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ORIGINAL ARTICLE

Retrospective Cohort Study

Liver resection for hepatocellular carcinoma using a microwave tissue coagulator: Experience of 1118 cases

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Abstract

AIM: To present our extensive experience of hepatectomy for hepatocellular carcinoma using a microwave tissue coagulator to demonstrate the effectiveness of this device.

METHODS: A total of 1118 cases (1990-2013) were reviewed, with an emphasis on intraoperative blood loss, postoperative bile leakage and fluid/abscess formation, and adaptability to anatomical resection and hepatectomy with hilar dissection.

RESULTS: The median intraoperative blood loss was 250 mL; postoperative bile leakage and fluid/abscess formation were seen in 3.0% and 3.3% of cases, respectively. Anatomical resection was performed in 275 cases, including 103 cases of hilar dissection that required application of microwave coagulation near the hepatic hilum. There was no clinically relevant biliary tract stricture or any vascular problems due to heat injury. Regarding the influence of cirrhosis on intraoperative blood loss, no significant difference was seen between cirrhotic and non-cirrhotic patients ($P = 0.38$), although cirrhotic patients tended to have smaller tumors and underwent less invasive operations.

CONCLUSION: This study demonstrated outcomes of an extensive experience of hepatectomy using heat coagulative necrosis by microwave tissue coagulator.

Key words: Hepatectomy; Hepatocellular carcinoma; Microwave; Microwave tissue coagulator

Core tip: This study represented the perioperative results of 1118 cases of hepatectomy for hepatocellular carcinoma by microwave tissue coagulator in a single institute. Although this study did not include comparative evaluation of two liver parenchyma transection techniques, the precise analysis of more than 1000 cases of hepatectomy over two decades could provide significant information for the readers.

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INTRODUCTION

Hepatectomy using heat coagulative necrosis (HCN) has been widely adopted, since Curro *et al*[1] reported promising data on the use of a radiofrequency energy device (Habib 4X, RITA Medical System, Mountain View, United Kingdom) to induce HCN in liver parenchyma along the intended line of liver resection[2,3]. Several reports of hepatectomy using radiofrequency energy-induced HCN confirmed that there was decreased operative blood loss and operative time[4-6]. However, it is not a new method in Japan and Southeast Asia; Tabuse *et al*[7] published a report on hepatectomy using a microwave tissue coagulator (MTC; Microtaze, Alfresa-pharma, Tokyo, Japan) to induce HCN in 1981. The basic concept and estimated clinical benefits are virtually the same between hepatectomies using radiofrequency- or microwave energy-induced HCN and percutaneous thermal tumor ablation using radiofrequency energy and microwave energy. Hepatectomies using MTC have increased in Western countries because new microwave energy devices for liver resection have been developed, and some of these devices have been approved by certification bodies in Europe and the United States such as CE marking and Center for Devices and Radiological Health[8].

In Japan, there have been several small-scale reports on clinical outcomes of hepatectomy using MTC that showed notable results in reducing intraoperative blood loss compared with traditional methods[9,10]. However, liver resection for hepatocellular carcinoma (HCC) using MTC has not become a gold standard procedure. A possible reason could be that the use of MTC is difficult in hepatectomy cases needing meticulous hilar dissection because of the fear of heat injury to major vasculature and intrahepatic bile ducts. Moreover, the risk of postoperative bile leakage and intra-abdominal fluid/abscess formation - due to insufficient closure of small intrahepatic bile ducts by HCN and the presence of remnants of the coagulated tissue - was thought to be high, although there was no solid evidence of an increased incidence of these complications. These concerns are problems that are common to thermal devices used for hepatectomy.

During the past three decades, we performed hepatectomies using MTC in more than 1000 cases of HCC, which included major and minor hepatectomies. Here, we present our extensive surgical experience, with an emphasis on intraoperative blood loss, adaptability to hepatectomies that needed hepatic hilar dissection, and postoperative complications of postoperative bile leakage and intra-abdominal fluid/abscess formation.

MATERIALS AND METHODS

Patients and methods

The records of 1175 patients who underwent hepatectomies using HCN induced by MTC from 1990 to 2013 were reviewed. Of these patients, 42 patients who underwent laparoscopic liver resection were excluded, and 15 patients with missing data on preoperative treatment history, operative results, and major histopathologic characteristics such as tumor size and number were also excluded from the study. A total of 1118 patients were included in this retrospective, cohort study and data on their clinicopathological characteristics were collected. The study protocol was approved by the Human Ethics Review Committee of Toranomon Hospital.

The indications for hepatectomy were basically the same as those recommended in the Consensus-Based Clinical Practice Manual of the Japan Society of Hepatology[11]. Patients with hepatitis B infection were defined as those who were seropositive for hepatitis B virus surface antigen, and patients with hepatitis C were defined as those who were seropositive for hepatitis C virus antibody.

Whether a curative hepatectomy was achieved or not was evaluated immediately after the operation. Resection was deemed curative if macroscopic tumor clearance was achieved (R0 and R1). Non-curative cases were those with R2 resection and the following resections: (1) hepatectomy with simultaneous local ablation of HCC that could not be removed surgically; and (2) hepatectomy with portal and/or IVC thrombus. The operative procedures and liver segment were defined according to the Brisbane 2000 system of nomenclature for hepatic anatomy and resections[12]. As an operative procedure, anatomical liver resection (AR) was defined as the resection of HCC together with related portal veins and corresponding territory. For tumors located centrally and/or those close to the major vessels, we performed an AR as appropriate. For tumors located peripherally or those with extrahepatic growths, we preferred limited non-anatomical resection (NAR). In our institute, there was a time period in which fresh frozen plasma (FFP) was routinely administered to patients after hepatectomy for HCC; we therefore divided the analysis of blood transfusion requirement into two time periods (1990-2003 and 2004-2013).

Postoperative complications were basically graded according to the Clavien-Dindo classification, and every case with a grade Ⅱ or higher complication was recorded as having a postoperative complication[13]. In this study, perioperative blood transfusion was not recorded as a class Ⅱ complication and was reported

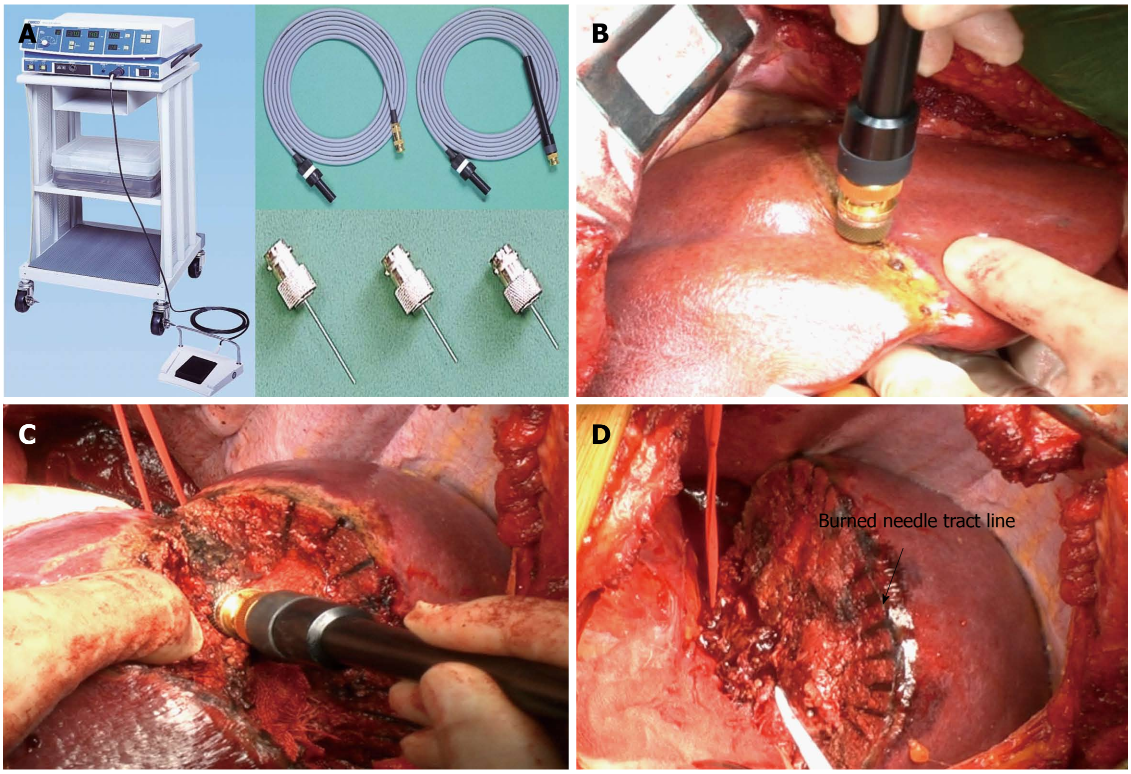

Figure 1 The microwave tissue coagulator and transection techniques. A: The generator and needle antenna of the microwave tissue coagulator; B: Repeated insertion along the intended resection line; C: An additional coagulative session during transection; D: The burned needle tracts can be used as landmarks for the transection plane.

separately because of the above-mentioned reason. Postoperative bile leakage was defined as the presence of an intra-abdominal fluid collection that was identified as bile macroscopically. Intra-abdominal fluid/abscess formation was defined as a fluid collection with an inflammatory reaction without obvious bile leakage.

Study design

Operative results such as intraoperative blood loss, the need for a blood transfusion, and postoperative complications including death, bile leakage and intra-abdominal fluid/abscess formation in two time periods (1990-2003 *vs* 2004-2013) were compared, as well as the presence of cirrhosis, and the resection procedure (AR *vs* NAR). The cumulative recurrence-free and overall survival rates of 749 patients who underwent primary curative hepatectomy without previous treatment were investigated to determine whether the use of MTC influenced long-term prognosis.

Microwave tissue coagulator

Basic information on the MTC has been reported in detail by Tabuse who is the medical pioneer in the surgical applications of MTC[14]. The MTC system consists of a microwave generator, a handpiece and a reusable needle antenna that can be adjusted in length from 10 mm to 45 mm (Figure 1A). There is an attachment device that changes the antenna angle to 90 degrees. This surgical tool is based on the principle that microwave irradiation of tissue with a frequency of 2450 Mhz (corresponding wavelength of 12 cm) *via* a monopolar antenna produces heat due to energy produced by the vibration of polar molecules in protein and water. The generation of heat will be limited to the electromagnetic field around the antenna, and the coagulation field is determined by the relationship between antenna length and tissue permittivity. In our experience, an area of liver parenchyma with a radius of approximately 5 mm around the antenna was coagulated in one session. Each coagulation session consisted of 30 to 45 s of coagulation and 5 s of dissociation.

Hepatectomy procedure

After laparotomy, the liver was mobilized according to the size and site of the lesion. An intraoperative ultrasonography was always performed before liver resection to reveal the presence of previously undetected lesions and the relationship between tumor, major structures such as Glisson's sheath, and the hepatic vein. The resection line was determined using ultrasonography and marked. Basically, the resection margin width was 10 mm from the tumor edge and it was altered according to the tumor characteristics and remnant liver function. The liver tissue was then coagulated by repeated insertion of the monopolar MTC needle electrode along the intended resection line (Figure 1B). The depth from the liver surface to

Table 1 Patient demographics and tumor characteristics

Characteristics	*n* (%)
Patient-related factors	
Sex (M/F)	882/236
Age (range) (yr)	63 (28-87)
Etiology	
Hepatitis B infection	294 (26)
Hepatitis C infection	648 (58)
Hepatitis B and C infection	12 (1)
Alcohol abuse	34 (3)
Others	136 (12)
Operative situation	
Primary curative hepatectomy without previous treatment	749 (67)
Primary curative hepatectomy with previous treatment	108 (10)
Primary non-curative hepatectomy	119 (11)
Second hepatectomy	123 (11)
Three or more hepatectomies	19 (2)
Baseline liver function	
Serum platelet count < 10^5 (μL)	309 (28)
Child-Pugh grade A	985 (88)
Child-Pugh grade B/C	131/2 (12)
Liver cirrhosis[1]	656 (59)
Pre-operative AFP value (ng/mL)	
< 20	612 (55)
≥ 20, < 100	244 (22)
≥ 100, < 400	116 (10)
≥ 400	131 (12)
Tumor-related factors	
Tumor size (mm)	22 (2-250)
≤ 2	502 (45)
< 2, ≤ 5	519 (46)
> 5	97 (9)
Solitary tumor	922 (82)
Poorly differentiated	233 (21)
Microscopic vascular invasion	270 (24)
Macroscopic vascular invasion	25 (2)

[1]The differentiation grade was based on the most poorly differentiated component in the entire specimen. AFP: Alpha-fetoprotein; DCP: Des-gamma-carboxyprothrombin.

the major Glisson's sheath and the hepatic vein was precisely determined by ultrasonography and direct puncture of these structures was avoided. The tip of the antenna is blunt, and the surgeon can easily sense the contact of the tip with Glisson's sheath or major vasculature, so that the antenna can be pulled out and the insertion angle changed. We inserted the antenna 5 to 10 mm away from major vasculature and bile duct according to the precise vascular map obtained by intraoperative ultrasonography to avoid heat injury to these structures. The coagulated liver parenchyma was divided by forceps and scissors, and additional HCNs were performed when the parenchymal transection reached the non-coagulated parenchyma as appropriate (Figure 1C). The major and approximately 3-5 mm or more size Glisson's sheath and hepatic vein greater than 5 mm were not coagulated unless the antenna was directly inserted into these structures. When those structures were exposed, they was ligated or sealed by ultrasonically activated scalpel or the vessel sealing system.

The Pringle maneuver was not employed routinely; it was mainly used in major hepatectomies or for controlling bleeding from the transection surface.

Statistical analysis

Data were analyzed using SPSS software version 21 (IBM SPSS, Chicago, IL, United States). All clinical and pathological features were categorized as either continuous or categorical variables. Continuous variables were summarized as medians and ranges. The Mann-Whitney *U* test was used to compare continuous variables between the two groups. The χ^2 or Fisher's exact test was used to compare categorical variables as appropriate. Cumulative overall survival and recurrence-free survival were determined by the Kaplan-Meier method. A P value of < 0.05 was considered statistically significant.

RESULTS

The clinicopathological characteristics of the 1118 patients are shown in Table 1. In regards to patient characteristics, 79% were men and the median age at the time of hepatectomy was 63 years old (range 28-83 years). Of the 1118 patients, 976 (87%) underwent a primary hepatectomy, 123 (11%) underwent a second hepatectomy, and 19 (2%) underwent a third or more hepatectomies. The main etiologies of HCC were hepatitis C virus infection (60%), hepatitis B virus infection (25%) or alcohol abuse (3%). Regarding baseline liver function, most patients had Child-Pugh grade A liver function (88%) and 131 patients had grade B (12%). Only two Child-Pugh grade C patients underwent a hepatectomy. Histologically proven liver cirrhosis was seen in 59% of patients, and 74% showed F3 or F4 stage liver fibrosis. With respect to tumor-related characteristics, the median maximum tumor diameter was 22 mm (mean, 28.0 ± 21.0 mm). Eighty-two percent of patient underwent hepatectomy for a solitary tumor and 85% of patients met the Milan criteria (945/1118). A poor histological differentiation grade was seen in 21% of cases and microscopic vascular invasion was seen in 24%.

Information on the type of operation and weight of the resected specimen is shown in Table 2. Major hepatectomy was performed in only 4% of cases. One hundred and three cases needed hepatic hilar dissection and AR was performed in 275 patients. Seventy-five percent of operations were NAR, and as a result, 49% of the cases had less than 50 g of tissue resected.

The intra- and postoperative results are shown in Table 3. The median operative time was 165 min (range, 40-685 min; mean, 178 ± 76 min), and the median operative blood loss was 250 mL (range, 5-58515 mL; mean, 497 ± 1900 mL). The Pringle maneuver was required in 18% of all cases and 14% of cases with cirrhosis, and the median occlusion time

Table 2 Patient demographics and tumor characteristics

	n (%)
Operative procedure	
Major hepatectomy	42 (4)
Right hepatectomy	15
Left hepatectomy	20
Right trisectionectomy	2
Left trisectionectomy	2
Central bisectionectomy	3
Minor hepatectomy	
Right anterior sectionectomy	26
Right posterior sectionectomy	23
Left medial sectionectomy	12
Left lateral sectionectomy	47
Bisegmentectomy	2
Segmentectomy	123 (11)
2	4
3	11
5	22
6	27
7	12
8	29
Sectionectomy or segmentectomy + limited resection	18
Limited resection	843 (75)
Multiple site	126
Single site	717
Weight of the resected specimen (g)[1]	
< 50	542 (49)
≥ 50, < 100	243 (22)
≥ 100, < 250	195 (18)
≥ 250, < 500	87 (8)
≥ 500	35 (3)

[1]Data was uncertain in 16 cases.

Table 3 Perioperative results and postoperative complications

Intraoperative results	
Operative time (min)	
median (range)	165 (40-685)
mean ± SD	180 ± 77
Intraoperative blood loss (mL)	
median (range)	255 (5-58515)
mean ± SD	504 ± 1890
Required Pringle maneuver	200 (18%)
Required intraoperative blood transfusion	300 (26%)
Red blood cell transfusion	88 (9%)
Plasma transfusion	281 (45%)
Postoperative results	
Required postoperative blood transfusion	369 (32%)
Red blood cell transfusion	111 (10%)
Plasma transfusion	356 (31%)
Complications	
Class Ⅱ[1]	120
Class Ⅲ	72
Class Ⅳ	14
Class Ⅴ	10
Perioperative blood transfusion	438
Surgical wound infection	58
Intra-abdominal fluid collection and/or abscess formation	37
Uncontrollable ascites	36
Bile leakage	33
Pneumonia and/or atelectasis	23
Postoperative bleeding	15
Uncontrollable pleural effusion	14

[1]Perioperative blood transfusion was excluded from this category.

was 13 min (range, 1-80 min). A positive resection margin in the pathological specimen (R1 resection) was seen in 11% of cases. Intra- and postoperative blood transfusions were required in 26% and 32% of cases, respectively. The overall perioperative blood transfusion rate reached 39%. However, when the study period was divided into two time periods, the rate of perioperative transfusion decreased from 66% (1990-2003) to 18% (2004-2013) (Table 4). Postoperative complications other than requirement of blood transfusion occurred in 19% of patients. The overall mortality rate was 0.9% (10/1118). Three patients died of postoperative liver failure, three died of postoperative liver abscess, two died of liver failure that was induced by postoperative pneumonia, one patient died of rupture of varices, and one patient died of intraoperative massive bleeding. The most common complication was surgical wound infection, which occurred in 5% of cases. Postoperative bile leakage occurred in 33 patients (3.0%) and intra-abdominal fluid/abscess formation was seen in 37 patients (3.3%). The complication rate in the group of 749 cases with no previous treatment that underwent a primary curative operation was 20%, while death, bile leakage, and intra-abdominal fluid/abscess formation occurred in 1.1%, 2.8%, and 3.5% of cases, respectively.

The results of subgroup analyses that closely examined the characteristics of hepatectomy using MTC are shown in Table 4. Comparison of the two time periods revealed that the proportion of cases requiring intra- and postoperative blood transfusion significantly decreased in the later period except for those requiring intra-operative red blood cell transfusions. Regarding the influence of cirrhosis on intraoperative blood loss, no significant difference was seen between cirrhotic and non-cirrhotic patients, although cirrhotic patients tended to have smaller tumors and underwent less invasive operations. AR was performed in 275 patients (25%) and the median intraoperative blood loss was 528 mL, which was approximately double the amount for NAR. Postoperative bile leakage and intraoperative fluid/abscess formation occurred in 4.4% and 4.4% of cases, respectively. Although this group included 103 cases that underwent hepatic hilum dissection that had HCN near the hepatic hilum (Figure 1D), there was no clinical relevant postoperative biliary tract stricture or vessel aneurysm due to heat injury to Glisson's sheath or the major hepatic vein.

The recurrence-free survival and overall survival curves of the 749 patients who had no previous treatment and underwent primary curative resection are shown in Figure 2. The 1-, 3-, and 5-year recurrence-free survival rates were 84%, 56%, and 40%, respectively. The 3-, 5-, and 10-year overall survival rates were 88%, 78%, and 49%, respectively.

Table 4 Subgroup analyses of perioperative variables

	Time period		*P* value	Presence of cirrhosis		*P* value	Operative procedure		*P* value
	1990-2003	2004-2013		LC	Non-LC		AR	NAR	
n	511	607		656	462		275	843	
Preoperative factors									
Presence of cirrhosis (%)	64	54	< 0.01	NA	NA		38	65	< 0.01
Tumor > 2 cm (%)	51	58	0.02	48	66	< 0.01	83	46	
Intraoperative results									
Operative time (min)	175	155	< 0.01	160	173	< 0.01	220	153	< 0.01
Intraoperative blood loss (mL)	272	242	0.11	250	270	0.38	528	203	< 0.01
Anatomical resection	23	25	1.00	16	37	< 0.01	NA	NA	
R1 resection (%)	12	11	0.78	12	10	0.39	9	12	0.33
Intraoperative BT required (%)	45	10	< 0.01	29	21	< 0.01	34	5	< 0.01
Red blood cell transfusion (%)	8	7	0.18	8	7	0.73	16	5	< 0.01
Plasma transfusion (%)	44	7	< 0.01	27	19	< 0.01	31	21	< 0.01
Postoperative results									
Postoperative BT required	56	12	< 0.01	37	24	< 0.01	39	29	< 0.01
Red blood cell transfusion	15	4	< 0.01	11	7	0.04	15	7	< 0.01
Plasma transfusion	55	10	< 0.01	36	23	< 0.01	38	28	< 0.01
All complications[1]	18	14	0.08	17	16	0.63	20	15	0.10
Death	1.4	0.5	0.20	1.4	0.2	0.053	1.4	0.7	0.27
Bile leakage	3.7	2.3	0.21	2.3	3.9	0.72	4.4	2.5	0.15
Intra-abdominal abscess formation	4.3	2.4	0.10	3.2	3.5	0.06	4.4	3.0	0.25

[1]Perioperative blood transfusion was excluded. BT: Blood transfusion; LC: Liver cirrhosis; AR: Anatomical resection; NAR: Non-anatomical resection R1, positive resection margin in histological specimen.

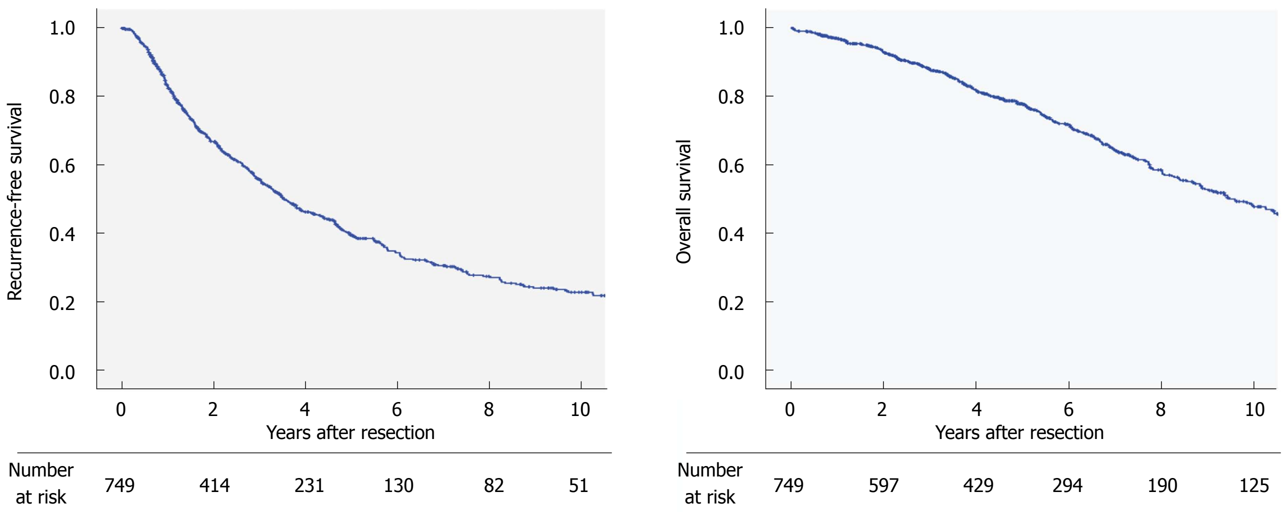

Figure 2 Recurrence-free and overall survival curves of patients with primary curative hepatectomy.

The local recurrence rate in primary curative hepatectomy was 3.4% in R0 resection, and 8.4% in R1 resection.

DISCUSSION

MTC has been used in hepatectomies extensively in Japan and Southeast Asian countries because this device can reduce intraoperative blood loss remarkably without using an inflow control. The excellent operative results without using an inflow control benefit patients with underlying liver dysfunction and those with anemia, low serum platelet count, and coagulopathy.

Although microwave energy has been used in tumor ablation treatment, a microwave energy device for hepatectomy had not been available in Western countries until recently. Recent successful liver resections using radiofrequency energy to induce HCN encouraged the development of microwave energy devices in Western countries, and this development has been noted recently.

The excellent intraoperative blood loss control by MTC during liver parenchyma resection was reported more than 10 years ago. Our results were compatible with those reported in the past and the results of liver resection using HCN induced by radiofrequency energy[9,10]. Although most of our operations were minor liver resections, the median blood loss of 250

Table 5 Summary of large-scale studies on hepatectomy for hepatitis C virus

Transection method	*n*	Study period	Etiology	LC	OT (median/mean)	OBL (median/mean)	MTS	BL/AFC	5-yr RFS/OS	Authors	Ref.
UD	398	1983-1997	HBV 22 HCV45	52	-	-/1848	5.0 cm	- -	23/34	Hanazaki	[15]
-	154	1991-1999	HBV 24 HCV 6	65	-	-	-	3.2/5.8	37/-	Fong *et al*	[16]
MTC	214	1992-2001	HBV 17 HCV 72	47	273/284 min	1010/1628 mL	3.9 cm	13%/-	28/58	Satoi	[10]
CC/UD	532	1994-2002	-	-	-	-/635 mL	-	9.0/8.4	-/-	Imamura *et al*	[17]
-	168	1999-2003	-	66	-	-/322 mL	5.1 cm	< 1%/< 1%	47/61	Shi *et al*	[18]
RFAR	55	2001-2007	HBV 24 HCV 38	100	-/165	-/22	-	1.8/9.0	-/-	Curro *et al*	[2]
UD	359	2001-2010	HBV 34 HCV 45	-	-/291	-/1288	-	12.8/8.6	-/-	Sadamori	[19]
MTC	1118	1990-2013	HBV 25 HCV 60	59	165/178 min	250/497 mL	2.2 cm	3.1/4.4	40/78	Present study	

LC: Liver cirrhosis; OT: Operative time; OBL: Operative blood loss; MTS: Median tumor size; BL: Bile leakage; AFC: Intra-abdominal abscess/fluid formation; RFS: Recurrence-free survival; OS: Overall survival; UD: Ultrasonic dissector; MTC: Microwave tissue coagulator; CC: Clamp crash; RFAR: Radiofrequency-assisted resection; HBV: Hepatitis B virus; HCV: Hepatitis C virus.

mL among more than one thousand cases was an outcome that was better than those in large series of hepatectomies for HCC using other resection techniques[2,10,15-19] (Table 5). Given that most of our patients had underlying liver dysfunction and 59% had histologically proven cirrhosis, our large-scale study clearly showed that MTC is effective in reducing intraoperative blood loss without using inflow control in hepatectomies for HCC. Moreover, a subgroup analysis showed that the intraoperative blood loss in cirrhotic patients was not significantly different from those without liver cirrhosis. The control of intraoperative blood loss without using inflow control, especially in patients with liver damage, is the biggest concern with techniques for liver parenchymal transection because it is closely related to postoperative short- and long-term prognoses of HCC. The effectiveness of MTC in these patients has been reported and our results confirmed its effectiveness[9,10].

Despite the superior control of intraoperative blood loss during liver parenchyma resection, the use of MTC in liver resections has decreased gradually in Japan as its use near the hepatic hilum and/or major vasculature was regarded to be technically difficult because of the potential risk of heat injury to these structures. Moreover, MTC was considered to increase postoperative bile leakage and resection surface abscess due to infection of the remnants of heat-coagulated tissue. However, both concerns have not been fully investigated by examining large patient numbers in the past; this study therefore focused on those complications.

Our study dispelled the misconception about heat injury to major vasculature and the hepatic hilum. This series included 275 cases of AR that needed HCN near the major Glisson's sheath and major hepatic vein, and there were 103 cases of hepatectomy that needed hepatic hilum dissection. None of them showed relevant clinical postoperative vascular and biliary tract problems due to heat injury. Recently, several studies from other institutes also reported the safety and effectiveness of hepatectomy using HCN in AR including cases that needed hepatic hilar dissection[20,21]. It is true that expert knowledge about intrahepatic anatomy and a certain amount of experience of liver resection are needed if MTC is used near the hepatic hilum, and surgeons have to pay close attention to avoid direct puncture of the first and second branch of Glisson's sheath or the main branch of the hepatic vein. However, considering that experienced hepatologists can perform percutaneous tumor ablation treatment by using radiofrequency energy and microwave energy near the hepatic hilum or major hepatic vein, it would be easy to understand that experienced surgeons can perform antenna insertion under direct visual and intraoperative ultrasonography guidance without injury to the major Glisson's sheath or major hepatic vein[22,23]. Moreover, the abundant blood flow of the major vasculature takes away heat energy, known as the "heat sink" effect, which might decrease heat injury to those structures unless they are punctured directly. Ng *et al*[24] reported that blood inflow occlusion during thermal ablation near the hepatic hilum caused bile duct injury and portal vein thrombosis. We therefore do not recommend the use of HCN near the hepatic hilum during blood inflow occlusion.

Intraoperative ultrasonography technique is critically important in determining the transection plane in AR using MTC. In cases of AR using MTC, we could not expose the hepatic vein every time because our intended resection plane is about 5 mm away from the major hepatic vein[25,26]. Therefore, we could not use the major hepatic vein as a landmark of the transection plane. Both in-depth simulation of the resection plane by ultrasonography and precise chasing of the burnt black needle tract line (Figure 1D) are tips for performing AR using MTC.

Regarding postoperative bile leakage and intra-abdominal fluid/abscess formation, our results did not show a remarkable difference compared with previous large-scale reports. The reported incidence of bile leakage after hepatectomy for liver malignancies without biliary reconstruction in recent large series ranged from less than 1% to 12.8%, although the definitions of postoperative bile leakage and tumor characteristics in each study were not consistent (Table 5). The overall incidence of bile leakage in our study, using our definition, was 3.0% overall and 4.4% in the group of patients who underwent AR. Considering the liver parenchyma transection area, the observed increase in the incidence of postoperative bile leakage in AR was not unexpected, and our results were compatible with those in previous reports (Table 5). Regarding postoperative intra-abdominal fluid/abscess formation, it is understandable that HCN tissue remnants of 5 mm thickness seemed to have caused postoperative infectious complications. Our results were not remarkably different from previous studies that focused on postoperative fluid/abscess formation (Table 5). Although this study did not compare other parenchyma transection devices, our findings examining a large number of patients were compatible with those of previous reports using non-HCN devices with respect to postoperative bile leakage and fluid/abscess formation. Possible reasons for the lower rate of bile leakage and fluid/abscess formation in our study include the higher proportion of non-anatomical limited resections compared with other studies and the retrospective study design. The shorter operative time and smaller operative blood loss might also decrease the risk of postoperative bile leakage because these operative results were reported as significant risk factors for postoperative bile leakage in a previous study[19]. Moreover, meticulous ligation of exposed Glisson's sheath approximately 3-5 mm in diameter would result in a lower bile leakage rate. Subsequently, the low postoperative bile leakage rate would result in a decrease in the incidence of postoperative fluid/abscess formation because of their relation to bile leakage.

The significant deviation of operative procedure (more minor hepatectomy and less major hepatectomy) in the present study needs to be assessed. There were two clear reasons: one is the unique characteristic of our study population. Most of our patients had underlying liver disease with impaired liver function, and they were therefore closely followed up and received HCC screening examinations. As a result, many of the HCCs that were detected were small and solitary, and the indicated procedure tended to be non-anatomical limited resection. The other reason is our policy of hepatectomy for HCC in patients with multicentric carcinogenic potential. Although some surgeons believe that AR with strict exposure of the hepatic vein should be applied in every case if possible, we believe that minimizing the extent of resection and preserving remnant liver function would benefit overall survival in patients with multicentric carcinogenic potential. Consensus on the treatment strategy for HCC in patients with multicentric carcinogenesis potential has not been reached. The postoperative overall survival rates in the present study were compatible with those in previous large-scale reports, and our results justify our treatment strategy.

With respect to study limitations, the current study was retrospective in its study design with a wide period of recruitment and it analyzed patients in a single center. Moreover, the current study was not designed to compare the postoperative results of MTC with those of other devices, and therefore, the reduction in blood loss and complications was not verified statistically. Comparing the incidence of postoperative bile leakage and fluid/abscess formation in our study with those of other studies might be inaccurate because patient characteristics and definition were not consistent. However, we think that the small blood loss and the low complication rate among more than 1000 hepatectomies are worth reporting because our study is the biggest study on single liver parenchyma transection technique.

Differences between the use of radiofrequency energy and microwave energy to induce HCN in hepatectomy were not examined in this study. A direct comparison study of liver resection using radiofrequency energy and microwave energy does not exist. In contrast, there are reports comparing these two energies to induce coagulation in percutaneous tumor ablation[27,28]. However, whether radiofrequency energy is superior to microwave energy with respect to the size of the coagulated area, local tumor control and safety has not been fully explored in those studies. A direct comparison of the two thermal ablation energies for hepatectomy is needed to determine the superiority of one energy over the other in hepatectomy.

In conclusion, this study demonstrated an extensive experience of hepatectomy using HCN by MTC. Although the current study did not directly compare with other transection techniques, the prevalence of postoperative fluid/abscess formation and bile leakage seemed to be consistent with that seen in other large-scale studies reported in the past.

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COMMENTS

Background

Hepatectomy using heat coagulative necrosis has been widely adopted, hepatectomies using microwave tissue coagulator have increased in Western countries in recent years. In Japan, there have been several small-scale reports on clinical outcomes of hepatectomy using MTC that showed notable results in reducing intraoperative blood loss compared with traditional methods, however, liver resection for hepatocellular carcinoma (HCC) using MTC has not become a gold standard procedure.

Innovations and breakthroughs

During the past three decades, the authors performed hepatectomies using MTC in more than 1000 cases of HCC, which included major and minor hepatectomies, they present their extensive surgical experience, with an emphasis on intraoperative blood loss, adaptability to hepatectomies that needed hepatic hilar dissection, and postoperative complications of postoperative bile leakage and intra-abdominal fluid/abscess formation.

Peer-review

It is a very important study with a large patients population.

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