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Saline conducted electric coagulation (SCEC): original experience in experimental hepatectomy

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Abstract: Objective: To evaluate the feasibility and superiority of a new coagulating and hemostatic method named "saline conducted electric coagulation (SCEC)". Methods: The Peng's multifunction operative dissector (PMOD) was modified to enable saline to effuse persistently out of its nib at a constant speed. In a group of six New Zealand rabbits, two hepatic lobes of each rabbits were resected respectively by SCEC and conventional electric coagulation (EC). The features of SCEC were recorded by photo and compared with conventional EC. After 7 d, the coagulating depth was measured in each residual hepatic lobe. Hepatic tissue was dyed by hematoxylin and eosin (HE) and studied under a microscope. Results: The coagulating depth increased with the continuation of SCEC time. Hepatectomies were performed successfully, no rabbit died in the perioperative period. The incisal surface of SCEC was gray-white with no red bleeding point. There was a thick solidified layer at the margin and a thin red-white intermittent layer between the solidified layer and normal hepatic tissue at the vertical section of SCEC. The mean coagulating depth of SCEC was 1.8 cm vs. 0.3 cm of conventional EC. Pathological examination showed a mild inflammatory reaction by SCEC. Conclusions: SCEC is a feasible and safe method for surgical hemostasis. As a new technique for liver resection, SCEC shows better coagulating effect and milder inflammatory reaction than conventional EC. Our study shows bloodless liver resection can also be performed by SCEC, especially for liver malignant tumor.

Key words: Saline, Electric coagulation, Hepatectomy, Hemostasis, Bloodless liver resection
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1 Introduction

Hemostasis is an important procedure in every surgical operation, especially critical in hepatectomy. There was a 3.2% of rehaemorrhagia morbidity after hepatectomy (Huang *et al*., 2009). Conventional electric coagulation (EC) plus hepatic infusion occlusion (Pringle's maneuver) was the most common method in liver resection in most hospitals in China, but it induced a large amount of blood loss and ischemic reperfusion injury during operation. In conventional EC it is difficult to stop liver bleeding, because eschar is formed by electric spark and high temperature which block electric current and prevent heat conduction to inner tissue. In recent years, bloodless liver resection by radio frequency energy without hepatic inflow occlusion was being undertaken (Ayav *et al*., 2007; Delis *et al*., 2007). Saline-linked surface radiofrequency ablation (SLSRFA) was a well developed technique for bloodless liver resection, using saline, a good coolant and electric conductor, to maintain the surface temperature and avoid eschar formation (Gnerlich *et al*., 2009). Cavitron ultrasonic surgical aspirator (CUSA) was another advanced technique in bloodless hepatectomy. It can shatter and aspirate hepatic tissue by a hollow titanium pipe with an ultrasonic frequency. However for most hospitals and patients, SLSRFA and CUSA seemed too expensive to undergo bloodless hepatic resection, notwithstanding its great advantages of bleeding control. Besides, a conventional electric

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scalpel had a very wide range used in all kinds of operations because of its convenience and low cost, especially irreplaceable in surgical incision into the abdominal cavity and more convenient than SLSRFA, CUSA, harmonic scalpel, and other instruments.

To solve the eschar problem of an electric scalpel and perform bloodless hepatic resection, we developed a new coagulating method named saline conducted electric coagulation (SCEC). We also designed a new electric scalpel to perform SCEC and applied for a patent for the electric scalpel. This instrument uses saline, the same as SLSRFA, to conduct electric current and cool coagulating surface, avoiding eschar occurrence. To evaluate the superiority and feasibility of SCEC, we modified Peng's multifunction operative dissector (PMOD) (Peng *et al*., 2003) to make saline effused from its nib and test the instrument in experimental liver resection. In this article, we reported our initial experience of SCEC in experimental rabbit hepatectomy.

2 Materials and methods

2.1 Materials

Male New Zealand rabbits (2.0–2.5 kg), self-made SCEC scalpel (Fig. 1), 9 g/L saline, 30 g/L carbrital (Sigma), micro injection pump (Zhejiang University Medical Instrument Co., Ltd.), and DEVEL ACC200 high-frequency electrome are used in this experiment.

Self-made SCEC scalpel is made by modifying PMOD (FDA 510(K) Number K040780; Hangzhou Shuyou Medical Instrument Co., Hangzhou, Zhejiang, China) according to patent specification (application No. 201010507487.4, Fig. 1). A knife-like electrode with a central saline outlet is inserted into the apical pipe of PMOD. Saline from microinjection pump is infused into the end of scalpel and effused out of the tip. The tip of electrode is sharp enough to dissect coagulated hepatic tissue. The modified SCEC scalpel has versatile functions, e.g., dissection, SCEC with saline infusion, and conventional EC without saline.

2.2 Methods

Six rabbits underwent hepatic resection. In each rabbit, two hepatic lobes were resected by SCEC and conventional EC respectively with the same scalpel. There were saline injections in SCEC group and no saline in EC group.

The electrome power was set as 60 W (conventional coagulating power in clinical hepatectomy). Firstly, SCEC was tested in a porcine liver ex vivo, to determine the optimal saline inflow rate. Coagulating effect was observed at liver surface by regulating inflow rate from 60 to 10 ml/h. There was a little water vacuole boiling and steam arising but no water flowing downward when coagulating the hepatic surface, forming a piece of gray-white coagulating face (Fig. 2). The inflow rate needed to be turned up if

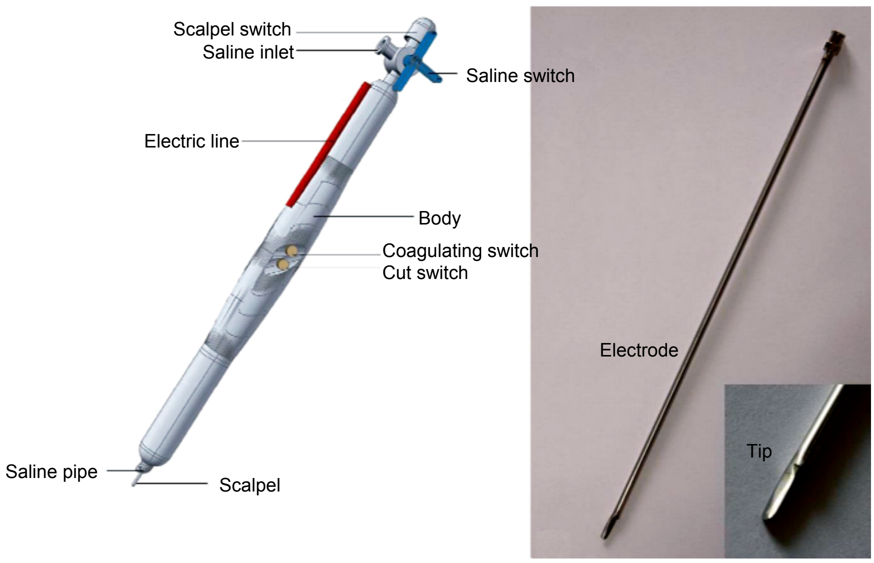

Fig. 1 Self-made SCEC scalpel according to patent specification
The electrode lies in the centre of the scalpel. Saline is infused into the end of electrode and effused out of the tip

eschar occurred or turned down if water flowed downward. The correlation between coagulating time and coagulating depth was also investigated. After saline inflow was regulated to the optimal rate, SCEC was performed at the porcine liver surface for 3, 5, 10, 30 s, respectively, and repeated 10 times in each group. Coagulating depth was measured in each coagulating point. Conventional EC was performed as a control.

A rabbit was anesthetized using 30 g/L carbrital (30 mg/kg, i.v.). A hepatic lobe was pulled out of the abdominal cavity. After saline inflow was regulated to the optimal rate, SCEC was executed at the scheduled hepatic dissecting line, forming a gray-white line about 1 cm in width at the liver surface. Then the coagulated liver tissue was dissected by the knife-like electrode until fresh liver tissue appeared. SCEC and dissection were performed alternately or simultaneously until the hepatic lobe was dissected from the liver. Secondly, another hepatic lobe was pulled out and resected by conventional EC all similar to the SCEC group but without saline inflow.

Coagulating power and saline inflow rate were recorded in each rabbit. After the operation, the excisional liver was recorded photographically. After 7 d, the rabbits were killed by air embolism and the residual livers were resected for measuring coagulating depth. Hepatic tissue was dyed by hematoxylin and eosin (HE) and studied under a microscope.

Data analysis was performed by software of SPSS 11.0. All data were expressed as mean±standard deviation (SD) and comparisons between groups were made using analysis of t test. P value <0.05 was considered for statistical significance.

Experimental procedures, animal care, and animal maintenance were approved by the Animal Studies Committee of Zhejiang University in accordance with the Animal Welfare Act and Regulations Concerning Experimental Animals.

3 Results

When coagulating power was set at 60 W, the optimal saline inflow rate was approximately 30–50 ml/h in porcine liver. The coagulating time and coagulating depth were recorded in Table 1. Persistent conventional EC (>30 s) formed an ulcer like coagulating face (Fig. 3a) with a mean depth of 1.55 mm, similar to that of 3 s by SCEC (Fig. 3b), obviously shallower than that of 5–30 s by SCEC (Figs. 3c–3e). The coagulating depth increased with the continuing of SCEC time.

Table 1 Coagulating time and coagulating depth of SCEC and EC

Method	Coagulating time (s)	Coagulating depth (mm)	t	P^*
EC	>30	1.55±0.37		
SCEC	3	1.45±0.37	0.600	0.550
SCEC	5	1.95±0.50	2.043	0.056
SCEC	10	3.2±0.48	8.580	0
SCEC	30	4.3±0.57	17.220	0

Coagulating power 60 W, saline inflow rate 40 ml/h. * Comparison between SCEC and EC

Hepatectomies were performed successfully in the six rabbits, and no rabbit died in the perioperative period. The saline inflow rate was 30–45 ml/h when the coagulating power was at 60 W (Table 2).

Table 2 Saline inflow rate in SCEC group

Rabbit	Coagulating power (W)	Saline inflow rate (ml/h)
1	60	35–42
2	60	30–38
3	60	40
4	60	35–45
5	60	38–45
6	60	33–42

The incisal surface of SCEC showed gray-white, no red bleeding point, and no black eschar. There was no obvious bleeding in the course of SCEC, and dissection process was easy and convenient without the interference of eschar. In EC group, bleeding occurred frequently caused by eschar away from the incisal surface. At the vertical hepatic section of SCEC group, there was a thick solidified layer at the margin and a thin red-white intermittent layer in the transition zone (Fig. 4a). Conventional EC group showed a thin black eschar layer and a thick red-white intermittent layer at the vertical section (Fig. 4b).

After 7 d, a clear border line separated the white necrotic layer from normal hepatic tissue in the residual liver (Fig. 5). The average coagulating depth of SCEC group was (18±2.3) mm, significantly larger than that of EC group [(3±1.2) mm, P<0.001].

Pathological examination showed denser color concentration of cytoplasm and nucleus in a normal hepatic cell than that in the necrotic region. The hepatic cells in white regions seemed to be normal in structure except for a little lighter color which demonstrated cell apoptosis in the white region. A layer of fibroplasias and granulocytes accumulated situated between the normal and necrotic hepatic cell, composing a transitional zone. There were more inflammatory cells accumulating in the transition zone in EC group (Fig. 6a) than in SCEC group (Fig. 6b), indicating a milder inflammatory reaction after SCEC.

Fig. 2 Coagulating effect by conventional EC (a) and SCEC (3 s (b), 5 s (c), 10 s (d), and 30 s (e))

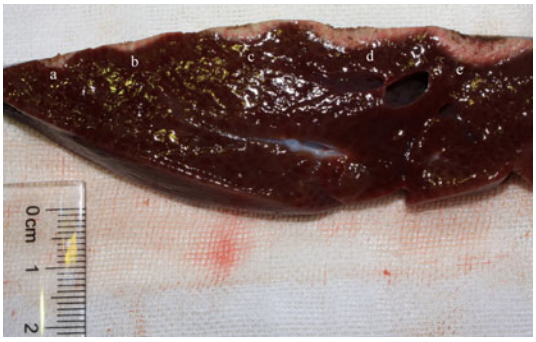

Fig. 3 Vertical section of conventional EC (a) and SCEC (3 s (b), 5 s (c), 10 s (d), 30 s (e))

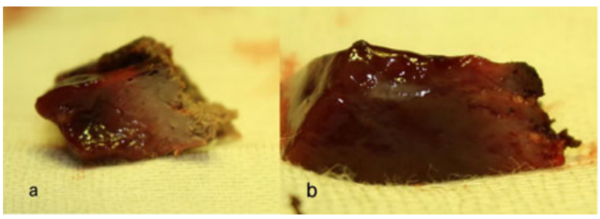

Fig. 4 Vertical sections of hepatic tissues by SCEC (a) and conventional EC (b)

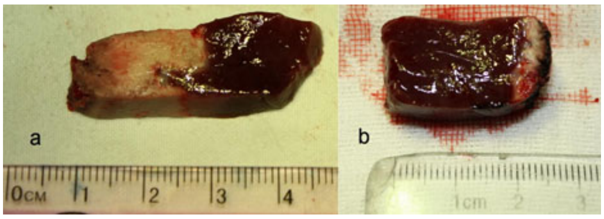

Fig. 5 Vertical sections of residual hepatic tissues by SCEC (a) and conventional EC (b) after 7 d

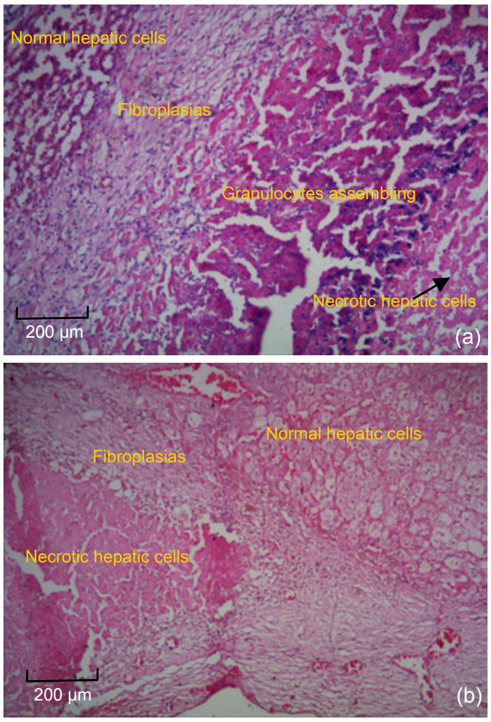

Fig. 6 HE-stained transition zones 7 d after conventional EC (a) and SCEC (b)

4 Discussion

Blood loss and ischemia reperfusion injury induced by occlusion of hepatoduodenal ligament are significant drawbacks in traditional hepatectomy. Several methods and instruments have been used to decrease blood loss in liver operations, such as ultrasonic scissors, vessel sealing system (LigaSure), argon beam coagulator, radio frequency ablation, and CUSA. Ultrasonic scissors and LigaSure have been widely used in laparoscopic surgery. It is easy to seal and cut vessels below 3 mm using these, but hard to stop interstitial bleeding (Borzellino *et al.*, 2006; Ikeda *et al.*, 2009). Argon beam coagulator shows a good coagulating effect on interstitial errhysis, but cannot coagulate acute bleeding and is short of cutting and dissection (Aoki *et al.*, 2007). As a kind of bloodless liver resection technology, SLSRFA, a new technique for applying radiofrequency energy to surface, has advanced quickly in recent years (Takatsuki *et al.*, 2009). The method uses saline, a good coolant and electrical conductor, to maintain the surface temperature of a vascular organ such as liver below 100 °C during SRFA, thereby preventing tissue charring. Its conical tip can ablate hepatic tissue to a depth of 4–20 mm, causing total cell necrosis and protein coagulation. Therefore, there was little blood loss or no hepatic inflow occlusion in liver resection by SLSRFA, which was called bloodless liver resection (Gnerlich *et al.*, 2009).

A conventional electric scalpel is still a necessary piece of equipment in open hepatic operations because it is cheaper and more convenient. However, charring is a troubling problem during EC, increasing the electric impedance and preventing heat conducting to inner tissue. There was always a large amount of blood loss in the course of hepatectomy by conventional EC and 30% of patients needed a blood transfusion in the perioperative period (Palavecino *et al.*, 2010). Eschar may detach from the hepatic cut surface, causing rehaemorrhagia after operations. Compared to conventional EC, there was no eschar formation during SCEC, because saline absorbed the redundant heat and evaporated to air when the temperature exceeded 100 °C. In the present study, SCEC manifested the advantages of deeper coagulating depth and milder inflammatory reaction than conventional EC. Heat was conducted to the inner tissue without eschar prevention and ran off with blood flow. The temperature descended gradually from surface to interior, contributing to a decrease in the inflammatory reaction in transition zone. We can also control coagulating depth by coagulating time. More coagulating time induces increasing coagulating depth and means better hemostasis. It is not always beneficial for patients to get deeper coagulation in the case of living donor hepatectomy, when the resected liver should have more viable liver cells. It is necessary to control coagulating depth to achieve a satisfying hemostasis and less necrosis as far as possible, which needs abundant experience and perfect operation.

When there was excessive saline flow downward the surface, it was advised to lower saline inflow rate, or hot saline may injure distant tissue. When there was an obvious electric spark and black eschar produced at the cut surface, saline inflow rate needed to be increased. An unwatered gray-white coagulating surface is the best coagulating effect with optimal coagulating depth and without risk of rehaemorrhagia. After the scheduled hepatic dissecting line was precoagulated, hepatic tissue could be dissected by the knife-like electrode until fresh hepatic tissue appeared again. Then SCEC and dissection were performed alternately by the same surgeon until a partial liver lobe was resected from the liver.

As well as SLSRFA, the dissected tissue temperature was kept at about 100 °C by heating and evaporating the saline. There was no eschar formation at the cut surface and heat was able to be conducted to the inner tissue, causing inner protein coagulation and hemostasis. Compared to SLSRFA, there is a knife-like electrode at the top of the instrument, so it is easy to dissect the coagulated hepatic tissue without another surgeon's assistance (Aloia *et al.*, 2005). Whilst in SLSRFA, two-surgeon technology was widely used because the tip of Monopolar Floating Ball (TissueLink Medical, Dover, NH, USA) was conical and cannot cut or dissect hepatic bile duct and vessels. Therefore, it needs another surgeon's help to dissect hepatic tissue by CUSA, ultrasonic scissor, or LigaSure (Aoki *et al.*, 2007). However, they all need special equipment that limits the development of two-surgeon technique in hepatectomy. In SCEC, coagulating and dissection can be executed by the same surgeon, decreasing the complexity of operation. It is also a good compensation for SLSRFA and CUSA, because it adds the function of dissection to SLSRFA and deeper coagulation to CUSA. Another problem of SLSRFA is steam popping which is caused by inside hyperthermia and exorbitant power (Topp *et al.*, 2004). The feature of SLSRFA is heating inner tissue by radio frequency while cooling hepatic surface by saline, so inner temperature is always higher than that of the surface, causing steam popping. SCEC coagulates inner tissue by conducting heat from hot saline at the hepatic surface, so the inner temperature is lower than that of the surface. We also observed steam popping when saline boiled persistently at the same point, but it can be easily avoided by decreasing saline inflow rate or moving the electrode.

CUSA is another advanced bloodless liver resecting technique. Hepatic tissue can be shattered and aspirated by a hollow titanium pipe; vessels and bile duct are reserved for additional coagulation or ligation. CUSA only damages exposed hepatic cells, protecting more residual liver function, but capillary hemorrhage is a troubling problem. The operating field is often blurred by accumulating blood and hepatic portal occlusion had to be used to decrease bleeding, causing ischemic reperfusion injury. SCEC has a better coagulating depth than CUSA. CUSA plus SCEC may be a perfect combination in hepatectomy, especially useful in living donor hepatectomy.

During conventional EC, there is always a range of electric impedance when an electrode touches tissue, and an electric spark can be produced when an electric switch is opened. However, saline decreases the electric impedance rapidly when an electrode touches tissue, there is no heat produced when the electric impedance decreases to a certain degree. So it is necessary to keep the saline inflow rate at an appropriate distance. We found that the knife-like tip was satisfactory to decrease the difficulty of SCEC. Hyperthermal steam produced by SCEC may injure peritoneum, so it is dangerous to perform SCEC in a laparoscopic operation, and an aspirator is necessary at least. Another danger of SCEC is that hot saline may flow downward if saline outflows too quickly. Putting a piece of carbasus below the resecting line can avoid the problem.

In our study, preliminary hepatectomy was successfully performed to evaluate the feasibility of SCEC. SCEC is a feasible and safe method for surgical hemostasis, especially in hepatic operations. It is cheaper and more convenient than other instruments because the high-frequency electrotome which combines with the SCEC scalpel has been established in most hospitals. As a new technique for hepatectomy, SCEC showed better coagulating effect and milder inflammatory reaction than conventional EC. Our study showed that bloodless liver resection can also be performed by SCEC, especially for liver malignant tumor because SCEC can extend the resection margin to 20 mm. It can also be used for partial spleen resection in traumatic spleen rupture which may protect splenic immune function of many traumatic patients. Of course, the perfect electric scalpel needs further clinical studies.

References

Aloia, T.A., Zorzi, D., Abdalla, E.K., Vauthey, J.N., 2005. Two-surgeon technique for hepatic parenchymal transection of the noncirrhotic liver using saline-linked cautery and ultrasonic dissection. *Ann. Surg.*, **242**(2):172-177. [doi:10.1097/01.sla.0000171300.62318.f4]

Aoki, T., Kato, T., Yasuda, D., Shimizu, Y., Murai, N., Sato, A., Koizumi, T., Otsuka, K., Kusano, T., Hayashi, K., *et al.*, 2007. Cyst wall resection and ablation by hand-assisted laparoscopic surgery combined with argon plasma coagulator for huge hepatic cysts. *Int. Surg.*, **92**(6):361-366.

Ayav, A., Jiao, L.R., Habib, N.A., 2007. Bloodless liver resection using radiofrequency energy. *Dig. Surg.*, **24**(4): 314-317. [doi:10.1159/000103664]

Borzellino, G., Ruzzenente, A., Minicozzi, A.M., Giovinazzo, F., Pedrazzani, C., Guglielmi, A., 2006. Laparoscopic hepatic resection. *Surg. Endosc.*, **20**(5):787-790. [doi:10.1007/s00464-004-2186-3]

Delis, S.G., Madariaga, J., Bakoyiannis, A., Dervenis, C., 2007. Current role of bloodless liver resection. *World J. Gastroenterol.*, **13**(6):826-829.

Gnerlich, J.L., Ritter, J.H., Linehan, D.C., Hawkins, W.G., Strasberg, S.M., 2009. Saline-linked surface radiofrequency ablation: a safe and effective method of surface ablation of hepatic metastatic colorectal cancer. *Ann. Surg.*, **250**(1):96-102. [doi:10.1097/SLA.0b013e3181ae91af]

Huang, Z.Q., Xu, L.N., Yang, T., Zhang, W.Z., Huang, X.Q., Cai, S.W., Zhang, A.Q., Feng, Y.Q., Zhou, N.X., Dong, J.H., 2009. Hepatic resection: an analysis of the impact of operative and perioperative factors on morbidity and mortality rates in 2008 consecutive hepatectomy cases. *Chin. Med. J. (Engl.)*, **122**(19):2268-2277. [doi:10.3760/cma.j.issn.0366-6999.2009.19.016]

Ikeda, M., Hasegawa, K., Sano, K., Imamura, H., Beck, Y., Sugawara, Y., Kokudo, N., Makuuchi, M., 2009. The vessel sealing system (LigaSure) in hepatic resection: a randomized controlled trial. *Ann. Surg.*, **250**(2):199-203. [doi:10.1097/SLA.0b013e3181a334f9]

Palavecino, M., Kishi, Y., Chun, Y.S., Brown, D.L., Gottumukkala, V.N., Lichtiger, B., Curley, S.A., Abdalla, E.K., Vauthey, J.N., 2010. Two-surgeon technique of parenchymal transection contributes to reduced transfusion rate in patients undergoing major hepatectomy: analysis of 1557 consecutive liver resections. *Surgery*, **147**(1):40-48. [doi:10.1016/j.surg.2009.06.027]

Peng, S.Y., Li, J.T., Mou, Y.P., Liu, Y.B., Wu, Y.L., Fang, H.Q., Cao, L.P., Chen, L., Cai, X.J., Peng, C.H., 2003. Different approaches to caudate lobectomy with "curettage and aspiration" technique using a special instrument PMOD: a report of 76 cases. *World J. Gastroenterol.*, **9**(10):2169-2173.

Takatsuki, M., Eguchi, S., Yamanouchi, K., Tokai, H., Hidaka, M., Soyama, A., Miyazaki, K., Hamasaki, K., Tajima, Y., Kanematsu, T., 2009. Two-surgeon technique using saline-linked electric cautery and ultrasonic surgical aspirator in living donor hepatectomy: its safety and efficacy. *Am. J. Surg.*, **197**(2):e25-e27. [doi:10.1016/j.amjsurg.2008.01.019]

Topp, S.A., McClurken, M., Lipson, D., Upadhya, G.A., Ritter, J.H., Linehan, D., Strasberg, S.M., 2004. Saline-linked surface radiofrequency ablation: factors affecting steam popping and depth of injury in the pig liver. *Ann. Surg.*, **239**(4):518-527. [doi:10.1097/01.sla.0000118927.83650.a4]