Original Article

Gas jet transection of liver parenchima: experimental research

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Background: There exists a great variety of liver parenchyma transection techniques. The objective of this research is to develop a new method of liver transection, and to compare it with the traditional ones.

Methods: A original gas jet transection method of biological tissues and the apparatus "Pneumojet" to make the method practicable were developed in our institute. Comparison between the efficiency of gas jet, water jet, ultrasonic methods of liver transection and clamp crushing technique were carried out on 24 mini-pigs. Pringle maneuver was not included.

Results: The mean blood loss was the smallest in the group of animals that had a gas jet transection (3.5±0.15 mL/cm^2) but the highest in the clamp crushing technique group (5.5±0.46 mL/cm^2). Indicators significantly showed the statistical difference ($P<0.001$). The transection speed was the highest in the Clamp crushing technique group (2.9±0.25 cm^2/min) and was credibly higher than in the gas jet (2.4±0.16 cm^2/min), ultrasonic (2.4±0.13 cm^2/min) and water jet (2.5±0.14 cm^2/min) transection groups. Compared with the water jet and ultrasonic methods of liver transection, the original method does not have statistically significant distinctions on the basic indexes of work.

Conclusions: The research conducted proves high efficiency and safety of the gas jet transection method. The gas jet transection, therefore, could be recommended for further improvement and clinical application.

Key Words: Gas jet transection; water jet transaction; ultrasonic transaction; clamp crushing; liver resection

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Introduction

Structural features of the liver, expecially features of its vascular anatomy, request special demands from modern techniques of a section of its parenchyma and from equipment applied to this purpose. Invention and introduction of such equipment has served as one of the major factors which have led to appreciable improvement of the surgical treatment for patients with a focal pathology in the liver over the last decades (1,2).

Prototype of modern transection methods is the digitoclasia method, offered by the Vietnamese surgeon Ton That Tung in 1939 (3). Subsequently the technique was improved slightly with the appearance of the application of clamps instead of manual techniques. It was given the name "clamp crushing" (4). The clamp crushing method is still being used by many surgeons even today (5-7). The further perfection of transection technologies has led to the modern devices such as, water jet scalpel, the most popular devices nowadays as well as the an cavitron ultrasonic surgical aspirator.

Based on various physical principles, all of these methods are allowed to destroy hepatic cells, thus vascular and secretory elements of a liver are kept intact. Besides, in the course of a resection, they can be used to clip, coagulate or legate them, depending on diameter.

It means that at interaction of working substance and liver tissue, the energy transmission is carried out in smaller quantity, rather than it is necessary for damaging of tubular structures, but sufficient for destruction of hepatic cells.

Figure 1 Apparatus for gas jet transaction "Pneumojet"

As we know, in the Universe the substance is presented by four basic modular conditions. *Plasma*—the most widespread condition of substance. The sun and stars are clots of hot plasma. In the 1969 year the attempt of the Japanese scientists (K. Hichimoto *et al.*) to apply plasma streams for a transection of hepatic tissue has not been crowned with success, but it's applied to coagulation nowadays. *The firm* condition, interaction with this substance is the most rasping and destructive in the nature (for example just like a liver tissue the clamp surface co-operates at a clamp crushing technique). *Liquid*, the substance in this condition possesses property of fluidity and high elasticity, thanks to what interaction with it is more sparing, but sufficient for processing even firm surfaces. Substance application in this condition, for tissues separation, corresponds to a water jet transection method. *Gas*, unlike liquids and firm bodies, the density of gases at normal pressure upon some usages is less than density of liquids that provides softer interaction of gas with other substances. In spite of it, so-called, aeration figures are arisen by influence of atmospheric gas on a stone.

Considering these features, the purpose of our research was to work out and apply gas jet transection method of liver parenchyma to its resection.

Materials and methods

The original method of gas jet transection of biological tissues and the apparatus for its realization "Pneumojet" (Patent № 41570 U, UA; Patent № 44610 U, UA; Patent № 44608 U, UA; Patent № 54798 U, UA; Patent № 56676 U, UA; Patent № 56677 U, UA; Patent № 54796 U, UA) was developed in the our institute (*Figure 1*). The way of separation of tissues of parenchymatous organs includes introduction on a surface of operated organ of handling medium under the pressure exceeding its durability, that allows to allocate vessels from a parenchyma till the crossing moment, and then sensitively to clip or legate them and just after that to cross, if necessary, by applying various ways of achievement of definitive hemostasis. A handling medium gas that provides minimum injury is chosen. It excludes an overhydratation of cells in a resection zone (feature of a water jet transection) and optimizes technological process whereas gas leaves from a surgery field independently.

A consecutive number of experimental researches of the parameters of work of "Pneumojet" referred on definition and their optimization. Comparison of clinical and morphological changes in a liver after application between various ways of separation of its parenchyma and studying of outcome reparative processes in a resection zone is put in a basis of the presented work.

Study of mechanisms of gas stream influence is carried out during the first investigation phase at which parameters of "Pneumojet" and a range of necessary pressure for selective separation of parenchyma of a liver have been defined. For this purpose resections of a cadaveric liver were carried out (n=12). During this procedure diameter of the damaged vascular structures at various parametres of work of "Pneumojet" were estimated.

In experiences on rabbits (Chinchilla) (n=32) work features of original apparatus "Pneumojet" were studied. Techniques of its application, various regimens were fulfilled, the damage rate of tissues of a liver and influence on animal's organism as a whole was estimated. The resection of the left and right medial shares of a liver was carried out. Reresections were carried out at 7-8 and 21 days, during that time a degree of change in a resection zone was estimated. Terms of observation over animals after operations have made till 1.5 years.

Efficiency and traumatism comparison of gas jet, ultrasonic, water jet methods of transection and clamp crushing technique were carried on 24 mini-pigs. Depending on transection technique of parenchyma of a liver, the animals have been parted on 4 groups. The 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), At carrying out of clamp crushing method a Kelly clamp was used.

Though operative tactics at carrying out of each operation could vary, we adhered to certain conditions. Liver resection was carried out in the fissural way, without preliminary vascular isolation. Pringle maneuver wasn't used as a method of the vascular control. The sizes of resected portion of a liver and, accordingly, wound surfaces that were formed as a result of operation, did not differ in investigated groups. The volume estimation of hemorrhage was carried out by the anesthesiologist and in each case consisted of quantity of blood saved up in capacity for the collecting (taking into account a deduction of a solution for transection) and volume in a used dressing material (dressing material).

For control of gas escape into a bloodstream through system of the hepatic veins, all mini-pigs underwent pneumotransection, have got: 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).

For possibility of comparison of transection efficiency the following parameters are defined. Speed of transection of liver parenchyma—the area ratio of the resection surface to resection time (cm²/min), blood loss—the volume ratio of hemorrhage at resection stage to the area of the resection surface (mL/cm²).

All experiments are conducted according to "the General principles of experiments on animals", approved by Ethics Committee of the GI "Institute of General and Urgent Surgery of AMS of Ukraine", I national congress on bioethics (20.09.2004, Kiev, Ukraine) and compounded with positions "the European convention on protection of vertebrate animals which are used for experiments and other scientific purposes" (Declaration of Helsinki).

Data were analysed using Stat Plus 2009 Professional 5.8.4. for Windows. Data are expressed as the 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

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

At the developed parameters of action of carbon-dioxide stream, in experiments on rabbits application possibility of gas jet transection of liver is proved. No one from 32 operated rabbits has died. The macroscopical estimation of organs was carried out right after liver transection (1 animal is deduced from experiment), hasn't taped the signs of gas escape into the bottom vena cava system, pulmonary trunk and its branches. At reresections on 7-8th and 21th day the complications did not observe, to the resection surface have been soldered an epiploon. There were no blood and bile in an abdominal cavity. Microscopically the edge of resected liver site has a little "lacerated" appearance, but the liver tissue is damaged a little, i.e. hepatocytes keep average euchrom nucleuses, glycogen in cytoplasma (*Figure 2*). Gas jet transection is accompanied by optically empty vacuoles in the resection margin (*Figure 3*). By 8 day the lysis of necrotic sites and lost cells comes to the end (*Figure 4*). There are begun processes of a fibrogenesis which finished by formation of connective tissue cicatrix on 21th day (*Figure 5*).

In experiments on mini-pigs the comparative estimation of parameters of transection of hepatic parenchyma is carried out by various ways. There are obtained the objective data testifying to 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 the pyesis of a postoperative wound on 8th day after ultrasonic resection of a liver took place.

Intraoperative angiopulmonography, monitoring of pressure in a pulmonary artery, intraoperative ultrasound of a pulmonary artery and heart have not taped data for hit of gas in a bloodstream.

Comparison of duration of operation and time spent for crossing of parenchyma of a liver, has not taped authentic differences in investigated groups (*Table 1*). The specific hemorrhage at a resection stage was smaller in group of animals that had a gas jet transection (3.54±0.33 mL/cm²) and

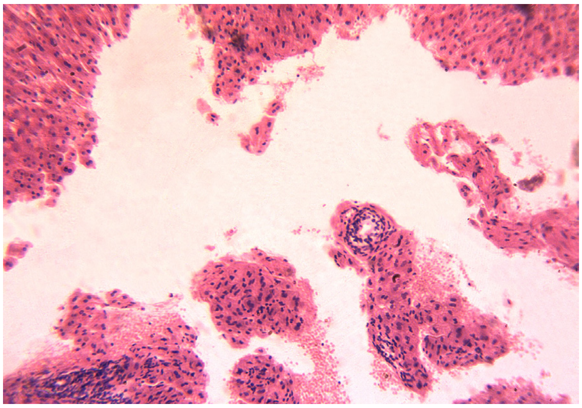

Figure 2 Rabbit liver after gas jet transection. The edge of the resection. Ragged edge, amorphous detritus, small focal hemorrhage. Hematoxylin and eosin-stained sections (original magnification ×100)

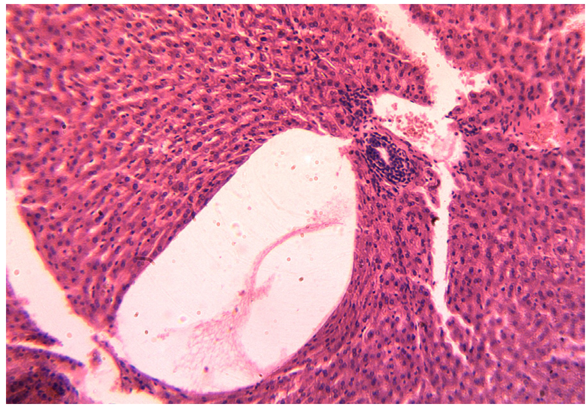

Figure 3 Rabbit liver after gas jet transection. The edge of the resection, area of necrobiosis. Parenchymal tears, optically empty vacuoles, small focal hemorrhage. Hematoxylin and eosin-stained sections (original magnification ×100)

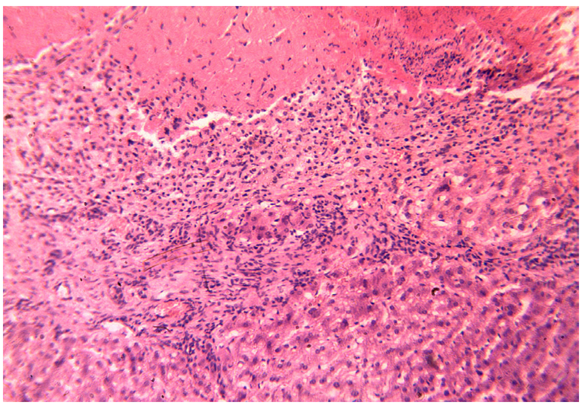

Figure 4 Rabbit liver on day 8 after gas jet transection. Edge resection (necrotic area, necrobiosis and proliferation). Dense necrotic detritus on the edge of resection, swelling of hepatocytes, the emerging granulation tissue, diffuse histiocytic inflammatory infiltration. Hematoxylin and eosin-stained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

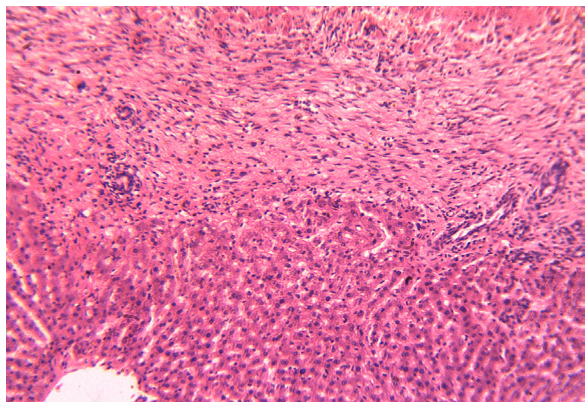

Figure 5 Rabbit liver on day 21 after gas jet transection. Edge resection (zone of proliferation). Maturing scar tissue, binuclear hepatocytes, lobular histiocytic infiltration. Hematoxylin and eosin-stained sections (original magnification ×100)

Table 1 Intraoperative transection-related feature

	Clamp crushing	Gas jet transection	Ultrasonic transection	Water jet transection
Mean transection speed, (cm^2/min)	2.9±0.25	2.4±0.16	2.4±0.13	2.5±0.14
Mean blood loss, (mL/cm^2)	5.5±0.46*	3.5±0.15	3.6±0.13	3.6±0.14

*Significant versus all other techniques maximum at clamp crushing technique 5.41±0.56 mL/cm^2 (Indicators have statistically authentic differences $P<0.001$).

Discussion

All properties of physical methods of liver parenchyma transection and, correspondingly, indications for their use can be evaluated comparatively only. At present we have information on 7 randomized studies which comprise comparison of efficiency indices for the basic methods of liver parenchyma transection.

A meta-analysis on these studies carried out by Viniyendra Pamecha *et al.* (8) proves blood transfusion requirements were lower with the clamp-crush technique than with the CUSA or hydrojet. The clamp-crush technique was quicker than the CUSA, hydrojet or RFDS. Infective complications and transection blood loss were greater with the RFDS than with the clamp-crush method. There was no significant difference between the techniques in mortality, morbidity, liver disfunction or intensive therapy unit and hospital stay. The clamp-crush technique is more rapid and is associated with lower rates of blood loss and otherwise similar outcomes when compared with other methods of parenchymal transection. It represents the reference standard against which new methods may be compared.

Another meta-analysis by Nuh N. Rahbari *et al.* (9) on overall morbidity, biliary leakage, transfusion rates, and mortality revealed no difference between the clamp crushing and alternative transection techniques. None of the identified studies demonstrated a clinically important benefit of an alternative transection method in terms of blood loss, parenchymal injury, transection time, and hospital stay. This meta-analysis does not indicate a benefit of any alternative transection technique on patients' perioperative outcome compared with the clamp-crush technique.

Thus the clamp-crush technique remains the reference technique for transection of parenchyma in elective hepatic resection. In connection with the aforementioned, an essential question arises: does the introduced method of gas jet transection have any advantages over the traditional ones? The research done has demonstrated high efficiency and safety of the offered way of gas jet transection of hepatic parenchyma at performance of resections of a liver. In comparison with a method of ultrasonic and hydrojet transection of liver tissue, the original way of gas jet transection has no statistically authentic differences for the basic indicators of work: speed of transection and blood loss. Undoubtedly, this only denotes comparability of the introduced method with presently widely-spread methods of ultrasound and water transection. However, gas jet transection is not accompanied by thermal damage of hepatocytes of resection surface, which are characteristic of CUSA, LigaSure and Aquamantys (10). This ensures minimal trauma and fast repair of hepatocytes, which was confirmed by our morphological studies. This fact is considered to be an inquestionable and the most considerable advantage of the suggested of gas jet transection.

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

The data we received according to technology of transection of parenchyma of a liver by clamp crushing method don't come to agreement with data of the world literature. In our opinion it is caused by the fact that overwhelming the primary majority of surgeons apply the given techniques of transection only in a combination to an episodic vascular occlusion. In our experiment Pringle maneuver wasn't used, that has provided, in our opinion, the large blood loss in comparison with other techniques. Application of vascular exclusion in transection by clamp crushing technique is inevitably followed by ischemic reperfusion syndrome, which makes comparison of this method with other ones which do not use Pringle maneuver impossible. In this respect, we cannot find the conclusions on the fact that the clamp-crush technique is more rapid and is associated with lower blood loss than other methods of parenchymal transaction quite plausible.

Further comparative morphological and clinical research will enable us to estimate effectiveness of gas jet transaction method for modern liver resection surgery. Thus we are going to continue our research in this sphere.

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