HPB, 2006; 8: 248–254

Taylor & Francis
Taylor & Francis Group

REVIEW ARTICLE

Radiofrequency ablation-assisted liver resection: review of the literature and our experience

PENG YAO & DAVID L. MORRIS

University of New South Wales, Department of Surgery, St George Hospital, Sydney, Australia

Abstract
Background. Surgical resection is the best established treatment known to provide long-term survival and possibility of cure for liver malignancy. Intraoperative blood loss has been the major concern during major liver resections, and mortality and morbidity of surgery are clearly associated with the amount of blood loss. Different techniques have been developed to minimize intraoperative blood loss during liver resection. The radiofrequency ablation (RFA) technique has been used widely in the treatment of unresectable liver tumors. This review concentrates on the use of RFA to provide an avascular liver resection plane. *Methods and results*. The following review is based on two types of RFA device during liver resection: single needle probe RFA and the In-Line RFA device. *Conclusion*. Liver resection assisted by RFA is safe and is associated with very limited blood loss.

Key Words: *Blood loss, RFA-assisted liver resection, In-Line device*

Introduction

Both primary and metastatic cancers of the liver are common and lethal diseases. In Western countries, primary liver cancer is comparatively rare, but is rapidly increasing due to the increased prevalence of hepatitis C, and metastatic colorectal carcinoma is the major indication for liver resection [1–3]. Primary liver cancer is, however, much more common in other parts of the world, representing 10–50% of malignancies in Africa and parts of Asia [4–6].

Currently, surgical resection is the optimal treatment known to provide long-term survival and possibility of cure for both primary and metastatic liver cancer [7–9]. Unfortunately, intraoperative blood loss has been a major concern during major liver resections, and mortality and morbidity are clearly associated with the amount of blood loss [10,11]. The mean blood loss has been reported to be between 600 ml and 1300 ml [12,13], with 28–47% of the patients requiring blood transfusion [12,14]. Several studies have shown that blood loss correlates adversely with length of hospital stay, complication rate, and patient survival [15,16]. It also has been shown that patients requiring more than 10 units of blood after liver resection for colorectal cancer metastasis have an increased risk of tumor recurrence and poor survival, probably due to immunosuppression [17,18].

Therefore, over the past decade many techniques have been developed to minimize intraoperative blood loss during liver resection [19–22]. Surgeons can decrease intraoperative blood loss by using hypotensive anesthesia to reduce the central venous pressure [23], Pringle's maneuver [24], or total vascular exclusion [25]. Parenchymal transection can be performed with the finger fracture or Kelly clamp/crush, using the ultrasonic dissector [20], the WaterJet dissector [26], or stapling devices [27].

Radiofrequency ablation (RFA) has been broadly used for unsectable liver tumors and produces coagulative necrosis of the liver parenchyma and thrombosis and coagulation of small blood vessels [28–33]. Several recent studies have shown that the use of RFA to assist liver resection decreased blood loss dramatically [34–44]. This new technique employs the heat produced by the radiofrequency device to coagulate the liver tissue before resecting it. A plane of tissue is coagulated by the RFA device, after which resection is performed along the coagulated tissue plane. By using

Correspondence: Professor David L. Morris, UNSW Department of Surgery, St George Hospital, Kogarah, NSW 2217, Australia. Tel: +61 2 9350 2070. Fax: +61 2 9350 3997. E-mail: david.morris@unsw.edu.au

ISSN 1365-182X print/ISSN 1477-2574 online
DOI: 10.1080/13651820600703272

Table I. Clinical details of RFA-assisted liver resection.

First author	Medical center, city, country	Year	No.	Age (years)	Types of resection	Operation time (min)	Blood loss	Transfusion	Complication	Hospital stay (days)
Navarra [34]	Department of Human Pathology, University of Messina, Messina, Italy	01/2001–01/2002	27		Open hepatectomy	47.5 (30–110)	30 ml (15–992)	Nil	Nil	8 (5–86)
Tepel [36]	Klinik fur Allgemeine Chirurgie und Thoraxchirurgie, Universitatsklinikum Schleswig-Holstein, Campus Kiel, Germany		7	74 (41–78)	1 segment (2); 2 segments (3); >2 segment (2)			1 case	Second degree burn to the thigh (1); bile leak (1)	
Navarra [37]	Department of Surgical Oncology and Technology, Imperial College School of Medicine, Hammersmith Hospital Campus, London, UK	01/2001–07/2002	42	57.5 (25–79)	1 segment (13); 2 segments (16); >2 segment (13)	50 (30–110)	30 ml (15–992)	Nil	Subphrenic abscess (1); chest infection (1); biliary leak (1)	
Weber [38]	Department of Surgical Oncology and Technology, Faculty of Medicine, Imperial College of Science, Technology and Medicine, Hammersmith Hospital Campus, London, UK	01/2000–06/2001	15	59 (36–75)	1 segment (8); 2 segments (6); >2 segments (1)	205 (95–300)	30±10 ml	Nil	Nil	8 (5–9)
Beppu [39]	Department of Gastroenterological Surgery, Graduate School of Medical Sciences, Kumamoto University, Kumamoto, Japan	2004	7	64	Laparoscopic hepatectomy	256	96 g	Nil	Nil	11
Weber [40]	Centre de Chirurgie Viscerale et Transplantation, Hopitaux Universitaires de Strasbourg, Avenue Moliere, Strasbourg, France	2002	1	43	Laparoscopic hepatectomy	300	75 ml	Nil	Nil	6
Stella [42]	Department of Surgery, Santa Corona Hospital, Pietra Ligure, Savona, Italy	06/2002–11/2002	8	64.8 (55–72)	1 segment (3); 2 segments (3); >2 segments (2)	220 (170–420)	46 ml (5–150)	Nil	Abscess (1)	9.4 (5–20)
Navarra [43]	Department of Surgical Oncology and Technology, Faculty of Medicine, Imperial College of Science, Technology and Medicine, Hammersmith Hospital Campus, London, UK	2002	1		Right hepatectomy	80	30 ml	Nil	Nil	9

this technique, blood loss has significantly decreased to a mean of 30 ml [38].

Currently, there are two types of RFA device used in liver resection: single needle probe RFA and In-Line RFA. Both were successfully used in animal and patient experiments to reduce blood loss in liver surgery. This review will attempt to characterize the unique clinical features of RFA-assisted liver resection.

Methods

Single needle probe RFA

RFA-assisted liver resections using a single needle probe have been done in different medical centres (Table I). All patients underwent careful preoperative assessment for their disease, including spiral computed tomography (CT) scanning or magnetic resonance imaging (MRI), and showed no evidence of unresectable extrahepatic disease. Surgical resections ranged from multiple metastasectomies to bisegmentectomies.

Liver resections were carried out under general anesthesia. The peritoneal cavity was examined for evidence of extrahepatic disease. After dividing intra-abdominal adhesions and the falciform ligament, the liver was then mobilized according to the size and site of the lesion to be resected. An intraoperative ultrasonogram was always performed prior to liver resection.

Habib's group has previously described the technique of RFA-assisted liver resection [38]. In step 1 (Figure 1), an inner line is made on the liver surface with diathermy to mark the periphery of the tumor, assisted with bimanual palpation and intraoperative ultrasound. It is important to do this first, because after RFA is used, the parenchyma is hardened and it becomes difficult to feel the tumor edge. Also, after RFA, it is impossible to visualize the tumor edge with intraoperative ultrasound; this is a real and important difference which must be understood with all RFA-assisted liver resections.

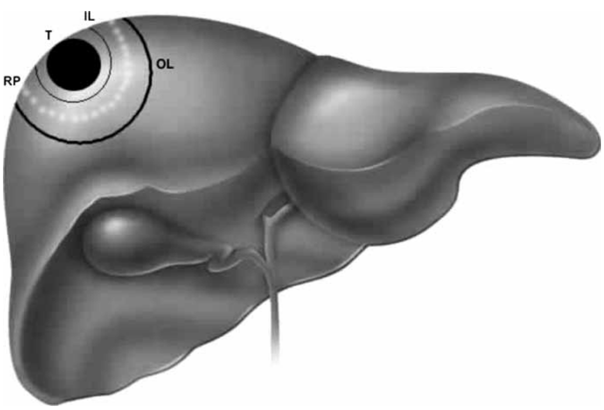

Figure 1. Single needle probe RFA-assisted liver resection. T, tumor; IL, inner line; OL, outer line; RP, resection plane.

In step 2, an outer line, again using diathermy, is made on the liver capsule 2 cm outside (away from) the inner line to mark the site where the probe is going to achieve coagulative necrosis.

In step 3, coagulative necrosis is produced along the outer line using a RFA probe, whilst Habib's group have used the saline-cooled RFA probe; essentially all ablation devices can be used for this purpose.

In step 4, further probe applications are deployed to obtain a zone of necrosis according to the depth of the liver parenchyma to be resected. Each application of RFA energy will need to be applied for about 60 s. The surgeon should check that each probe is correctly positioned by means of ultrasound.

In step 5, the liver parenchyma is transected by using the scalpel. The plane of division should be situated midway between the inner and outer line so as to leave a 1 cm resection margin away from the tumor and leave *in situ* 1 cm of burned coagulated surface.

All of these groups achieved very good results [34,36–40,42,43] (Table I). Habib et al. demonstrated that blood loss could be reduced to $<30 \pm 10$ ml for a right hepatectomy, and practically zero blood loss on most occasions [38]. In all of their 108 patients, only one case needed blood transfusion [36]. Other complications included: one second degree burn to the thigh [36], two bile leaks [36,37], one subphrenic abscess [37], and one chest infection [37]. These complications were from two studies [36,37]. Patients in other studies underwent an uneventful recovery; no significant bile leak, abscess, or requirement for transfusion was encountered.

In-Line RFA

The In-Line RFA device was developed by our group [35,41]. The principle of the In-Line RFA device is that a very precise RFA area is created between electrodes of alternating polarity leading to localized heating and coagulation of tissue including blood vessels up to approximately 3 mm. This transection plane is then dissected almost bloodlessly and the larger vessels/biliary structures are tied, sewn or otherwise secured.

The In-Line radiofrequency ablation probe (Figure 2) is a 5 cm long plastic device and it comprises six metal electrodes spaced along the device, each 6 cm long. The electrodes can be deployed to any depth up to a maximum of 4 or 6 cm depending on the model used (Figures 3 and 4). The effective length of the coagulation is 5 cm and its width is 1 cm (Figure 5). The In-Line RFA device is bipolar and does not require a patient return plate.

Before use, the resection line should be marked. In nonanatomic resection, we transect the liver along this line; in anatomic resection, after dividing the landmark vessels on the cutting surface, we deploy the In-Line RFA along this resection line. We strongly

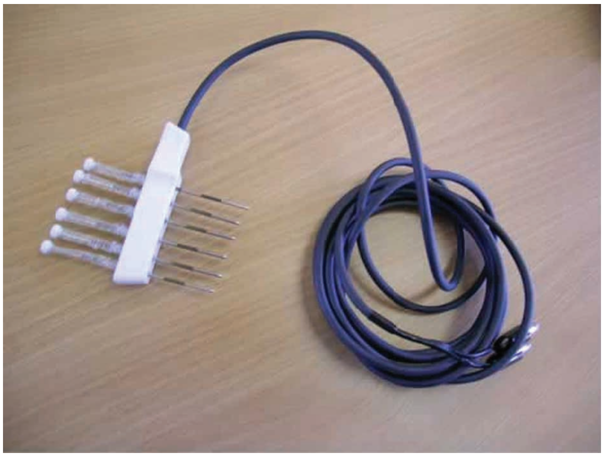

Figure 2. Prototype In-Line RFA probe.

recommend that intraoperative ultrasound is used to ensure that there are no important structures in the chosen resection line. This is particularly important when a vascular biliary sheath crosses the resection plane and must be avoided. The In-Line RFA device will coagulate almost any structure that it encounters and this should not be deployed through or within 1 cm of a structure that must not be damaged.

During coagulation, the device will become very hot and the operator should hold the handle rather than the body of the device. A start out coagulation time of 3 min is used, after which the electrodes are twisted half a turn and pulled back individually. The probe is removed. The electrodes should be redeployed and cleaned if further coagulation is required. The device is re-used until the resection line has been completely treated – typically three applications are required for a right hepatectomy.

The parenchymal dissection of the coagulated transaction line is now completed using either the Kelly crush or a more sophisticated means of transection, such as the ultrasonic dissector or WaterJet. Large vessels and sheaths which are revealed by this dissection may then be ligated, sewn, clipped, or otherwise secured.

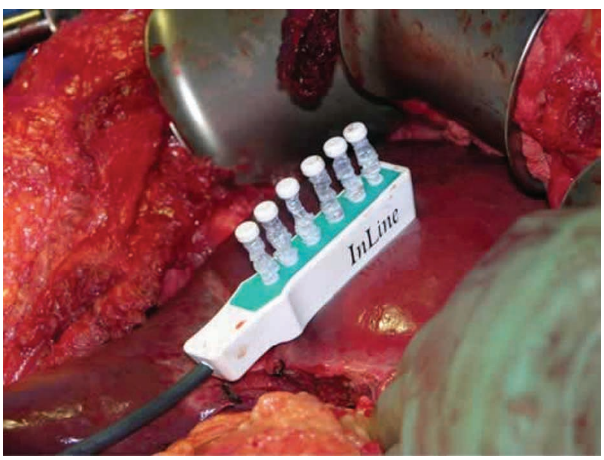

Figure 3. Prototype In-Line RFA deployment.

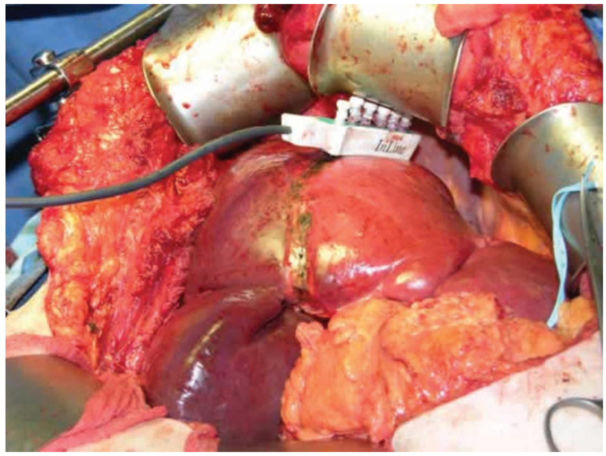

Figure 4. Prototype In-Line RFA deployment.

In our earlier experiments, we demonstrated that In-Line RFA-assisted liver resection could reduce blood loss dramatically [35,41]. In a pilot study of eight patients where half of each resection was done with In-Line RFA and the remainder with an ultrasonic aspirator alone, we also reported a significant difference in blood loss ($p = 0.004$) [44]. From March 2002 to November 2004, a total of 38 patients underwent In-Line RFA-assisted liver resection, 12 were anatomic resections, the majority of the remaining resections were bisegmentectomy (Table II). The mean blood loss was 50 ± 12.64 ml, and all of 38 patients had an uneventful recovery. During the postoperative period, no significant increase in bile leaks, abscess, or secondary hemorrhage was found [45]; however, we accept that this is undoubtedly an issue that requires further monitoring.

Conclusion

RFA has been used to treat liver tumors for many years. In 1990 McGahan et al. and Rossi et al. used RFA to destroy hepatic tumors in animal livers [46,47]. Since then, RFA has been used widely in the treatment of unresectable liver tumors [48–51].

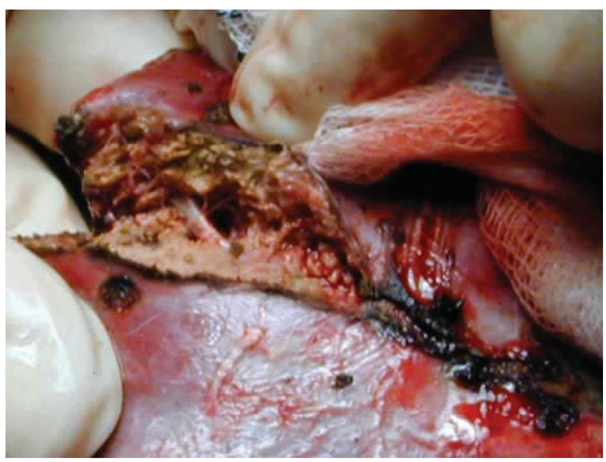

Figure 5. Avascular liver resection plane.

Table II. Clinical details of In-Line RFA-assisted liver resection.

No.	Sex	Date of treatment	Resection segments	Blood loss (ml)	Liver quality
1	F	3/12/2002	Left hepatectomy	60	Normal
2	M	8/24/2002	Right hepatectomy	80	Mild steatosis
3	M	8/31/2002	S 6,7	50	Normal
4	M	8/1/2003	S 6,7	50	Severe steatosis
5	M	8/2/2003	S 6	50	Normal
6	F	8/2/2003	S 6,7	0	Normal
7	F	8/6/2003	S 5,6	50	Normal
8	F	8/23/2003	S 3	20	Normal
9	M	10/9/2003	S 8	0	Normal
10	M	10/12/2003	S 6,7	50	Cirrhotic
11	F	10/12/2003	Right hepatectomy	80	Normal
12	F	10/17/2003	S 2,3	0	Normal
13	F	10/17/2003	S 4a	0	Normal
14	F	12/4/2003	S 7,8	60	Mild steatosis
15	M	12/6/2003	S 4,5,8	70	Mild steatosis
16	F	12/10/2003	S 5,6	40	Moderate steatosis
17	M	12/11/2003	S 4b	0	Mild steatosis
18	M	12/12/2003	S 4	0	Mild steatosis
19	F	12/20/2003	Right hepatectomy	90	Normal
20	F	12/21/2003	S 5,6,7	50	Moderate steatosis
21	M	5/11/2004	S 4b, 5,6	50	Normal
22	F	5/12/2004	S 6	0	Cirrhotic
23	F	5/15/2004	Extended left hepatectomy	100	Mild steatosis
24	M	5/15/2004	S 2,3	0	Mild steatosis
25	M	6/19/2004	Left hepatectomy	80	Normal
26	M	6/25/2004	S 5,6,7	60	Normal
27	F	6/26/2004	S 7-subs	40	Normal
28	F	7/9/2004	Right hepatectomy	100	Mild steatosis
29	M	7/24/2004	Left hepatectomy	80	Cirrhotic
30	M	7/28/2004	Right hepatectomy	100	Mild steatosis
31	M	8/31/2004	Right hepatectomy	90	Mild steatosis
32	M	9/10/2004	S 6,7	60	Normal
33	F	10/6/2004	S 2, 3	0	Mild steatosis
34	M	10/7/2004	S 2,3	0	Normal
35	M	10/14/2004	S 7,6	50	Mild steatosis
36	M	10/21/2004	Extended left hepatectomy	150	Mild steatosis
37	F	11/2/2004	Right hepatectomy	100	Normal
38	F	11/7/2004	S 2,3	40	Normal

Furthermore, RFA of liver tumors is currently being performed percutaneously and laparoscopically [52–55].

The first description of RFA-assisted liver resection was published by Habib's group [38]. This technique was clearly a major advance, and no morbidity and mortality were observed. It was shown that anesthetic time, operative time, hospital stay, and amount of blood loss could be decreased. Liver resection became a comparatively safer procedure. Subsequent studies demonstrated the merit of this technique [34,36,37,39,40,42,43].

Our In-Line RFA device is bipolar which has many advantages [56,57]. The monopolar system is very slow approach, requiring many ablations to cover the designed resection plane. On the contrary, our In-Line device allows much more rapid (3 min for 6 × 5 × 1 cm) and precise treatment. The resection plane then can be dissected almost bloodlessly with an ultrasonic aspirator and only a few larger vessels and biliary ducts need to be ligated. Secondly, the bipolar device does not require grounding pads, because both electrodes are located on the probe and the alternating current circuit is confined within the target tissue.

Before use, the resection line should be marked. We recommend that intraoperative ultrasound is used to ensure that there are no important structures in the chosen resection line. This is particularly important when a vascular biliary sheath crosses the resection plane and must be avoided. The In-Line RFA device will coagulate almost any structure that it encounters and this should not be deployed through or within 1 cm of a structure that must not be damaged.

The In-Line device can similarly be used in segmental liver resection and nonanatomical resections. It is easy to learn to use the device. We believe the ability to sculpt a resection will be a useful tool in parenchymal sparing hepatic surgery, particularly in cirrhotics. The technique of RFA-assisted liver resection has a promising future.

References

[1] El-Serag HB, Mason AC. Rising incidence of hepatocellular carcinoma in the United States. N Engl J Med 1999;340:745–50.

[2] Taylor-Robinson SD, Foster GR, Arora S, Hargreaves S, Thomas HC. Increase in primary liver cancer in the UK, 1979–94. Lancet 1997;350:1142–3.

[3] El-Serag HB, Mason AC. Rising factors for the rising rates of primary liver cancer in the United States. Arch Intern Med 2000;160:3227–30.

[4] Farmer DG, Rosove MH, Shaked A, Busuttil RW. Current treatment modalities for hepatocellular carcinoma. Ann Surg 1994;219:236–47.

[5] Akriviadis EA, Llovet JM, Efremidis SC, Shouval D, Canelo R, Ringe B, et al. Hepatocellular carcinima. Br J Surg 1998;85:1319–31.

[6] Fong Y, Sun RL, Jarnagin W, Blumgart LH. An analysis of 412 cases of hepatocellular carcinoma at a Western center. Ann Surg 1999;229:790–9.

[7] Wood TF, Rose DM, Chung M, Allegra DP, Fosbag J, Bilchik AJ. Radiofrequency ablation of 231 unresectable hepatic tumors: indications, limitations, and complications. Ann Surg Oncol 2000;7:593–600.

[8] Bilchik AJ, Wood TF, Allegra DP. Radiofrequency ablation of unresectable hepatic malignancies: lessons learned. Oncologist 2001;6:24–33.

[9] Harmon K, Ryan J, Biehl T, Lee F. Benefits and safety of hepatic resection for colorectal metastases. Am J Surg 1999;177:402–4.

[10] Ekberg H, Tranberg KG, Andersson R, Jeppsson B, Bengmark S. Major liver resection: perioperative course and management. Surgery 1986;100:1–8.

[11] Nagorney DM, Van Heerden JA, Ilstrup DM, Adson MA. Primary hepatic malignancy: surgical management and determinants of survival. Surgery 1989;106:740–9.

[12] Jarnagin WR, Gonen M, Fong Y, DeMatteo RP, Ben-Porat L, Little S, et al. Improvement in perioperative outcome after hepatic resection: analysis of 1,803 consecutive cases over the past decade. Ann Surg 2002;236:397–406.

[13] Kokudo N, Vera DR, Tada K, Koizumi M, Seki M, Matsubara T, et al. Predictors of successful hepatic resection: prognostic usefulness of hepatic asialoglycoprotein receptor analysis. World J Surg 2002;26:1342–7.

[14] Rees M, Plant G, Wells J, Bygrave S. One hundred and fifty hepatic resections: evolution of technique towards bloodless surgery. Br J Surg 1996;83:1526–9.

[15] Nagasue N, Ono T, Yamanoi A, Kohno H, El-Assal ON, Taniura H, et al. Prognostic factors and survival after hepatic resection for hepatocellular carcinoma without cirrhosis. Br J Surg 2001;88:515–22.

[16] Hanazaki K, Kajikawa S, Shimozawa N, Mihara M, Shimada K, Hiraguri M, et al. Survival and recurrence after hepatic resection of 386 consecutive patients with hepatocellular carcinoma. J Am Coll Surg 2000;191:381–8.

[17] Jensen LS, Andersen AJ, Christiansen PM, Hokland P, Juhl CO, Madsen G, et al. Postoperative infection and natural-killer-cell function following blood-transfusion in patients undergoing elective colorectal surgery. Br J Surg 1992;79:513–6.

[18] Stephenson KR, Steinberg SM, Hughes KS, Vetto JT, Sugarbaker PH, Chang AE. Perioperative blood transfusions are associated with decreased time to recurrence and decreased survival after resection of colorectal liver metastases. Ann Surg 1988;208:679–87.

[19] Nuzzo G, Giuliante F, Giovannini I, Tebala GD, de Cosmo G. Hepatic resections in normothermic ischemia. Surgery 1996;120:852–8.

[20] Tranberg KG, Rigotti P, Brackett KA, Bjornson HS, Fischer JE, Joffe SN. Liver resection. A comparison using Nd-YAG laser, an ultrasonic surgical aspirator, or blunt dissection. Am J Surg 1986;151:368–73.

[21] Hansen PD, Isla AM, Habib NA. Liver resection using total vascular exclusion, scalpel division of the parenchyma and a simple compression technique for haemostasis and biliary control. J Gastrointest Surg 1999;3:537–42.

[22] Yamamoto Y, Ikai I, Kume M, Sakai Y, Yamauchi A, Shinohara H, et al. New technique for hepatic parenchymal resection using a Cavitron ultrasonic surgical aspirator and bipolar cautery equipped with a channel for water dripping. World J Surg 1999;23:1032–7.

[23] Poon RT. Recent advances in techniques of liver resection. Surg Technol Int 2004;13:71–7.

[24] Chang YC. Low mortality major hepatectomy. Hepatogastroenterology 2004;51:1766–70.

[25] Mackenzie S, Dixon E, Bathe O, Sutherland F. Intermittent hepatic vein-total vascular exclusion during liver resection: anatomic and clinical studies. J Gastrointest Surg 2005;9:658–66.

[26] Penchev RD, Kjossev KT, Losanoff JE. Application of a new water jet apparatus in open hepatobiliary surgery: hepatic resection, cholecystectomy, common bile duct lavage. Int Surg 1997;82:182–6.

[27] Wang WX, Fan ST. Use of the Endo-GIA vascular stapler for hepatic resection. Asian J Surg 2003;26:193–6.

[28] Hamazoe R, Maeta M, Murakami A, Yamashiro H, Kaibara N. Heating efficiency of radiofrequency capacitive hyperthermia for treatment of deep-seated tumors in the peritoneal cavity. J Surg Oncol 1991;48:176–9.

[29] Nicoli N, Casaril A, Mangiante G, Ciola M, Hilal MA, Marchiori L. Surgical treatment for liver metastases from colorectal carcinoma: results of 228 patients. Hepatogastroenterology 2004;51:1810–4.

[30] Llovet JM. Treatment of hepatocellular carcinoma. Curr Treat Options Gastroenterol 2004;7:431–41.

[31] Head HW, Dodd GD 3rd. Thermal ablation for hepatocellular carcinoma. Gastroenterology 2004;127(5 Suppl 1):S167–78.

[32] Gananadha S, Wulf S, Morris DL. Safety and efficacy of radiofrequency ablation of brain: a potentially minimally invasive treatment for brain tumours. Minim Invasive Neurosurg 2004;47:325–8.

[33] Steinke K, Sewell PE, Dupuy D, Lencioni R, Helmberger T, Kee ST, et al. Pulmonary radiofrequency ablation – an international study survey. Anticancer Res 2004;24:339–43.

[34] Navarra G, Lorenzini C, Curro G, Sampiero G, Habib NH. Radiofrequency-assisted hepatic resection – first experience. Ann Ital Chir 2004;75:53–6; discussion 56–7.

[35] Gananadha S, Morris DL. Novel In-Line multielectrode radiofrequency ablation considerably reduces blood loss during liver resection in an animal model. Aust N Z J Surg 2004;74:482–5.

[36] Tepel J, Klomp HJ, Habib N, Fandrich F, Kremer B. Modification of the liver resection technique with radiofrequency coagulation. Chirurg 2004;75:66–9.

[37] Navarra G, Lorenzini C, Curro G, Basaglia E, Habib NH. Early results after radiofrequency-assisted liver resection. Tumori 2004;90:32–5.

[38] Weber JC, Navarra G, Jiao LR, Nicholls JP, Jensen SL, Habib NA. New technique for liver resection using heat coagulative necrosis. Ann Surg 2002;236:560–3.

[39] Beppu T, Ishiko T, Sugiyama S, Doi K, Yoshimura Y, Tanaka H, et al. Radio-frequency ablation (RFA) assisted endoscopic hepatectomy for hepatocellular carcinoma. Gan To Kagaku Ryoho 2004;31:1740–2.

[40] Weber JC, Navarra G, Habib NA, Bachellier P, Jaeck D. Laparoscopic radiofrequency-assisted liver resection. Surg Endosc 2003;17:834.

[41] Haghighi KS, Steinke K, Hazratwala K, Kam PC, Daniel S, Morris DL. Controlled study of inline radiofrequency ablation

(ILRFA) assisted transection of ovine liver. J Surg Res 2005; 123:139–43.
[42] Stella M, Percivale A, Pasqualini M, Profeti A, Gandolfo N, Serafini G, et al. Radiofrequency-assisted liver resection. J Gastrointest Surg 2003;7:797–801.
[43] Navarra G, Dpalding D, Zacharoulis D, Nicholls JP, Kirby S, Costa I, et al. Bloodless hepatectomy technique. HIPB 2002; 4:95–7.
[44] Haghighi KS, Wang F, King J, Daniel S, Morris DL. In-Line radiofrequency ablation to minimize blood loss in hepatic parenchymal transection. Am J Surg 2005;190:43–7.
[45] Yan TD, Kusyk T, Morris DL. A prospective study of In-Line Radiofrequency transection – its efficacy and complications. HPB 2006 (in press).
[46] McGahan JP, Browning PD, Brock JM, Tesluk H. Hepatic ablation using radiofrequency electrocautery. Invest Radiol 1990;25:267–70.
[47] Rossi S, Fornari F, Pathies C, Buscarini L. Thermal lesions induced by 480 KHz localized current field in guinea pig and pig liver. Tumori 1990;76:54–7.
[48] Matsuno N, Nakamura Y, Iwamoto H, Hama K, Akashi I, Konno S, et al. Radiofrequency ablation of unresectable hepatic malignancies. Chirurgia (Bucur) 2004;99:205–10.
[49] Ng KK, Lam CM, Poon RT, Ai V, Tso WK, Fan ST. Thermal ablative therapy for malignant liver tumors: a critical appraisal. J Gastroenterol Hepatol 2003;18:616–29.
[50] Curley SA. Radiofrequency ablation of malignant liver tumors. Ann Surg Oncol 2003;10:338–47.
[51] Iannitti DA, Dupuy DE, Mayo-Smith WW, Murphy B. Hepatic radiofrequency ablation. Arch Surg 2002;137:422–6; discussion 427.
[52] Machi J, Uchida S, Sumida K, Limm WM, Hundahl SA, Oishi AJ, et al. Ultrasound-guided radiofrequency thermal ablation of liver tumors: percutaneous, laparoscopic, and open surgical approaches. J Gastrointest Surg 2001;5:477–89.
[53] Omata M, Tateishi R, Yoshida H, Shiina S. Treatment of hepatocellular carcinoma by percutaneous tumor ablation methods: ethanol injection therapy and radiofrequency ablation. Gastroenterology 2004;127(5 Suppl 1):S159–66.
[54] Berber E, Senagore A, Remzi F, Rogers S, Herceg N, Casto K, et al. Laparoscopic radiofrequency ablation of liver tumors combined with colorectal procedures. Surg Laparosc Endosc Percutan Tech 2004;14:186–90.
[55] White TJ, Roy-Choudhury SH, Breen DJ, Cast J, Maraveyas A, Smyth EF, et al. Percutaneous radiofrequency ablation of colorectal hepatic metastases – initial experience. An adjunct technique to systemic chemotherapy for those with inoperable colorectal hepatic metastases. Dig Surg 2004;21:314–20.
[56] Tacke J, Mahnken A, Roggan A, Gunther RW. Multipolar radiofrequency ablation: first clinical results. Rofo 2004;176: 324–9.
[57] Hamner CE, Lutterman A, Potter DD, Sundt TM III, Schaff HV, Francischelli D. Irrigated bipolar radiofrequency ablation with transmurality feedback for the surgical Cox-Maze procedure. Heart Surgery Forum 2003;6:418–23.