Diameter and Pressure of the Water-Jet For Liver Resection

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Objective: **The aim of this study was to evaluate the effect of various nozzle diameter and different liquid delivery pressure on efficacy of water-jet in experimental liver resection.**
Method: **Depending on the used nozzle diameter, the animals were divided into two groups. In the first group of animals, the nozzle diameter was 0.1 mm and this group was divided into 3 subgroups depending on the liquid pressure applied: 8 ATM, 12 ATM and 16 ATM, with 5 water-jet liver dissection is in each subgroup. Water-jet dissection with nozzle diameter of 0.2 mm was used in the second group of animals, which was divided into three subgroups with 5 water-jet liver dissection in each, depending on liquid pressure: 4 ATM, 8 ATM and 12 ATM. The criteria such as blood loss, operation time, parenchymal necrosis, expired liquid volume, and postoperative complications were used for comparison.**
Results: **Water-jet with a diameter of 0.1mm and pressure of 12 ATM showed faster cutting with reasonable blood loss when compared to the low pressure subgroup (8 ATM) and result in lesser parenchymal necrosis, smaller expired liquid volume and acceptable speed of resection when compared to the high pressure subgroup (16 ATM). Increase of the pressure from 4 to 12 ATM of water-jet with diameter of 0.2 mm resulted in increase of blood loss and necrosis, but did not effect the speed of resection significantly. Despite lesser blood loss and smaller necrosis, the water-jet at 4 ATM had slower speed of resection. Water-jet with diameter of 0.2 mm and pressure of 8 ATM cut liver more faster without significantly effecting blood loss and necrosis in comparison to that at a pressure of 4 ATM.**
Conclusion: **Our study showed that, increasing the nozzle diameter and liquid delivery pressure resulted in an increase of blood loss and tissue necrosis. Water-jets with diameter of 0.1 mm and pressure of 12 ATM is more acceptable for resection of normal livers.**

Key words: *Liver resection, water-jet*

Cutting faster, creating lesser blood loss and negligible tissue damage are the most important requirements in techniques for resection of liver parenchyma. Resection techniques such as laser(1), electrocautery(2), microwave tissue coagulator(3), argon beam coagulation(4) plazma scalpel(5) have limited use in hepatic surgery, because of thermal injury to the liver parenchyma and insufficient bleeding control. Other techniques such as digitoclasia or clamp crushing(6,7), Cavitron Ultrasonic Surgical Aspirator (CUSA)(1,8-10), suction knife(11,12) and water-jet(13-18), which are based on separating intrahepatic vessels and ducts from parenchyma seem more acceptable techniques for liver resection today. Water-jet dissection, where a liver parenchyma is washed away by high pressure liquid jet leaving intrahepatic vessels and ducts undamaged, is popularised after Papachristou's report at 1982 (13). Recently, several water-jet devices were designed and this technique has increasing use in clinical practice (14-26). However, some aspects of this resection technique is not clearly defined. Occasionally, different nozzle diameters (from 0.06 to 0.25 mm)(14,15,24,26) and liquid delivery pressures (from 4 to 1000 ATM)(1,14-17,20,21,26) are preferred for water-jet dissection of liver parenchyma.

The aim of this study was to evaluate the effect of various nozzle diameters and different liquid delivery pressure on efficacy of water-jet in experimental liver resection.

Material and Method

Fifteen dogs, weighting 16-18 kg, were used in this study. The study was performed in the Surgical Department of Veterinary School of Yüzüncü Yıl University. One day before operation, the animals received no food without water restriction. Under Kethalar+Euphloran+Rompun anaesthesia, right subcostal laparotomy was performed. The left lateral and median lobes of liver were selected for resection. Two liver resection performed in each animal. The line of incision projected on the center of the lobe and distal half of parenchyma was resected in all animals. Portal clamp was not used.

For resection of the liver parenchyma, a water-jet device (Özmenmakina, İzmir, Turkey) was used. The device was composed of a pressurized liquid source, a flexible connecting tube and a hand piece, which extends nozzle with diameter of 0.1 and 0.2 mm. A sterile physiologic saline solution is delivered at pressures of 1-150 ATM. An incision on fibrous capsule is made by electrocauthery. Then water-jet is directed to the transsection line and parenchyma is washed away for leav-

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Table I. Results of the liver resection with water-jet with different pressures in group I (nozzle diameter of 0.1mm).

Subgroups	I a n=5	Ib n=5	Ic n=5
Pressure	8 ATM	12 ATM	16 ATM
Blood loss intensity (ml/cm^2)	5.3±0.5	7.1±0.6	8.5±0.7*
Speed of resection (cm^2/min)	5.6±0.5	8.3±0.6*	10.1±1*
Depth of necrosis at resection (mm)	1.2±0.3	1.5±0.5*	2.7±0.7*✦
Depth of necrosis at 7 days (mm)	0.2±0.08	0.3±0.1	0.7±0.1*✦
ALT			
Preoperative	24±3	21±3	22±3
After 1 day	322±25	385±30	540±35*✦
After 3 days	152±17	186±19	215±29
After 7 days	78±7	91±8	101±12
AST			
Preoperative	18±2	20±2	19±2
After 1 day	346±28	405±33	589±36*✦
After 3 days	188±22	206±25	249±28
After 7 days	85±8	101±10	121±15
Area of resection surface (cm^2)	22.5±4	20.1±3	23.4±3
Expired liquid volume (ml)	729±53	580±61	856±47

Table II. Results of the liver resection with water-jet with different pressures in group II (nozzle diameter of 0.2mm).

Subgroups	II a n=5	IIb n=5	IIc n=5
Pressure	4 ATM	8 ATM	12 ATM
Blood loss intensity (ml/cm^2)	6.5±0.3	7.4±0.6	10.8±0.7*✦
Speed of resection (cm^2/min)	6.1±0.5	9.5±0.7*✦	6.4±0.5
Depth of necrosis at resection (mm)	1.6±0.3	1.9±0.2	3.2±0.4*✦
Depth of necrosis at 7 days (mm)	0.3±0.1	0.4±0.1	0.9±0.1*✦
ALT			
Preoperative	22±3	20±3	23±3
After 1 day	391±31	453±37	689±45*✦
After 3 days	172±18	214±20	301±28
After 7 days	89±8	106±11	132±13
AST			
Preoperative	19±2	22±2	21±2
After 1 day	412±32	492±38	691±43*✦
After 3 days	208±21	239±27	314±31
After 7 days	98±9	119±11	142±16
Area of resection surface (cm^2)	22.5±3	21.4±2	20.1±3
Expired liquid volume (ml)	793±81	643±62	976±85

** - p<0.05 in comparison with IIa subgroup (pressure of 4 ATM)*
F - p<0.05 in comparison with IIb subgroup (pressure of 8 ATM)

ing the intrahepatic vessels and ducts undamaged. The exposed vessels and ducts are then ligated and divided.

Depending on the used nozzle diameter, the animals were divided into two groups. In the first group of animals, the nozzle diameter was 0.1 mm and this group was divided into 3 subgroups depending on the used liquid pressure: 8 ATM in the Ia subgroup, 12 ATM in the Ib subgroup and 16 ATM in the Ic subgroup, with 5 liver resections in each subgroup. Water-jet dissection with a nozzle diameter of 0.2 mm was used in the second group of animals, which was divided into three subgroups with 5 liver resection in each, depending on liquid pressure: 4 ATM, 8 ATM and 12 ATM in the IIa, IIb and IIc subgroups respectively.

The criteria such as blood loss, operation time, parenchymal necrosis, expired liquid volume, and postoperative complications were used for comparison.

Blood loss were evaluated by a parameter (blood loss intensity - BLI, ml/cm^2), which represents blood loss per 1 cm^2 area of a resected surface and was calculated by the following formula:

BLI= Blood loss during parenchyma resection / area of resected surface

For assessment of operation time, the speed of resection (SR) was calculated. SR represents resected surface area (cm^2) per minute and was calculated by the following formula:

SR= Area of resected surface / time from onset of parenchymal dissection to control of hemostasis.

For assessment of parenchymal damage, serum transaminase levels (alanine aminotransferase - ALT and aspartate aminotransferase-AST) one, three, seven days after operation were measured. Depth of necrosis in the specimens from resected livers, and from the remnant livers 7 days after operation were evaluated by light microscopy.

The results were presented as mean±SEM. Each trait was analyzed within nozzle diameter with respect to liquid pressure. Hence, one-way variance analysis was performed for data analysis and Duncan Multiple comparies ion was used to compare means of each liquid pressure for related trait. Before data analysis an outlier and normality test used for assumptions.

Results

Results of the water-jet liver resection with a nozzle diameter of 0.1 mm were shown in Table 1. Blood loss appears to increase by increasing jet pressure and the differences between Ia and Ic subgroups were statistically significant ($p<0.05$). Speed of resection was lower when 8 ATM jet pressure was used compared to that of 16 ATM pressure ($p<0.05$). Water-jet at 12 ATM pressure cut the liver significantly faster than that of 8 ATM pressure ($p<0.05$) but the difference between water-jets at 12 and 16 ATM pressures on SR was not significant. A significant increase of the necrosis depth was noted by increasing jet pressure. The postoperative serum ALT and AST levels were higher in Ic subgroup than those in the Ia and Ib subgroups and the differences between these levels on the first day after operation were statistically significant. Regarding the liquid volume used it was higher in Ic and lower in Ia subgroup despite the fact that the resected surface areas of these subgroups were comparable.

As a result water-jet with a diameter of 0.1 mm and a pressure of 12 ATM was associated with faster cutting, comparable blood loss than the low pressure subgroup (8 ATM) and lower parenchymal necrosis, smaller wasted liquid volume and comparable speed of resection when compared with the high pressure subgroup (16 ATM).

Results of the liver resection with water-jet with a diameter of 0.2 mm are shown in Table 2.

The resection of the liver using water-jet with a diameter of 0.2 mm and increasing the liquid delivery pressure from 4 to 12 ATM resulted in increase of blood loss and necrosis, but did not affect speed of resection significantly. Despite the less blood loss and smaller necrosis, the water-jet at 4 ATM had slower speed of resection. Water-jet with a diameter of 0.2 mm and a pressure of 8 ATM proved to cut the liver faster without significantly affecting blood loss and necrosis when compared to that of 4 ATM pressure.

Comparison of the two acceptable methods from groups I and II (Ib and IIb respectively) showed that the water-jet with a diameter of 0.1 mm and a pressure of 12 ATM appeared to be associated with unsignificant but relatively lesser blood loss, wasted liquid volume, speed of resection and necrosis.

Discussion

Since 1982, when Papachristou described liver resection with water-jet(13), several authors have reported experimental and clinical use of this device. Currently, the water-jet dissector is used as the main method for liver parenchymal transection in some clinics(13-22). Usefulness of water-jet in laparoscopic hepatectomy and nephrectomy has been described in many reports(26-28). Baer and Rau, who have the most extensive clinical experience on the water-jet dissector, showed that water-jet is significantly faster and associated with lesser blood loss compared to the blunt dissection and CUSA(19-25). Simple usage, low price and faster visualisation of intrahepatic vessels and ducts larger than 0.2 mm in diameter, which provide cutting liver parenchyma rapidly with lesser blood loss, seemed to be the main advantages of the water-jet dissector (13,15,22,24,26).

Although water-jet dissection has attracted the attention of surgeons in time, some details of this technique are not clarified completely. Occasionally, different nozzle diameter and liquid delivery pressure for water-jet dissection of liver parenchyma are described in the literature.

Rau et. al preferred water-jet with a diameter of 0.1mm and liquid delivery pressure of 60-80 bar resection of liver (23,24).

Baer suggested that, low pressure impairs efficiency of the water-jet dissection and prefer to use high pressure (200-1000 bar) jet with diameters 0.06-0.2 mm.(19-22).

Une reported that water-jet with a diameter of 0.2 mm and pressure of 12-18 kgf/cm^2 is sufficient for dissection of normal livers, whereas pressure of 15-20 kgf/cm^2 is required for safe resection of the cirrhotic livers (15,17). A similar pressure value is described by others (26).

Our results showed that water-jet with low pressure (4 ATM) and smaller nozzle diameter (0.1 mm) was associated with lesser blood loss, wasted liquid volume and necrosis but had slower resection speed. Increasing both the nozzle diameter and liquid delivery pressure resulted in increased blood loss, necrosis and wasted liquid volume, but differently affected speed of resection. Elevation of pressure from 12 to 16 ATM in water-jet with a diameter of 0.1 mm did not significantly affect the speed of resection. However, a significant decrease in speed of resection was noted when pressure of the water-jet with a diameter of 0.2 mm was elevated from 8 to 16 ATM. Such effects of nozzle diameter and pressure on speed of resection may be explained by the higher delivered liquid volume and mass achieved by increasing both the nozzle diameter and pressure. Subsequently force and kinetic energy of the delivered liquid is increased resulting in an extensive necrosis and damage of relatively large vessels. The latter increased both blood loss and time for hemostasis control which contributed to decrease of the speed of resection.

Concerning blood loss, speed of resection and parenchymal necrosis, only two of the six investigated water-jet regimens were more acceptable techniques for water-jet dissection of the liver. These groups were water-jet with a diameter of 0.1 mm and a pressure of 12 ATM, and with a diameter of 0.2 mm and a pressure of 8 ATM, which appeared to be associated with not significant but relatively lesser blood loss, wasted liquid volume, speed of resection and necrosis, so they were preferred as suitable useful regimes.

As a result we suggest that, in clinic practice, depending on changes of the liver parenchyma, some parameters of the water-jet dissection may be different from our experimentally obtained parameters, which, essentially, are related to normal dog livers. Establishing safe limits of nozzle diameter and liquid delivery pressure for the water-jet dissection of patient's liver requires an appropriate clinic investigation.

In conclusion, our experimentally obtained results showed that, in the water-jet dissection of the liver parenchyma increasing both the nozzle diameter and liquid delivery pressure results in increased blood loss and tissue necrosis. Water-jets with a diameter of 0.1 mm and pressure of 12 ATM was more acceptable for resection of normal livers.

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