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Gas Jet Transection of Liver Parenchima. Experimental research*

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Rezumat

Secționarea cu jet de gaz a parenchimului hepatic. Cercetare experimentală

Scop: Există o mare varietate de tehnici de secționare a parenchimului hepatic. Obiectivul acestei cercetări constă în elaborarea unei noi metode de secționare a ficatului și compararea acesteia cu cele deja existente.
Metode: Metoda originală de secționare a țesuturile biologice cu jet de gaz, precum și aparatul necesar acesteia au fost dezvoltate în cadrul institutului nostru. Au fost comparate eficiența jetului de gaz, jetului de apă, ultrasunetelor în secționarea hepatică și tehnica de triturare instrumentară a parenchimului hepatic cu ajutorul pensei Kelly pe 24 de porci de statură mică. Nu am utilizat manevra Pringle.
Rezultate: Cea mai mică medie a pierderii de sânge s-a înregistrat în grupul de animale supuse tehnicii de secționare cu jet de gaz (3,5±0,15 ml/cm²), iar cea mai mare în grupul de Kellyclazii (5,5±0,46 ml/cm²). Indicatorii prezintă diferențe statistice semnificative ($p < 0,001$). Viteza medie de secționare înregistrată a fost maximă în cadrul grupului de triturare instrumentară (2,9±0,25 cm²/min), credibil mai mare decât în cazul metodelor cu jet de gaz (2,4±0,16 cm²/min), cu ultrasunete (2,4±0,13 cm²/min) și cu jet de apă (2,5±0,14 cm²/min). La compararea cu metoda cu jet de apă și cu ultrasunete, metoda noastră originală nu prezintă diferențe statistice semnificative în termeni de indici de lucru bazali.
Concluzii: Cercetarea efectuată dovedește eficiență și siguranță ridicate ale metodei de secționare cu jet de gaz. Această metodă poate fi, prin urmare, recomandată pentru viitoare îmbunătățiri și implementare clinică.

Cuvinte cheie: secționare cu jet de gaz, secționare cu jet de apă, secționare prin metoda cu ultrasunete, triturare instrumentară, rezecție hepatică

Abstract

Background: There is a great variety of liver parenchyma transection techniques. The objective of this research lies in developing a new method of liver transection and comparing it to the existing ones.
Methods: The original gas jet transection method of biological tissues and the apparatus for its realization «Pneumojet» were developed in our institute. Efficiency comparison of gas jet, water jet, ultrasonic methods of liver transection and clamp crushing technique were carried out on 24 mini-pigs. We did not use Pringle manoeuver.
Results: The mean blood loss was the smallest in the group of animals that had a gas jet transection (3.5±0.15 ml/cm²) and the highest in the clamp crushing technique group (5.5±0.46 ml/cm²). Indicators present statistically authentic differences ($p < 0.001$). The transection speed was the highest in the Clamp crushing technique group (2.9±0.25 cm²/min) and was credibly higher than in the gas jet (2.4±0.16 cm²/min), ultrasonic (2.4±0.13 cm²/min) and water jet (2.5±0.14 cm²/min)

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transection groups. Compared to the water jet and ultrasonic methods of liver transection the original method does not have statistically reliable distinctions on the basic indexes of work.
Conclusions: The research conducted proves high efficiency and safety of the gas jet transection method. Gas jet transection, therefore, can be recommended for further improvement and clinical application.

Key words: gas jet transection, water jet transection, ultrasonic transection, clamp crushing, liver resection

Introduction

Liver structure features, and, first of all, the features of its vascular anatomy make special demands to modern techniques for parenchyma sectioning and to the equipment employed for this purpose. Development and introduction of such equipment has served as one of the major factors which have led to appreciable improvement of the results of the surgical treatment of patients with a focal pathology of the liver over the last decades (1,2).

The prototype of modern transection options is the digitoclasia method, set forth by the Vietnamese surgeon Ton That Tung in 1939 (3). Subsequently, the technique has been mildly improved at the expense of application of clamps instead of manual techniques and has received the name «clamp crushing» (4). This is the manner in which it is used by many surgeons even today (5-7). The further perfectioning of transection technologies has led to the development of modern devices such as: a water jet scalpel, which is the most popular nowadays, and a cavitron ultrasonic surgical aspirator.

Being based on various physical principles, all of these technologies allow the destruction of hepatic cells, while keeping vascular and secretory elements of the liver intact, as in the course of a resection there is the possibility to clip, coagulate or legate them, depending on diameter.

This means that during the interaction between the working substance and the liver tissue the energy transmission is carried out in smaller quantity than would be necessary for the damage of tubular structures, but sufficient for the destruction of hepatic cells.

As we know, in the Universe, substance is present in four basic modular conditions. Plasma is the most widespread condition of substance. The Sun and stars are clots of hot plasma. In the XXth century the attempt of Japanese scientists to apply plasma streams for the transection of hepatic tissue has not been crowned with success, but it is applied to coagulation nowadays. In the case of solid condition, the interaction with a substance is the most rasping and destructive in nature (for example, just like in the case of interaction between the liver tissue and the clamp surface in the clamp crushing technique). In liquid form substance possesses the properties of fluidity and high elasticity, thanks to which interaction with it is more sparing, but sufficient for processing even solid surfaces. Substance application in this form, for tissue separation, corresponds to a water jet transection method. Gas - unlike liquids and solid bodies, the density of gases at normal pressure upon some usages is less than the density of liquids, which leads to a softer interaction of gas with other substances. In spite of this, so-called aeration figures are obtained through the influence of atmospheric gas on a stone.

Considering these features, the purpose of our research was the development and application of a gas jet transection method of the liver parenchyma to be employed for its resection.

Materials and Methods

The original method of gas jet transection of biological tissues and the apparatus for its realization «Pneumojet» (Patent No 41570 U, UA; Patent No 44610 U, UA; Patent No 44608 U, UA; Patent No 54798 U, UA; Patent No 56676 U, UA; Patent No 56677 U, UA; Patent No 54796 U, UA) was developed in the our institute (*Fig. 1*). The methods for separating tissues of parenchymatous organs include application on the surface of the operated organ of a handling medium under a pressure exceeding its resistance, which allows the extraction of vessels from the parenchyma until the transition moment, and then their careful clipping or ligature, and only after that, if necessary, mobilization while applying various methods of definitive haemostasis. As a handling medium that provides minimum injury, gas is chosen and excludes an overhydration of cells in the resection zone (feature of a water jet transection) and optimizes the technological process, as gas leaves a surgery field independently.

A consecutive number of experimental researches on the working parameters of «Pneumojet» addressed their definition and optimization. The comparison of clinical and morphological changes in a liver after the application of various ways of separation of its parenchyma and the study of the outcome of repairing processes in a resection zone represent the basis of the presented work.

Figure 1. *«Pneumojet» apparatus for gas jet transection*

An analysis of the mechanisms of gas stream influence was carried out during the first investigation phase, during which the parameters of «Pneumojet» and a range of necessary pressures for selective separation of liver parenchyma have been defined. For this purpose, resections of a cadaveric liver were carried out (n=12). During this procedure, the diameter of the damaged vascular structures under various working parameters of «Pneumojet» were estimated.

The working features of the original «Pneumojet» apparatus were studied through experiments on rabbits (Chinchilla) (n=32). Through various techniques and regimens, the damage rate of the liver tissue and the influence on the animal's organism as a whole were estimated. The resection of the left and right medial segments of the liver was performed. Re-resections were carried out after 7-8 and 21 days, during which time a degree of change in the resection zone was estimated. Animals were followed up 1.5 years after the operations.

Efficiency and traumatism comparisons of gas jet, ultrasonic, water jet methods of transection and clamp crushing technique were carried out on 24 mini-pigs. Depending on the transection technique of the liver parenchyma, the animals were divided in 4 groups. Gas jet transection was carried out by the original apparatus «Pneumojet», the ultrasonic – by ultrasonic surgical aspirator «SONOCA 300» (Soring, Germany), water jet – by «Hydrojet» (Erbe, Germany), and for the carrying out of the clamp crushing method a Kelly clamp was used.

Though operative tactics for carrying out each operation could vary, we adhered to certain conditions. Liver resection was carried out by fissural method, without preliminary vascular isolation. Pringle manoeuver wasn't used as a method of vascular control. The sizes of the resected portions of the liver and, accordingly, the wound surfaces that were formed as a result of the operation did not differ between the investigated groups. Volume estimation of the haemorrhage was carried out by the anaesthesiologist and in each case consisted of the quantity of blood stored as a collection (taking into account the deduction of the solution for transection) and the volume drenched by the used dressing material (dressing material).

For control of gas escape into the bloodstream through the hepatic vein system, all mini-pigs undergoing pneumotransection were submitted to: intraoperative angiopulmonography («Tridoros Optimatic – 1000» by «Siemens» production), monitoring of pressure in a pulmonary artery (cardiomonitor «Utas», Ukraine), intraoperational ultrasound of a pulmonary artery and heart («SAL 77A» by «Toshiba» production).

To enable comparison of transection efficiency, the following parameters were defined: speed of transection of the liver parenchyma – the area ratio of the resection surface to resection time (cm^2/min), blood loss – the volume ratio of haemorrhage during resection stage from the area of the resection surface (ml/cm^2).

All experiments were conducted according to the «General Principles of Experiments on Animals», approved by The First National Congress on Bioethics (20.09.2004, Kiev, Ukraine) and respecting the provisions of the «European Convention on Protection of Vertebrate Animals which are Used for Experiments and Other Scientific Purposes».

Data were analysed using Stat Plus 2009 Professional 5.8.4. for Windows. Data are expressed as mean ± standard deviation. The statistical significance of differences among groups was assessed using Student's t-test (unpaired). Differences were considered statistically significant at $p < 0.05$.

Results and Discussions

A range of parameters of dynamic gas pressure on exit from a nozzle, at which the hepatic parenchyma is destroyed have been defined on cadaveric liver, and vessels and ducts more than 0.1 mm in diameter remain intact during the first stage of experimental research. However, further mathematical modelling of the gas efflux processes from a nozzle for minimization of the expense of gas and definition of optimum gas medium was required, that should, in our opinion, finally provide minimum damage and maximum safety. There is a mathematical model developed with the corresponding software which has allowed us to optimize the working parameters of «Pneumojet». As a handling medium carbon dioxide was chosen as the medium possessing an optimum parity density – solubility.

At the developed parameters of action of carbon-dioxide stream, in experiments on rabbits the possibility of application of gas jet transection of liver has been proved. None of the 32 operated rabbits died. Macroscopic evaluation of organs was carried out right after liver transection (1 animal was excluded from the experiment), and did not register signs of gas escape into the bottom vena cava system, pulmonary trunk and its branches. At re-resection, on the 7-8th and 21th day no complications were observed, and portions of omentum had adhered to the resection surface. There was no blood or bile in the abdominal cavity. Microscopically, the margins of the resected liver site had a somewhat "lacerated" appearance, but little damage was done to the liver tissue, i.e. hepatocytes kept average euchromatic nuclei, glycogen was present in the cytoplasm (*Fig. 2*). Gas jet transection is accompanied microscopically by empty vacuoles in the resection margin (*Fig. 3*). By the 8th day the lysis of necrotic sites and lost cells comes to an end (*Fig. 4*). Processes of fibrogenesis begin, and are finished by formation of connective tissue scars on the 21st day (*Fig. 5*).

In experiments on mini-pigs the comparative estimation of the parameters of transection of hepatic parenchyma is carried out through various methods. Objective data are obtained, testifying to the absence of gas escape into the right departments of heart, pulmonary artery and its branches during gas jet transection. All 24 animals have survived after resection. There were no lethal outcomes; only in one case suppuration of a postoperative wound on the 8th day after ultrasonic resection of the liver occurred.

Intraoperative angiopulmonography, monitoring of pressure in a pulmonary artery, intraoperative ultrasound of a pulmonary artery and heart did not register data for penetration of gas into the bloodstream.

The comparison of duration of surgery and time spent for

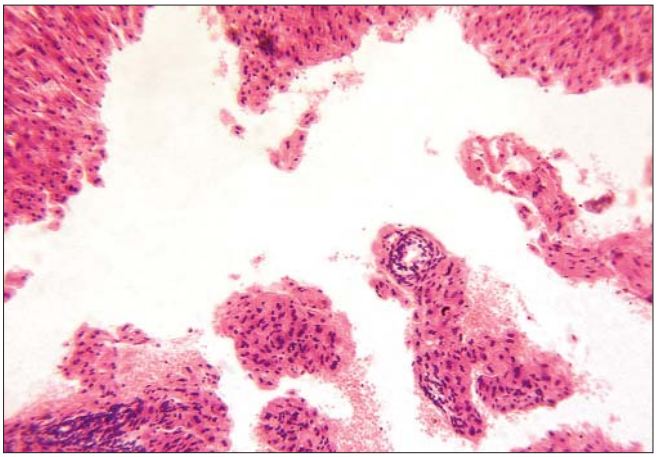

Figure 2. *Rabbit liver after gas jet transection. The edge of the resection. Ragged edge, amorphous detritus, small focal haemorrhage. Hematoxylin and eosin-stained sections (original magnification × 100)*

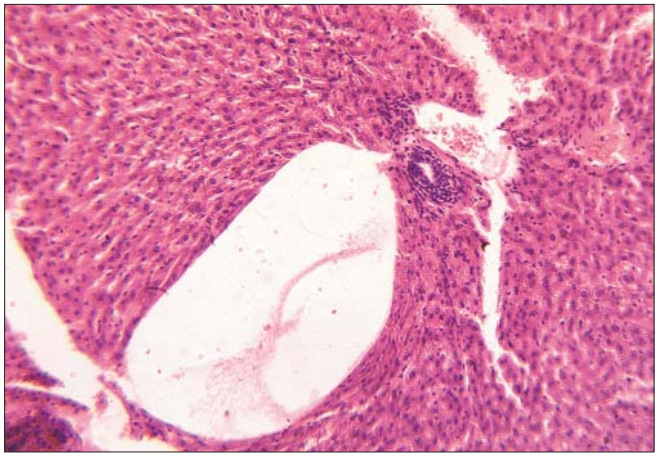

Figure 3. *Rabbit liver after gas jet transection. The edge of the resection, area of necrobiosis. Parenchymal tears, optically empty vacuoles, small focal haemorrhage. Hematoxylin and eosin-stained sections (original magnification × 100)*

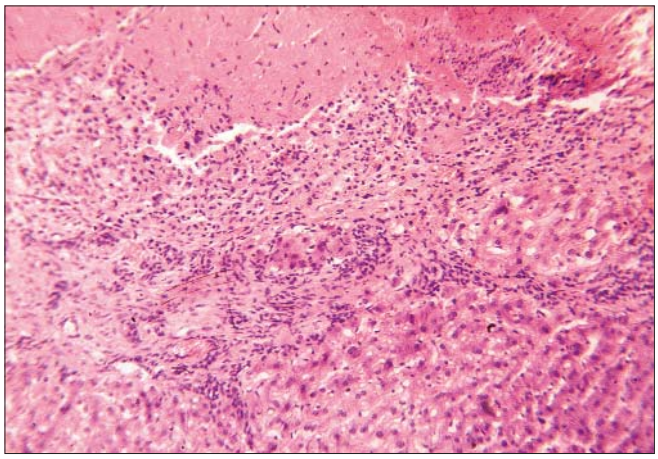

Figure 4. *Rabbit liver on day 8 after gas jet transection. Edge resection (necrotic area, necrobiosis and proliferation). Dense necrotic detritus on the edge of resection, swelling of hepatocytes, the emerging granulation tissue, diffuse histiocytic inflammatory infiltration. Hematoxylin and eosin-stained sections (original magnification × 100)*

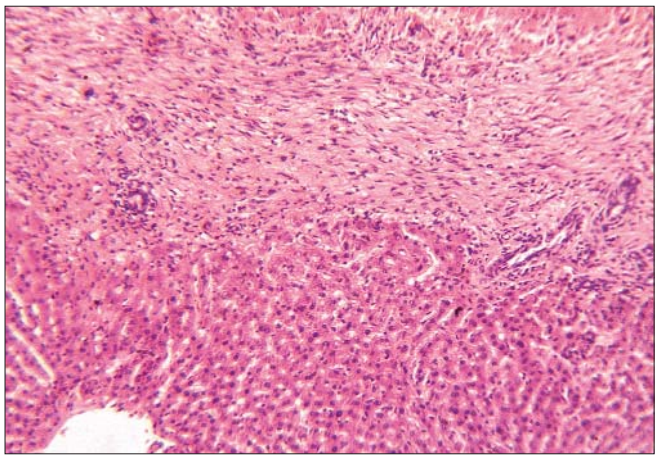

Figure 5. *Rabbit liver on day 21 after gas jet transection. Edge resection (zone of proliferation). Maturing scar tissue, binuclear hepatocytes, lobular histiocytic infiltration. Hematoxylin and eosin-stained sections (original magnification × 100)*

crossing of the parenchyma of a liver did not register significant differences in the investigated groups (*Table 1*). The specific haemorrhage at resection level was smaller in the group of animals that had a gas jet transection (3.54±0.33 ml/cm ²) and maximum for the clamp crushing technique 5.41±0.56 ml/cm² (Indicators present statistically significant differences $p < 0.001$).

The research carried out has shown high efficiency and safety of the proposed method of gas jet transection of hepatic parenchyma in performing resections of the liver. In comparison to the method of ultrasonic and water jet transection of liver tissue the original way of gas jet transection

Table 1. *Intraoperative Transection-Related Feature*

	Clamp crushing	Gas jet transection	Ultrasonic transection	Water jet transection
Mean transection speed, (cm²/min)	2.9±0.25	2.4±0.16	2.4±0.13	2.5±0.14
Mean blood loss, (ml/cm²)	5.5±0.46*	3.5±0.15	3.6±0.13	3.6±0.14

** Significant versus all other techniques*

presents no statistically significant differences regarding the basic working parameters: speed of transection and blood loss, allowing us to recommend it for clinical application.

Gas jet transection is not accompanied by thermal damage of hepatocytes in the resection area, which is characteristic for CUSA, LigaSure and Aquamantys (8). This ensures minimal trauma and fast repair of the hepatocytes, which was confirmed by our morphological studies.

Application of clamp crushing technique, from our point of view, is justified only in combination with an episodic vascular occlusion (Pringle manoeuver), implying a larger injury and representing a disadvantage of the given technique.

The data we obtained in connection to the technology of transection of the liver parenchyma by clamp crushing method is not in agreement with data provided by medical literature. In our opinion, this is due to the fact that the majority of surgeons apply the given technique of transection only in combination with an episodic vascular occlusion. In our study the Pringle manoeuver was not used, as it determines, in our opinion, greater blood loss in comparison with other techniques.

Experimental research and the first clinical applications have obtained the expected effect. Nevertheless, research in this direction proceeds.

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References

1. Jarnagin WR, Gonen M, Fong Y, DeMatteo RP, Ben-Porat L, Little S, et al. Blumgart LH. Improvement in perioperative outcome after hepatic resection: analysis of 1.803 consecutive cases over the past decade. Ann Surg. 2002;236(4):397-406.
2. Poon RT, Fan ST, Lo CM, Liu CL, Lam CM, Yuen WK, et al. Improving perioperative 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(4):698-708.
3. Tung TT (1939) La vascularisation Veineuse du Foie et se Applications aux Resections Hepatiques. Hanoi: Tese.
4. Lin TY. A simplified technique for hepatic resection: the crush method. Ann Surg. 1974;180(3):285-90.
5. Kim K H, Lee SG. Usefulness of Kelly clamp crushing technique during hepatic resection. HPB (Oxford). 2008;10(4):281-4.
6. Takayama T, Makuuchi M, Kubota K, Harihara Y, Hui AM, Sano K et al. (2001) comparison of ultrasonic vs clamp transection of the liver. Arch Surg. 2001;136(8):922-8.
7. Xia F, Lau WY, Ma KS, Bie P. Modified conventional clamp-crushing technique in liver parenchymal transection. Hepatobiliary Pancreat Dis Int. 2012;11(4):442-5.
8. S Hammond J, Muirhead W, Zaitoun AM, Cameron IC, Lobo DN. Comparison of liver parenchymal ablation and tissue necrosis in a cadaveric bovine model using the Harmonic Scalpel, the LigaSure, the Cavitron Ultrasonic Surgical Aspirator and the Aquamantys devices. HPB (Oxford). 2012; 14(12):828-32.