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Liver resection using a water jet

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Summary. The water-jet method has been used during hepatic resection. The instrument cuts the hepatic tissue with the high pressure of the fine water flow, while the exposed elastic intrahepatic vessels are spared injury. A comparative study on the water-jet method with the previously employed conventional methods was undertaken. Hepatic resections were performed on 35 patients using the water-jet method. Cirrhosis of the liver was associated with 10 of the 24 patients with hepatocellular carcinoma. An ordinary saline solution was used as the jet, which was projected at a pressure of between 12 kg/cm^2 and 20 kg/cm^2 through a 0.15/mm-diameter nozzle. A higher jet pressure was needed to cut the fibrotic hepatic parenchyma. In the case of normal liver, the intrahepatic vessels of more than 0.2 mm were well preserved. In most of the cases, the loss of blood when cutting the hepatic parenchyma can be easily reduced with a jet pressure of 15–16 kg/cm^2, thus preserving the fine vessels more than 0.2 mm in diameter without injury. When the same pressure was applied in the cutting of a cirrhotic liver, it took much longer time compared to that of a non-cirrhotic normal liver parenchyma. The cut surface was smooth compared to that after using CUSA, although its disadvantages lie in the formation of air bubbles, which obscure the operative field. The controlled projection of a jet of water under optimal pressure may ensure a safe hepatic resection of both normal and cirrhotic livers. Furthermore, because of its uncomplicated form, a wide range of applications can be expected, while the lower cost will also expedite its large-scale use for economic reasons.

Introduction

The management and control of bleeding from the cut surface of a hepatic parenchyma is an important aspect in hepatectomy. For this purpose, hepatic resection needs to be performed without impairing the fine intrahepatic vessels.

Previously, hepatic resection was performed by the finger fracture or the clumping and separation methods. But with these procedures, the small intrahepatic vessels and ducts could not be saved satisfactorily.

Recently many advances have been made in the field of hepatic resection with sophisticated instruments such as CUSAs, lasers and microwave coagulators being used. Very recently, the water-jet method has been tried during hepatic resection [2, 4]. The instrument cuts the hepatic tissue with the high pressure of the fine water flow, while the exposed elastic intrahepatic vessels and bile ducts are spared injury. A comparative study on the water-jet method with previously employed conventional methods was undertaken.

Materials and methods

Water-jet cutter. The equipment was specially manufactured by Sugino Machine Co., Ltd, and consisted of a pressure-generating pump and a flexible hose connected to the handpiece or the head (Fig. 1).

The pump is able to generate a maximum jet pressure of 25 kg/cm^2. The water jet flow is projected through the tip of the handpiece while fluctuations are stabilized by an air chamber. The handpiece has a microvalve which can regulate the projection of the water jet (on/off). The steel nozzle has a pinhole opening of 0.1–0.15 mm diameter [3]. In this clinical study, the nozzle with a diameter of 0.15 mm was mostly used. An ordinary saline solution was used as the jet fluid. The volume of the saline solution was about 50 ml/min under a pressure of 15–18 kg/cm^2

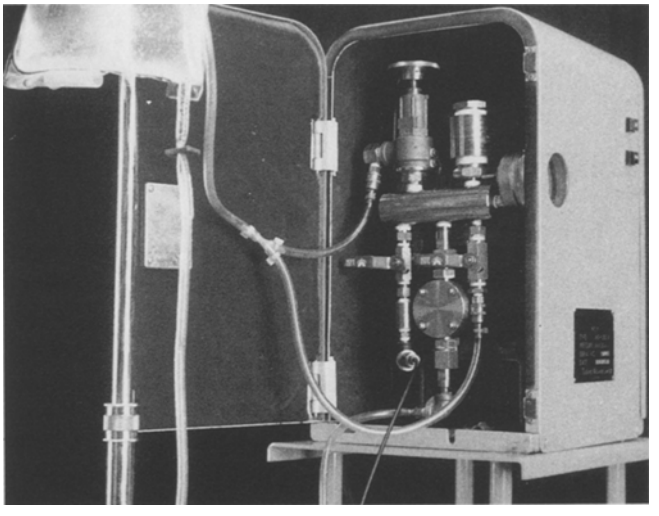

Fig. 1. The equipment consists of a pressure-generating pump and a flexible hose connected to the handpiece

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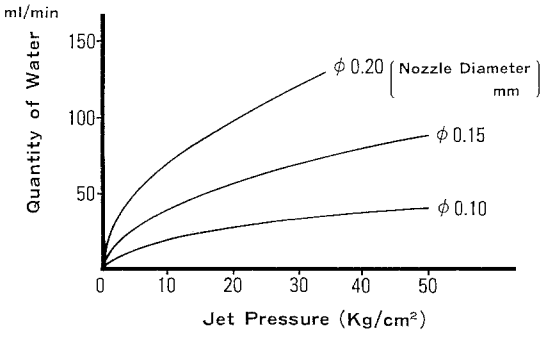

Fig. 2. Relation between jet pressure and quantity of water

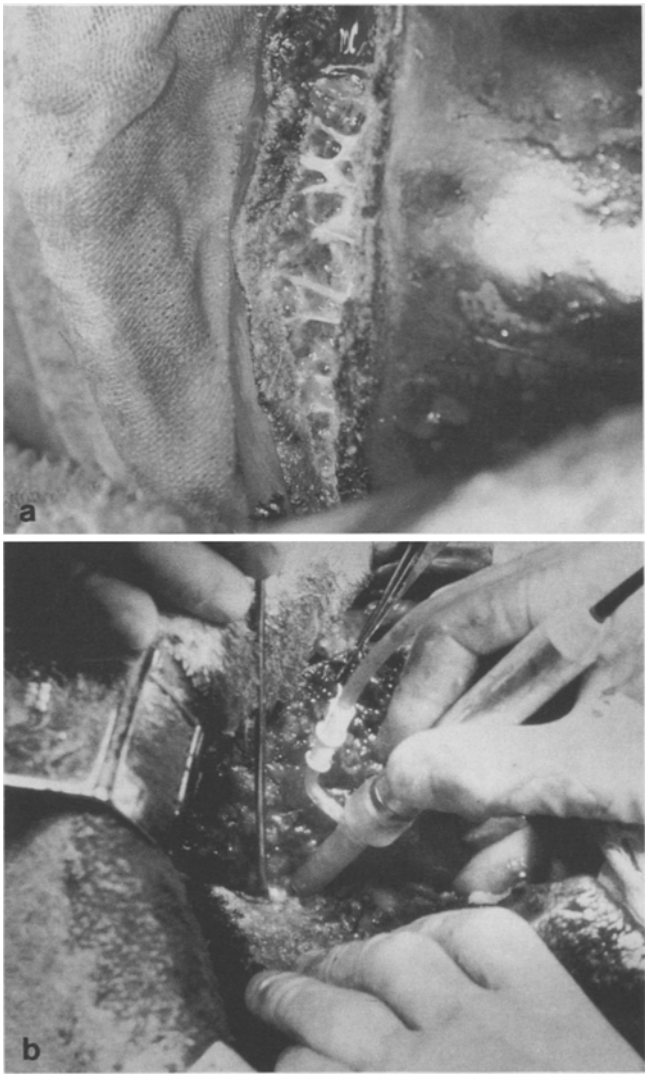

Fig. 3.a Preserved fine vessels during resection of liver parenchyma using a water jet. **b** Right hepatic lobectomy using a water jet

(Fig. 2). The flexible hose connecting the handpiece to the pressure-generating unit is made of hard rubber and is 8 mm in diameter. It can withstand a maximum pressure of 50 kg/cm^2. The apparatus is gas-sterilized 1 day before the operation.

Method of cutting the liver tissue. The fragile hepatic parenchyma was washed out by the high pressure of the water jet. The intrahepatic vessels were capable of withstanding the jet pressure and were thus preserved. In the case of chronic hepatitis or cirrhosis of the liver, it was not so easy to resect the hepatic parenchyma under normal jet pressure (10–18 kg/cm^2) because the hepatic parenchyma had become fibrotic and hard. A higher jet pressure was therefore needed. The optimal pressure had to be maintained very carefully when resecting the fibrotic and chronic inflammatory tissue. In the case of a normal liver, the intrahepatic vessels less than 0.2 mm in diameter were exposed and cut after diathermy coagulation, while the thick vessels were cut following ligation (Fig. 3a).

Clinical study. From July 1986 until November 1987, hepatic resections were performed on 35 patients (26 male, 9 female) using the water-jet method. Their ages ranged from 8 years to 76 years, the average being 52 years. Twenty-four patients had hepatocellular carcinoma, one had cholangiocarcinoma, one had metastatic liver cancer from the colon, two had hepatic hemangioma, five had echinococcosis of the liver, and one had a liver granulomatous abscess. Cirrhosis of the liver was associated with 10 of the 24 patients with hepatocellular carcinoma (Table 1).

Operative procedure. Right trisegmentectomy was performed in two cases, extended right and left hepatic lobectomy in five, and right lobectomy in nine cases. At least one segmentectomy was performed in five cases, subsegmentectomy in four, and nine patients underwent partial resection (Table 2). A jet of ordinary saline solution was projected at a pressure of between 12 kg/cm^2 and 20 kg/cm^2 through a nozzle 0.15 mm in diameter. After ligation of the main branches of the vessels, a hepatic resection was performed (Fig. 3b).

Table 1. Clinical cases operated upon using a water jet

Liver condition	Total	M	F
Hepatocellular carcinoma	24 (10/41.7 %)[a]	19	5
Cholangiocellular carcinoma	1	1	0
Metastatic liver cancer	1	0	1
Hepatic hemangioma	2	2	0
Echinococcosis of the liver	5	3	2
Liver abscess	1	1	0
Focal nodular hyperperplasia	1	0	1
Total	35	26	9
Age (years)	52.0 ± 14.0		

[a] Cases with cirrhosis, June 1986 – November 1987

Table 2. Operative procedures by water jet

Procedure	No. of cases
Partial resection	9 (5)[a]
Subsegmentectomy	4 (2)
Segmentectomy	5 (3)
Bisegmentectomy	10 (0)
More than lobectomy	7 (0)
Total	35 (10)

[a] With cirrhosis

A histopathological examination of the resected liver was made. The postoperative courses were assessed in comparison with those of patients operated on by a CUSA.

Results

Results of the operation

The resected liver masses weighed from 10 g to 2240 g, the average being 515 ± 486 g. The amount of operative bleeding ranged from 90 ml to 8361 ml. The maximum amount of bleeding (8361 ml) occurred during posterior segmentectomy on a patient with a recurrence of hepatocellular carcinoma after the primary resection. The patient had cirrhosis and a gross hepatic dysfunction. Following the resection, a severe uncontrolled oozing of blood was noticed from the cut surface of the liver. The average amount of blood loss was 1529 ± 1596 ml. A significant decrease in the amount of blood loss was found in bisegmentectomy, trisegmentectomy and extended lobectomy compared with the CUSA procedure (Table 3a). In subsegmentectomy, smaller amounts of blood loss were seen compared with those seen with the previous conventional CUSA method. In other procedures, however, no significant differences were found (Table 3b). A minimal loss of blood was seen in the partial resection of the liver. Five or six cases did not require a blood transfusion. In most of these cases, the hepatic parenchyma could be easily separated with a jet pressure of 15–16 kg/cm^2, thus preserving the fine vessels more than 0.2 mm in diameter without injury. When the same pressure was applied on a cirrhotic liver, it took longer time compared to the performance on a non-cirrhotic, normal liver parenchyma. An accelerated pressure of 18–20 kg/cm^2 frequently injured the fine vessels, resulting in bleeding (Fig. 3b).

Table 3. Total blood loss during operation using the water jet compared with the CUSA procedure

Cases	Operation	Blood loss (ml)	
		Water jet	CUSA
a) Total	Partial resection	808 ± 754 (n=9)	1310 ± 1725 (n=33)
	Subsegmentectomy	1538 ± 1334 (n=4)	2158 ± 1716 (n=15)
	Segmentectomy	3701 ± 2784 (n=5)	2771 ± 2451 (n=19)
	Bisegmentectomy	870 ± 303[a] (n=10)	2956 ± 3134 (n=11)
	More than lobectomy	1839 ± 907[a] (n=7)	3368 ± 2152 (n=13)
	Average	1529 ± 1596 (n=35)	2248 ± 2247 (n=91)
b) With cirrhosis	Partial resection	1095 ± 910 (n=5)	1591 ± 1646 (n=12)
	Subsegmentectomy	1092 ± 107 (n=2)	3006 ± 2104 (n=7)
	Segmentectomy	5383 ± 2859 (n=3)	3651 ± 2846 (n=9)
	Bisegmentectomy		1866 ± 814 (n=3)
	Average	2381 ± 2432 (n=10)	2535 ± 2149 (n=31)

[a] $P < 0.05$

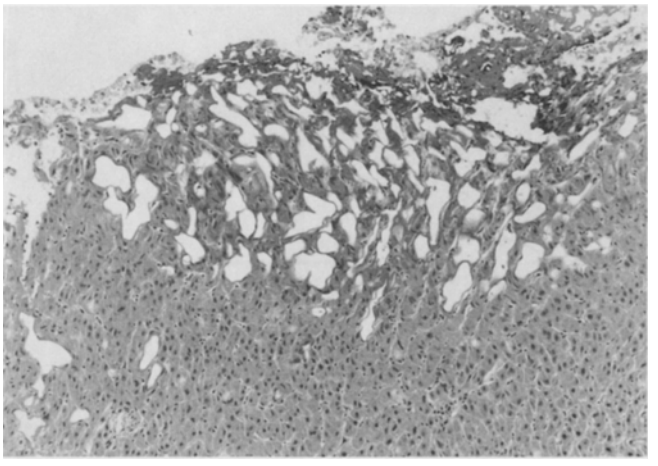

Fig. 4. Microscopic findings of the cut margin of the liver. Hematoxylin/eosin; × 100 (reduced to 80%)

The formation of air bubbles combined with splashing water from the water jet made it difficult to see the operative field clearly. However, the acryl head cover connected to the suction tube reduced the amount of air bubbles.

Histopathological study

The surface cut by the water jet was smooth compared to that cut by a CUSA [5]. Fluid accumulation was seen to a slight degree in between the cord-like arrangement of hepatocytes up to a depth of 2–3 cm from the cut margin. There were no signs of hepatic degeneration or necrosis (Fig. 4).

The postoperative investigations on the peripheral blood, liver functions, serum and urine electrolytes did not find any significant difference between the patients treated with the water jet and those with the CUSA.

Discussion

The experimental study and clinical trial of the water-jet method provided a very hopeful indication for the progressive and routine use of this new device during hepatic resection. It seems to be better than the CUSA method [5], being more economical and convenient, especially for non-cirrhotic liver resection.

Its disadvantages lie in the formation of air bubbles obscuring the operative field, and the splashing of the blood-mixed fluid, which might cause the operating surgeon or the nurse to become cross-infected. With this device, the details of the operating area could not be easily seen, but the discovery of a solution which does not produce many bubbles and a further improvement in the hand piece may remove these drawbacks.

We did not experience pressure fluctuations of the projecting water during the operation, and the slight delay between switching on the device and the projection of the fluid was of little inconvenience. The blocking of the outlet hole sometimes interrupted the operation, but it was not a common occurrence.

An ordinary physiological saline solution was used as the jet, and there were no adverse effects on the liver functions or on the serum electrolyte balance. Further studies are needed to discover whether the physiological saline solution is the best fluid for the jet. Indeed, a better fluid may have to be considered, to ensure a smoothly cut margin, to reduce hemorrhage, and to improve wound healing and the hepatic functions. To achieve these goals, a proper hemostatic agent as well as other medicated agents may be added to the fluid.

Equipment sterilization is another point for consideration; the gas-sterilization method was used in our case. After detaching the plunger pump, the hoses and the handpiece, the whole unit was gas-sterilized. This method of sterilization was inconvenient because of the size of the equipment. The development of a smaller, simpler unit could make sterilization easier, which may facilitate the frequent use of the device whenever required.

Conclusion

The conventional equipment (CUSAs, lasers, microwave coagulators) so far used in hepatic resections are not totally safe in the resection of a cirrhotic liver. The controlled projection of jet water under optimal pressure may ensure the safe hepatic resection of both normal and cirrhotic livers. Furthermore, because of its uncomplicated form, it is expected to find a wide range of applications. The lower cost will also expedite its large-scale use for economic reasons.

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