Transection Devices

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9.1 Introduction

The risk of massive bleeding during liver transection and postoperative biliary leaks are due to the complex biliary and vascular anatomy of the liver. Hemorrhage was once the leading cause of death in liver resection, and the now reduced hospital mortality rate of ≤5% can be attributed to better intraoperative bleeding control. Hemorrhage and perioperative blood transfusion not only increase the risk of operative morbidity and mortality but jeopardize long-term survival after resection of liver malignancies because of the associated immunosuppression, leading to a higher risk of tumor recurrence [1]. Bleeding control is the result of the evolution of different aspects of liver surgery and anesthesia. Technological advances led to the development of specific instruments for liver transection; intraoperative ultrasound allows better delineation of the transection plane; and a better understanding of physiology and anatomy improved control of inflow and outflow. Inflow occlusion and low central venous pressure (CVP) anesthesia have been widely used to reduce bleeding from inflow vessels and backflow in the transection surface. Inflow occlusion (Pringle maneuver) has been used since the early twentieth century to prevent bleeding during transection, which is performed by crushing the liver parenchyma with the fingers or forceps (Kelly-clamp crushing), and the concomitant low CVP induced by anesthesia further minimizes blood loss by preventing retrograde bleeding from the hepatic veins. Assuming that inflow occlusion and low CVP cause significant damage due to ischemia and reperfusion, there has been a growing interest in using new devices that facil-

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itate bloodless transection, obviating the need for inflow occlusion. In the laparoscopic setting, these factors, associated with the struggle to perform an intermittent Pringle maneuver and clamp crushing, have led to a wide diffusion of a variety of transection devices, mostly derived from those routinely used in open surgery. This chapter provides a description of the main transection device features and considerations on the Pringle maneuver associated with clamp crushing in the laparoscopic setting.

9.2 Main Features of Transection Devices

The ideal surgical instrument for liver transection must effectively cut through the parenchyma while simultaneously recognizing and sealing any vessels or bile ducts. In reality, because no such single instrument yet exists, transection is achieved by a combination of instruments and techniques, which first facilitate division of the liver tissue, with subsequent vessel identification and sealing. The two basic actions of liver transection can be achieved by a variety of energy types [2].

9.2.1 Mechanical Energy

Manual fragmentation of the liver parenchyma is the more primeval transection device. The "finger fracture technique" under cycles of inflow occlusion was first introduced by Lin et al. in 1958. This technique was subsequently improved through the use of surgical instruments, such as a small Kelly clamp for blunt dissection. Nowadays, clamp crushing remains one of the most widely used techniques for liver transection in open surgery. A more evolved device employing mechanical energy is the water-jet dissector. The Hydro-Jet® (ERBE, Tuebingen, Germany) employs a pressurized jet of water to fragment the liver parenchyma tissue and expose the vascular and ductal structures. In all systems employing mechanical energy, vessels and bile duct must be sealed by other devices, clipped, or ligated before division. The endoscopic stapler can be considered the only method employing mechanical energy that crushes and divides the liver parenchyma, securing blood and bile vessels at the same time. A straight clamp is used to fracture the hepatic parenchyma, and subsequently, this portion of the liver is transected with a vascular stapler.

9.2.2 Alternating Current

High-frequency alternating current can be delivered in either a monopolar or a bipolar fashion. Most electrosurgical devices work in a radiowave frequency range of 500,000 Hz to 3 MHz. The monopolar device is composed of a generator, an electrode of application, and an electrode for the returning current to complete the circuit. The patient's body becomes part of the circuit when the system is activated. As the effectiveness of energy conversion into heat is inversely related to the area of contact, the application electrode is designed to be small to efficiently generate heat, and the returning electrode is designed to be large to disperse energy and prevent burn injury to the patient. Generated heat is dependent on three other factors in addition to the size of the contact area: power setting/frequency of the current; length of activation time; whether the waveform released from the generator is continuous or intermittent. Unipolar devices can be used to incise tissue when activated with a constant waveform and to coagulate when activated with an intermittent waveform. In the cutting mode, much heat is generated relatively quickly over the target area, with minimum lateral thermal spread. As a result, the device cuts through tissue without coagulating underlying vessels. In contrast with the coagulation mode, the electrocautery generates less heat on a slower frequency, with potential for large lateral thermal spread. This results in tissue dehydration and vessel thrombosis. A blind waveform can be chosen to take advantage of both cutting and coagulation mode. A large grounding pad must be placed securely on the patient for the unipolar electrocautery device to function properly and prevent thermal burn injury to the patient at the current reentry electrode site. Bipolar electrocautery establishes a short circuit between the tips of the instrument, whether a tissue grasper or forceps, without requiring a grounding pad. The tissue grasped between the tips of the instrument completes the circuit. In generating heat that only affects the tissue within the short circuit, it provides precise thermal coagulation. Bipolar electrocautery is more effective than the monopolar instrument for coagulating vessels because it adds the mechanical advantage of tissue compression between the tips of the instrument to the thermal coagulation. Bipolar electrocautery is particularly useful for conducting a procedure in which lateral thermal injury or arcing phenomenon need to be avoided. The argon-beam coagulator is a special form of monopolar electrocautery. The device creates a monopolar electric circuit between a handheld probe and target tissue by establishing a steady flow of electrons through a channel of electrically activated ionized argon gas. This high-flow argon gas conducts electrical current to the target tissue, where it generates thermal coagulation. The depth of thermal penetration of tissue varies from fractions of a millimeter to a maximum of 6 mm, depending on three factors: (1) power setting, (2) distance between probe and target, and (3) length of application. It is most commonly used to control oozing on the cutting liver surface.

9.2.3 Radiofrequency Energy

Radiofrequency (RF) is a rate of oscillation in the range of about 3 kHz to 300 GHz, which corresponds to the frequency of radio waves and alternating currents carrying radio signals. RF usually refers to electrical rather than mechanical oscillations; therefore, RF devices work basically as a monopolar and bipolar electrocautery. A special feature of RF current is the “skin effect”: the current does not penetrate deeply into electrical conductors but flows along their surfaces. The rapid alternating directional movements of ions in the tissue surrounding the probe result in the release of kinetic energy, determining high temperatures. It can raise the temperature of target tissue to >100°C and cause protein denaturation, desiccation, and coagulation necrosis, with a built-in sensor terminating the transmission of the current automatically at a particular set point, preventing overheating and unwanted collateral damage. To date, RF devices are largely used for resection and ablation of liver tumors. The most popular RF-based devices for parenchymal transection are LigaSure, TissueLink, and radiofrequency-assisted devices. LigaSure (Valley Lab, Tyco Healthcare, Boulder, CO, USA) is designed to seal small vessels. By a combination of compression pressure and bipolar RF energy, it causes shrinkage of collagen and elastin in the vessel wall, and it is effective in sealing small vessels up to 7 mm in diameter. Gyrus Plasma Trisector (PK) (Gyrus Group PLC, Gyrus International, Ltd., UK) is a novel RF system based on bipolar technology and is available for open and laparoscopic surgery. The PK system uses high-powered pulsed bipolar energy to produce a plasma kinetic field around the working elements and is designed to operate at temperatures that allow effective tissue dissection but to cause minimal collateral damage and adherence to tissue. The TissueLink (Medical, Inc., Dover, NH, USA) is new technology using saline-linked RF energy. In this instrument, saline runs to the tip of the electrode to couple RF energy to the liver surface and achieve coagulation. The radiofrequency-assisted devices are designed to be inserted along the transection plane serially 1- to 2-cm apart, and RF energy is applied for 1–2 min to create overlapping cylinders of coagulated tissue, followed by transection of the coagulated liver using a simple scalpel. Devices in this category are the Cool-tip RF electrode (Radionics Inc., Burlington, MA, USA) and the Laparoscopic Habib™ 4X (LH4X; RITA Medical Systems, Inc. California, CA, USA). The LH4X consists of a 2 × 2 array of needles arranged in a rectangle and uses bipolar RF energy to create an area of necrosis that can be cut with scissors or scalpel.

9.2.4 High-frequency Sound Waves

Ultrasound effects on living tissue depend on its frequency. At a low power level, it causes no tissue damage and is mainly used for diagnostic purposes. With a high frequency setting, ultrasound can be used to dissect, cut, and coagulate. There are several high-frequency ultrasonic devices available for surgical practice. The Harmonic Scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA) and the LOTUS (Laparoscopic Operation by Torsional Ultrasound; S.R.A. Developments Ltd., Devon, UK) use ultrasonically activated shears to seal small vessels between the vibrating blades. The blade longitudinal

(Harmonic Scalpel) or tortional (LOTUS) vibration with a frequency of 55.5 kHz can dissect liver parenchyma easily. The coagulation effect is caused by protein denaturation, which occurs as a result of destruction of the hydrogen bonds in proteins and generation of heat in the vibrating tissue. Blood vessels up to 2–3 mm in diameter are coagulated on contact with the vibrating blade. The tissue-cutting effect derives from a saw mechanism in the direction of the vibrating blade.

The Cavitron Ultrasonic Surgical Aspirator (CUSA) (Tyco Healthcare, Mansfield, MA, USA) fragments and aspirates liver parenchyma with ultrasonic energy, thus exposing vascular and ductal structures that can be ligated, clipped, or sealed with other transection devices. CUSA uses lower frequency ultrasound energy and works basically as an ultrasound probe combined with an aspirator. The main feature of CUSA is the ability to fragment and aspirate tissue of low collagen and high water content (hepatocytes), leaving intact anatomical structures with high collagen content, such as blood and biliary vessels.

9.3 What is the Best Transection Device?

Even though some of these devices have gained wide acceptance for hepatectomy, their efficacy has been tested in only a few randomized studies conducted in the open surgical setting. In a recent meta-analysis, data from 556 patients undergoing elective liver resection and randomized in seven trials were reviewed [3]. In that systematic review, there were no significant differences in mortality and complication rates (including bile leak) of liver resection, irrespective of the method used for parenchymal transection. Markers of liver parenchymal injury or liver dysfunction were also similar, and there was no difference in intensive care unit or hospital stay between groups. On the other hand, the clamp crushing coupled with the Pringle maneuver appeared to have the lowest blood loss and lowest transfusion requirements compared with the other techniques. Clamp crushing was quicker than CUSA, Hydro-Jet, and RFDS. Ikeda et al. randomized 120 patients to undergo clamp crushing or liver resection with the LigaSure. In both groups, intermittent pedicle clamping was applied, and the technique of parenchymal transection differed only for the method of securing blood and bile vessels. After liver capsule cauterization, the liver parenchyma was fractured by clamp crushing, and vascular structures, including portal triads and hepatic veins, were sealed with LigaSure in one group and ligated in the other. The two groups did not differ in terms of transection speed and postoperative morbidity [4]. Therefore, there is no evidence of superiority of any technique over clamp crushing and the Pringle maneuver for open liver resections. Clamp crushing is hardly reproducible laparoscopically and several concerns limited the wide diffusion of the Pringle maneuver among laparoscopic liver surgeons.

Encircling the liver pedicle is technically challenging with the rigid laparoscopic tools, and the risk of injury to the inferior vena cava and structures within the liver pedicle is considered potentially life threatening. Moreover, an effective intermittent clamping is difficult to achieve due to the continuous changes of the visual field between the section line and liver pedicle. Finally, some preclinical data show that a high abdominal pressure could decrease liver backflow, enhancing ischemic damage induced by inflow occlusion [5, 6].

These are several reasons the use of the other devices has been adopted in laparoscopic liver resection instead of clamp crushing. Nevertheless, to date, there are no randomized studies demonstrating the superiority of one technique or device over the others for liver transection in laparoscopic surgery. A consensus among authors regards the use of vascular staplers to secure and divide the portal pedicles and hepatic veins [7–9]. Similarly, transection of the superficial liver layer (2 cm beneath the glissonian sheet), with the absence of large vessels and bile ducts, is unanimously considered safe with all devices, monopolar and ultrasonically activated shears included. When a deeper transection is required, two methods can be followed: (1) indiscriminately coagulate all tissues and vessels along the transection plane, or (2) destroy the liver parenchyma to expose the inner vascular and biliary structures to be clipped or sealed separately and then divided.

RF-based devices work in the first manner. The LigaSure Atlas crushes the parenchyma between the instrument jaws and then coagulates any vessel and bile duct to at least 7 mm in diameter. The reported advantage of this device is the minimal adjacent tissue damage due to thermal spread [10]. In fact, when compared with other laparoscopic devices used for hepatic parenchymal dissection, the LigaSure device demonstrates a lower mean temperature in the surrounding parenchyma. In a study by Kim et al., the mean temperature in the liver was 121.3 ± 9.7°C and 76 ± 2.9°C for the Harmonic scalpel and LigaSure, respectively [11]. The LH4X is another bipolar RF device. It produces coagulative necrosis along the line of intended parenchymal transection without vascular clamping of either portal triads or major vessels. The area of necrosis is then cut with laparoscopic scissors [12]. Limitations of RF-based devices are possible vascular injuries when the transection plane is close to a major liver vessel, and the wide area of necrosis at the surgical margin, which can increase the risk of postoperative septic complications and make identifying marginal recurrences difficult during follow-up [13].

Rather than creating massive coagulation of the transection plane, ultrasonic and water-jet devices fragment the liver parenchyma, leaving intact arteries, veins, and bile ducts crossing the line of division, which can be sealed or clipped and divided using the ultrasonic coagulating cutter, electrocautery, or an RF-based device [7, 8, 14]. Therefore, the choice of transection techniques in laparoscopic and open surgery is a matter of surgeon preference, as there are no data from prospective randomized trials that compared different techniques. Frequently, liver transection is performed using more than one device. Therefore, it will be difficult to design controlled studies to prospectively compare all the available devices [15].

9.4 Clamp-crushing Technique in Laparoscopic Liver Surgery

Whereas clamp crushing associated with intermittent Pringle maneuver is considered the safer and more accurate method of parenchymal transection in open liver surgery, its use in the laparoscopic practice seems to be neglected [3]. As discussed above, there are many technical and theoretical reasons explaining this preference of laparoscopic surgeons. Despite the extensive use of high-tech devices, the principle behind clamp crushing – to fragment the parenchyma while preserving vascular structures – has been reproduced by some devices, such as water-jet devices and CUSA. Moreover, parenchymal fragmentation under intermittent inflow occlusion has been described in laparoscopic series. Cuschieri, in 2005, claimed that to transect the liver he uses a long-jawed crushing laparoscopic forceps under intermittent Pringle maneuvers carried out with a laparoscopic vascular clamp introduced through a port on the right flank [16]. Lee et al., in their series of 100 laparoscopic hepatectomies, used clamp crushing in selected cases [21].

Renewed interest in this old-school technique is paralleled by ingenious and easy techniques to achieve a safe and reproducible inflow occlusion. Four groups independently describe a novel way to clamp the liver pedicle extracorporeally [17–19]. The availability of a tourniquet encircling the liver pedicle that can be managed from the outside has the advantage of guaranteeing intermittent and effective inflow occlusions, as in open surgery. This feature is especially appreciable when major bleeding occurs, as the surgeon or the assistant can rapidly occlude the inflow, avoiding the struggle of looking for the liver pedicle in a bloody field and changing the focus of attention from the bleeding site.

With the advent of robotics, clamp crushing has become the standard for parenchymal transection in our institution. Using the EndoWrist bipolar Precise forceps (Intuitive Surgical Systems, Sunnyvale, CA, USA), the parenchyma can be easily fragmented, exposing the inner vessels as in open surgery. The on-table surgeon uses the device to perform intermittent inflow occlusion, thereby allowing the console surgeon to focus attention only on the transection line [20]. The wristed instruments gave back to the laparoscopic surgeon the possibility of performing curved and angled resections in all liver segments, an ability that was lost with the rigid laparoscopic tools. The effect of the poor ergonomics of laparoscopic devices has detrimental effects on the outcome of liver resection.

Straight resections are easier, forcing the surgeon to favor major hepatectomies for lesions located in the posterior liver segments. Therefore, it is the author's opinion that robotic clamp crushing may improve parenchymal preservation, even for deeply located lesions, thus widening the indications for a minimally invasive approach even to lesions in the posterolateral segments and located close to major liver vessels.

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