A Radiofrequency-Assisted Minimal Blood Loss Liver Parenchyma Dissection Technique

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Key Words
Liver resection • Minimal blood loss • Radiofrequency-assisted technique

Abstract
Background/Aims: Intraoperative blood loss is still a major concern for surgeons operating on the liver since it is associated with a significantly higher rate of postoperative complications and shorter long-term survival. An original radiofrequency (RF)-assisted minimal blood loss technique for transecting liver parenchyma is presented. Methods: In a prospective study, starting November 2001 and ending December 2005, a total of 90 RF-assisted liver resections were done. Pre-cut coagulative desiccation was produced by the Cool-tip™ (Valleylab, Tyco) water-cooled, single, RF tumor ablation electrode connected to a 480-kHz 200 W generator (Valleylab Cool-tip™ RF System). Vascular occlusion techniques and low central venous pressure anesthesia were not used. Results: Only 14 (15.5%) patients received blood transfusion (mean transfused blood volume 397 ml; mode 310 ml) and 10 of 14 patients received <310 ml of blood. There was no statistical difference between the patients who underwent major and minor liver resection in frequency of blood transfusion. Blood loss was associated with dense adhesions and difficult liver mobilization and not with liver transection. Conclusion: The ‘sequential coagulate-cut’ RF-assisted liver resection technique is a safe liver transection technique associated with minimal blood loss and it has facilitated tissue-sparing liver resection.

Introduction
Liver resection is nowadays done for a variety of primary or metastatic liver tumors, for benign liver disease, in liver trauma and for harvesting a graft in living related liver transplantation [1–3]. Improved imaging techniques, refinements in surgical technology, and a better understanding of the hepatic anatomy, physiology and cell biology has allowed for optimal tailoring of the procedure to the patient’s individual needs. Improved postoperative and long-term results are mainly due to performing parenchyma-sparing, segment-oriented resection which reduces the risk of liver failure and increases the chance of re-resection for recurrence [2, 3]. High-volume centers achieve mortality rates in the range of 0–3.0% [1–5]. Lowering of the postoperative risk has broadened the indications for liver resection and there is an increasing tendency to offer it as a treatment modality to older patients, patients with concomitant disease and patients with excessive tumor burden.
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Table 1. Indications for liver resection

<table>
<thead>
<tr>
<th>Indications for resection</th>
<th>Patients</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRC metastases</td>
<td>59</td>
<td>65.7</td>
<td></td>
</tr>
<tr>
<td>Primary liver cancer</td>
<td>17</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Giant liver hemangioma</td>
<td>3</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>Lung cancer metastases</td>
<td>2</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Ovary cancer metastases</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Gallbladder cancer</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Liver hydatid cyst</td>
<td>2</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Liver cystadenoma</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Recurrent liver abscess</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Liver actinomycosis</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Solitary necrotic liver nodule</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Metastasis – undetectable primary tumor</td>
<td>1</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

Total 90 100.0

Nevertheless, liver surgery still remains a complex surgical procedure in the general surgical unit, requiring well-trained, experienced and skilled surgeons as well as significant resources. Peroperative blood loss still is a major concern for surgeons operating on the liver since it is associated with a significantly higher rate of postoperative complications and shorter long-term survival [2, 3]. Refinements of vascular occlusion techniques, use of low central venous pressure (CVP) anesthesia and application of innovative technology for liver transection are some of the factors that have significantly reduced procedure-associated hemorrhage and improved the safety of liver resection. All these routines have their indications, hemodynamic consequences, and limitations mainly in patients with chronic liver disease and when doing non-anatomical resection. A surgical technique, which includes the use of an energized instrument that can safely deal with transection of liver parenchyma and hemostasis at the same time, could possibly overcome these drawbacks.

A new technique using radiofrequency (RF) energy to coagulate liver resection margins and perform tissue-sparing bloodless liver resection is described.

**Material and Methods**

In a prospective study, starting November 2001 and ending December 2005, a total of 90 RF-assisted liver resections were done. There were 44 women and 46 men. The youngest patient was 18 and the oldest 78 years old (mean 57.71 years). Indications for liver resection were malignant tumors in 81 and benign disease in 9 patients (table 1). The majority of patients (59/90) had been previously operated for colorectal cancer. All patients operated for hepatocellular carcinoma (17/90) were Child’s grade A, and histology of non-tumorous liver tissue-confirmed cirrhosis.

All patients included in this study met the following criteria: (a) no extrahepatic spread of the disease – the only exception was resectable pulmonary colorectal metastases operated as a second stage procedure; (b) liver lesion or lesions that can be resected with adequate (R0) margins; (c) a sufficient amount of remnant functional liver parenchyma; (d) no obstructive jaundice, and (e) no simultaneous operative procedures on other organs.

Preoperative work-up of the patients included: (a) accurate liver imaging for planning the extent of resection utilizing contrast-enhanced multislice CT or NMR; (b) the lidocaine test in order to assess hepatic functional reserve in patients with large or multiple liver tumors; (c) tumor markers – CEA, AFP and Ca19-9 levels in all patients operated for malignancy, and (d) a diagnostic and staging laparoscopy if intraperitoneal seeding was suspected.

A standardized RF-assisted two-surgeon liver resection technique was done in all patients. The same two surgeons working in tandem performed all of the operations.

Pre-cut coagulative desiccation was produced by the Cool-tip™ (Valleylab, Tyco) water-cooled, single, RF tumor ablation electrode (electrode in the text) connected to a 480-kHz 200-watt generator (Valleylab Cool-tip™ RF System). The 17-gauge (4.5-Fr) electrode was 10 or 20 cm long, and had an active non-insulated tip 1 or 3 cm long. The RS232 port of the generator was connected to a notebook computer running specially designed software, that monitored electrode RF emission time (min), total delivered (Coulombs) and maximal delivered current (mA). The device delivered maximum power in the range of 50–100 W and induced coagulation and desiccation of liver parenchyma and small vessels without char formation in approximately 8–10 s.

Minor hepatectomy was defined as resection of <2 liver segments. Major hepatectomy was defined as resection of >2 liver segments. In patients undergoing non-anatomical liver resection, a surgical resection margin (tumor clearance) of ≥2 mm was considered satisfactory [6–8].

In all patients, biochemical liver function tests were monitored before, on the 1st, 2nd, 3rd, 5th and 7th day after liver resection. Liver sequestration, liver abscess, subphrenic abscess, bile leakage, sepsis, chest involvement and postoperative bleeding were considered procedure-related complications.

**The Technique**

Under general anesthesia a midline incision with a right sagital prolongation (J incision) without opening the diaphragm is performed. Intra-abdominal adhesions and the falciform ligament are divided. The peritoneal cavity is thoroughly examined for evidence of extrahepatic spread and local recurrence in patients previously operated for malignant disease. A Thompson retractor is always used to ensure good exposure of the liver. The patient is in an anti-Trendelenburg position (15° head up). The tumor-containing liver lobe is mobilized in a standard way to the extent necessary for the intended resection, avoiding unnecessary liver mobilization and manipulation.

Intraoperative ultrasound, assisted by bimanual palpation, is always done to determine the accurate position, extent, number of the tumors and their relation to the hepatic veins and glissonian...
pedicles. The upper and lower surface of the liver are marked with diathermy in order to provide a roadmap for the resection.

Inflow and outflow occlusion of the liver vessels, low CVP anesthesia, and topical hemostatic agents were not used during transection of the liver parenchyma.

Liver transection is started by inserting the entire non-insulated tip of the electrode into the liver parenchyma. The tip of the electrode is inserted parallel to the liver surface, 2–3 mm beneath the liver capsule and along the marked lines. RF energy is applied by rapidly increasing the output to maximum power, which, when using the 30-mm tip electrode, produces an approximately 30-mm-long and 6-mm-wide cylinder of pale, desiccated liver tissue in <10 s. Coagulative desiccation progresses upwards, from the inserted non-insulated tip of the electrode, to the liver surface causing the tissue to change to a pale color. After the cylinder of desiccated liver tissue is achieved, with the electrode still in place, the desiccated tissue is cut with a surgical scalpel all the way to the non-insulated tip of the electrode (fig. 1).

A coagulate-cut cycle can be described as the process of creating a 30-mm long and 6–8 mm wide cylinder of coagulated and desiccated liver tissue by applying RF energy through the non-insulated tip of the electrode inserted into the liver parenchyma and then dividing the coagulated tissue by surgical scalpel or scissors. Essentially, the non-insulated tip of the electrode is used in the same way the tip of the CUSA is used. Division of the liver parenchyma always progresses from the intact or cut surface of the liver into the bulk of the liver and from the anterior to the posterior aspect of the liver. Transection of the liver parenchyma is achieved by sequential coagulate-cut cycles always under direct visual guidance regardless of whether we are doing an anatomical or non-anatomical liver resection.
The consequent resection margins consist of coagulated and desiccated, practically welded, liver tissue. Since small blood vessels are occluded during the multiple rapid sequential coagulate-cut cycles, the operative field is practically bloodless. All relevant intraparenchymal structures can be visually identified without prior thermal damage and subsequently divided or preserved (fig. 2, 3).

When operating for colorectal cancer liver metastases, the sequential coagulate-cut RF-assisted technique facilitates non-anatomical, limited, tissue-sparing liver resection regardless whether the transection planes are straight or curved. Coagulation and division of the liver parenchyma starts at the point nearest to the presumed inflow routes. The transection plane is molded according to the relation of the tumor to the hepatic veins and glissonian pedicles sparing as much unaffected liver parenchyma as possible.

When operating for hepatocellular cancer, segment-oriented, anatomical, liver resection, whenever possible, is preferred. Following intraoperative ultrasound exploration, the involved pedicle is identified and approached through a hepatectomy performed by the sequential coagulate-cut technique. The pedicle is temporarily clamped, the demarcated zone evaluated, and if satisfactory, liver transection is done by guiding the electrode along the demarcation line using the sequential coagulate-cut technique with minimal blood loss.

**Results**

The types of liver resection performed are listed in table 2. Major liver resection was done in 20 (22.2%) patients, single or multiple segmentectomy in 36 (40.0%) patients and non-anatomical resection in 34 (37.7%) patients.

Major liver resection was done in 20 (22.2%) patients: (a) right hepatectomy in 12 (13.3%) patients; (b) left hepatectomy in 5 (3.3%) patients; (c) extended left hepatectomy in 2 (2.2%) patients, and (d) resection of 3 segments in 3 (3.3%) patients. Single or multiple segmentectomy was done in 36 (40.0%) patients and non-anatomical resections in 34 (37.7%) patients. A total of 14 (15.5%) patients underwent anatomical liver resection with concomitant non-anatomical resection. Re-resection for re-

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**Fig. 2.** a The liver is transected for a right hepatectomy. The rim is thin and the coagulated surface is only a few millimeters thick. b Six months after right hepatectomy, the transected surface is clean of debris, there is no coagulated tissue and it is coated with a small cellular layer without adhesions.

**Fig. 3.** Left lateral segmentectomy for a large hemangioma. Excellent hemostasis and thin coagulated rim.
current liver malignancy was done in 9 (10%) patients. Multiple non-anatomical resections was done in 20 (22.2%) patients (range 2–6). Thirty-seven (29.1%) patients underwent simultaneous resection on both sides of the liver. The average time necessary for transection of the liver parenchyma was 93 min (median 75 min; mode 60 min).

A total of 14 (15.5%) patients received blood transfusion (mean transfused blood volume 397 ml; mode 310 ml). There was no statistical difference between the patients that underwent major and minor liver resection in frequency of blood transfusion. Only 1 (5.5%) patient of all cirrhotic operated patients received a transfusion (tables 3, 4).

There were eleven different postoperative complications. The most frequent complication was chest involvement (10 patients). There was no biliary fistula in the current series. The perioperative morbidity was 13.4% (17 patients) and 4 patients developed more than one complication. One patient was re-operated for sequestrated coagulated liver tissue and one other patient for abdominal wound dehiscence.

The perioperative mortality rate was 3.3% (table 5). A 78-year-old patient died after liver resection for CRC liver metastases. In the early postoperative period he developed oliguria that progressed to a short period of anuria with stable liver function. The kidney dysfunction was
corrected, but he soon developed uncontrollable diarrhea and sepsis in spite of intensive therapy. He died on the 28th day after operation. Autopsy revealed small sclerotic kidneys and pseudomembranous colitis. Liver function was not affected by the operation. A 75-year-old patient, operated for CRC metastases, died of cerebral infarction as verified at autopsy. A 67-year-old patient, operated for hepatocellular carcinoma, died of intractable liver failure. She had a right hepatectomy done for a 5-cm lesion infiltrating the right main pedicle. The operation was uneventful, there was no blood loss. Liver function deteriorated in the postoperative period and the ensuing hepatic failure was fatal.

Discussion

Major blood loss during liver resection increases perioperative morbidity and mortality [2, 3]. Concomitant massive blood transfusion has profound effects on postoperative complication rates and it is associated with a worse prognosis following surgery for both hepatocellular cancer and colorectal liver metastases [1–5, 9–11]. Intraoperative bleeding during liver resection can occur during liver mobilization, dissection of the vasculobiliary structures or transection of the liver parenchyma.

There are no anatomical planes in the liver through which bloodless transection of the parenchyma can be performed. Significant bleeding from the cut liver surface during transection is unavoidable and should be efficiently controlled. Commonly used methods for controlling intraoperative blood loss during transection of the liver parenchyma are: (1) pretranssection surgical techniques that temporarily interfere with blood supply to the liver (Pringle maneuver) – inflow and outflow occlusion (clamping) of the liver vessels and low CVP anesthesia, and (2) surgical techniques for transecting the liver parenchyma – transection procedures, special instruments, energized instruments and topical hemostatic agents.

Control of hepatic inflow and outflow enables surgeons to perform liver resection in a practically devascularized (ischemic) field with decreased morbidity and mortality. The main disadvantage of these procedures is that they can facilitate liver failure in patients suffering from chronic liver disease due to ischemia-reperfusion injury and that their use is time limited [9]. Patients with marginal liver function are very sensitive to alterations in liver blood supply, especially for longer periods, and the consequences cannot be always accurately predicted.

The mechanism of ischemia-reperfusion injury that causes hepatocyte death is only partially understood. Interruption of blood flow to the liver results in warm ischemia and consequent mitochondrial dysfunction, loss of intracellular ionic homeostasis and cellular injury [12]. Reperfusion, on the other hand, as an oxidative stress leads to: (1) the development of reactive oxygen species, (2) early Kupffer cell activation, (3) no-reflow microvascular disturbance, and (4) activation of neutrophils [13, 14]. The end result is apoptosis and necrosis of hepatocytes.

Intermittent portal clamping and protective preconditioning ischemia can attenuate the degree of the ischemia-reperfusion injury and can prolong ischemia duration [15]. Impaired regenerative capacity of the liver can diminish effectiveness of these procedures [16, 17].

Surgical techniques for safe transection of the liver parenchyma are based on two principles: (1) the separation of the soft liver parenchyma from blood vessels and biliary ducts, and (2) performing subsequent definitive surgical hemostasis. Anatomical, segment-oriented, liver resection facilitates this type of transection of the liver parenchyma because the interface between adjacent liver segments is a vascular ‘watershed’ containing significantly fewer blood vessels. With standard operating techniques, segmental-oriented liver resection generally reduces perioperative mortality and morbidity [2]. The crucial question is whether it is always necessary to utilize anatomical boundaries between segments to transect the liver, especially when operating for small, multiple or bilateral CRC metastases that are likely to recur. Furthermore, metastases can cross intersegmental boundaries and engage a minor part of an adjacent segment. Performing segment-oriented liver resection as a standard procedure will inevitably sacrifice a wider extent of functioning liver parenchyma and can, especially in patients with marginal liver function, precipitate liver insufficiency.

Weber et al. [18] described in detail the principle and procedure of bloodless liver resection using RF energy. This procedure is known as the original Habib ‘two-circle’ RF-assisted bloodless liver resection technique.

The concept of inducing intracellular ionic agitation by high-frequency electric current to produce heat and to cause coagulative necrosis in liver tumors is not new and it is the basis for RF tumor ablation [19, 20]. The exposed tip of the electrode (CoolTip®), since it is actively water-cooled, is not the source of conductive heat, so tissue heating, due to charring, is not an imminently self-limiting process. Ionic agitation, in contiguous liver tissue,
produces heat by friction. The innovative step in RF-assisted liver resection is that coagulation of normal liver parenchyma is much more rapid than coagulation of tumor tissue. Rapid heating of normal liver tissue causes desiccation and collagen bonding resulting in tissue shrinkage and permanent ‘welding’ of all vascular and biliary branches. This principle is the basis of the Weber and Habib technique [18]. The liver tissue, along the resection line, is precoagulated by multiple full-thickness electrode insertions and an ‘avascular’ tissue plain is created. Dividing the liver along this clearly visible ‘avascular’ tissue plane with a surgical scalpel is virtually bloodless and no inflow or outflow clamping is necessary.

The sequential coagulate-cut procedure described in this paper was developed by the authors in January 2002 and it is based on the principle described by Weber et al. [18]. The crucial difference is in the way the electrode is used. Instead of inserting the electrode through the entire liver parenchyma and retracting it during coagulation and desiccation, we prefer to use the electrode in a similar way that the CUSA hand piece is used for advancing through liver parenchyma under visual guidance. Manipulating the electrode in this way makes it possible to perform tissue-sparing liver resection with a narrow resection margin of 3–5 mm. The parenchyma transection plane is not precoagulated and its shape and direction can be altered during the division of the liver to accommodate the site, size, shape and spread of the tumor. This technique is known as the Belgrade or the Milićević-Bulajić technique and it has been published in detail [21].

Perioperative blood loss was not associated with the parenchyma transection technique in the series. It was predominantly due to dense adhesions from previous colorectal surgery and difficult liver mobilization.

There was no substantial blood loss related to the transection of the liver parenchyma (mean 6.6 ml, max. 70 ml, SD 16,395). Significant blood loss was not related to the extent of the liver resection but rather to dense adhesions and difficult liver mobilization (mean 132.9 ml, max. 900 ml, SD 151,123). A total of 76 (84.5%) operated patients did not receive blood transfusion. Only 14 (15.5%) patients received blood transfusion (mean transfused blood volume 397 ml; mode 310 ml). Detailed analysis revealed that 10 of the 14 patients received <310 ml of blood (mean 277 ml; mode 310 ml) and that the transfusion was not indicated by the operating surgeon but rather by the on-duty anesthetist who did not have a detailed knowledge of the RF-assisted resection procedure. Only 4 (3.1%) patients had indications for blood transfusion and received more than 2 units each (mean 700 ml). There were no statistical differences between the patients that underwent major or minor liver resection in terms of indications for blood transfusion. Only 1 patient with a cirrhotic liver received a blood transfusion.

Mortality and morbidity were not associated with the RF-assisted liver transection technique.

The ‘sequential coagulate-cut’ technique has several advantages: (a) RF energy is applied under direct vision and vital structures within the liver can be avoided; (b) vital structures can be ligated in order to save time and keep delivered RF energy at a minimum; (c) the liver resection can be extended to include devitalized liver parenchyma should it occur; (d) the rim of the coagulated liver and the transection plane is minimal, only several millimeters thick; (e) identification of segmental pedicles during transection is facilitated and temporary clamping is possible; (f) it is possible to use this procedure on cirrhotic livers as well; (g) if the non-insulated tip of the electrode is carefully manipulated and prolonged contact avoided, working around the VCI and portal vein is safe, and (h) atypical and typical liver resection can be safely performed without the need for inflow clamping or vascular exclusion.

**Conclusion**

The ‘sequential coagulate-cut’ RF-assisted liver resection technique has affected the way we do liver resection. More difficult patients with more extensive disease are rendered operable. Vascular occlusion techniques are not used in routine practice anymore. Blood loss is minimal and disease-free margins can be obtained even with tissue-sparing liver surgery. Altogether, less extensive liver resection is performed more frequently because it is possible to efficiently control intraoperative bleeding even in complex, irregularly-shaped, atypical, liver resection. Re-operation for liver tumor recurrence is more frequently possible due to the initial tissue-sparing procedure and the RF-assisted safe technique for atypical liver resection. Re-resection is facilitated since irregularly-shaped tissue-sparing resection is possible. Postoperative bile leakage is infrequent. The operating and ICU time has been reduced. Liver resection has become simpler. Further controlled studies are needed to evaluate the true merits of RF-assisted liver resection.
References


