JBUON 2016; 21(2): 412-418
ISSN: 1107-0625, online ISSN: 2241-6293 • www.jbuon.com
E-mail: editorial_office@jbuon.com

ORIGINAL ARTICLE

Microwave versus saline-linked radiofrequency (Aquamantys) assisted liver resection in a porcine liver resection model. A safety and feasibility pilot study

Dimitrios Kaparelos[1], Demetrios Moris[1], Michalis Kontos[1], Alexandros Papalampros[1], Athanasios Petrou[1], Christos Tsigris[1], Emmanouil Pikoulis[1], Nikolaos Kavantzas[2], Apostolos Papalois[3], Evangelos Felekouras[1]

[1]1st Department of Surgery, Laikon General Hospital, National and Kapodistrian University of Athens, Athens; [2]Laboratory of Pathology, National and Kapodistrian University of Athens, Athens; [3]Experimental Research Center of ELPEN, Athens, Greece

Summary

Purpose: *The aim of this study was to compare the feasibility, efficacy and safety of microwave ablation and saline-linked radiofrequency (Aquamantys) in liver resection.*

Methods: *Sixteen domestic pigs (8 per group) underwent thermoablations. Group A consisted of 8 pigs in which microwave left lateral liver resection was performed. Group B consisted of 8 pigs which underwent left lateral liver resection by the Aquamantys system. After 28 days of close follow-up, the animals were sacrificed in order to study the macroscopic and microscopic findings of each intervention on the liver edge.*

Results: *An average of 47.13 min was enough for the entire operation to take place using Aquamantys, whereas an average of 59.13 min was needed in the microwave liver resection group. Mean blood loss was 40 ml (range 5-85) with Aquamantys whereas mean blood loss was 72.37 ml (range 42-100) using microwave. Postoperative complications rates were extremely low in both groups. There was no intra- or postoperative mortality.*

Conclusions: *Our study demonstrated that left lateral liver resection using Aquamantys system is technically feasible in the porcine model and proved to be highly effective and a safer hemostatic method compared to microwave ablation.*

Key words: *Aquamantys, liver resection, microwave, radiofrequency ablation*

Introduction

Hepatic resection remains the gold standard in the treatment of malignant liver tumors; however, a large number of patients have disease that is not amenable to surgical therapy [1]. This may be due to unfavorable anatomy, the presence of multiple tumors or poor hepatic reserve [2]. Therefore, several ablative treatment modalities have been developed for local control of liver tumors in patients with non-resectable liver disease.

Microwave liver resection facilitates flexible treatment approaches, including percutaneous, laparoscopic and open surgical access [3]. A microwave generator, which emits electromagnetic energy, is connected with a thin (14.5-gauze) microwave antenna placed directly into the tumor. Electromagnetic microwaves agitate water molecules in the surrounding tissue producing friction and heat, thus inducing cellular death via coagulation necrosis [3]. The main advantages of microwave when compared with existing thermoablative technologies include consistently higher intratumoral temperatures, larger tumor ablation volumes, faster ablation times and an improved convection profile [4-7].

Correspondence to: Demetrios N. Moris, MD, PhD. Anastasiou Gennadiou 56, 11474, Athens, Greece. Tel: +30 210 6440590, E-mail: dimmoris@yahoo.com
Received: 18/11/2015; Accepted: 04/12/2015

Another thermoablative technology is the Aquamantys system, which combines radiofrequency energy and saline. Salient's proprietary transcollation technology simultaneously integrates saline and radiofrequency energy, allowing thermal energy to gently reach targeted tissues via saline-induced liquid electrodes (transcollation is the transformation of fibrous collagen due to the remodeling in its basic triple helix-structure). The latter starts a biomechanical cascade, resulting in a permanent seal of targeted tissue. Its use is "friendlier" to most surgeons, easy-to-learn (most surgeons are comfortable after 5–6 procedures) [8]. It seals blood and bile ducts up to 6 mm in diameter, is able to reduce blood loss and the recourse to vessel occlusion techniques. Moreover, it offers good results in cirrhotic livers [9] and destroys any additional cancer cells at the margin of resection.

The purpose of this study was to compare these two thermoablative techniques in relation to safety, efficacy and feasibility on liver resection in a porcine model.

Methods

This protocol was approved by the General Directorate of Veterinary Services, according to Greek legislation regarding ethical and experimental procedures (Presidential Decree 160/1991, in compliance with the EEC Directive 86/609 and Law 2015/1992 and in conformance with the European Convention 'for the protection of vertebrate animals used for experimental or other scientific purposes, 123/1986'). Animal handling and care was in accordance with the National guidelines for ethical animal research.

This study was performed at the Experimental Research Center of ELPEN, which is located in the region of Attica (European Ref Number EL 09 BIO 03). Approval from the Ethical Committee of Animal Care of East Attica County was obtained before implementation of this study.

Sixteen male domestic Landrace pigs with an average weight of 36 kg (aged 19-21 weeks) were used. All the animals were kept in the animal facilities of the experimental research center for one week before surgery. Twenty–four hrs before surgery, all animals were subjected to deprivation of food, but had free access to water. Preoperatively, animals with abnormal biochemical blood tests were excluded from the protocol. All the studies were performed by the same investigators.

Under general anesthesia the pigs were placed in a supine position. Two large-bore vein catheters were placed for intravenous fluid and drug administration. The animals were closely monitored for vital parameters throughout the entire operation. Anesthesia was achieved by intramuscular administration of 0.6 mg/kg midazolam (Roche, Athens, Greece), 0.05 mg/kg atropine sulfate (Demo, Athens, Greece) and 10 mg/kg ketamine hydrochloride (Merial, Lyon, France). Intravascular access was obtained via the auricular vein followed by endotracheal intubation (size 6.0 mm cuffed endotracheal tube, Portex, Mallinckrodt Medical, Ireland). Anesthesia continued by positive pressure mechanically ventilation (Alpha Delta lung ventilator, Siare, Bologna, Italy) with FiO2 21%, isoflurane and nitric oxide. The tidal volume was set at 10 ml/kg, with a respiratory frequency of 13/min to achieve a normal arterial PCO2 in the range of 35–45 mm Hg. During the operation, anesthesia preserved using propofol infusion (0.15 mg/kg/min), fentanyl (0.6 μg/kg/min) and pancuronium (0.06 mg/kg every 20 min).

In this study, all surgical procedures were performed under aseptic conditions. Laparotomy was performed through a midline incision. Complete mobilization of the left lateral lobe was performed. The ablation of the liver parenchyma started with the coagulation of the segment III portal triad. After this manoeuver, a clear demarcation line appeared between segment III and the rest of the liver parenchyma. Then, the needle electrode was inserted in consecutive sites into the hepatic parenchyma, along the demarcation line, so that a tissue zone between segment III and left medial lobe was gradually ablated. Afterwards, the segment's II portal pedicle was coagulated. Finally, meticulous coagulation of the surrounding liver tissue of the left lateral hepatic vein and then the vein itself was applied and division followed. The specimen was removed and the abdomen was closed.

The left lateral resection of group A was assisted using a 3.7 cm active tip antenna and a 915 MHz microwave generator (VivaWaveTM System,ValleylabTM, Covidien, Greece) while the left lateral resection of group B was assisted by the use of 2.3 bipolar sealer and a pump generator (AquamantysTM, Salient Surgical Technology, ST Medical Products, Greece).

Blood loss was measured. Then, the animals were returned to their cages and remained under close monitoring until they were euthanasized. The liver, the operative field, and the whole peritoneal and thoracic cavities were thoroughly investigated. The liver was then harvested, cut appropriately, and fixed in 10% buffered formalin solution for 48 hrs. Following that, the tissue was thoroughly sampled, routinely processed, and embedded in paraffin. Sections (4 micrometers thick) were stained with hematoxylin-eosin and evaluated by light microscopy.

The same procedure was followed for the Aquamantys system, but this time the saline-linked radiofrequency dissecting sealer was inserted in the region of the left lobe.

Statistics

Statistical analysis of the results was performed with SPSS v.11 statistical package (SPSS IBM, Armonk,

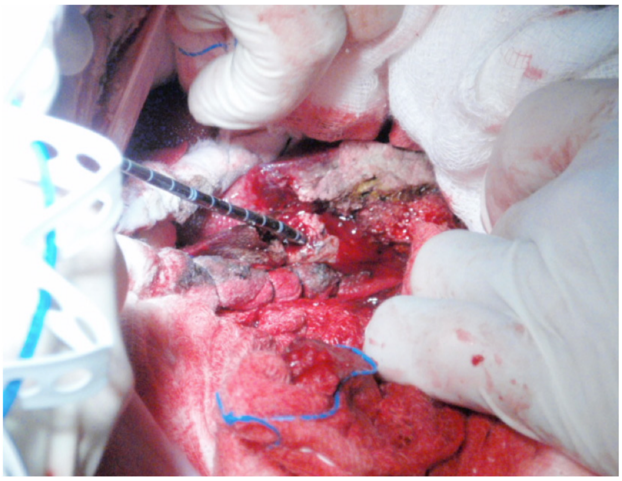

Figure 1. Liver resection by microwave ablation. Severe blood loss. Notice the soaking gauzes.

NY, USA). The results obtained were assessed by one-way ANOVA. Statistical significance was set at p <0.05.

Results

Eight pigs underwent liver resection using the Aquamantys system. An average of 47.13 min (range 32-56) was enough for the entire operation. Mean intraoperative blood loss was 40 ml (range 5-85). Major bleeding was controlled by suture ligations while minor bleeding was successfully controlled by Aquamantys coagulation (Figure 1). No clinically detectable complications were noted. Postoperative blood loss was not observed at one month follow-up, while postoperative complications developed in 2 pigs in the form of wound infections. There was no mortality either during or after surgery. Thorough post mortem investigation of the abdominal cavity showed adhesions of the liver to the stomach, diaphragm and spleen in 6 of 8 pigs. An adhesion of 1 cm in size of the greater omentum with the left medial lobe of the liver was noted in 2 animals. No abdominal abscesses, bilomas or necrotic liver segments were found. Finally, in 2 animals, no adhesions were found.

The other group of pigs underwent liver resection using the microwave technology. An average of 59.13 min (range 35-72) was the operative time for this group. Blood loss was 72.37 ml (range 42-100). We encountered minor bleeding in small bleeding vessels and major bleeding in larger vessels and large intrahepatic bile ducts. These were controlled by the use of silk ligations. Two out of 8 pigs developed pleural effusion and jaundice one month after the operation, whereas 4 pigs had wound infections (Table 1). No mortality was observed during or after the operation. After meticulous post mortem examination of the abdominal cavity, adhesions of liver with the stomach, spleen, diaphragm and intestinal loops were found. In 4 out of 8 pigs we found fistulae behind the ensiform appendix by which the peritoneal cavity communicated with the external environment.

Blood loss was significantly less in the Aquamantys group than in the microwave group (p=0.0143) (Table 2).

Microscopically, three different zones were found applying the microwave device: (i) a central zone of distorted liver cell plates and absence of viable hepatocytes (Figure 2A and 2C); (ii) an intermediate zone of swollen and dead hepatocytes-the sinusoids contained erythrocyte remnants (Figures 2A and 2B); and (iii) a peripheral zone consisting of intact liver cell plates (Figure 2A). In this zone the sinusoids were congested

Table 1. Postoperative complications of microwave and Aquamantys

Complications	*Type of ablation*		*Total*
	Microwave *N (%)*	*Aquamantys* *N (%)*	*N (%)*
Pleural effusion	2/8 (25)	0/8 (0)	2/16 (12.5)
Jaundice	2/8 (25)	0/8 (0)	2/16 (12.5)
Wound infection	4/8 (50)	2/8 (25)	6/16 (37.5)

Table 2. Intraoperative blood loss

	Type of ablation		*Total (16)*	*p-value*
	Microwave	*Aquamantys*		
Intraoperative blood loss, ml, mean (SD)	40 (26.18)	72.37 (19.7)	56.18 (27.94)	0.0143
Range	5-85	42-100	5-100	

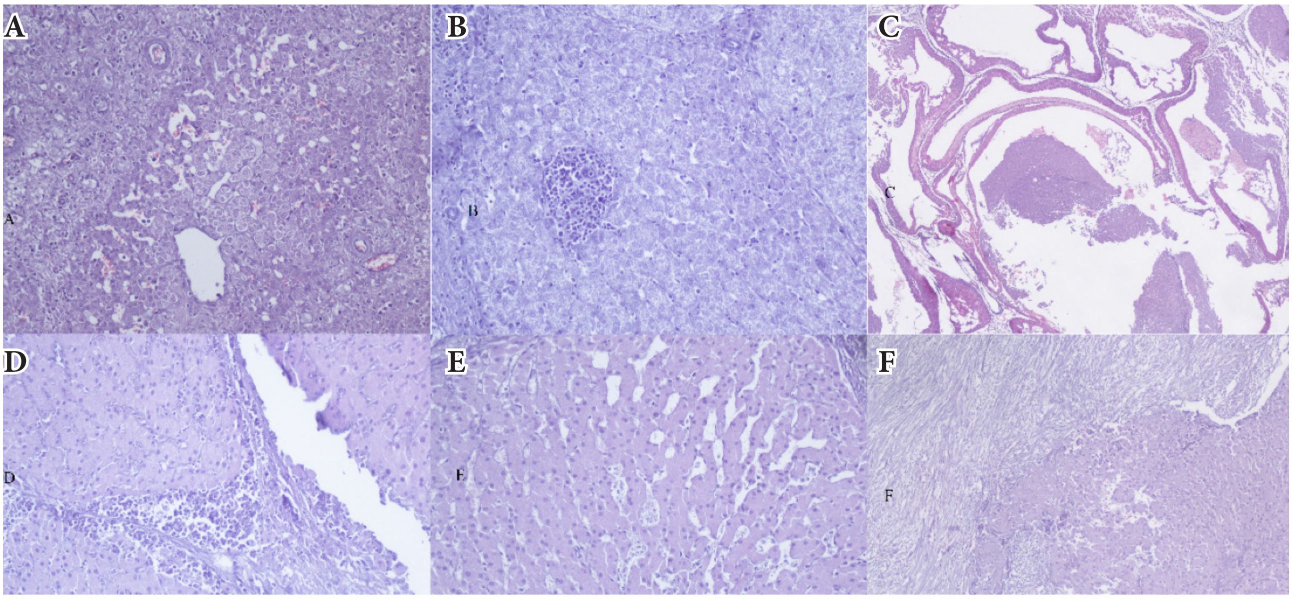

Figure 2. A: Photomicrograph from peripheral lesion treated with microwave ablation. Congestion of sinusoids. Hematoxylin-eosin stain; original magnification x100. **B:** Photomicrograph from intermediate lesion treated with microwave ablation. Hepatocytes are swollen. Destroyed red blood cells filling sinusoids. Hematoxylin-eosin stain; original magnification x100. **C:** Photomicrograph from central lesion treated with microwave ablation. Liver thermos lesions. Gross distortion of liver cell plates. No presence of viable hepatocytes. Hematoxylin-eosin stain; original magnification x40. **D:** Photomicrograph of zone treated with Aquamantys ablation. Necrotic tissue appears shrunk and basophilic. Hematoxylin-eosin stain; original magnification x100. **E:** Photomicrograph from lesion treated with Aquamantys ablation. Congestion of sinusoids with intact hepatocytes. Hematoxylin-eosin stain; original magnification x 100. **F:** Photomicrograph from lesion treated with Aquamantys. Hepatic parenchyma is perfectly intact in the normal zone whereas in the zone of hepatic necrotic tissue the necrotic cells appear shrunk and basophilic, alternating with amorphous eosinophilic material. Hematoxylin-eosin stain; original magnification x40.

with intact erythrocytes. The pathology of the liver by applying the Aquamantys® device revealed the following: i) a normal zone where the hepatic parenchyma was perfectly intact (Figure 2D); ii) a zone which could not be easily discriminated from the normal in which the sinusoids were congested with intact hepatocytes (Figure 2E); and iii) a zone of hepatic necrotic tissue (Figure 2F).

Discussion

Liver resection is considered the treatment of choice for liver tumors. Despite standardized techniques and technological advances for liver resections, an intra-operative hemorrhage rate ranging from 700 and 1200 ml is reported with a post-operative morbidity rate ranging from 23 to 46% and a surgical death rate ranging from 4 to 5% [10-15]. On the other hand, technical innovations focusing on minimizing bleeding during liver parenchymal transection and the need for blood transfusion have increased worldwide liver resections both for primary and for secondary liver tumors as an intention to treat strategy.

The parameter "Blood loss" plays a central role in liver surgery and different strategies to minimize it are the key to morbidity and mortality improvement rates. Bleeding has to be considered of major concern for the liver surgeon due to several reasons. At first, it is certainly the major intraoperative surgical complication and cause of death and historically one of the major postoperative complications together with bile leaks and hepatic failure [14-18].

Also, a high intraoperative blood loss is associated with higher rate of postoperative complications and shorter long-term survival [19-22]. Although the mechanism of bleeding in surgical interventions is multifactorial, technical factors may also be responsible for a significant amount of intraoperative and early postoperative bleeding [8].

Conversely, the Pringle manoeuver represents a valuable tool for managing intraoperative bleeding but places the patient at a high risk of liver damage due to ischemic reperfusion syndrome and other complications, such as splanchnic congestion and hemodynamic alterations due to vascular occlusion [22-28].

The need to avoid the complications related to major vascular occlusions has resulted in the use of liver parenchymal transection without clamping techniques. There are many devices focusing on the reduction of intraoperative blood loss such as the water-jet scalpel (WJS), the cavitron ultrasonic aspirator (CUSA®), the tissue link monopolar floating ball (TMBF), argon-beam coagulation, ligasure, vascular staplers and clip appliers.

CUSA fails to coagulate or achieve hemostasis so the need for its concomitant usage with other instruments to achieve hemostasis and biliostasis is imperative.

TMFB is not able to coagulate vessels over 2-3 mm in diameter which have to be clipped, ligated or sealed with other instruments [29]. So the instrument should be used in combination with other instruments or clips or ties.

A disadvantage of ligasure application is that the coagulated tissue often sticks to the instrument's jaws causing new bleeding when the device is moved away [17].

WJS can't coagulate and some studies demonstrate that it cannot achieve a reduction of intraoperative blood loss and operating time if compared with traditional techniques [30,31]; with this technique, a possible cancerous seeding of the abdominal organs and infection of the operators by hepatic viruses could not be excluded. Moreover, some cases of gas embolism are described in the literature after the usage of this device [32].

In our study, we evaluated the microwave system as a hemostatic and dissecting tool for liver resection in this porcine model. We observed that microwave was hardly sufficient in controlling small vascular vessels and biliary structures within the liver parenchyma and insufficient in controlling larger vessels and large intrahepatic bile ducts. Thus we had to control the above using suture ligations. Hence, the microwave approach did necessitate additional hemostasis in order to control intraoperative bleeding and accomplish the procedure safely in all animals.

Moreover no mortality was observed whereas as far as morbidity was concerned, 2 animals developed pleural effusions and jaundice. These results have been reproduced by other authors, who reported a low morbidity and mortality, and a 2% local recurrence rate [33].

As far as the histopathological findings are concerned, we have to point out that the majority of the specimens revealed less extent of necrosis compared to the Aquamantys group. Therefore microwave is not much effective in destroying any-by chance-existent cancer tissue and minimizing the possibilities of local recurrence [34].

Furthermore, the electromagnetic energy of the microwave device spreads to a larger area than the Aquamantys energy and therefore it could more easily destroy "noble" structures, which are nearby the target tissue (Figures 2D, E and F). Thus microwave energy application near the hilus, the vena cava or bile ducts must be avoided for fear of portal vein thrombosis, dissemination and biloma formation [34]. Early reported series of microwave ablation suggested that the complication rates were encouragingly low [35,36] but results from later series reported high complication rates of 14.2% in patients treated for hepatocellular carcinoma and 20.6% in those with hepatic metastases. The authors suggested a number of approaches to avoid bleeding, biloma formation and dissemination [35].

In the present study, when we applied the Pringle manoeuver in 3 out of 8 pigs, we noticed that in these pigs blood loss was lower, and visualization of the vascular structures was better as a result of efficient ablation of these structures. Limited experimental work has been performed on the safety and efficacy of microwave ablation near large vessels. Several experimental [37] and clinical studies [38,39] reported that the ablation size increased with vascular clamping and was also associated with a lower local recurrence rate.

Aquamantys® delivers radiofrequency energy and causes protein denaturation. Thus, blood vessel wall collagen shrunks, resulting in hemostasis. At the same time saline, which is delivered to the surgical field, distributes energy on a broader band allowing safer and efficient vessel sealing [40]. Saline prevents the temperature to exceed 100oC and there is no charring with eschar formation, which is a common disadvantage of conventional electrosurgical devices which operate at high temperatures.

This series demonstrated that Aquamantys® was efficient in controlling small vascular and biliary structures within the liver parenchyma whereas larger vessels and large intrahepatic bile ducts were either ligated or clipped. Therefore, a minimal blood loss is a possible target to meet using this new bipolar sealer, similarly to previous experiences [9,41]. Furthermore, the Pringle manoeuver was not applied in our method of Aquamantys®, indicating that the portal triad or other isolated vascular occlusion are rarely necessary at open hepatectomies with Aquamantys®. Thus, this modality removes the dangers of hepatic inflow occlusion incurred with alternative techniques, such as the Pringle manoeuver [22,25-28] and therefore ensures that liver resection becomes a comparatively safer procedure. No morbidity or mortality were observed.

Moreover, it is worth mentioning that Aquamantys® gives surgical trainees the chance to develop their skills in this procedure, since its use is easy to learn after 3-4 procedures, as indicated by the decline in operative times. Taking into account the postoperative complications and their management (Figure 4) it can be assumed that Aquamantys® system can result in reduced administration of antibiotics and therefore reduced cost of care in cases of patients undergoing liver resection using Aquamantys® ablation.

The histologic changes after Aquamantys® ablation to the liver have been previously described. A well-known problem in hepatectomies is the inability to achieve R0 surgical margins, since the cancer tissue is expanding in bigger depth than it could be conceivable preoperatively or during surgery. It is also known that the negative surgical margins define to a great extent the percentages of local recurrence and survival. The extent of necrosis and fibrosis produced by Aquamantys® was surprisingly considerable (Figures 2D, E and F). This shows that Aquamantys® is effective in destroying any -by chance- existent cancer tissue and minimizing the possibilities of local recurrence. Possibly this is due to the disruption of the extracellular matrix, which can reach a distance of 3-5 mm from the resection margin, and also to the wide band of coagulation, which is adjacent to the line of transection, as it is already reported [42].

Conclusions

Our study demonstrates that Aquamantys® modality is technically feasible and reproducible in the porcine model and can serve as an excellent training model for liver surgery. Aquamantys® has proved to be a highly effective and safe hemostatic method and is proposed as an alternative weapon in the surgeon's armamentarium.

Naturally, further future animal and clinical studies, even a multiinstitutional trial, are truly needed to confirm our results and evaluate the relative performance of Aquamantys® ablation with respect to local recurrence of liver tumors.

References

1. Cance WG, Stewartak, Menck HR. The National Cancer Data Base Report on treatment patterns for hepatocellular carcinomas: improved survival of surgically selected patients, 1985-1996. Cancer 2000;88:912-920.
2. Cha C, Lee FT Jr, Rikkens LF, Niederhuber JE, Nguyen BT, Mahvi DM. Rationale for the combination of cryoablation with surgical resection of hepatic tumors. J Gastrointest Surg 2001;5:206-213.
3. Simon JC, Dupuy DE, Mayo-Smith WW. Microwave ablation: Principles and Applications. Radiographics 2005;25:S69-S83.
4. Skinner MG, Iizuka MN, Kolios MC, Sherar MD. A theoretical comparison of energy sources - microwave, ultrasound and laser - for interstitial thermal therapy. Phys Med Biol 1998;43:3535-3547.
5. Stauffer PR, Rossetto F, Prakash M, Neuman DG, Lee T. Phantom and animals tissues for modelling the electrical properties of human liver. Int J Hyperthemia 2003;19:89-101.
6. Wright AS, Lee FT Jr, Mahvi DM. Hepatic microwave ablation with multiple antennae results in synergistically larger zones of coagulation necrosis. Ann Surg Oncol 2003;10:275-283.
7. Shock SA, Meredith K, Warner TF et al. Microwave ablation with loop antenna: in vivo porcine liver model. Radiology 2004;231:143-149.
8. Westerkamp AC, Lisman T, Porte RJ. How to minimize blood loss during liver surgery in patients with cirrhosis. Hepato Pancreat Biliary Surg 2009;11:453-458.
9. Geller DA, Tsung A, Maheshwari V et al. Hepatic resection in 170 patients using saline-cooled radiofrequency coagulation. Hepato Pancreat Biliary Surg 2005;7:208-2013.
10. Poon RT, Fan ST, Lo CM et al. Improving outcome expands the role of hepatectomy in management of benign and malignant hepatobiliary diseases: analysis of 1222 consecutive patients from a prospective database. Ann Surg 2004;240:698-708.
11. Rees M, Plant G, Wells J et al. One hundred and fifty hepatic resections: evolution of technique towards bloodless surgery. Br J Surg 1996;83:1526-1529.
12. Doci R, Gennari L, Bignami P et al. Morbidity and Mortality after Hepatic Resection of Metastases from Colorectal Cancer. Br J Surg l995;377-381.
13. Belghiti J, Hiramatsu K, Benoist S et al. Seven hundred hepatectomies in the 1990s: an update to evaluate the actual risk of liver resection. J Am Coll Surg 2000;191:38-46.
14. Gozzetti G, Mazziotti A, Grazi L et al. Liver Resection without Blood Transfusion. Br J Surg 1995;82:1105-1110.
15. Cunningham JD, Fong Y, Shriver C et al. One hundred

consecutive hepatic resections: Blood loss, transfusion and operative technique. Arch Surg 1994;129:1050-1056.

16. Descottes B, Lachachi F, Durand-Fontanier S et al. Right hepatectomies without vascular clamping: report of 87 cases. J Hepatobiliary Pancreat Surg 2003;10:90-94.
17. Romano F, Franciosi C, Caprotti R, Uggeri F, Uggeri F. Hepatic surgery using the ligasure vessel system. World J Surg 2005;29:110-112.
18. Jarnagin WR, Gonen M, Fong Y et al. Improvement in Perioperative Outcome after Hepatic Resection: Analysis of 1803 consecutive cases over the past decade. Ann Surg 2002;236:397-406.
19. Navarra G, Spalding D, Zacharoulis D et al. Bloodless Hepatectomy Technique. Hepato Pancreat Biliary Surg 2002;4:95-97.
20. Rosen CB, Nagorney DM, Taswell HF et al. Perioperative blood transfusion and determinants of survival after liver resection for metastatic colorectal carcinoma. Ann Surg 1992:216:493-505.
21. Stephenson KR, Steinberg SM, Hughes KS, Vetto JT, Sugarbaker PH, Chang AE. Perioperative blood trasfusions are associated with decreased time to recurrence and decreased survival after resection for colorectal liver metastases. Ann Surg 1988;208:679-687.
22. Torzilli G, Makuuchi M, Midorikawa Y et al. Liver Resection Without Total Vascular Exclusion: Hazardous or Beneficial? An analysis of our experience. Ann Surg 2001;233:167-175.
23. Pringle JH. Notes on the arrest of hepatic haemorrhage due to trauma. Ann Surg 1908;48:541-549.
24. Makuuchi M, Hasegawa H, Yamazaki S. Ultrasonically guided subsegmentectomy. Surg Gynecol Obstet 1985;161:346-350.
25. Grace PA. Ischaemia-reperfusion injury. Br J Surg 1994;81:637-647.
26. Smyrniotis VE, Kostopanagiotou GG, Gamaletsos EL et al. Total versus selective hepatic vascular exclusion in major liver resections. Am J Surg 2002;183:173-178.
27. Smyrniotis VE, Kostopanagiotou GG, Contis JC et al. Selective hepatic vascular exclusion versus Pringle manoeuver in major liver resections: prospective study. World J Surg 2003;27:765-769.
28. Wu CC, Hwang CR, Liu TJ, P'eng FK. Effects and limitations of prolonged intermittent ischaemia for hepatic resection of the cirrhotic liver. Br J Surg 1996;83:121-124.
29. Arita J, Hasegawa K, Kokudo N. Randomized clinical trial of the effect of a saline-linked radiofrequency coagulator on blood loss during hepatic resection. Br J Surg 2005;92:954-959.
30. Izumi R, Yabushita K, Yagi M et al. Hepatic resection using a water jet dissector. Surg Today 1993;23:31-35.
31. Rau HG, Wichmann MW, Schinkel S et al. Surgical techniques in hepatic resections: Ultrasonic aspirator versus Jet-Cutter. A prospective randomized clinical trial. Zentralbl Chir 2001;126:586-590.
32. Rau HG, Duessel AP, Wurzbacher S. The use of water-jet dissection in open and laparoscopic liver resection. Hepato Pancreat Biliary Surg 2008;10:275-280.
33. Iannitti DA, Martin RC, Simon CJ et al. Hepatic tumor ablation with clustered microwave antennae: the US Phase II Trial. Hepato Pancreat Biliary Surg (Oxford) 2007;9:120-124.
34. Shimada S, Hirota M, Beppu T et al. Complications and management of microwave coagulation therapy for primary and metastatic liver tumours. Jpn J Surg 1998;28:1130-1137.
35. Saitsu H, Mada Y, Taniwaki S et al. Investigation of microwave coagulo-necrotic therapy for 21 patients with small hepatocellular carcinoma less than 5 cm in diameter. Nippon Geka Gakkai Zasshi 1993;94:359-365.
36. Sato M, Watanabe Y, Ueda S et al. Microwave coagulation therapy for hepatocellular carcinoma. Gastroenterology 1996;110:1507-1514.
37. Takamura M, Murakami T, Shibata T et al. Microwave coagulation therapy with interruption of hepatic blood in- or outflow: an experimental study. J Vasc Interv Radiol 2001;12:619-622.
38. Ishida T, Murakami T, Shibata T et al. Percutaneous microwave tumor coagulation for hepatocellular carcinomas with interruption of segmental hepatic blood flow. J Vasc Interv Radiol 2002;13 (2 Pt 1):185-191.
39. Shibata T, Murakami T, Ogata N. Percutaneous microwave coagulation therapy for patients with primary and metastatic hepatic tumors during interruption of hepatic blood flow. Cancer 2000;88:302-311.
40. Felekouras E, Petrou A, Neofytou K et al. Combined ultrasonic aspiration and saline-linked radiofrequency precoagulation: a step toward bloodless liver resection without the need of liver inflow occlusion: analysis of 313 consecutive patients. World J Surg Oncol 2014;12:357-364.
41. Romano F, Garancini M, Uggeri F et al. Bleeding in hepatic surgery: sorting through methods to prevent it. Hepato Pancreat Biliary Surg 2012;1:1-7.
42. Currò G, Lazzara S, Barbera A et al. The Aquamantys® system as alternative for parenchymal division and hemostasis in liver resection for hepatocellular carcinoma: a preliminary study. Eur Rev Med Pharmacol Sci 2014;18:2-5.