraction along the cleavage plane throughout the dissection. The tip of the hand-held applicator (Figure 1A) is kept 1–2 mm away from the tissue in a 'no-touch' fashion. A foot pedal initiates the high-powered precision water jet that is connected to an adjustable power module (Figure 1B). Optimal dissection is achieved at a pressure setting of 550–650 pounds per square inch (psi) for a liver with normal consistency, but varies with cirrhotic and fibrotic livers requiring greater pressure ($>$700 psi) and steatotic livers needing less. A smooth, reproducible, back-and-forth waving motion is used for a few seconds at a time over a 2–3 cm distance. Fluid build-up, consisting of saline and blood as well as disintegrated parenchymal tissue, is scavenged throughout the dissection by the suction element that is integrated with the applicator tip. A second dedicated suction device is held nearby over the transection plane to enhance visualization. We

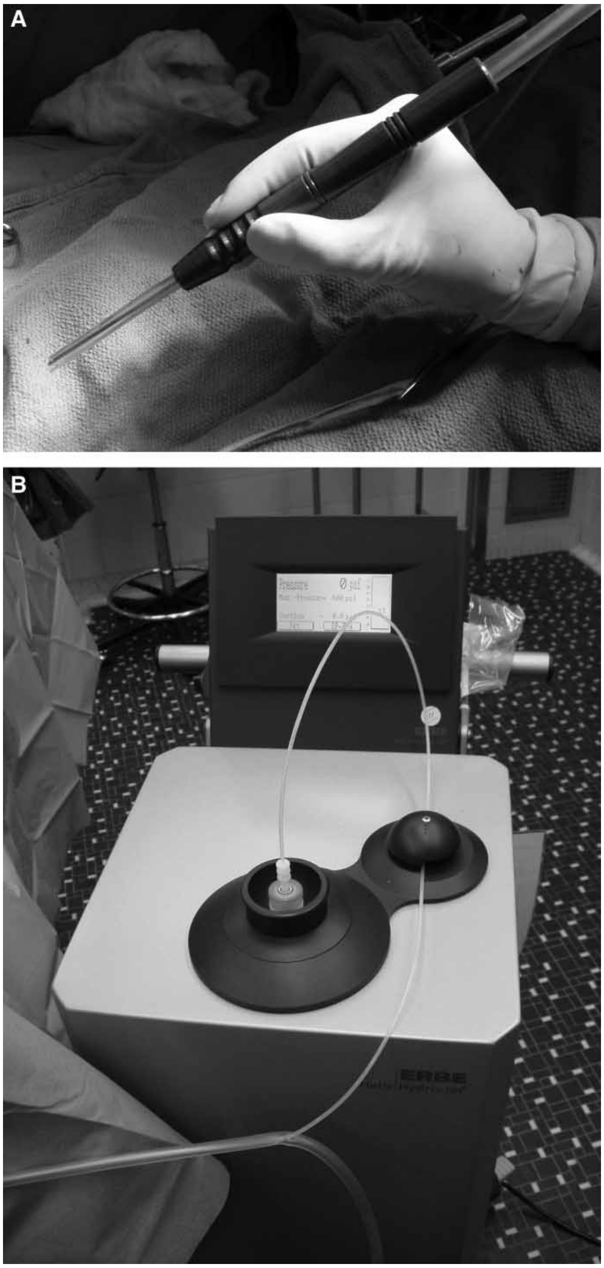

Figure 1. The hand-held applicator, containing the Water-jet channel and a continuous suction circuit, is light and flexible.

have found it useful to intermittently stop water application and assess the extent of dissection while obtaining hemostasis with a monopolar cautery. It is at this point that the fine, trabecular infrastructure of the parenchyma becomes apparent, and is either cauterized or ligated with clips depending upon the caliber of the elements. Blood loss generally consists of minor slow oozing from the side walls, not brisk vascular hemorrhage, and is easily controlled with the cautery. Large, intrahepatic vascular structures such as the middle hepatic vein and its segmental branches are easily and safely identified with the Water-jet. These are further exposed by circumferentially 'cleaning' the surrounding parenchymal tissue for distances that allow safe, controlled application of occlusive ligatures or the Endo-GIA stapler. A 'drilling' motion, where the jet stream is applied in a constant position over and under the edges of these structures, avoiding the center of the vessel itself, has proven to be extremely effective in their identification. This technique is also useful in precisely defining the hilar plate that invests the bile duct elements before transection.

Estimated blood loss (EBL) was determined by the attending anesthesiologist in each case and consisted of a combination of blood accumulation in the suction device (with the saline used in producing the jet stream subtracted) and that weighed from surgical sponges. The need for transfusion of blood products was determined by the attending surgeon in consultation with the anethesiologist. For purposes of this analysis, reported transfusion requirements reflect the intraoperative period and the ensuing 24 h. Perioperative hemodynamic instability or a hematocrit below 24 g/dl were accepted triggers for transfusion. Operative mortality is measured within 30 days or during the initial hospitalization following of the operation. Complications are reported according to the scale developed by Clavien et al. [31,32] for surgery-related complications.

Statistical analyses were determined using χ^2 for categorical data, and the two-tailed Student's t test for continuous data. Significance was determined at $p <$ 0.05. For non-parametric continuous data, the Wilcoxon rank sum test was employed. Binary data are reported as proportions, and continuous data are reported as median with range or mean $\pm$ standard deviation.

Results

A total of 101 hepatic resections were performed using the Water-jet for parenchymal transection. There were 37 females and 64 males with a median age of 54.5 years (range 17–84). Indications for operation are outlined in Table I. Malignant diseases, predominantly colorectal metastases and hepatoma, were the indication in three-quarters of the cases.

Table I. Indications for resection.

Indication	Total (%)
Malignant conditions	
Colorectal metastases	43 (43%)
Hepatocellular carcinoma	24 (24%)
Gallbladder cancer	5 (5%)
Non-colorectal metastases	2 (2%)
Cholangiocarcinoma	2 (2%)
Transplant	
Living donor	22 (22%)
Benign conditions	
Adenoma	1 (1%)
Other	2 (2%)
Total	101 (100%)

Benign conditions including living donor hepatectomies for transplantation (22%) comprised the remaining quarter of the cases. All cirrhotic patients were classified as Child's A. A history of hepatitis was present in 23 (23%) patients. Twelve had hepatitis B virus infection, seven had hepatitis C, one patient was infected with both hepatitis B and hepatitis C, and finally, three patients had a history of alcohol-induced cirrhosis. Eight of the patients (8%) had previously had a partial hepatectomy. Three patients had a portal vein embolization before their hepatectomy. Over a quarter of the patients ($n=28$) had received chemotherapy for colorectal cancer before their hepatectomy. In addition, one patient had undergone extensive upper abdominal radiation for a childhood lymphoma. Comorbidities, defined as pre-existing diabetes mellitus, obesity, or cardiovascular, respiratory, or renal conditions, were present in 41% of the patients, and preoperative American Society of Anesthesiologists (ASA) scores were: ASA = 1 (14%), ASA = 2 (39%), ASA = 3 (38%), and ASA = 4 (8%). One procedure was performed emergently for a ruptured hepatocellular carcinoma (HCC) and accounted for the largest individual blood loss of any case (7500 ml). Table II outlines general preoperative demographics.

Table III describes the procedures performed. Major hepatectomies were performed 76% of the time, and 24 minor resections were performed. Twenty-two patients (22%) had a morphologically cirrhotic liver, and another nine (9%) had an abnormal consistency–most often marked steatosis. Operative time averaged just under 5 h with a median of 289 min (mean 292), and ranged from 126 to 505 min. Nonselective vascular inflow occlusion (Pringle maneuver) was employed three times (3%). Reconstruction of the biliary tract was required in seven instances (7%).

Table II. Preoperative features.

Parameter	Value
Number of patients	101
Age (mean; range)	54.5 (17–84)
Male:female	64:37
Indications	
Colorectal metastases	43 (43%)
Hepatocellular carcinoma	23 (23%)
Other malignancies	9 (9%)
Benign lesions	4 (3%)
Living donor transplant	22 (22%)
Comorbidities*	41%
ASA score	
1	14 (14%)
2	40 (39%)
3	38 (38%)
4	9 (9%)
Hepatitis	23 (23%)
B	12 (12%)
C	7 (7%)
B and C	1 (1%)
Alcohol-induced cirrhosis	3 (3%)
Cirrhosis	22 (22%)
Fatty liver	9 (9%)
Redo operation	8 (8%)
Previous chemotherapy	28 (28%)
Portal vein embolization	3 (3%)
Preoperative hemoglobin (g/L)	134.6 ± 13.5
Preoperative platelet count ($\times 10^9$)	234.8 ± 65.6
Preoperative INR (s)	1.01 ± 0.08

*Comorbidities were classified as: pre-existing diabetes, cardiovascular, respiratory, or renal conditions, or obesity.

Table III. Extent of resection.

Procedure	Frequency (%)
Minor hepatectomy	
Segmental resection (two segments or less)	14 (14%)
Left lateral sectionectomy (segments II and III)	7 (7%)
Non-anatomic wedge resection	2 (2%)
Living donor hepatectomy	
Right hemi-hepatectomy (segments V–VIII)	21 (21%)
Left lateral sectionectomy (segments II and III)	1 (1%)
Hemi-hepatectomy	
Right hemi-hepatectomy	26 (26%)
Left hemi-hepatectomy	5 (5%)
Extended hepatectomy	
Extended right hepatectomy	16 (16%)
Extended left hepatectomy	7 (7%)
Other major resections	
Meso-hepatectomy	1 (1%)
Segment V, VI, VII	1 (1%)
Total	101 (100%)

The median estimated blood loss (EBL) was 900 ml (mean 1190, range 100–7500). Twenty-four patients (24%) had > 1500 ml blood loss, and only 14 patients had > 2000 ml blood loss. Median EBL for living related donor hepatectomy was reduced to 775 ml (mean 945, range 450–2000), despite the lack of selective inflow occlusion required for these cases. Of the 22 patients with grossly evident cirrhosis, the median blood loss was also substantially lower at 600 ml (mean 968, range 100–4300). However, the livers with gross steatotic features demonstrated a markedly higher median blood loss at 1950 ml (mean 2475, range 500–6200).

Overall, 18 patients (18%) received a perioperative transfusion (defined: intraoperative through first 24 h) of packed red blood cells (PRBCs) for an average of 0.62 units per case (median 0, range 0–12). Ten of the patients transfused received only ≤ 2 units of blood while eight (8%) received > 2 units of blood. Of note, however, within these 18 patients, 4 living donor hepatectomy patients received a single autologous, pre-donated unit of blood. Therefore, 14 patients received heterologous transfusions for an overall average of 0.59 units per case. In addition, five patients received fresh frozen plasma (FFP)

Table IV. Operative features and postoperative outcomes.

Parameter	All cases	Major resections
Number of patients	101	77
Procedure		
Hemihepatectomy	33 (33%)	33 (42.9%)
Extended hepatectomy	23 (23%)	23 (29.8%)
Living donor hepatectomy	22 (22%)	21 (27.3%)
Minor hepatectomy	23 (23%)	N/A
Median operative time (mean; range)	289 min (292; 126–505)	315 min (318; 168–505)
Pringle maneuver used	3 (3%)	3 (4%)
Biliary reconstruction	7 (7%)	6 (7.7%)
Blood loss		
Median EBL (mean; range)	900 ml (1190; 100–7000)	1000 (1273; 200–7500)
Blood loss >2000 ml	14 (14%)	12 (15.6%)
Transfusions		
No. of patients transfused any PRBCs	18 (18%)	15 (19.5%)
PRBC unit/case (mean)	0.62	0.70
No. of patients transfused heterologous PRBCs	14 (14%)	11 (14.2%)
No. of patients with >2 U PRBCs	8 (8%)	6 (7.7%)
No. of patients transfused FFP	5 (5%)	5 (6.5%)
No. of patients transfused platelets	2 (2%)	2 (2.6%)
Median length of stay (mean; range)	7.0 days (8.4; 4–28)	8.0 days (9.1; 4–28)
Mortality	1 (1.0%)	1 (1.3%)
Patients with complications	40 (40%)	32 (41.6%)
Total number*	50	41
Grade I	19 (38.8%)	16 (39%)
Grade Iia	13 (26.5%)	11 (26.8%)
Grade Iib	16 (30.6%)	12 (29.3%)
Grade IIIa	1 (2%)	1 (2.4%)
Grade IIIb	0	0
Grade IV	1 (2%)	1 (2.4%)

EBL, estimated blood loss; FFP, fresh frozen plasma; PRBCs, packed red blood cells. Major resections are defined as three or more segments. Complications were graded by the system developed by Clavien et al. [31,32].
*Grades are reported as number and percentage of total complications.

perioperatively for an average of 0.24 units per case (median 0, range 0–10). Only two patients were given platelet infusions for a mean of 0.10 units per case (median 0, range 0–5).

Complications were categorized by the grading system developed by Clavien et al. [31,32]. Forty (40%) patients had 50 complications. Nineteen patients had minor grade 1 complications that were easily controlled without major interventions required. Over half of the complications ($n = 29$) were graded as grade 2 – those classified as life-threatening, requiring some form of intervention, or leading to a prolonged hospital stay, yet do not lead to residual disability or organ resection. Only one patient suffered a grade 3 complication with long-term disability (postoperative myocardial infarction). One patient expired (grade 4 complication) from liver failure secondary to a septic focus on postoperative day (POD) 28 for an overall operative mortality of 1%. Length of stay (LOS) was a median of 7 days (mean 8.4, range 4–28).

Outcomes for major hepatectomies (three segments or greater) were focally reviewed in that the impact of parenchymal transection technique may be less pronounced in minor resections. Three-quarters of the total cohort (77 patents) required a major hepatectomy with the Water-jet and their outcomes are also delineated in Table IV. Overall outcomes generally mirror those for the whole cohort of all 101 resections. However, with these larger resections, operative time, blood loss, and LOS are, not unexpectedly, increased over those of the total cohort.

Liver function as measured by biochemical enzyme changes was assessed pre- and postoperatively for all patients. Initial, peak, and delta (peak minus initial) values were determined for international normalized ratio (INR), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and total bilirubin. INR averaged 1.01 s and peaked 1.6 days later at 1.61 s for a delta of 0.60 s. Preoperative AST averaged 33.4 IU/L and peaked 0.81 days later at 329.4 IU/L for a delta of 325 IU/L. Likewise, mean preoperative ALT was 33.3 IU/L and peaked at 340.6 IU/L 1.01 days later for a delta value of 347.2 IU/L. Finally, preoperative mean bilirubin was 10.4 mg/L. This peaked 3.2 days later at 43.64 mg/L for an average delta value of 32.7 mg/L. Thirty (30%) of the patients were discharged with a bilirubin greater than normal (> 22 mg/L). There were no discernable differences found that suggested that the Water-jet technique is more (or less) damaging to the parenchyma than either ultrasonic dissection or other techniques (data not shown).

Finally, the results of Water-jet dissection were compared to a contemporary collection of 78 patents where CUSA was employed from July 2001 to June 2002. As stated earlier, this had been the preferred technique for parenchymal transection at our institution for over a decade. Preoperative demographics (indications, comorbidities, magnitude of resection, laboratory values) were equivalent between the two groups. Although there was a 440 ml reduction in the mean EBL with the Water-jet when compared with the CUSA, the median values were similar (825 ml for Water-jet vs 900 ml for CUSA) and there was no statistical difference ($p = 0.16$). However, there was a significant improvement in patients requiring blood transfusion in favor of the Water-jet (13% vs 27%; $p = 0.031$), as well as those who required >2 units of blood when transfused. Complications were less frequent in the Water-jet group (39% vs 53%; $p = 0.07$), and mortality rates were 1% for Water-jet vs 6.4% for CUSA. LOS was significantly lower for the Water-jet group (8.4 days vs 10.7 days; $p = 0.03$). These overall positive findings in favor of the Water-jet were further accentuated when comparing the cohort of major resections between the two techniques (data not shown).

Discussion

The precision cutting technology of the Water-jet was initially developed for specific and fine engraving in the metal and glass industries. It has subsequently been modified for medical application, and has so far found utility in a variety of operative procedures ranging from partial nephrectomy and total mesorectal excision to parotidectomy and orthopedic discectomy. The initial descriptions of this application to hepatic surgery have largely been case reports and small series, confined to a limited number of European centers [26–29]. This current series demonstrates the efficient application of this novel instrument for hepatic parenchymal dissection at a major North American hepatobiliary and transplantation unit. We have applied the Water-jet technology to a variety of indications for liver surgery including both oncologic and benign resections, as well as graft procurement for living donor transplantation. This represents the largest single experience in the literature to date.

The strengths of this analysis are that a large volume of cases was performed over a short timespan without any major variations in operative approach. In our series, six fellowship trainees performed the parenchymal dissection under the direct guidance of five attending surgeons. The technique was applied not only on parenchyma with selective vascular occlusion, but also, in the instance of living donor hepatectomy for transplantation, on tissue without any vascular control during the parenchymal transection phase. Multiple consistencies of hepatic parenchyma, including cirrhotic and fatty tissue, were also tested, as were various indications for resection (benign, malignant, and infectious). Nonselective inflow occlusion was rarely necessary. The exceptional quality of performance by the Water-jet was enough to convince our group to abandon use of the previously favored CUSA.

The Water-jet technique is relatively simple and easy to learn, for both the surgeons and the operative nursing staff. It has a short learning curve (fewer than 10 cases) as the surgeon becomes familiar with the technique. This fact, combined with the perceived superior precision attained, quickly made this the preferred application of each of the five surgeons in the study. We have recently adopted a two-handed technique in which the operating surgeon holds the applicator in his dominant hand, and another suction device in the other hand. This may be more efficient than when a second assistant operates the auxiliary suction. We have found that a precise 'up and down' or vertical motion in the same plane over a distance of 2–3 cm provides better exposure than a more random side-to-side circular motion against each side wall. Distraction (with sutures or manual retraction) of each side wall of the dissection cleft aids this process by exposing the base of the plane. As only the fine trabecular structures and medium caliber structures remain in the superficial dissection, there is an impression of less 'oozing' throughout the case, and less cautery is required on the cut surface t o obtain hemostasis. Dissection of large venous structures, or the biliary plate, is usually complete enough to allow for even endovascular stapler ligation. Occlusion or ligation with suture material is rarely required.

The surgeon may initially feel uncomfortable with the fact that the liquid produced by the jet stream from the applicator tip builds up in the dissection field, and thus obscures direct vision of the structures. However, we have actually found this to be beneficial in that the Water-jet, as a no-touch technique, is less traumatic to the vascular structures than the directly applied ultrasonic aspirator tip. The application is atraumatic, so that dissection without direct visualization can be safely adopted. The jet power can be adjusted in accordance with the consistency of the parenchyma. For normal tissue, we employ settings between 500 and 650 psi. We have found that dissection of cirrhotic or fibrotic tissue is more efficient at levels of 700–800 psi, and that less pressure is required for steatotic livers that disintegrate with less force.

The primary finding of this report is contained blood loss and, therefore, infrequent requirements for blood product transfusion when using Water-jet dissection. The median EBL in this series was 900 ml for all degrees of resection, and 1 L for the subset of patients requiring major resections. Only one-quarter of the patients lost >1500 ml of blood and just 15%

lost >2000 ml. The percentage of patients requiring a perioperative transfusion of PRBCs, of any sort, was 18%. This rate is even lower when considering those patients who received heterologous transfusions only (14%). This low transfusion profile is quite favorable when compared with recent literature from other centers with expertise and high volume in hepatic resective surgery [1,4,5,33,34]. Mirroring this is a trend in minimal administration of other blood products such as FFP and platelets as well. Although the Water-jet dissection clears off the fine, trabecular hepatic infrastructure found a few centimeters beneath the surface of Glisson's capsule more efficiently than other techniques (Figure 2A), these findings of limited blood loss and fewer transfusions can be better explained by the precise identification and clearance of the portal and hepatic venous structures deep within the parenchyma of the liver (Figure 2B) afforded by the Water-jet device. This fact has been important in facilitating the current practice of routine and safe inclusion of the middle hepatic vein with living donor right hepatectomy at our institution (Figure 3).

Operations performed on living donors for transplantation were included in this analysis for a number of reasons. First, they compose a significant proportion (> 20%) of the total hepatic resections performed at our institution. Secondly, in that they

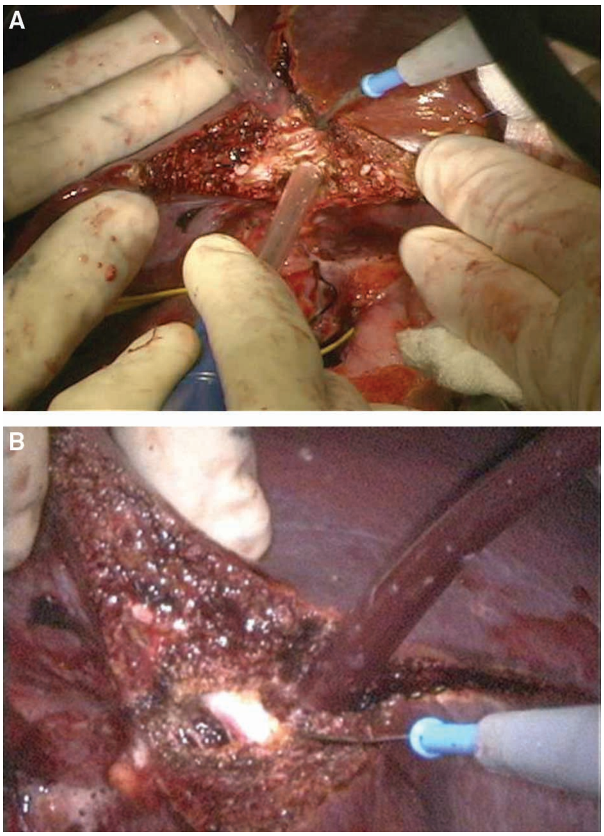

Figure 2. (A) The fine trabecular hepatic vascular and biliary infrastructure is exposed following superficial Water-jet dissection. (B) Deep portal and hepatic venous branches are precisely defined.

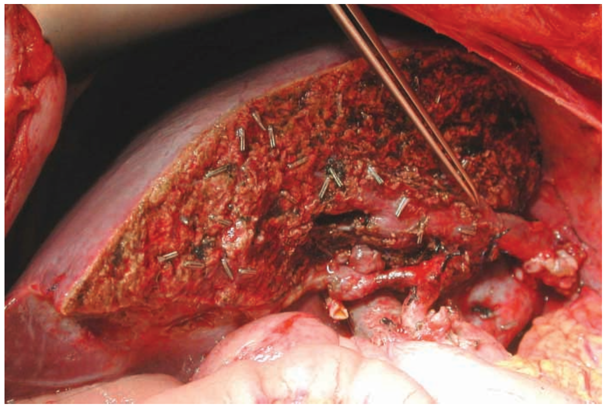

Figure 3. Precise dissection of the entire length of the middle hepatic vein using the Water-jet is illustrated in a living donor right hemi-hepatectomy.

are performed on entirely normal hepatic tissue, they provide another subset of parenchymal morphology on which to evaluate the effects of this device (i.e. normal tissue). Furthermore, since these cases are performed with no inflow or outflow occlusion at all, they allow for analysis of the technique under the most demanding conditions for hemostatic control. Interestingly, despite these obstacles, in this scenario there was markedly better control with 225 ml less median blood loss than observed in the other major resections.

Other liver consistencies were analyzed in this study. Cirrhotic livers with gross fibrosis pose the most difficult conditions for hepatic transection to the surgeon. There has been skepticism about the ability of the Water-jet to transect these livers with equivalent proficiency. We feel that the Water-jet performs in a superior manner to other techniques – particularly since the amount of force applied can be varied in real time according to the conditions encountered (i.e. elevating the psi). Our data support this subjective impression and indicate that there is markedly less median blood loss in these challenging livers (600 vs 900 ml), although to be fair, there is a decreased proportion of 'major' resections in this subset (45% vs 77%). On the other hand, and not surprisingly, steatotic livers had markedly higher EBL (by over 1 L) when compared with patients with more normal liver consistency, reflecting the more inflamed nature of this parenchyma.

This report lacks the strength of a randomized, controlled series in head-to head comparison with other techniques. However, these outcomes from Water-jet dissection compare favorably with a contemporaneous cohort of resections performed using CUSA at our institution prior to the introduction of the Water-jet. The two groups were equivalently well matched with respect to preoperative comorbidities and demographics as well as operative variables. The sequential comparison over a relatively short timeframe (2 years) also minimizes differences in other factors that may influence comparisons that are detached temporally. Similar comparisons, with mixed results, have been attempted in limited (fewer that 25 patients per group) prospective studies comparing the Water-jet to other transection modalities. Rau et al. found the Water-jet to be significantly faster than the CUSA with less required Pringle occlusion and fewer transfusions [35]. Alternatively, Lesurtel et al. report better speed and efficiency with crush clamp technique (with Pringle maneuver) over Water-jet, CUSA, or dissecting sealer – each used without Pringle technique [36]. We are of the subjective opinion that the Water-jet is more efficient in terms of speed of transection. Unfortunately, the operative time described in this current report indicates incision to closure time, and we did not prospectively record the hepatic parenchymal dissection aspect alone, which would be more relevant to gauge the efficiency of the tool. Numerous emerging instruments have recently been introduced for parenchymal dissection, and a formal prospective comparison is certainly justified between the Water-jet and these modalities to determine superiority. In the end, they may each have a certain niche.

There is no direct evidence yet (either basic or clinical) that this technique aerosolizes viral particles during dissection of infected hepatocytes. Nor are there any firm data to suggest that it has an unfavorable profile in regards to dissemination of tumor should the hepatic dissection plane violate tumor. However, early work from a German center indicates equivalent survival for crush clamp, CUSA, and Water-jet techniques when applied to resections for both colorectal metasatases and HCC [37]. These questions also remain avenues for further investigation.

Conclusion

This analysis describes the largest experience to date using Water-jet technology for parenchymal dissection during hepatectomy. The precision achieved with Water-jet dissection allows for excellent identification of intrahepatic vascular structures, particularly the main branches and segmental tributaries of the portal and hepatic venous system. This has led to low blood transfusion requirements, fewer complications, decreased LOS, and minimal mortality. These findings are particularly evident in the subset of major hepatic resections and this tool has proven to be quite effective for hepatectomies in the setting of living donation transplantation. The Water-jet has an equivalent safety and outcomes profile to that of other popular parenchymal dissection techniques.

Disclaimer

Dr Vollmer has provided educational and scientific consultation for the ERBE organization, makers of the Water-jet, and has received monetary compensation for such services. The ERBE organization has made no financial contribution to the creation of this manuscript.

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