



915-MHz microwave-assisted laparoscopic hepatectomy: a new technique for liver resection

Xiaogang Dong^{1,2,3,4,5} · Zhongquan Sun^{1,3,4,5} · Tianchun Wu^{1,3,4,5} · Wenjia Guo⁶ · Sheng Yan^{1,3,4,5} · Shusen Zheng^{1,3,4,5}

Received: 31 March 2017 / Accepted: 17 October 2017 / Published online: 29 October 2018
© Springer Science+Business Media, LLC 2018

Abstract

Background Hemorrhage during the liver transection is the major hazard for laparoscopic hepatectomy (LH). We aimed to evaluate the feasibility and safety of a 915-MHz microwave device used in LH.

Methods Data were retrospectively analyzed regarding 60 patients who underwent LH with or without 915-MHz microwave coagulation at our center from January 2016 to June 2016. 30 patients underwent the 915-MHz microwave-assisted LH (MW group), and 30 patients otherwise were considered as control group.

Results No perioperative mortality was observed. Intraoperative blood loss amounts in microwave group and control group were 26.83 ml and 186.33 ml, respectively ($P < 0.001$). The durations of parenchyma transaction (55.17 vs. 70.83 min, $P < 0.001$), blood occlusion (2.17 vs. 25.33 min, $P < 0.001$), and operation (120.67 vs. 148.00 min, $P < 0.001$) were much shorter in microwave group compared with control group. Lower incidence of postoperative complications (0.0 vs. 14.3%, $P = 0.038$) and shorter length of postoperative hospital stay (6.00 vs. 7.23 days, $P = 0.027$) were also noted in the microwave group, compared with the control group.

Conclusion 915-MHz microwave-assisted LH was found to be safe and efficient.

Keywords Laparoscopic hepatectomy · 915-MHz microwave · Thermal coagulation · Bloodless · Outcome

Excessive intraoperative blood loss and blood transfusion were the primary risk factors associated with the incidence of postoperative complications and long-term survival [1]. Especially in patients who underwent laparoscopic hepatectomy (LH), achieving hemostasis through compression, sutures, and other means were more difficult than in those undergoing laparotomy [2]. Mastering the skills of

laparoscopic operations and adopting reliable hemostasis apparatus were the fundamental means of resolving this problem.

Various instruments were designed and applied to minimize the blood loss during the laparoscopic liver resection by coagulation of liver parenchyma on the resection plane, including the Habib™ 4X [3, 4] and 2450-MHz microwave device [5]. However, a few shortcomings impeded the application of such instruments, such as additional port for introducing the Habib™ 4X [6], and excessive thermal

Zhongquan Sun and Xiaogang Dong have contributed equally to this work.

✉ Sheng Yan
shengyan@zju.edu.cn

✉ Shusen Zheng
shusenzheng@zju.edu.cn

¹ Division of Hepatobiliary and Pancreatic Surgery, Department of Surgery, First Affiliated Hospital, School of Medicine, Zhejiang University, 79 Qingchun Road, Hangzhou 310003, Zhejiang Province, China

² Department of Hepatopancreatobiliary Surgery, Affiliated Tumor Hospital of Xinjiang Medical University, Urumqi 830011, Xinjiang Uygur Autonomous Region, China

³ Key Laboratory of Combined Multi-Organ Transplantation, Ministry of Public Health, Hangzhou 310003, Zhejiang Province, China

⁴ Key Laboratory of Organ Transplantation, Hangzhou 310003, Zhejiang Province, China

⁵ Collaborative Innovation Center for Diagnosis Treatment of Infectious Diseases, Hangzhou 310003, Zhejiang Province, China

⁶ Department of Cancer Research Institute, Affiliated Tumor Hospital of Xinjiang Medical University, Urumqi 830011, Xinjiang Uygur Autonomous Region, China

injury of the residual liver parenchyma caused by 2450-MHz microwave device [7].

The delivery of microwave did not depend on tissue texture and impedance, and the efficacies of heat production and the heating rate were both higher with microwave than with radiofrequency [8–10]. 915 and 2450 MHz were the frequencies currently used for tumor therapy, of which, 915 MHz conferred higher heat efficacy and larger range of coagulation under the same operational parameter. As the ratio of transverse diameter (TD)/longitudinal diameter (LD) regarding the coagulation zone of 915-MHz microwave was less than that of the 2450-MHz microwave [11], a cylindrical coagulation zone was more easily achieved by 915-MHz microwave which was more optimal for creating a coagulated resection plane. In the present study, we determined to investigate the feasibility, safety, and clinical value of 915-MHz microwave-assisted liver dissection in laparoscopic hepatectomy.

Materials and methods

Microwave thermal coagulation system

The microwave ablation system comprised a KY-2100 portable, microwave generator and a 915-B-type cooled-shaft microwave antenna (Kangyou Medical Technology Co. Ltd., Nanjing, China). The power output ranged from 5 to 100 W with the frequency of 915 MHz ($\pm 1\%$). The antenna shaft was coated with Teflon to prevent adhesion. There were dual channels inside the antenna shaft, and distilled water was circulated within the shaft by a peristaltic pump with a velocity of 40 rounds/min. The length of the antenna was 18 cm, the outside diameter was 1.9 mm, the width of the crack was 1.5 mm, and the distance from the crack to the top of the antenna was 22 mm.

Patients

All patients considered for LH between January 2016 and June 2016 at The First Affiliated Hospital, the School of Medicine, Zhejiang University, were offered the alternative of 915-MHz MW-assisted LH, and 30 patients underwent MW hepatectomy (MW group) after the consent was obtained. Data of 30 patients who underwent standard LH (control group) during the same period were retrospectively collected. All patients included in the present study were diagnosed with unifocal lesion and had no previous operation history. All patients' profiles were collected from medical records on July 31, 2016.

Surgical procedure

The anesthesia and pneumoperitoneum were established conventionally. Lesions were located using the combination of intraoperative ultrasound guidance and preoperative three-dimensional (3D) images reconstructed using IQQA-Liver (EDDA Technology Inc., Princeton, USA) [12]. The resection line, which was determined by resection range, was marked on the liver capsule with a monopolar electrical coagulation hook to guide the insertion of microwave antenna.

The antenna was penetrated into the liver through a 2-mm incision on the abdominal wall. The coagulation began at the site 1 cm away from one end of the marked line. The puncture depth did not exceed the thickness of the parenchyma, and the emission power of microwave was 50 W and the emission duration was 100 s. After the completion of the first coagulation procedure, the antenna was pulled out 5 cm along the puncture tract to coagulate the next cylindrical parenchyma connected to the previous one, until the coagulation zone reached the capsule of liver. Then, the antenna was pierced into the parenchyma 2 cm away from first site along the marked line, as measured by a curved separation clamp. The above was process repeated until the parenchyma on the resection plane was coagulated completely. A few small abdominal incisions might be required to complete the whole process of coagulation. The parenchyma was dissected using Cavitron Ultrasonic Surgical Aspirator (CUSA) (Tyco Healthcare, Mansfield, MA) or a Harmonic Scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA) along the coagulated plane, and hemostasis was achieved conventionally (Fig. 1). Low central venous pressure (0–5 mm Hg) was maintained during parenchyma dissection. If the lesions were located near the first or second porta hepatis, the coagulation would be conducted in parenchyma near the main portal vein or major hepatic vein.

The liver parenchyma was transected directly using Harmonic Scalpel or CUSA in the control group. Conventional hemostasis was performed as in MW group.

Ethic statement

The study was approved by the Ethics Committee of the First Affiliated Hospital, the School of Medicine, Zhejiang University, and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki as revised in 2000. Informed consent was obtained from patients before LH, as well as other participants.

Statistics

The continuous variables were presented as the means \pm standard deviation following statistical analysis with the t-test or ANOVA. Enumeration data were analyzed

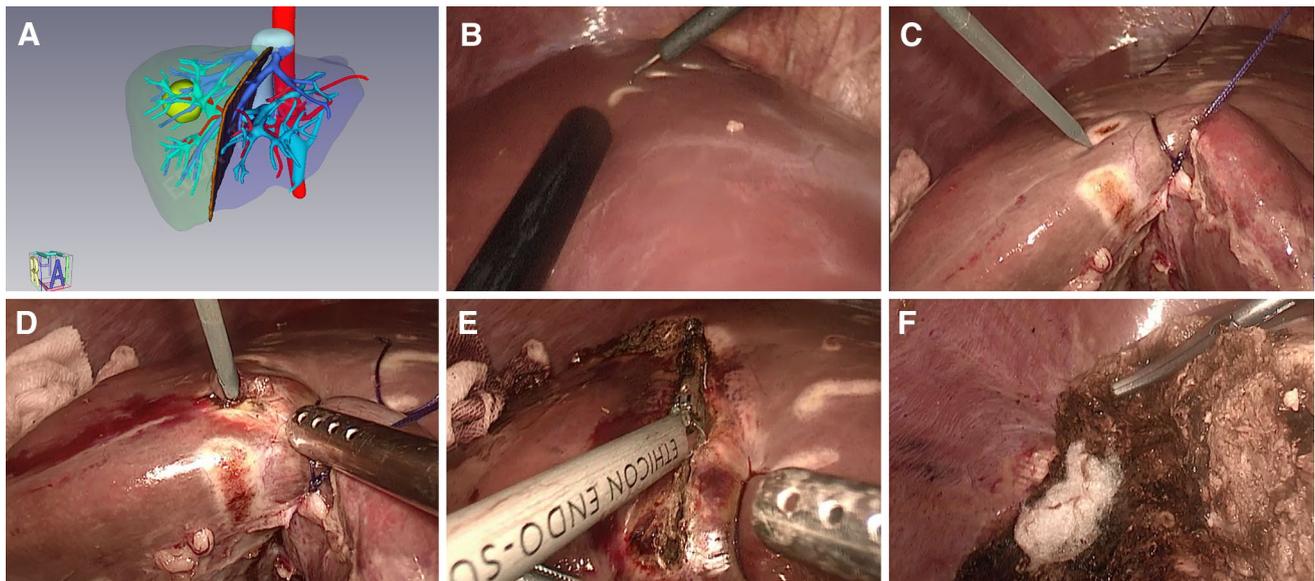


Fig. 1 Procedures of ultrasound-guided 915-MHz microwave coagulation-assisted liver resection in laparoscopic hepatectomy. **A** Preoperative 3D reconstruction of the liver, tumor (highlighted in yellow), and artery/portal vein/hepatic vein and the simulated resection plane (brown section) conducted by IQQA-Liver. The tumor was located in the right liver. **B** The resection line (dotted line) is marked on the liver capsule using a monopolar electrical coagulation hook guided

by intraoperative ultrasound. **C** Parenchyma is pierced into the microwave antenna along the resection line. **D** Coagulation is employed along the marked line of resection. **E** Liver resection is performed by cutting the coagulated tissue with an ultrasonic scalpel after the resection plane is completely coagulated. **F** Margin of resection after LH is shown after resection has been completed. No bleeding or bile leakage occurs. (Color figure online)

by means of the χ^2 test or the Fisher's exact test. All analyses were performed using the statistical software package SPSS 23.0 (SPSS Inc., Chicago, USA). $P < 0.05$ was considered significant.

Results

In total, 60 patients were included in the present study. 47 (78.3%) patients were male. The median age was 53 years (mean 54, range 32–77). The median tumor diameter was 3.90 cm (mean 4.25, range 2.00–8.00). 54 patients (90.0%) were diagnosed with malignancy. No significant difference regarding the baseline data of MW group and control group was noted (Table 1).

The duration of operation, parenchymal transaction, and first porta hepatis occlusion in the MW group was significantly shorter than those in control group ($P < 0.001$, $P < 0.001$, and $P < 0.001$, respectively, Table 2). The volume of intraoperative blood loss in the MW group was significantly less than that in the control group ($P < 0.001$, Table 2). None of the patients required blood transfusions in either the MW group or the control group.

There were no significant differences in preoperative serum alanine aminotransferase (ALT) and alanine aminotransferase (AST) levels between the two groups. The serum ALT and AST levels in the MW group were

significantly lower than those in the control group on days 1 and 3 after surgery (Table 2). In addition, on day 5 after surgery, the ALT levels in the MW group were still lower than those in the control group ($P = 0.001$, Table 2), but there was no significant difference in the AST levels between the two groups ($P = 0.350$, Table 2). Lower volume of drainage in the MW group than that in the control group was noted on days 1, 3 and 5 after surgery ($P < 0.05$), and the drainage volume in the MW group was approximately zero on postoperative day 5. No major complications occurred in the MW group, and 2 cases of biliary leakage, 1 case of intra-abdominal abscess and 1 case of bleeding occurred in the control group ($P = 0.038$, Table 2). The mean postoperative length of hospital stay was 6.00 days in the MW group, which was significantly less than that of 7.23 days in the control group ($P = 0.027$, Table 2). All four patients were treated conservatively and gained full recovery. R0 resection was confirmed in all 60 cases.

Discussion

Operation is the best option for treating liver tumors [13]. Laparoscopic hepatectomy had become widely accepted in the field of hepatic surgery for its greater visual field and less-invasive characters [14, 15]. Intraoperative blood loss is still one of the major complications in LH, which

Table 1 Characteristics of patients in microwave group and control group

	MW group (n = 30)	Control group (n = 30)	p value
Median age (years) [#]	55.43 ± 11.42	53.13 ± 10.91	0.428
Sex (M)	23 (76.7%)	24 (80.0%)	0.754
Median tumor size (cm) [*]	4.00 (2.00–8.00)	3.80 (2.50–6.60)	0.571
Chronic hepatitis	24 (80.0%)	25 (83.3%)	0.754
Cirrhosis	24 (80.0%)	25 (83.3%)	0.754
ALT	23.30 7.52	22.63 (8.34)	0.746
AST	23.43 7.48	22.20 (7.61)	0.529
Diagnosis			0.974
Hepatocellular carcinoma	24 (80.0%)	25 (83.3%)	
Hepatic adenoma	1 (3.3%)	1 (3.3%)	
Focal nodular hyperplasia	2 (6.7%)	2 (6.7%)	
Colon adenocarcinoma metastasis	3 (10.0%)	2 (6.7%)	
Type of resection			0.990
Segmental resection	17 (56.7%)	17 (56.7%)	
Bisegmentectomy	2 (6.7%)	2 (6.7%)	
Lobar hepatectomies	3 (10.0%)	3 (10.0%)	
Left hepatectomy	2 (10.0%)	3 (10.0%)	
Right hepatectomy	6 (20.0%)	5 (16.7%)	

Data are presented as #: means ± standard deviation or as *: median (range), or as numerical value (percentage)

Table 2 Comparison of operative outcomes between the microwave group and control group

	MW group	Control group	P value
Duration of the first porta hepatic occlusion (min)	2.17 ± 4.09	25.33 ± 20.63	< 0.001
Duration of parenchymal transection (min)	55.17 ± 14.47	70.83 ± 14.44	< 0.001
Duration of operation (min)	120.67 ± 27.16	148.00 ± 29.61	< 0.001
Intraoperative blood loss (ml)	26.83 ± 18.82	186.33 ± 86.16	< 0.001
Postoperative ALT levels (U/L)			
Day 1	98.07 ± 52.87	154.47 ± 53.98	< 0.001
Day 3	53.16 ± 23.09	80.73 ± 30.23	0.001
Day 5	32.80 ± 7.69	42.00 ± 11.42	0.001
Postoperative AST levels (U/L)			
Day 1	85.27 ± 37.26	129.73 ± 46.33	< 0.001
Day 3	48.03 ± 24.58	71.27 ± 30.89	0.002
Day 5	30.57 ± 8.14	35.73 ± 10.30	0.350
Drainage volume of the abdominal cavity (ml)			
Day 1	38.00 ± 33.18	84.5 ± 77.13	0.004
Day 3	9.67 ± 10.82	33.83 ± 55.83	0.027
Day 5	1.33 ± 2.91	11.55 ± 26.02	0.044
Cumulative complications (%)	0 (0.0%)	4 (13.3%)	0.038
Length of postoperative stay (days)	6.00 ± 1.31	7.23 ± 2.66	0.027

Data are presented as means ± standard deviation or as numerical value (percentage)

significantly associated with poor outcomes, especially in cirrhotic patients [16]. Different techniques, such as radiofrequency [17] and microwave ablation devices [5], were adopted to reduce the blood loss through the coagulation of hepatic parenchyma on transaction plane; however, disadvantages, such as insufficient coagulation range or the

unnecessary residual hepatic parenchyma injury impeded the application of those techniques.

The present study provided a feasible approach for performing LH efficiently and safely using 915-MHz microwave antenna to acquire sufficient coagulation range. Less or even no blood loss was achieved during the

liver dissection at the cost of mild injury of residual liver parenchyma. In patients receiving 915-MHz microwave-assisted LH, shorter durations of blood flow occlusion, parenchymal transection, and operation were needed. It had less impact on postoperative liver function. And less postoperative complications, as well as shorter length of postoperative hospital stay, were noted in MW group, compared with conventional LH. Those advantages made the 915-MHz microwave antenna an ideal option for LH.

The dissection of liver parenchyma by CUSA or Harmonic Scalpel was more efficiently after coagulation. Although time was taken for achieving coagulation, the total operation time was still shortened. The cirrhotic liver parenchyma was more susceptible to ischemia and hypoxia than non-cirrhotic one, and bled more easily during the dissection process [18]. Shorter occlusion duration of the first porta hepatis in patients receiving 915-MHz microwave coagulation reduced the ischemic and anoxic injury. And with the additive effect of less blood loss, better postoperative liver function, and less peritoneal drainage were established, which led to lower incidence of postoperative complications and shorter length of postoperative hospital stay.

Hepatocellular carcinoma usually had independent blood supply, and the compression of the tumor during operation was associated with hematogenous metastasis [19]. Occlusion of microvessels by coagulation before the dissection reduced the possibility of hematogenous metastasis, which contributed to lower incidence of recurrence and better long-term survival.

The limitations of the present study included the retrospective single-center design, relatively small sample size, and lack of long-term follow-up. Prospective multicenter research with large sample size and long-term follow-up are required.

In conclusion, LH using Harmonic Scalpel assisted by 915-MHz microwave coagulation simplified the course of liver parenchyma dissection and reduced the blood loss, especially in cirrhotic livers. In patients receiving 915-MHz microwave coagulation, lower incidence of postoperative complications and better outcomes were confirmed. Thus, the 915-MHz microwave-assisted laparoscopic hepatectomy was feasible and safe.

Acknowledgements This study was supported by the National Natural Science Foundation of China (Grant Nos. 81372626 and 81572975), the National S&T Major Project (No. 2012ZX10002017), the Key research and development project of science and technology department of Zhejiang, China (No. 2015C03053), the Innovative Research Groups of National Natural Science Foundation of China (No. 81421062), and the Major Program of National Natural Science Foundation of China (No. 91542205).

Compliance with ethical standards

Disclosures Xiaogang Dong, Zhongquan Sun, Tianchun Wu, Wenjia Guo, Sheng Yan, and Shusen Zheng declare that they have no conflicts of interest or financial ties to disclose.

References

1. Song T (2015) Recent advances in surgical treatment of hepatocellular carcinoma. *Drug Discov Ther* 9:319–330
2. Ishizawa T, Gumbs AA, Kokudo N, Gayet B (2012) Laparoscopic segmentectomy of the liver: from segment I to VIII. *Ann Surg* 256:959–964
3. Weber JC, Navarra G, Jiao LR, Nicholls JP, Jensen SL, Habib NA (2002) New technique for liver resection using heat coagulative necrosis. *Ann Surg* 236:560–563
4. Pai M, Navarra G, Ayav A, Sommerville C, Khorsandi SK, Damrah O, Jiao LR, Habib NA (2008) Laparoscopic Habib 4X: a bipolar radiofrequency device for bloodless laparoscopic liver resection. *HPB* 10:261–264
5. Tan K, Du X, Yin J, Dong R, Zang L, Yang T, Chen Y (2014) Microwave tissue coagulation technique in anatomical liver resection. *Biomed Rep* 2:177–182
6. Zacharoulis D, Sioka E, Tzovaras G, Jiao LR, Habib N (2013) Laparoscopic left lateral sectionectomy with the use of Habib 4X: technical aspects. *J Laparoendosc Adv Surg Tech A* 23:549–552
7. Zhou W, Liang M, Pan H, Liu X, Jiang Y, Wang Y, Ling L, Ding Q, Wang S (2013) Comparison of ablation zones among different tissues using 2450-MHz cooled-shaft microwave antenna: results in ex vivo porcine models. *PLoS ONE* 8:e71873
8. Dewall RJ, Varghese T, Brace CL (2012) Visualizing ex vivo radiofrequency and microwave ablation zones using electrode vibration elastography. *Med Phys* 39:6692–6700
9. Andreano A, Brace CL (2013) A comparison of direct heating during radiofrequency and microwave ablation in ex vivo liver. *Cardiovasc Interv Radiol* 36:505–511
10. Pillai K, Akhter J, Chua TC, Shehata M, Alzahrani N, Al-Alem I, Morris DL (2015) Heat sink effect on tumor ablation characteristics as observed in monopolar radiofrequency, bipolar radiofrequency, and microwave, using ex vivo calf liver model. *Medicine* 94:e580
11. Simo KA, Tsirlina VB, Sindram D, McMillan MT, Thompson KJ, Swan RZ, McKillop IH, Martinie JB, Iannitti DA (2013) Microwave ablation using 915-MHz and 2.45-GHz systems: what are the differences? *HPB* 15:991–996
12. Chen L, Luo HP, Dong SL, Chen XP (2016) Safety assessment of hepatectomy for huge hepatocellular carcinoma by three dimensional reconstruction technique. *Zhonghua Wai Ke Za Zhi* 54:669–674
13. Kokudo T, Hasegawa K, Matsuyama Y, Takayama T, Izumi N, Kadoya M, Kudo M, Ku Y, Sakamoto M, Nakashima O, Kaneko S, Kokudo N (2016) Survival benefit of liver resection for hepatocellular carcinoma associated with portal vein invasion. *J Hepatol* 65:938–943
14. Ocuin LM, Tsung A (2016) Minimally invasive hepatic surgery. *Surg Clin North Am* 96:299–313
15. Perini MV, Starkey G, Fink MA, Bhandari R, Muralidharan V, Jones R, Christophi C (2015) From minimal to maximal surgery in the treatment of hepatocarcinoma: a review. *World J Hepatol* 7:93–100
16. Tranchart H, O'Rourke N, Van Dam R, Gaillard M, Lainas P, Sug-ioka A, Wakabayashi G, Dagher I (2015) Bleeding control during

- laparoscopic liver resection: a review of literature. *J Hepatobiliary Pancreat Sci* 22:371–378
17. Chen J, Dong X, Tang Z, Gao SL, Wu YL, Fang HQ (2013) Clinical study of liver resection with bipolar radiofrequency device: Habib 4X. *Zhonghua Yi Xue Za Zhi* 93:2553–2556
 18. Kanazawa A, Tsukamoto T, Shimizu S, Kodai S, Yamazoe S, Yamamoto S, Kubo S (2013) Impact of laparoscopic liver resection for hepatocellular carcinoma with F4-liver cirrhosis. *Surg Endosc* 27:2592–2597
 19. El-Assal ON, Yamanoi A, Soda Y, Yamaguchi M, Igarashi M, Yamamoto A, Nabika T, Nagasue N (1998) Clinical significance of microvessel density and vascular endothelial growth factor expression in hepatocellular carcinoma and surrounding liver: possible involvement of vascular endothelial growth factor in the angiogenesis of cirrhotic liver. *Hepatology* 27:1554–1562