Original Article

Image-guided Radiofrequency Ablation of Liver Malignancies: Experience at Singapore General Hospital

Shoen CS Low,[1] *MBBS (Hons)*, Richard HG Lo,[1] *FAMS, FRCR*, Te-Neng Lau,[2] *FAMS, MRCP (UK), FRCR*, London Lucien PJ Ooi,[3] *FAMS, FRCS (Edin & Glas), MD*, Chee-Keong Ho,[1] *AM (Malaysia), MBBS (Malaya), M Med (Radiology, UKM)*, Bien-Soo Tan,[1] *FAMS, FRCR*, Alexander YF Chung,[4] *MBBS, FRCS (Edin)*, Wen-Hsin Koo,[5] *MBBS, FRCP (Edin)*, Pierce KH Chow,[3,4] *FAMS, FRCS (Edin), M Med (Surg), PhD*

Abstract

Introduction: The aim of this paper was to study the efficacy, side effects and complications of radiofrequency (RF) ablation of primary and metastatic liver malignancies. Materials and Methods: We retrospectively reviewed 57 patients (39 men, 18 women; mean age, 63 years; age range, 44 to 83 years) who underwent RF ablation for liver malignancies from January 2002 to December 2004. A total of 87 tumours were ablated – 71 (81.6%) hepatocellular carcinomas and 16 (18.4%) metastases (from primaries in the colon, stomach and pancreas). RF ablation was performed either percutaneously (n = 71) under conscious sedation or intraoperatively (n = 16) under general anaesthesia. Follow-up ranged from 1 month to 41 months (mean, 15.2) and included computed tomography (CT) 1 day, 1 month and 3 months after ablation, and half-yearly thereafter. Patients were observed for local tumour progression and for the emergence of new tumours. Results: Four patients with a total of 5 tumours were lost to follow-up. Of the remaining 82 tumours treated, complete ablation was attained in 66 tumours after a single procedure, giving a primary effectiveness rate of 80.5%. Seven (8.5%) required 2 procedures to achieve complete ablation, giving a secondary effectiveness rate of 89% after 2 ablations. One tumour (1.2%) required 3 procedures to achieve complete ablation. One tumour required 4 procedures to date, with the latest follow-up CT still demonstrating incomplete ablation. Two tumours (2.4%) had an initial RF ablation and subsequent transarterial chemoembolisation (TACE). One tumour had an initial RF ablation followed by ^{32}Phosphorus-biosilicon (BrachySil®) injection, the latter as part of a Phase IIA trial. One tumour required 2 RF ablations and a subsequent TACE. Lastly, 3 tumours received initial RF ablation but subsequent local tumour progression was not treated as the patients were deemed unfit for repeat ablation. No procedure-related deaths or major complications were encountered. Minor complications were reported in 2 patients (3.8%) – subcapsular haematoma and thermal injury to the adjacent gastric antrum, both not necessitating surgical intervention. Conclusions: RF ablation is an effective, safe and relatively simple procedure for the treatment of unresectable liver malignancies.

Ann Acad Med Singapore 2006;35:851-7

Key words: Hepatocellular carcinoma, Liver neoplasms, Radiofrequency ablation, Therapeutic chemoembolisation

Introduction

Radiofrequency (RF) ablation for the treatment of focal liver malignancies is a relatively new image-guided procedure that is gaining increasing acceptance in the radiologic and surgical community, particularly as an alternative treatment option for patients who have inoperable tumours.[1-3] The potential benefits of minimally invasive image-guided ablation, as compared to conventional surgical options, include (a) the ability to ablate and/or palliate tumours in non-surgical candidates; (b) reduced morbidity and cost, and improved quality of life; and (c) the ability to perform these procedures percutaneously without the need for general anaesthesia. In some centres, the procedure is even performed on outpatients.

In the treatment of hepatocellular carcinoma (HCC), surgery is currently the treatment of choice in fit and

[1] Department of Diagnostic Radiology, Singapore General Hospital, Singapore
[2] Department of Radiology, Mount Elizabeth Hospital, Singapore
[3] Department of Surgical Oncology, National Cancer Centre, Singapore
[4] Department of General Surgery, Singapore General Hospital, Singapore
[5] Department of Medical Oncology, National Cancer Centre, Singapore
Address for Reprints: Dr Richard HG Lo, Department of Diagnostic Radiology, Singapore General Hospital, Outram Road, Singapore 169608.

selected patients. In the West, the Barcelona criteria for resection is widely used.[4] Consequently, surgery is indicated in patients with single, asymptomatic HCC and extremely well-preserved liver function without clinically significant portal hypertension or abnormal bilirubin levels. However, less than 5% of cirrhotic patients with HCC meet these criteria.[5] In the East, there is generally a more aggressive policy towards surgical resection, guided in many places by the use of tests of functional liver reserves such as the indocyanine green retention test. In spite of this, the resection rates are only about 10%. In addition, unfavourable anatomy may preclude surgery. Liver transplantation can be performed in patients with non-resectable HCC who have 1 tumour smaller than 5 cm or up to 3 tumours smaller than 3 cm each.[6] However, even for patients who meet the acceptance criteria, transplantation is limited by scarce organ supply, and tumour progression during the prolonged waiting period results in substantial patient drop-out.[7]

In this setting, image-guided tumour ablation has a major role in the management of HCC.[3,8] Several methods of tumour ablation have been developed; these include intratumoural injection of ethanol, and thermal ablation with radiofrequency, laser, microwave or cryosurgery.[2] In the past, percutaneous ethanol injection has been the most widely used technique. However, the major limitation of ethanol injection is the high local recurrence rate, which may be as high as 43%.[9] This is generally due to uneven distribution of the ethanol. Also, several studies have shown that RF ablation can achieve more effective local tumour control than ethanol injection.[10,11] This has caused RF ablation to receive a great deal of attention in the percutaneous treatment of HCC.

In the case of liver metastases, the use of RF ablation has been most widely explored for colorectal tumours.[12] Liver resection is currently the first line of treatment for those with surgical disease, but there are many patients for whom resection is not suitable either because of comorbidity, tumour location or inadequate hepatic reserve. RF ablation, either in isolation or in conjunction with systemic chemotherapy, may have a role in the treatment of limited but inoperable colorectal liver metastases. As liver metastases usually occur in an otherwise normal liver, the extent of disease that can be safely treated is greater than for patients with HCC arising on a background of cirrhosis. Most centres currently will accept patients with as many as 5 tumours, with a maximum diameter of 5 cm.[12]

Materials and Methods

Patients

We retrospectively reviewed patients who underwent RF ablation as part of an Institutional Review Board-approved Health Service Development Programme project funded by the Ministry of Health, Singapore. Written informed consent was obtained from every patient prior to treatment.

Between January 2002 and December 2004, 57 patients (39 men, 18 women; mean age, 63 years; age range, 44 to 83 years) with 87 tumours were treated with RF ablation. Of these, 49 patients with 71 (81.6%) tumours had HCC arising on a background of liver cirrhosis or chronic hepatitis. Eight patients with 16 (18.4%) tumours had metastases. Five patients in this latter group had a colorectal primary, 2 had primaries in the stomach, and 1 patient had a pancreatic primary. Of the 2 patients with gastric primaries, the histological diagnosis in one was adenocarcinoma, while that of the other was a gastrointestinal stromal tumour (GIST). The patient with a pancreatic primary had an islet cell tumour.

Forty-one patients were treated for a single tumour (71.9%), 14 for 2 tumours (24.6%), and 2 for 3 tumours (3.5%), making a total of 75 tumours. Of the 53 patients followed-up (4 patients were lost to follow-up), 21 patients developed 28 new tumours remote from the index lesion. Of these, 8 patients underwent RF ablation for these new tumours (n = 12). These 12 tumours were included in our total tumour number of 87. Of the 57 patients, 44 patients with 71 (81.6%) tumours had RF ablation through a percutaneous approach while 13 patients with 16 (18.4%) tumours had RF ablation performed intraoperatively during open surgery.

Four patients with 5 tumours were lost to follow-up. These patients were not included in the study. Of the remaining 53 patients with 82 tumours, the maximum diameter of the tumours ranged from 0.5 cm to 6.6 cm in cross-section, with a mean of 2.5 cm. Table 1 depicts the distribution of tumours according to size. Fifty-five (67.1%) of the 82 tumours were small (<3 cm in maximum diameter). Twenty-four (29.3%) were medium (3.0 cm to 5.0 cm) and 3 (3.6%) were large (>5.0 cm).

All patients with HCC had RF ablation only when the tumour was deemed inoperable. Several patients were initially planned for a trial of dissection with a view to

Table 1. Distribution of Tumours According to Size, and Effect of Tumour Size on Outcome of Radiofrequency Ablation

	Maximum diameter of tumour (n = 82)		
	Less than 3.0 cm	**3.0 to 5.0 cm**	**Greater than 5.0 cm**
Number of tumours	55	24	3
Number of tumours showing complete ablation after 1 ablation	48 (87.3%)	18 (75.0%)	0 (0%)
Number of tumours showing complete ablation after 2 ablations	5 (9.1%)	2 (8.3%)	0 (0%)

curative resection, but this was converted to RF ablation on-table because of unfavourable intraoperative findings. The patients with liver metastases had RF ablation for the purpose of palliation.

The diagnosis of HCC was made during contrast-enhanced computed tomography (CT) or magnetic resonance (MR) studies when a lesion demonstrated the classical features of arterial enhancement with rapid wash-out of contrast on the portal venous and delayed phases. If the imaging features were not consistent with HCC, histological correlation was performed.

Contraindications to RF ablation included: severe thrombocytopaenia (platelet count <80 x 10^9/L), severe cirrhosis (Child-Pugh class C), advanced neoplastic disease (that is, tumour diameter >10 cm, extrahepatic malignancy or lobar portal venous thrombosis) or clinically significant ascites. Patients with coagulation disorders (prothrombin time and/or partial thromboplastin time >3 s above normal limits) required intra-procedural fresh frozen plasma (FFP) cover. In addition, a relative contraindication was a tumour location that precluded the application of the ablation technique. However, intraoperative RF ablation enabled technically difficult tumours to be treated, including tumours adjacent to the diaphragm, bowel or gallbladder. During open surgery, these organs could be displaced away from the mobilised liver.

In all patients, the aim of treatment was to achieve complete ablation. Therefore, patients who, on follow-up, had local tumour progression amenable to further treatment underwent additional RF ablation(s). When repeat RF ablation was not feasible, transarterial chemoembolisation (TACE) was performed after discussion with the referring clinician. In 1 patient with residual tumour after RF ablation, ^{32}Phosphorus (^{32}P)-biosilicon (BrachySil®) was administered in the context of a Phase IIA trial.

Ablation Technique

The patients were admitted 1 day prior to the procedure and the relevant blood investigations were performed. After the procedure, the patient was observed overnight before discharge the following day. RF ablation was performed either percutaneously or intraoperatively. Percutaneous ablation was performed with the patient under conscious sedation using a combination of intravenous midazolam and fentanyl. Real-time ultrasound, either alone or combined with CT fluoroscopy, was used for imaging guidance. For lesions located in the right lobe, an intercostal approach with the patient in the left lateral decubitus position was generally preferred. For lesions located in the left lobe, a subcostal approach was most often used. Intraoperative RF ablation was performed during open surgery under general anaesthesia and using real-time ultrasound imaging guidance. Intravenous prophylactic antibiotics (single-dose cephalosporin and metronidazole) were routinely administered. RF ablation was performed with a 460 kHz, 200 W RF generator and a 17-gauge internally cooled, straight single needle or three-needle cluster (Radionics®, Burlington, MA, USA).

Grounding was achieved by attaching 2 dispersive pads (4 if a clustered electrode was used), each with a surface area of approximately 400 cm^2, to the patient's thighs. During the procedure, a thermocouple embedded within the needle tip continuously measured local tissue temperature. Tissue impedance was monitored using circuitry incorporated within the generator. A peristaltic pump was used to infuse cold normal saline solution into the lumen of the needle at a rate sufficient to maintain the tip temperature at 15°C to 25°C.

During RF application, generator output was monitored constantly and adjusted to apply maximum current without causing impedance rises of more than 10 Ω. As RF energy was applied, ultrasound demonstrated a hyperechoic focus developing around the uninsulated (exposed) portion of the needle. This has been attributed to tissue vapourisation.[13] The appearance and progression of hyperechogenicity was used to guide the duration of therapy. RF energy was applied until the tumour appeared completely hyperechoic and/or the hyperechoic focus did not increase in size for several minutes. In cases in which multiple electrode insertions were required, each subsequent electrode placement was directed to an area of the tumour where hyperechogenicity was not evident. In some cases, however, hyperechogenicity obscured the deeper portions of the tumour and made repositioning of the needle difficult. Each application of RF energy lasted 8 minutes to 12 minutes, and in most cases, the entire procedure and treatment session lasted approximately 1 to 1.5 hours. At the end of the procedure, needle track coagulation was performed during withdrawal.

Post-treatment Assessment and Follow-up

A helical CT study performed in the arterial, portal venous and equilibrium phases of the liver ("triphasic" CT) was done 24 hours after RF ablation to look for complications and to assess for completeness of treatment. Local effectiveness of RF ablation was assessed by triphasic CT performed 1 month and 3 months after the procedure, and thereafter every 6 months.

During any of the follow-up CT studies, and for patients with HCC, hypoattenuating, non-enhancing areas observed during both the arterial and portal venous phases were considered to represent complete tumour ablation (Fig. 1). Conversely, any portion of the treated HCC showing

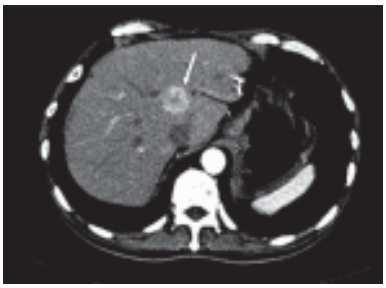

Fig. 1a.

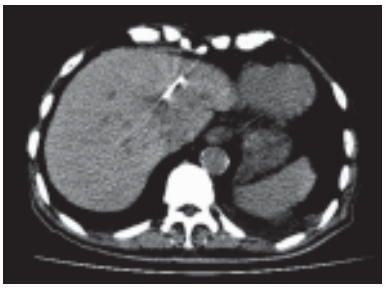

Fig. 1b.

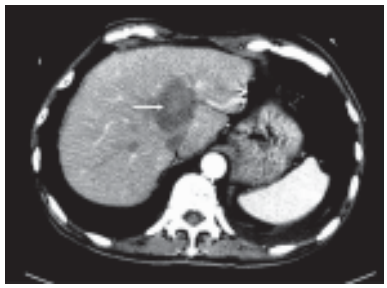

Fig. 1c.

Fig. 1. Complete tumour ablation in a patient post-resection of a hepatocellular carcinoma in the left hepatic lobe.
a. Arterial phase CT scan 14 months post-resection showed a new tumour nodule (arrow) in segment 4 of the left hepatic lobe with marked enhancement. The tumour showed wash-out of contrast during the portal venous and delayed phase scans (not shown), characteristic of hepatocellular carcinoma.
b. The tumour was ablated under combined ultrasound and CT guidance with a single electrode needle; focal metallic density indicates tip of needle within the tumour nodule.
c. CT scan 1-day post-ablation showed no area of contrast enhancement during the arterial phase to indicate residual tumour; instead, a hypodense area has replaced the previous tumour nodule. Note that this area is larger than the original tumour and includes a cuff of normal liver, indicating complete ablation. Minimally hyperdense foci (arrow) within the ablated area represent haemorrhage.

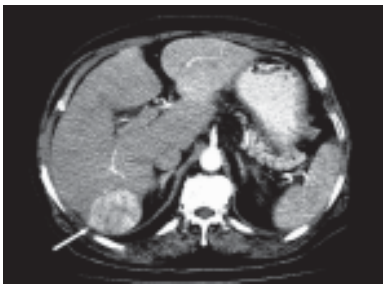

Fig. 2a.

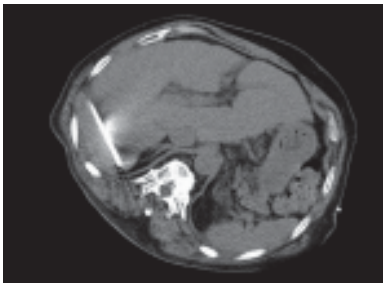

Fig. 2b.

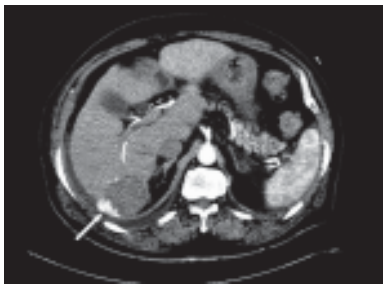

Fig. 2c.

Fig. 2. Local tumour progression in a patient with a hepatocellular carcinoma in segment 6 of the right hepatic lobe.
a. Arterial phase CT scan showed marked enhancement of the tumour mass (arrow). There was contrast wash-out in the portal venous and delayed phase scans (not shown), consistent with hepatocellular carcinoma.
b. RF ablation was performed using a clustered electrode (with 3 needles). This was a technically difficult procedure due to the large size of the tumour (>5 cm).
c. CT scan 1-day post-ablation showed peripheral areas (arrow) of marked enhancement during the arterial phase (with wash-out in the portal venous and delayed phases) indicative of local tumour progression.

persistent intralesional enhancement was considered to represent residual viable neoplastic tissue (Fig. 2). According to accepted nomenclature,[14] and because it is virtually impossible to determine whether there was incompletely treated viable tumour that continued to grow, or if a new tumour grew at the original site, these are termed foci of "local tumour progression". In cases of local tumour progression, a repeat RF ablation, TACE or ^{32}P-biosilicon injection was performed. We generally favoured repeat RF ablations, but the decision as to which modality to use was made jointly with the managing clinician. Besides local tumour progression, patients were also observed for the emergence of new lesions remote from the index tumour.

The primary effectiveness rate was defined as the percentage of tumours that were successfully eradicated (as shown on post-treatment CT) after the first RF ablation.[14] The secondary effectiveness rate included tumours that had undergone a successful repeat ablation following the identification of local tumour progression on post-treatment CT.

The follow-up period was calculated from the date of the first RF ablation until May 2005 or death, whichever was earlier. Similarly, the survival time was calculated from the date of the first RF ablation until May 2005 or death, whichever was earlier. Major complications were defined as those that, if left untreated, might threaten the patient's life, lead to substantial morbidity and disability, or result in hospital admission or a substantially lengthened hospital stay.[14] All other complications were considered minor.

Results

Therapeutic Efficacy

Four patients with 5 tumours were lost to follow-up. These patients were not included in the study. In the

remaining 53 patients with 82 tumours, follow-up ranged from 1 month to 41 months (mean, 15.2).

In 66 (80.5%) of the 82 tumours, complete tumour ablation was depicted at spiral CT performed 1 month after ablation. The primary effectiveness rate was thus 80.5%. In 16 (19.5%) out of 82 tumours, there was local tumour progression on follow-up CT. Of these 16 tumours, 7 required a second procedure to achieve complete ablation, giving a secondary effectiveness rate of 89% (73 out of 82 tumours) after 2 ablations. One tumour required 3 procedures to achieve complete ablation. One tumour has required 4 ablations to date, with the latest follow-up CT still demonstrating local tumour progression. This tumour was not well demonstrated on ultrasound or non-enhanced CT fluoroscopy, making for technically difficult ablations. Two other tumours had an initial RF ablation and a subsequent TACE. One tumour had an initial RF ablation followed by ^{32}P-biosilicon injection. One tumour required 2 RF ablations and a subsequent TACE. Lastly, 3 tumours received initial RF ablation but subsequent local tumour progression was not treated as the patients were deemed unfit for further treatment. These results are summarised in Table 2.

The effect of tumour size on outcome of RF ablation is depicted in Table 1. Of the 55 small (maximum diameter <3.0 cm) tumours, 48 showed complete tumour ablation after a single procedure, giving a primary effectiveness rate of 87.3%. A further 5 tumours showed complete ablation after 2 procedures, giving a secondary effectiveness rate of 96.4%. The primary and secondary effectiveness rates for medium (3.0 cm to 5.0 cm) tumours were 75.0% and 83.3%, respectively. All 3 of the large (>5.0 cm) tumours required more than 2 procedures for complete ablation.

Table 2. Summary of Results of Radiofrequency Ablation of Liver Malignancies done at Singapore General Hospital (January 2002 to December 2004)

No. and type of treatments performed to achieve complete tumour ablation	No. of tumours (n = 82)
One RF ablation	66 (80.5%)
Two RF ablations	7 (8.5%)
Three RF ablations	1 (1.2%)
Four RF ablations*	1 (1.2%)
One RF ablation followed by TACE	2 (2.5%)
One RF ablation followed by ^{32}P-Biosilicon injection (as part of a Phase IIA trial)	1
Two RF ablations followed by TACE	1

CT: computed tomography; ^{32}P: 32-Phosphorus; RF: radiofrequency; TACE: transarterial chemoembolisation

Note: Three patients (with 1 tumour each) had an initial RF ablation, developed local tumour progression on follow-up CT scan, but were deemed unfit for further procedures.

* With local tumour progression despite 4 ablations. A technically difficult procedure (see text).

Side Effects and Complications

No procedure-related death or major complication was observed. Minor complications were seen in 2 (3.8%) of 53 patients. One patient developed a subcapsular haematoma not requiring surgery or blood transfusion. The other patient developed thermal injury to the adjacent gastric antrum, detected on follow-up CT scan but not requiring surgical intervention.

The majority of patients who underwent RF ablation under conscious sedation experienced mild-to-moderate pain during the procedure. This ceased following cessation of the RF application. In most patients, a small asymptomatic right pleural effusion developed after the procedure. This spontaneously resolved within a month.

We experienced technical difficulties with 4 patients. One patient had extreme problems with breath-holding. This patient developed local tumour progression during follow-up, which was not subjected to further treatment because the patient was deemed unfit. The second patient had a tumour that was not well demonstrated on ultrasound or non-enhanced CT fluoroscopy and has had 4 ablations to date, with local tumour progression still evident. In another patient, the entire tumour was completely obscured by air pockets after the first application of RF energy and re-positioning of the needle for re-ablation could not be done. The last patient had difficulties with breath-holding, and a lesion located high in the dome of the liver. However, these last 2 patients showed no residual tumour post-ablation.

New Tumours and Mean Survival

Of the 53 patients followed up, 21 patients developed 28 new tumours remote from the index lesion. Of these, 8 patients underwent RF ablation for these new tumours (n = 12). Three other patients underwent TACE, and another 2 received ^{32}P-biosilicon injections. In the remaining patients, no further ablative therapy was performed.

On follow-up, 13 (24.5%) of the 53 patients died. The mean survival time for these patients was 10.2 months. Of these 13 patients, 7 died of decompensated liver failure, 2 died of extensive metastases and 4 patients died of unrelated disease. The 40 patients who were alive at the end of the study survived a mean of 15.5 months after the initial RF ablation. The overall mean survival was 15.2 months.

Discussion

RF ablation is an effective method for the treatment of hepatic malignancies, with a primary effectiveness rate of 80.5% and a secondary effectiveness rate (after 2 ablations) of 89%.

These figures compare favourably with those reported previously. Rossi et al[15] treated 39 patients with small (≤3 cm in diameter) HCC using a conventional needle electrode, with a mean follow-up of 23 months. The same authors published a subsequent study involving 23 patients using a expandable umbrella-type electrode, with a mean follow-up of 12 months.[16] Livraghi et al[13] performed RF ablation on 42 patients with small (≤3 cm) HCCs, with a mean follow-up of 10 months. In all these studies, complete necrosis was observed in at least 90% of the treated lesions at 6 months. A more recent study[17] showed a primary effectiveness rate of 83% after 1 ablation and a secondary effectiveness rate of 92% after 2 ablations. These investigators performed RF ablations on solitary HCCs less than 5 cm in diameter or multiple (up to 3) HCCs ≤3 cm each. They treated a total of 187 patients with 240 tumours.

However, these studies dealt mainly with small- (≤3 cm) and medium-sized (3 to 5 cm) tumours. To emphasise the importance of size on the completeness of RF ablation achieved, Livraghi et al[13] ablated HCCs measuring >3 cm in diameter (range, 3.1 to 9.5; mean diameter, 5.4) in 114 patients, achieving complete necrosis in only 47.6% to 71% for non-infiltrating tumours measuring 3.1 cm to 5.0 cm. For non-infiltrating tumours >5.0 cm in size, they achieved complete necrosis in only 25% of tumours. Indeed, we experienced higher effectiveness rates for smaller tumours compared to larger ones.

Currently, the treatment of choice for HCC is surgical resection; image-guided ablation is an option for patients with inoperable tumours. However, only minimal data on long-term results are available. In a recent study, Lencioni et al[17] used RF ablation as the sole first-line anticancer treatment in patients with early-stage HCC who were excluded from surgery. They achieved overall survival rates of 97% at 1 year, 67% at 3 years, and 41% at 5 years. However, the follow-up period had a wide range, with a mean of 2 years. A relatively small number of patients were followed up for 5 years and the authors recommend interpreting the 5-year survival rate with caution. Nevertheless, their findings indicate that RF ablation can be currently considered as the first-line treatment of choice for patients with early-stage HCC who are excluded from surgery.

In our centre, we performed the ablations either percutaneously or intraoperatively. Percutaneous ablation has several advantages over intraoperative application. It is less invasive, relatively inexpensive, associated with minimal morbidity, can be repeated as necessary to treat local tumour progression, and can be performed on an outpatient basis under conscious sedation. However, there are some patients who may not be able to tolerate percutaneous RF ablation with only conscious sedation. General anaesthesia may be preferred in these patients and also when the procedure is expected to be difficult and protracted. The intraoperative approach can be performed via laparoscopy or open surgery. Intraoperative ultrasound examination allows the detection (and treatment) of small tumours not demonstrated by other imaging. Intraoperative RF ablation, however, is associated with higher morbidity and mortality, longer hospital stays, requires general anaesthesia (with its attendant risks), is more expensive and may not be feasible to repeat, particularly with open surgical techniques.

We experienced no procedure-related deaths or major complications. A fairly low rate (3.8%) of minor complications was observed. This again compares favourably with the available literature. In the largest such study to date,[18] 2320 patients with 3554 tumours were treated. Six procedure-related deaths occurred, giving a mortality rate of 0.6%. Two deaths were caused by multiorgan failure following intestinal perforation. There was 1 case of septic shock following *Staphylococcus aureus* peritonitis due to a break in sterile technique. One patient died of massive haemorrhage following tumour rupture. Another of liver failure following stenosis of the right bile duct, and there was 1 case of sudden death from unknown causes 3 days after RF ablation. The same study showed a major complication rate of 2.2% (50 patients). The most frequent major complications were peritoneal haemorrhage, neoplastic seeding, intrahepatic abscesses and intestinal perforation. Minor complications were observed in 4.7% of patients. These researchers found that the most important major complication due to thermal damage was that of perforation of the gastrointestinal wall, which occurred in 0.7% of patients. This complication was particularly dangerous in fragile patients (i.e., those with advanced cirrhosis). Perforation was observed only when the tumour was within 1 cm of the liver capsule and adjacent to a gastrointestinal lumen. An additional risk factor was prior abdominal surgery or chronic cholecystitis in the region adjacent to the tumour; these conditions led to documented fibrotic adhesions between the bowel and liver. The authors surmised that tight adhesion of the bowel to the liver may have precluded the normal peristalsis and migration of the bowel away from the liver, which in turn caused thermal injury to the bowel during the procedure. In our single patient with thermal injury to the anterior wall of the gastric antrum, the index tumour was located in the inferior aspect of the left lobe (segment 3), close to the antrum.

Our study has several limitations, most of which stem from its retrospective nature. Firstly, for patients with HCC, RF ablation was not the first-line therapy in all patients; several patients received RF ablation for tumour

recurrence post-surgical resection, post-TACE or post-^{32}P Biosilicon injection. One patient had combined surgical resection and intraoperative RF ablation, at the same sitting, for multifocal HCC. Secondly, several patients did not receive repeat RF ablations after local tumour progression was detected at follow-up CT. Instead, they received either TACE or ^{32}P-biosilicon injections. For these reasons, our mean overall survival of 15.5 months would not reflect the impact on survival of RF ablation alone. Rather, it is more reflective of the combination treatments of surgery, TACE and local ablative techniques. A dedicated, prospective study utilising only RF ablations would be more accurate in depicting the effectiveness of this procedure after 2 or more ablations, and its impact on patient survival. However, combination therapies (such as combined TACE and RF ablation, or combined surgery, RF ablation and TACE) may have a role in the treatment of HCC. Other limitations of the study include the relatively small study size and short follow-up period. The latter, in particular, makes interpretation of patient survival time less accurate.

Lastly, although the effectiveness of good technique has been demonstrated in this study, the acid test of RF ablation in the treatment of HCC is its survival benefit when compared to surgical resection. Likewise, in the treatment of colorectal liver metastases, the 2 crucial questions that must be addressed are whether ablative therapy is equal in curability to surgical resection for resectable metastases, and whether ablative therapy has any additional survival benefits over systemic chemotherapy in the treatment of non-resectable disease.[19] In these issues, crucial evidence is still awaited.

Conclusion

This study adds to the growing body of literature indicating that RF ablation is an effective procedure for the treatment of HCC and liver metastases. Currently, it is most accepted as an alternative mode of therapy when the tumour is inoperable. The advantages of RF ablation lie in the ability to perform the procedure percutaneously without the need for general anaesthesia; the possibility of repeating the procedure to obtain complete ablation; and the treatment of tumours that are surgically unresectable. RF ablation is also a safe procedure with only a small risk of major and minor complications.

Acknowledgements

We would like to acknowledge the financial support from the Health Service Development Programme of the Ministry of Health, Singapore for part of this project.

REFERENCES

1. McGahan JP, Dodd GD 3rd. Radiofrequency ablation of the liver: current status. Am J Roentgenol 2001;176:3-16.
2. Dodd GD 3rd, Soulen MC, Kane RA, Livraghi T, Lees WR, Yamashita Y, et al. Minimally invasive treatment of malignant hepatic tumours: at the threshold of a major breakthrough. Radiographics 2000;20:9-27.
3. Lau WY, Leung TW, Yu SC, Ho SK. Percutaneous local ablative therapy for hepatocellular carcinoma: a review and look into the future. Ann Surg 2003;237:171-9.
4. Llovet JM, Burroughs A, Bruix J. Hepatocellular carcinoma. Lancet 2003;362:1907-17.
5. Bruix J, Llovet JM. Prognostic prediction and treatment strategy in hepatocellular carcinoma. Hepatology 2002;35:519-24.
6. Mazzaferro V, Regalia E, Doci R, Andreola S, Pulvirenti A, Bozzetti F, et al. Liver transplantation for the treatment of small hepatocellular carcinomas in patients with cirrhosis. N Engl J Med 1996;334:693-9.
7. Yao FY, Bass NM, Nikolai B, Merriman R, Davern TJ, Kerlan R, et al. A follow-up analysis of the pattern and predictors of dropout from the waiting list for liver transplantation in patients with hepatocellular carcinoma: implications for the current organ allocation policy. Liver Transpl 2003;9:684-92.
8. Lencioni R, Cioni D, Crocetti L, Bartolozzi C. Percutaneous ablation of hepatocellular carcinoma: state-of-the-art. Liver Transpl 2004;10(2 Suppl 1):S91-S97.
9. Khan KN, Yatsuhashi H, Yamasaki K, Yamasaki M, Inoue O, Koga M, et al. Prospective analysis of risk factors for early intrahepatic recurrence of hepatocellular carcinoma following ethanol injection. J Hepatol 2000;32:269-78.
10. Livraghi T, Goldberg SN, Lazzaroni S, Meloni F, Solbiati L, Gazelle GS. Small hepatocellular carcinoma: treatment with radio-frequency ablation versus ethanol injection. Radiology 1999;210:655-61.
11. Lencioni R, Goletti O, Armillotta N, Paolicchi A, Moretti M, Cioni D, et al. Radio-frequency thermal ablation of liver metastases with a cooled-tip electrode needle: results of a pilot clinical trial. Eur Radiol 1998;8: 1205-11.
12. Gillams AR. The use of radiofrequency in cancer. Br J Cancer 2005;92:1825-9.
13. Livraghi T, Goldberg SN, Lazzaroni S, Meloni F, Ierace T, Solbiati L, et al. Hepatocellular carcinoma: radio-frequency ablation of medium and large lesions. Radiology 2000;214:761-8.
14. Goldberg SN, Charboneau JW, Dodd GD 3rd, Dupuy DE, Gervais DA, Gillams AR, et al. Image-guided tumor ablation: proposal for standardization of terms and reporting criteria. Radiology 2003;228: 335-45.
15. Rossi S, Di Stasi M, Buscarini E, Quaretti P, Garbagnati F, Squassante L, et al. Percutaneous RF interstitial thermal ablation in the treatment of hepatic cancer. Am J Roentgenol 1996;167:759-68.
16. Rossi S, Buscarini E, Garbagnati F, Di Stasi M, Quaretti P, Rago M, et al. Percutaneous treatment of small hepatic tumors by an expandable RF needle electrode. Am J Roentgenol 1998;170:1015-22.
17. Lencioni R, Cioni D, Crocetti L, Franchini C, Pina CD, Lera J, et al. Early-stage hepatocellular carcinoma in patients with cirrhosis: long-term results of percutaneous image-guided radiofrequency ablation. Radiology 2005;234:961-7.
18. Livraghi T, Solbiati L, Meloni MF, Gazelle GS, Halpern EF, Goldberg SN. Treatment of focal liver tumors with percutaneous radio-frequency ablation: complications encountered in a multicenter study. Radiology 2003;226:441-51.
19. Poston GJ. Radiofrequency ablation of colorectal liver metastases: Where are we really going? [Editorial] J Clin Oncol 2005;23:1342-4.