Liver Resection With a New Multiprobe Bipolar Radiofrequency Device

Ahmet Ayav, MD, PhD; Long Jiao, MD, FRCS; Robert Dickinson, PhD; Joanna Nicholls, MSc; Miroslav Milicevic, MD; Ricardo Pellicci, MD; Philippe Bachellier, MD; Nagy Habib, ChM, FRCS

**Hypothesis:** Liver resection can be associated with marked blood loss. A novel multiprobe bipolar radiofrequency device (Habib 4X; RITA Medical Systems Inc, Fremont, California) has been developed to assist in liver resection and to reduce intraoperative blood loss.

**Design:** Prospective study.

**Setting:** Tertiary referral unit.

**Patients:** Sixty-two patients requiring liver resection between November 1, 2004, and February 28, 2006, primarily for metastatic cancer.

**Intervention:** Liver resection with the radiofrequency device.

**Main Outcome Measures:** Intraoperative blood loss, liver parenchyma transection time, and complications.

**Results:** There were 51 minor and 11 major hepatectomies. Mean (SD) transection time was 39 (27) seconds per square centimeter. Mean (SD) blood loss was 4.8 (5.6) mL per square centimeter. No patient required hepatic inflow occlusion. One patient required blood transfusion. There were no deaths, and the morbidity rate was 18%. Mean (SD) hospital stay was 8 (3) days.

**Conclusions:** This new bipolar radiofrequency device allows minor and major hepatectomies to be performed with minimal blood loss, low blood transfusion requirement, and reduced mortality and morbidity rates.


Surgical resection remains the most effective treatment for liver tumors, but it can still be associated with marked blood loss, which can affect postoperative recovery and long-term survival. Various intraoperative methods have been adopted by surgeons to minimize blood loss, including hypotensive anesthesia, hepatic pedicle clamping, and total vascular exclusion. These techniques involve clamping of inflow vessels to reduce bleeding during transection, which increases morbidity, mortality, and liver dysfunction, especially in patients with preexisting chronic liver disease. Despite these maneuvers, intraoperative blood loss ranges from 250 to 900 mL during liver resection, with 7% to 56% of the procedures requiring intraoperative blood transfusion.

In recent years, to avoid complications related to pedicle clamping, techniques for liver resection without clamping have been described. Devices such as the CUSA ultrasonic surgical aspiration system (Valleylab, Boulder, Colorado), harmonic scalpel, bipolar scissors, hydrodissectors, LigaSure diathermy (Valleylab), and monopolar floating ball have been developed to reduce blood loss during parenchymal transection. Radiofrequency energy has been widely used in the field of liver tumors, especially for in situ ablation of the tumors. A technique for liver resection has been described that uses a monopolar radiofrequency with a Cool-Tip needle (CT1200; Tyco Healthcare, Hants, England) and has been reported to reduce intraoperative blood loss and postoperative morbidity. However, 2 major drawbacks related to the use of radiofrequency have been recognized. The first is that it uses monopolar radiofrequency energy, which generates a current that passes from the active electrode within the liver through the body to a ground electrode on the skin surface; this carries risks of skin burn from the grounding pad, myocardial infarction, myoglobinuria, and cardiac arrhythmia.
binemia, and cardiac arrhythmias.\textsuperscript{25-28} As a result, the applied power must be curtailed to minimize such burns, hence increasing the heating time for each coagulation. The second drawback is that radiofrequency is time consuming because, even if the individual coagulation of non-tumoral liver is known to be quicker than that of fibrotic tumors, many probe applications are required to obtain an avascular plane along the resection line, especially for major hepatectomies or when multiple tumors-ectomies are mandatory.\textsuperscript{29}

To solve the problem, multiple electrode systems and bipolar devices have been designed, but to date none of them has been used to perform liver resection because they are actually used to ablate tumors.\textsuperscript{30} A new multi-probe bipolar radiofrequency device (Habib 4X; RITA Medical Systems Inc, Freemont, California) consisting of an array of needles arranged in a square has been developed and used in our unit to assist in liver resection. The present study assessed the feasibility and safety of liver resection with this new device.

METHODS

From November 1, 2004, to February 28, 2006, all patients who underwent liver resection with this new device at the Hammersmith Hospital were prospectively enrolled for the study. The device has been approved by the New Medical Device and Procedures Committee in England. All patients underwent careful preoperative assessment of their disease, including spiral computed tomography, magnetic resonance imaging, and/or positron emission tomography. All cases were discussed at a multidisciplinary meeting, and patients were fully informed of the risks, benefits, and alternatives to hepatic resection. Patient data were collected prospectively and included demographic details, nature and number of tumors, operative procedure, operating time, results of preoperative and postoperative liver function tests, perioperative complications, mortality rate, hospital stay, and outcome. Operative time was defined as the overall time of the surgical procedure measured from the start to closure of the skin incision, while the resection time was defined as the time from the start of radiofrequency to the completion of parenchymal transection. The overall blood loss was the combination of the weight of the surgical swabs and the amount of blood in the suction system for the whole operation. Blood loss during liver parenchyma transection was recorded in a similar way. All resected specimens were measured to calculate the resection surface to evaluate the resection time as well as the blood loss per square centimeter.

DESIGN OF THE RADIOFREQUENCY DEVICE

The radiofrequency device we used is a handheld electrosurgical instrument consisting of a $2 \times 2$ array of 4 needles spaced at the corners of a 6 × 7-mm rectangle. There are 2 versions: 1 with long (120-mm) needles and 1 with short (60-mm) needles. The needles act as radiofrequency electrodes and are made of stainless steel (Tomlinson Tube & Instrument Ltd, Warwickshire, England) with a polished titanium nitride nonstick coating (Tecvac Ltd, Cambridgeshire, England; Integrated Surgical Sciences Corp, Sedalia, Colorado) to facilitate insertion and removal from the liver tissue. The long device can reach distal regions of the liver being treated by applying radiofrequency energy at various depths. The volume heated by such long needles would be too great for rapid heating, so the active portion of the needles is restricted to the most distal 40 mm by insulating the proximal portion of the electrodes with a polyethylene coating, leaving the distal portion uninsulated (Figure 1). The short-needle device has been designed to perform precise coagulation of shallow tissues, especially for coagulating superficial vessels that may be bleeding after resection. Pairs of needles on the short (6-mm) side of the rectangle are connected together, and each pair is connected to 1 terminal of a bipolar radiofrequency generator (1500X; RITA Medical Systems Inc).

SURGICAL PROCEDURE

With the patient under general anesthesia, without reduction of central venous pressure, a modified right subcostal incision is made. After exploration to exclude extrahepatic or peritoneal disease, the liver is mobilized according to the size and site of the lesion to be resected. Intraoperative ultrasonography is always performed before liver resection to confirm the number, size, and location of the tumors, and to disclose any previously undetected lesions. It can also detect any aberrant or variant blood vessels or bile ducts that need to be preserved in cases of nonanatomic resection. Dissection of the hepatic pedicle is performed only for tumors located close to the hilus to facilitate separation of the tumor from hilar structures. For tumors close to hepatic veins, dissection is again performed first, to separate the tumor from the veins with ligation of these vessels. Otherwise, the hepatic veins and/or pedicle vessels are coagulated with radiofrequency without dissection or ligation beforehand.

Once the tumor is localized by bimanual palpation and intraoperative ultrasonography, a line is made on the liver capsule with argon diathermy 1 cm away from the edge of the tumor. It is important to mark the resection line before starting the radiofrequency energy because the liver tissue hardens and induces image changes on intraoperative ultrasonography, which can obscure the visualization of the tumor edge. The sealers is then introduced into the liver parenchyma along this line, which represents the future resection line. Radiofrequency power is set at 125 W to allow adequate coagulation of liver parenchyma before its division. This will ensure sealing of small vessels. However, for larger vessels such as hepatic or portal vein or in case of bleeding after ablation with 125 W, the power is reduced to 75 W to ensure sealing of these vessels at the expense of time. A series of coagulations is made, repositioning the device at a mean (SD) distance of 10 (3) mm each time to create a band of coagulation. At this stage, the liver paren-
chyma is divided with a scalpel. The liver parenchyma should be supported with fingers on both sides of the device to avoid pulling suddenly with force, which might lead to parenchymal fracture and bleeding. The plane of division is situated between the lines defined by the 2 electrodes (Figure 2). This technique allows a small amount of coagulated liver parenchyma to be left behind (less than 10 mm in depth), which is enough to ensure sealing of blood vessels and bile ducts. For deeply placed tumors, the radiofrequency device can be applied first to the surface of the liver to open it with the scalpel and then reapplied to continue the resection deeper into the liver. Because the liver is a global structure with a third dimension, it is extremely important to remain oriented to the division line at all times to avoid wandering away from the proper plane. To do this, a step-by-step approach is adopted, alternating application of radiofrequency with division of coagulated liver parenchyma to maintain a stereotactic plane by tactile feeling with 1 hand placed at the inferior surface of the liver along the future transection plane. The surface of the liver parenchyma left behind is homogeneous, without visible bile duct structures or blood vessels. Thus, no ties or clips are used to ensure biliary or blood vessel control, even for portal or hepatic veins. A 30F Robinson drain is usually placed at the site of resection before closing the abdomen. In the beginning of our experience, we used to monitor the tissue electrical impedance during heating, and the power was disabled when the impedance increased by 5 Ω from the quiescent value. If the impedance increased by more than 5 Ω, we noticed carbonization on the needles, which can cause tissue adhesion and bleeding when the device is removed from the liver. To avoid this, new generators (RITA 1500X; RITA Medical Systems Inc) are preprogrammed to switch the power off automatically when the impedance increases by 5 Ω.

From November 1, 2004, to February 28, 2006, 62 consecutive patients underwent liver resection with the Habib 4X multiprobe bipolar radiofrequency device. There were 52 first, 8 second, and 2 third hepatectomies. Clinical details of the patients are summarized in the Table. Most of the patients in this series (35 [56%]) had a solitary tumor in the liver. All of the procedures were completed as planned. Procedures undertaken were single segmentectomy or tumorectomy in 37 cases, multiple segmentectomies or tumorectomies in 9 cases, left lateral sectionectomy in 5 cases, left hepatectomy in 2 cases, and right hepatectomy in 9 cases. Five of the 9 patients who underwent right hepatectomy had undergone previous embolization of the right branch of the portal vein because of a small remnant liver (left lobe).

The overall operative time (mean [SD]) was 157 (56) minutes (median, 150 minutes; range, 60-300 minutes). The mean (SD) parenchymal transection time was 43 (32) minutes (median, 30 minutes; range, 8-120 minutes). The mean (SD) parenchymal transection time per square centimeter was 39 (27) seconds (median, 23 seconds; range, 14-108 seconds). The mean (SD) overall intraoperative blood loss was 267 (292) mL (median, 195 mL; range, 10-707 mL), and the mean (SD) blood loss during parenchyma transection was 75 (60) mL (median, 50 mL; range, 10-200 mL). The mean (SD) blood loss per square centimeter was 4.8 (5.6) mL (median, 2.1 mL; range, 0.17-19.6 mL). No patient required hepatic inflow occlusion (Pringle maneuver) during the procedure. Only 1 patient underwent blood transfusion either during or after the operation, which entailed a third hepatectomy for colorectal metastases. The overall blood loss was 707 mL and the patient received 2 U of red blood cells. Most of the blood loss (650 mL) occurred during dissection to gain access to the liver rather than parenchymal transection. No patient received fresh frozen plasma at any stage, and none was admitted to the intensive care unit postoperatively. No patients developed grounding pad skin burn, myocardial infarction, myoglobinemia, or cardiac arrhythmia during or after the procedure. There were no deaths.

Table. Patient and Tumor Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>59 (12)</td>
</tr>
<tr>
<td>Sex, No. M/F</td>
<td>28/34</td>
</tr>
<tr>
<td>Metastases</td>
<td>51 (82)</td>
</tr>
<tr>
<td>Colorectal</td>
<td>39</td>
</tr>
<tr>
<td>Neuroendocrine</td>
<td>3</td>
</tr>
<tr>
<td>Pancreas</td>
<td>2</td>
</tr>
<tr>
<td>Breast</td>
<td>2</td>
</tr>
<tr>
<td>Ovarian</td>
<td>2</td>
</tr>
<tr>
<td>GIST</td>
<td>1</td>
</tr>
<tr>
<td>Sarcoma</td>
<td>1</td>
</tr>
<tr>
<td>Melanoma</td>
<td>1</td>
</tr>
<tr>
<td>Hepatocellular carcinoma</td>
<td>6 (10)</td>
</tr>
<tr>
<td>Cholangiocarcinoma</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Gallbladder carcinoma</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Biliary cyst</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Angioma</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Tumor size, mean (SD), mm</td>
<td>44 (32)</td>
</tr>
<tr>
<td>No. of lesions, mean (SD)</td>
<td>2.0 (1.8)</td>
</tr>
</tbody>
</table>

Abbreviation: GIST, gastrointestinal stromal tumor.
The postoperative course was uneventful in 51 patients (82%). Morbidity occurred in 11 patients. Three patients developed an intra-abdominal fluid collection diagnosed on computed tomography, of which only 1 needed radiologic drainage; the other 2 were treated with antibiotics alone without the need for drainage because of the very small size of the collection. In the case of radiologic drainage, the collection was an abscess and not biliary fistulas. Eight patients developed a right pleural effusion, which was diagnosed on systematic chest radiography. Six of these patients were treated with physiotherapy alone and 2 with additional aspiration. Right pleural effusion occurred after 3 right hepatectomies and 5 segmentectomies of the upper part of the liver (ie, segment VII or VIII). No patient developed postoperative hemorrhage, biliary leak, or liver failure, and no patient required reoperation. Serum aspartate transaminase, alanine transaminase, and bilirubin levels rose at postoperative day 1 and normalized between postoperative days 3 and 7. Findings on pathologic examination showed that the resection margin, which normally consisted of approximately 5 mm of coagulative zone owing to the resection technique, was free of tumor in all cases. The mean postoperative stay was 8 (3) days.

COMMENT

To date, several multiple electrode systems and bipolar radiofrequency devices have been designed, but none has been used for liver resection. To our knowledge, this is the first series in which bipolar radiofrequency energy has been used to coagulate the liver parenchyma before transecting it with a simple knife and without additional ties or clips. Haghhighi et al reported the use of a multineedle probe to coagulate a line of liver parenchyma before resection with an in-line radiofrequency ablation system. Even if this system worked in a bipolar mode, the authors used radiofrequency primarily to prepare the transection plane. Transection was performed with an ultrasonic aspirator, and the vessels were sealed with the use of diathermy or clips. In our experience, the radiofrequency field created between the 4 electrodes causes ionic agitation, friction, and tissue heating, which led to occlusion of bile duct and blood vessels up to 7 mm in diameter. In the 9 cases of right hepatectomy, the right hepatic vein was sealed intraparenchymally after multiple applications of the probe with the power set at 75 W. None of these patients had previous extraparenchymal control or division of the right hepatic vein. Furthermore, among these first 62 cases, no postoperative hemorrhage or biliary fistula occurred, confirming the ability of the radiofrequency energy to seal vessels and bile ducts.

In this study, the mean blood loss during parenchymal transection was 75 mL, which is lower than in most major published series. We did not encounter major bleeding during mobilization of the liver because with this radiofrequency technique there is no need for extensive mobilization or dissection of the hepatic pedicle. However, in the case of a second or third hepatectomy, bleeding can still occur during the liver mobilization phase, as seen in 1 of our patients.

The monopolar (CoolTip) radiofrequency-assisted liver resection previously reported produces a margin of 1 to 2 cm, and some have expressed concern that necrotic tissue is left behind. With the multiprobe bipolar radiofrequency device used in this study, the plane of division is situated between the line defined by the 2 electrodes (Figure 2), indicating that the depth of necrotic tissue left behind is less than 10 mm, which is enough to ensure hemostasis and biliary control. In this series, there was no postoperative bleeding or biliary fistula, which confirms the accuracy of the sealer to close blood vessels and biliary ducts. In this series, no additional ties or clips were applied on vessels along the resection line. All vessels, including the right hepatic vein in cases of right hepatectomy, were coagulated with the device. For major hepatectomy with this technique, there is no need for hilar or extraparenchymal dissection to control large pedicles because radiofrequency, when applied repeatedly at a power of 75 W, is adequate to seal off larger pedicles, including arterial, venous, and biliary structures. Other groups using this method for liver resection have also reported this phenomenon. Furthermore, we believe that the coagulated zone left in the resection margin may improve the clearance of this margin and may reduce the incidence of local recurrence. In our own experience with liver resection with monopolar radiofrequency, we encountered 2 cases of local recurrence in the resection margin among 156 patients. This low incidence needs to be confirmed in a larger series with long-term follow-up.

No major postoperative morbidity, such as hemorrhage, biliary fistulas, or liver failure, occurred in patients undergoing liver resection with this device. Minor complications, consisting of intra-abdominal collections and right pleural effusion, occurred in a few patients. These complications were not directly related to the resection technique; they occur frequently with conventional parenchymal transection techniques. Postoperative liver function tests showed a significant increase in transaminase and bilirubin levels postoperatively at day 1, which normalized spontaneously between postoperative days 3 and 7. Liver function changes have also been reported in patients undergoing liver resection with an ultrasonic dissector and/or monopolar floating ball without pedicle clamping. These transient abnormalities are most likely related to the zone of coagulative necrosis left behind along the resection margin and are completely different from the whole-liver ischemic damage that is caused by hepatic inflow occlusion and can lead to postoperative liver failure, especially in the case of underlying liver disease.

The rate of major hepatectomies was quite small in this series. We believe that the use of this radiofrequency-assisted liver resection technique has more than halved the number of right hepatectomies compared with resections performed previously with conventional techniques. In our experience, the rate of major hepatectomy dropped from 64% to 20% with the current technique, allowing us to safely perform more minor and fewer major hepatectomies. Even
though segmental and nonanatomic resections are commonly classified as minor hepatectomies, they are often more challenging and technically demanding and can cause more bleeding than classic lobar resection. This new device allows the liver surgeon to safely perform multiple tumorectomies with minimal blood loss rather than major hepatectomies, thus minimizing the excision of nontumoral liver parenchyma and diminishing the risk of postoperative liver failure. This is especially relevant in cases of liver resection for liver metastases, which is the most common indication for liver resection in our experience. For this indication, if technically feasible, we undertake liver resection to obtain tumor clearance by performing nonanatomic resection (ie, minor hepatectomy) with curative intent to spare liver parenchyma, bearing in mind that these patients may present with other liver metastases and undergo second or third hepatectomies.39

The heat coagulative necrosis plane is created much faster with this bipolar device than with the monopolar probe, allowing us to reduce the mean (SD) parenchymal transection time to 43 (32) minutes with the multiprobe bipolar radiofrequency device as opposed to 75 (51) minutes with the monopolar probe, without jeopardizing the effectiveness of the procedure.37 It is expected that with increased experience this technique will reduce the transection time even further.

This 4-needle bipolar radiofrequency device for liver resection has decreased liver parenchymal transection time and has been used safely for both major and minor hepatectomies, with minor blood loss and without increasing the postoperative morbidity rate. It offers a useful additional method for transection of liver parenchyma for hepatobiliary surgeons.

Accepted for Publication: January 5, 2007.

Correspondence: Nagy Habib, ChM, FRCS, Department of Surgery, Hammersmith Hospital, Imperial College School of Medicine, Du Cane Road, London W120NN, England (nagy.habib@imperial.ac.uk).

Author Contributions: Study concept and design: Ayav, Jiao, Dickinson, Nicholls, Milicevic, Pellicci, Bacheller, and Habib. Acquisition of data: Ayav. Analysis and interpretation of data: Ayav and Jiao. Drafting of the manuscript: Ayav, Jiao, and Dickinson. Critical revision of the manuscript for important intellectual content: Ayav, Jiao, Nicholls, Milicevic, Pellicci, Bacheller, and Habib. Statistical analysis: Ayav. Administrative, technical, and material support: Dickinson. Study supervision: Habib.

Financial Disclosure: Drs Habib and Dickinson have financial interest in EMcision, which is an Imperial College partner that licensed the Habib 4X to RITA Medical Systems Inc.

REFERENCES

30. Livraghi T, Goldberg SN, Lazzaroni S, Meloni F, Solbiati L, Gazelle GS. Small he-
he use of hepatic resection for metastatic colorectal cancer has grown enormously during the past few decades. Because of data compiled from numerous centers throughout the world, it has become clear that patients with 1 to 3 hepatic metastases will be cured with a hepatic resection 30% of the time. No chemotherapy can offer comparable statistics. Furthermore, there are no data to suggest that taking out a lobe or a full segment is superior to just removing the metastases as long as the margin is 1 cm.

Many new instruments have been developed to help with hepatic resections by reducing bleeding. Among them have been the CUSA ultrasonic surgical aspiration system, harmonic scalpel, and others. The introduction of such instruments has generally come after laboratory research and marketing on the part of the manufacturers. Actual studies of the clinical usefulness of these instruments, such as the present report, have generally not been performed.

The Habib 4X is a multiprobe bipolar radiofrequency device developed to assist in liver resections. The authors of this report include Dr Habib, who helped to develop this device. This is a report of their use of the device in 62 consecutive liver resections. The report shows that using the device resulted in minimal blood loss and acceptable operative times. The complications were the same as those seen after hepatectomies. This report is not a randomized study, but this kind of device does not really require a randomized study. The point of the device is to help surgeons perform resections more easily and without additional complications.

This report has shown us that the Habib 4X can be used safely and, in experienced hands, it performs well. Now it is up to other surgeons to decide whether this is useful to them.

M. Margaret Kemeny, MD

Correspondence: Dr Kemeny, Cancer Center of Queens, Queens Hospital Center, 82-68 164th St, Jamaica, NY 11432 (kemenym@nychhc.org).