Section A-Research paper

An Overview about Laparoscopic Splenectomy and Bleeding Control during the Procedure

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Abstract

The spleen, originally called the organum plenum mysterii by Galen, has long been an important organ for surgeons. The first splenectomy was performed by Andirano Zaccarello in 1549 on a young woman with an enlarged spleen who survived for 6 years after surgery. Traditionally, surgical removal of the spleen was done via an open approach using either an upper midline or left subcostal incision. With the advent of minimally invasive techniques, laparoscopic splenectomy became a standard procedure for elective removal of the spleen for most indications. Since the first report of laparoscopic splenectomy by Delaitre and Maignien in 1991, it has been increasingly used; however, several technical challenges remain related to removing this fragile, well vascularized organ that lies close to the stomach, colon, pancreas, and kidney. Indications for laparoscopic splenectomy are the same as those for open splenectomy except when emergency splenectomy and exploratory laparotomy for traumatic injuries are needed. Laparoscopic splenectomy is indicated for various benign hematologic diseases, malignant hematologic diseases, secondary hypersplenism, and other anatomic disorders of the spleen. Severe intra-operative bleeding has limited the application of complex laparoscopic splenectomy (LS), including laparoscopic total splenectomy (LTS) and laparoscopic partial splenectomy (LPS). Therefore, reducing bleeding risk in complex LS has become a subject of major interest. In LTS for splenomegaly and hypersplenism secondary to portal hypertension, the splenic artery can be ligated with a titanium clip or a Hem-o-lock clip to render the spleen smaller, softer, and easier to operate on. However, in patients with severe local edema or unclear blood vessel exposure, the splenic artery should not be forcibly separated to prevent uncontrollable massive bleeding.

Keywords: Laparoscopic Splenectomy, Bleeding Control

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With the advent of minimally invasive techniques, laparoscopic splenectomy became a standard procedure for elective removal of the spleen for most indications. Since the first report of laparoscopic splenectomy by Delaitre and Maignien in 1991, it has been increasingly used; however, several technical challenges remain related to removing this fragile, wellvascularized organ that lies close to the stomach, colon, pancreas, and kidney **(1).**

Indications

Indications for laparoscopic splenectomy are the same as those for open splenectomy except when emergency splenectomy and exploratory laparotomy for traumatic injuries are needed. Laparoscopic splenectomy is indicated for various benign hematologic diseases, malignant hematologic diseases, secondary hypersplenism, and other anatomic disorders of the spleen **(2).**

The most common benign hematologic disease treated with laparoscopic splenectomy is immune thrombocytopenic purpura (ITP), and the procedure is recommended when medical therapy, including steroids and intravenous gammaglobulin, fails or long-term steroids are needed. Laparoscopic splenectomy can also be warranted in other benign conditions, including other types of thrombotic purpura, hereditary spherocytosis, major and intermediate thalassemia with secondary hypersplenism or severe anemia, sickle cell disease, and refractory autoimmune hemolytic anemia **(2).**

Laparoscopic splenectomy for malignant diseases of the spleen can be performed for diagnostic or therapeutic reasons. Indications include myeloproliferative disorders, lymphoproliferative diseases, hairy cell leukemia, Hodgkin and non-Hodgkin lymphoma, malignant vascular tumors, malignant lymphomas, and lymphangiosarcomas **(2).**

Although the use of laparoscopic splenectomy in trauma has been reported, its role has been limited because most hemodynamically stable patients with splenic injuries are successfully treated nonoperatively, and unstable patients require emergency laparotomy for control of hemorrhage and to evaluate possible associated traumatic injuries. However, there is growing evidence that it can be a feasible option in the trauma setting in appropriately selected patients **(2).**

Contraindications

Contraindications for laparoscopic splenectomy are similar to those for all laparoscopic surgical procedures. They include the inability to tolerate general anesthesia, uncontrollable coagulopathy, and the need for laparotomy for associated procedures **(3).**

Although reports on the safety of laparoscopic splenectomy in patients with cirrhosis and portal hypertension have been published, many have considered the presence of these conditions to be an absolute contraindication for laparoscopic splenectomy **(3).**

Massive splenomegaly has been regarded as a relative contraindication; however, the hand-assisted technique may facilitate removal of large spleens in a minimally invasive fashion. Good results are being reported for laparoscopic removal of very large spleens, and it has been suggested that with advances in laparoscopic technology and expertise, laparoscopic splenectomy may become the gold standard operation even for massive spleens and splenic malignancies **(3).**

Patient Preparation

Anesthesia

General anesthesia is required for laparoscopic splenectomy. Adjuncts for pain management are left to the discretion of the surgeon and anesthesiologist.

Positioning

There are two major approaches to laparoscopic splenectomy: lateral and anterior.

Lateral approach

For the lateral or semilateral approach, the patient is positioned in the right lateral decubitus position at an angle of approximately 45-90° **(4).**

Positioning and stabilization of the patient are facilitated by the use of a beanbag mattress, though various rolls and pads may be used. The patient is positioned with the umbilicus at or near the break in the table. This allows more distance between the lower ribs and iliac crest when the table is flexed and the bolster/kidney rest is elevated. All pressure points must be adequately padded. The surgeon and camera operator stand on the patient's right side, with the video monitors above and lateral to the patient's left shoulder **(5).**

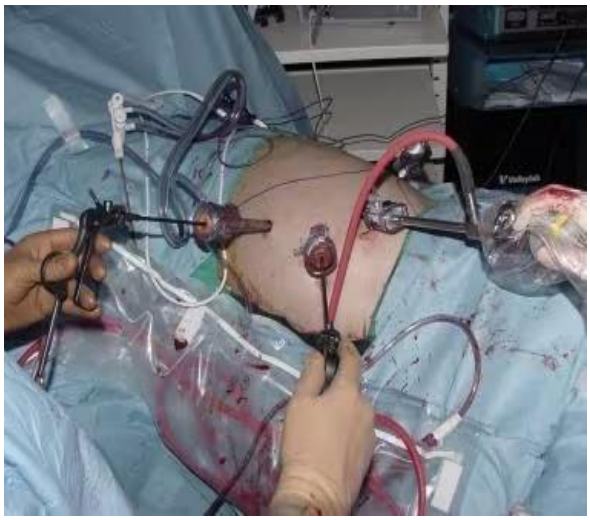

Fig. 1: Laparoscopic splenectomy. Port placement for lateral approach **(5).**

Anterior approach

For the less frequently used anterior approach, the patient is placed supine in the modified lithotomy position; this allows the surgeon to operate while standing between the patient's legs or on the right side of the patient **(5).**

Technique

Approach Considerations

In the performance of a laparoscopic splenectomy, it is essential always to be mindful that conversion to open surgery may be warranted, possibly on an emergency basis. To prepare for this possibility, when the patient is placed in the lateral position, a wide field should be prepared to allow access to the midline in the event that upper-midline or hand-assist access is needed. Also, it may be helpful to mark the skin two fingerbreadths below the left costal margin before insufflation, in the event that a left subcostal incision proves necessary **(6).**

Before splenic mobilization is initiated, diagnostic laparoscopy should be used to look for accessory spleens, which are present in 12-16% of patients and as many as 32% of patients with immune (idiopathic) thrombocytopenia purpura (ITP). Accessory spleens are commonly found in the splenic hilum, along the splenic vessels, in the greater omentum, and in the splenorenal ligament. For large spleens and early in the experience of surgeons undertaking laparoscopic splenectomy, a hand-assisted technique may reduce conversion rates and operating time **(6).**

Single-port approaches to laparoscopic splenectomy have been described that appear to be safe and effective; however, they have not been shown to have clear advantages over conventional approaches. Robotic-assisted techniques have also been described. These techniques will not be addressed further here **(7).**

There is increasing interest in performing partial splenectomy as a means of avoiding the consequences of total splenectomy and preserving the function of the organ. A study by Makansi et al found laparoscopic partial splenectomy to have perioperative outcomes comparable to those of the equivalent open procedure in children and adolescents. Partial spelenectomy also will not be addressed further in this article **(7).**

Lateral Approach to Laparoscopic Splenectomy

For the lateral approach, the operation begins with safe laparoscopic abdominal access. This can be accomplished with an open or a closed technique, in accordance with the skill, experience, and comfort level of the surgeon **(8).**

Although an open cutdown technique for the direct insertion of the first trocar is sometimes favored, an optical trocar technique with pre-insufflation using a Veress needle can be quite useful, especially in patients who are obese. The use of the Veress needle is contraindicated in patients with massive splenomegaly or severe

thrombocytopenia and in children because of the limited working space and risk of splenic injury and bleeding **(8).**

The first trocar, either a 5- or a 12-mm port, is usually placed in the midclavicular line 2-6 cm below the costal margin, depending on the size of the spleen. Preoperative imaging with computed tomography (CT) or ultrasonography (US) can facilitate operative planning by assessing splenic size, locating accessory spleens, and aiding in decisions regarding port placement and surgical technique (laparoscopic, hand-assisted, or open) **(9).**

Subsequent trocars are placed after diagnostic laparoscopy; placement varies, depending on the patient's body habitus and spleen size. All ports should be placed 3-4 cm below the inferior tip of the spleen to allow adequate working space for visualization and safe instrument exchange. A medial trocar is placed just off the midline/subxiphoid region in the left subcostal position. A third trocar is placed in the anterior axillary line in the left subcostal region. **(9).**

A fourth trocar (placed laterally off the tip of the 11th rib) is often needed and can assist greatly in manipulating large spleens. This trocar is inserted after mobilization of the splenic flexure and is placed lateral to the other ports. Trocar size can range from 5 to 12 mm, depending on the surgeon's preference **(10).**

A 12-mm trocar is needed for extraction of the specimen and an endoscopic stapling device (if one is to be used to divide the splenic hilum). One potential strategy is to start with all 5-mm trocars and a 30° 5-mm laparoscope when visualization is satisfactory. After initial dissection and splenic mobilization, the port that gives the best angle for hilar ligation can be "upsized" to 12 mm for use of the endoscopic stapler. Alternatively, all ports may be 12 mm, allowing the use of of a 10-mm laparoscope and stapler that can be interchanged between ports **(10).**

These choices are surgeon-dependent and are made on the basis of the difficulty of the case and the surgeon's experience **(11).**

Once the trocars have been placed, diagnostic laparoscopy is again performed to look for accessory spleens, which can be found in the hilum, omentum, mesocolon, or mesentery **(11).**

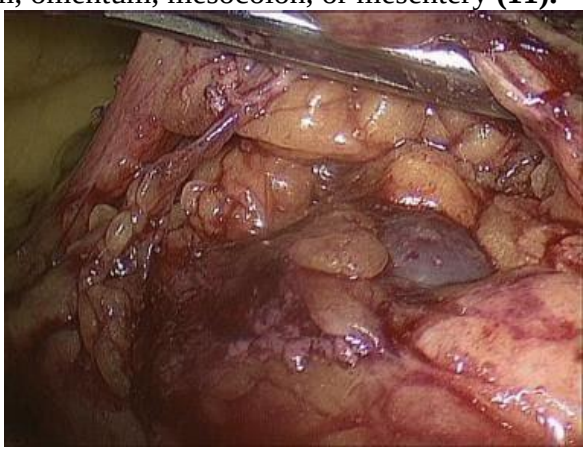

Fig. 2: Laparoscopic splenectomy. Accessory spleen found in splenocolic ligament **(11).**

After the gastrosplenic ligament and the short gastric vessels are divided, the spleen is elevated to expose the hilum. This can be done with fan retractors, snake retractors, or long atraumatic bowel graspers. In elevating the spleen, care should be taken not to injure the parenchyma and cause bleeding **(12).**

With elevation of the spleen, the hilum and the tail of the pancreas are usually visible. When the hilum is not adequately visualized, the splenophrenic ligament can be divided superiorly to facilitate splenic mobilization. After the splenic hilum and the tail of the pancreas are well visualized, an endoscopic stapler with a vascular load can be used for ligation and division of the splenic vasculature **(12).**

Another popular dissection technique is to divide the gastrosplenic ligament first, then the splenocolic and splenorenal ligaments. This allows the spleen to be suspended by the lateral and posterior attachments. The remainder of the dissection and control of the splenic hilum is similar to that described previously **(13).**

When the splenic hilum is controlled and divided (with visual confirmation, as the splenic parenchyma becomes discolored and appears devascularized), the spleen can be grasped by the handle of the splenocolic

ligament left on the inferior border of the spleen and flipped onto its ventral surface with the hilum facing up. At this time, an impervious retrieval sac can be advanced through the 12-mm port and unfolded in the left upper quadrant **(13).**

The process of placing the spleen into the bag can be difficult and frustrating. Several different retrieval sacs are available. The surgeon should make sure that these sacs are sturdy enough to prevent rupture and large enough to envelop the entire spleen. Opening the bag widely and having a handle (either the perihilar tissue or portion of the splenocolic ligament) can greatly facilitate placement of the spleen into the retrieval sac. Gravity can also be used by placing the patient in Trendelenburg position as the spleen is carefully advanced into the bag **(14).** After the spleen is in the retrieval sac, the purse-string suture is pulled tight and brought up through the 12-mm trocar. The 12-mm trocar is then removed, pulling the neck of the bag up through the abdominal wall **(14).**

Anterior Approach to Laparoscopic Splenectomy

The anterior approach was the first technique described for laparoscopic splenectomy; however, it is seldom used today, except when the spleen is very large and, occasionally, when the hand-assist technique is to be employed **(15).**

For the anterior approach, the patient is placed in the lithotomy position to allow the surgeon to operate while standing between the patient's legs with the assistants on either side of the patient **(15).**

Safe abdominal access, as described earlier, is obtained at the umbilicus and typically involves placement of a 12-mm trocar that will accommodate a 10-mm 30° scope for visualization. Port sites vary according to individual surgeon preference but generally include three or four additional ports in a semicircle adjacent to the left upper quadrant **(15).**

Briefly, the technique involves liver retraction and medial retraction of the stomach.

After a search for accessory spleens, the splenocolic ligament is incised near the lower pole of the spleen with a hook cautery, scissors, or an electrosurgical device. The lower pole of the spleen is elevated gently to expose the splenic hilum and tail of the pancreas **(15).**

The branches of the splenic artery can then be carefully dissected and clipped as close to the spleen as possible to avoid injury to the tail of the pancreas. Although a stapling device or electrosurgical device may be used for splenic hilar ligation, caution is recommended, since it is usually much harder to distinguish the plane between the tail of the pancreas and splenic hilum in the anterior approach **(16).**

After control of the hilum, the short gastric vessels are ligated, and the spleen is detached and placed in a retrieval sac as previously described **(16).**

Hand-Assisted Laparoscopic Splenectomy

Hand-assisted laparoscopic surgery (HALS) is another technique for laparoscopic splenectomy that offers benefits of both open and laparoscopic techniques and has proved beneficial in patients with splenomegaly (craniocaudal length >22 cm or width >19 cm). For inexperienced surgeons, HALS may shorten the learning curve; for experienced surgeons, it may facilitate minimally invasive splenectomy for massively enlarged spleens that otherwise would not be amenable to a purely laparoscopic approach **(16).**

HALS splenectomy can be used with the anterior or lateral approach and positioning as described previously. It is generally agreed that the nondominant hand should be placed into the abdomen. Many commercial hand-assist devices are available **(17).**

Trocar positions can vary, depending on the hand dominance of the surgeon. For right- or left-hand-dominant surgeons, the hand-assist device can be placed in the midline at or slightly below the inferior pole of the spleen. The incision should be 7-8 cm (or 1 cm less than the surgeon's glove size) and should be located 2-4 cm caudal to the inferior pole of the enlarged spleen **(17).**

Laparoscopic ports are placed as described previously for the lateral approach; however, when the spleen is extremely large, the trocars must be placed more inferiorly than normal **(10).**

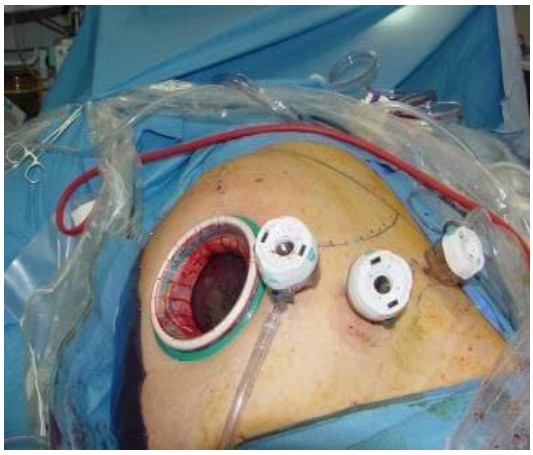

Fig. 3: Hand-assisted laparoscopic splenectomy. Enlarged spleen may be removed in total from hand-assist incision **(10).**

Complications

Complications related to laparoscopic splenectomy are similar to those of open splenectomy or other major abdominal procedures and include the following **(4).**

- Intraoperative and postoperative hemorrhage
- Infection, including wound infection, pneumonia, and overwhelming postsplenectomy infection (OPSI; also referred to as postsplenectomy sepsis syndrome or overwhelming postsplenectomy sepsis [OPSS])
- Injury to other structures, such as the colon, stomach, or, most notably, the pancreatic tail

Other complications specifically associated with laparoscopic and open splenectomy include the following:

- ✓ Risk of missed accessory spleens
- ✓ Portal vein thrombosis

Bleeding

Bleeding is one of the most common and feared complications related to laparoscopic splenectomy and is the most common reason for conversion to an open approach **(4).**

Postoperative bleeding following laparoscopic splenectomy occurs in approximately 3% of patients. Bleeding can be encountered following technical misadventures such as tearing the splenic capsule or failing to achieve adequate control of the splenic hilar vessels. Meticulous dissection around the splenic capsule can limit parenchymal tears. The surgeon should try to avoid grasping the spleen. Staplers, clips, and electrosurgical devices can be used to control the splenic hilar vessels, though the surgeon should be prepared if these instruments fail **(4).**

Subsequent bleeding can usually be controlled with additional clips or ligation of the vessels more proximal, if adequate dissection of the hilar vessels has been carried out. Treatment of postoperative bleeding from the staple line is more challenging and may require a return to the operating room, though the use of postoperative splenic artery embolization has been described with success in one patient **(4).**

Pancreatic tail injury

Pancreatic tail injury is another feared complication of both open and laparoscopic splenectomy, which can cause pancreatic abscesses or fistulas. Careful dissection of the splenic hilum and adequate visualization of the pancreatic tails are mandatory before vessel ligation. It is generally believed that the lateral approach makes this dissection easier and the plane between the pancreatic tail and splenic hilum more visible than is the case with the anterior approach **(18).**

Drains are rarely necessary in laparoscopic splenectomy; however, if the surgeon is concerned about a possible pancreatic tail injury, a closed suction drain should be used **(18).**

Overwhelming postsplenectomy infection

OPSI is a well-known major long-term risk for splenectomy patients. Patients are at lifelong risk for the development of

OPSI; however, the highest risk is in the first 2 years after surgery. Although the reported risk of OPSI is relatively low (3.2%), associated mortalities as high as 40-50% have been described **(19).**

Therefore, in patients undergoing elective splenectomy, vaccination against meningococcal, pneumococcal, and Haemophilus influenzae type B infections at least 15 days before the procedure is recommended. In patients undergoing emergency splenectomy, vaccination is recommended within 30 days after the procedure. The pneumococcal vaccine should be repeated every 5 years, and patients should receive an influenza vaccine annually **(19).**

Missed accessory spleens

Accessory spleens are present in as many as 12-32% of patients, and a thorough evaluation for accessory spleens should be made after initial trocar placement. Accessory spleens are typically located in splenic hilum, along the splenic vessels, in the greater omentum, and along the splenorenal ligament and are usually accessible in both the lateral and anterior approach **(9).**

Although the risk of missing accessory spleens was once a proposed shortcoming of the laparoscopic approach, the detection rates for accessory spleens with laparoscopy appear to be similar to those with the open approach **(9).**

Portal vein thrombosis

Portal vein thrombosis is increasingly being recognized as a complication of splenectomy and should be considered in patients suffering from postoperative anorexia, abdominal pain, ileus, low-grade fevers, and elevated platelet and leukocyte counts. Portal vein thrombosis has been reported to occur in 0.7-14% of patients **(2).**

Risk factors associated with portal vein thrombosis include splenomegaly, myeloproliferative disorders, and hemolysis, with incidences reported to be as high as 80% in these high-risk patients. In one study, a platelet count increasing to more than eight times the baseline preoperative level after surgery was a risk factor for portal vein thrombosis after laparoscopic splenectomy. A preoperative splenic vein diameter of 8 mm or greater has also been suggested as a risk factor for portal or splenic vein thrombosis. A study by Swinson et al found specimen weight, myelofibrosis, and mean platelet count to be predictive of portal vein thrombosis after elective laparoscopic splenectomy **(2).**

Whether the technique of surgery (ie, open or laparoscopic) affects the rate of portal vein thrombosis remains unclear. Anticoagulation therapy is recommended for all symptomatic patients **(2).**

Bleeding Control In Laparoscopic Splenectomy

Severe intra-operative bleeding has limited the application of complex laparoscopic splenectomy (LS), including laparoscopic total splenectomy (LTS) and laparoscopic partial splenectomy (LPS). Therefore, reducing bleeding risk in complex LS has become a subject of major interest **(20).**

Through spleen computed tomography (CT), multi-slice spiral CT angiography of the splenic artery, magnetic resonance angiography, three-dimensional reconstruction of the spleen, splenic artery angiography, and visual artificial simulation splenectomy, the anatomy of the splenic artery can be defined. Gastroscopy, ultrasound, and CT can be used to evaluate spleen size and the conditions of esophageal and gastric varices **(20).**

In LTS for splenomegaly and hypersplenism secondary to portal hypertension, the splenic artery can be ligated with a titanium clip or a Hem-o-lock clip to render the spleen smaller, softer, and easier to operate on. However, in patients with severe local edema or unclear blood vessel exposure, the splenic artery should not be forcibly separated to prevent uncontrollable massive bleeding **(20).**

Regarding LTS for splenomegaly and hypersplenism secondary to portal hypertension, we used iodized oil and gelfoam particles to embolize the entire spleen parenchyma and the distal portion of the splenic artery and then used coils to embolize the main splenic artery. LTS was performed approximately 1 h after embolization. Regarding LPS for benign splenic tumors, we proposed a scheme including ultraselective intubation of the branch arteries of the partial spleen to be resected, embolization of the splenic parenchyma and the distal portion of the splenic artery with iodized oil and gelfoam particles, and embolization of the

branch arteries of the spleen with appropriate coils. LPS was performed approximately 1 h after embolization. The results showed that the above procedures are safe and effective **(21).**

The structure and function of the spleen will not be damaged by surgery if the duration of splenic pedicle occlusion is within 2 h. The anatomical space between the pancreatic tail and the retroperitoneum, which is called the retropancreatic tunnel, is loose. An occlusion belt can be inserted through this tunnel to bind the total splenic artery and vein and pancreatic tail, which blocks the splenic artery and vein at the same time **(21).**

Studies have shown that occlusion of the blood flow through the spleen is simple, safe, and feasible. For LPS, the occlusion belt can also be pre-introduced in the retropancreatic tunnel. The main splenic artery can be temporarily blocked to control intra-operative bleeding during LPS **(21).**

After the main splenic artery is blocked, the blood flow into the spleen at the resection site can be well controlled. After transection of the blood vessel branches at the target site, the warm ischemia time of the spleen can be controlled within 1 h, and the spleen parenchyma can be transected. After transection, the main splenic artery can be opened, and the blood supply of the remaining spleen parenchyma can be restored without irreversible ischemic injury **(22).**

Ligament transection should follow the principles of "simple ligament before complex ligament," "proximal ligament before distal ligament," and "easy operation before difficult operation." The order of separation and transection should be determined individually according to the patient's body position, spleen size, and surrounding adhesions to achieve in situ splenectomy to the greatest extent possible. An ultrasonic scalpel and LigaSure can be used to separate and transect the middle and lower parts of the gastrosplenic ligaments and then transect the splenocolic ligaments, the splenorenal ligaments, and the splenophrenic ligaments **(22).**

In LPS, when the spleen parenchyma is fully separated and compressed, it can be transected using a surgical stapler. After complete transection, bleeding at the spleen section can be stopped by applying pressure with hot saline gauze, electrocoagulation, and argon beam coagulation. After ensuring the absence of active bleeding, the spleen section can be covered with hemostats **(21).**

If bleeding that is difficult to treat with electrosurgery occurs, an appropriate vascular suture can be selected for hemostasis. The length of the suture should be appropriate, preferably approximately 12 cm. Non-invasive forceps can be used for knotting to reduce the degree of wear on the suture and ensure secure knotting. The surgeon should comprehensively consider the equipment, technical and specific disease conditions, and other factors while selecting the most suitable methods; master the anatomical basis of splenectomy; understand the surgical indications; and operate carefully **(21).**

Additionally, the application of new technology and equipment is the key to control bleeding during complex LS **(21).**

Conventional monopolar electrosurgery remains a popular laparoscopic modality because of its low cost, general availability, and diverse range of available tissue effects **(23).**

However, potential shortcomings of monopolar electrosurgery, including the need for a dispersive electrode, the relatively high power settings, the possibility of stray current injuries, and the inability to seal vessels larger than 1–2 mm diameter, led to the development of conventional bipolar electrosurgery to address these issues **(23).**

More recently, ultrasonic energy sources were developed to limit the risks associated with electrosurgery, at the same time providing more efficient vessel sealing and tissue transection. Advanced bipolar technologies were subsequently introduced with optimized vessel compression and the delivery of electrical energy to provide even better vessel sealing capabilities **(23).**

These new vessel sealing technologies are so successful that they have largely made the need for laparoscopic suturing of vascular pedicles redundant. All electrosurgical devices achieve their tissue effects via the passage of electrical current through the target tissue, with the sequential conversion of electrical energy to mechanical energy to thermal energy **(24).**

Ultrasonic devices also sequentially convert electrical energy to mechanical energy to thermal energy to facilitate vessel sealing but without the passage of electrical current through the tissue. The tissue effects

possible with monopolar electrosurgery include tissue vaporization and transection, fulguration, desiccation, and small vessel coaptation **(24).**

Monopolar electrosurgery tissue effects

Tissue effect	Current waveform	Mode
Vaporization (tissue destruction and/or transection)	Continuous	Noncontact
Fulguration (tissue destruction and small vessel hemostasis [≤ 1-mm diameter])	Interrupted	Noncontact
Desiccation (tissue dehydration)	Continuous or interrupted	Contact
Coagulation (protein denaturation and coagulum formation)	Continuous or interrupted	Contact
Coaptation (small vessel hemostasis [≤ 2-mm diameter])	Continuous or interrupted	Contact (vessel compression)

The tissue effects possible with advanced bipolar and ultrasonic technologies encompass a smaller subset of these tissue effects **(24).**

However, these new vessel sealing technologies have a significant advantage over monopolar electrosurgery in their ability to seal larger vessels (i.e, 5–7 mm diameter); with this, they have revolutionized modern laparoscopy **(24).**

A comparison of the tissue effects with monopolar electrosurgery, bipolar electrosurgery, and ultrasonic devices

Energy source	Tissue vaporization	Tissue transection	Fulguration	Desiccation	Coagulation and coaptation
Monopolar	Yes	Yes	Yes	Yes	Yes (≤2-mm diameter)
Bipolar	No	Yes*	No	Yes	Yes (≤7-mm diameter)
Ultrasonic	No	Yes	No	Yes	Yes (≤5-mm diameter)†

* With cutting mechanism incorporated into instrument tip.

† 7-mm diameter vessel sealing possible with advanced bipolar (less with conventional bipolar).

Furthermore, this vessel sealing capability is achieved without some of the risks inherent in monopolar electrosurgery. However, both advanced bipolar and ultrasonic technologies exert their surgical effects via the production of heat, and their use is not free of the risk of lateral thermal spread injury **(25).**

Advanced Bipolar Devices

In reality, all electrosurgery is ‘‘bipolar’’ inasmuch as there needs to be 1 electrode from which the electrical current enters tissues and another electrode through which the current leaves the patient and returns to the electrosurgical unit (ESU) **(25).**

By convention, monopolar electrosurgery refers to the arrangement of a single small electrode contained within the surgical instrument that delivers focused alternating electrical current to the target tissue to impart the desired surgical effect **(26).**

The second electrode is placed on the patient at a site remote from the surgical site to complete the electrical circuit; it is relatively large in size and is designed to disperse current (and prevent tissue heating) as it leaves the patient on its way back to the ESU **(26).**

The tissue effects available with monopolar electrosurgery are achieved using either contact (‘‘closed circuit’’) or noncontact (‘‘open circuit’’) modes, with either continuous (ESU ‘‘cut’’ setting) or interrupted (ESU ‘‘coag’’ setting) current waveforms **(27).**

In bipolar electrosurgery, both electrodes are contained within the surgical device, with current passing from 1 electrode to another. Current passes through tissue grasped between the electrodes to achieve the desired surgical effect **(28).**

There are significant advantages to this arrangement over monopolar electrosurgery, mostly relating to the fact that the electrical current in bipolar electrosurgery does not have to take pathways through the patient to complete the circuit with the ESU. For example, power settings are typically lower, there is no need for a remote return electrode attached to the patient (eliminating the risk of return electrode injury), and there is no generation of capacitance-coupling current (eliminating the risk of capacitive coupling injury) **(6).**

Bipolar electrosurgery uses alternating current so the orientation of the ‘‘active’’ and ‘‘return’’ electrodes also rapidly alternates, resulting in an even distribution of thermal effects on the tissue grasped between the electrodes. In addition, because a continuous current waveform is used, the voltage is less for a given power setting and the tissue temperature rise to achieve the desired surgical effect is less. With prolonged activation, an interrupted current waveform may result in tissue temperatures exceeding 200C with resultant carbon deposition and the adherence of tissue to the instrument jaws **(29).**

Bipolar electrosurgery is a modality in which there is minimal ability to vary the operational parameters; the electrical current is only delivered in a ‘‘closed circuit’’ (both electrodes are in contact with the target tissue), a continuous current waveform is standard, and both electrodes are the same size (for a given instrument) and have a relatively large surface area to maximize contact with the tissues **(28).**

In contrast, monopolar electrosurgery offers more flexibility in that many of the operational parameters can be varied, which accounts for the range of available tissue effects **(28).**

It should be noted that when a monopolar forceps is activated whilst grasping tissue between the jaws (or, analogously, if a nonactive forceps holding tissue is intentionally contacted by a monopolar electrosurgical instrument), the electrosurgical tissue effect is essentially the same as that obtained with bipolar forceps (desiccation, coagulation, and coaptation; **(29).**

However, in this case, the electrical current must still pass back through the patient to a remote return electrode. Both monopolar and bipolar electrosurgery achieve the respective range of tissue effects by the conversion of radiofrequency electrical energy into mechanical energy and thence into thermal energy **(30).**

With noncontact mode monopolar electrosurgery, tissue temperatures greater than 100C and 200C result from continuous and interrupted waveforms, respectively, yielding vaporization and fulguration tissue effects **(31).**

As mentioned previously, the tissue effects available with contact mode monopolar electrosurgery and bipolar electrosurgery are essentially the same, and the tissue temperatures are lower, typically in the range of 60 to 100C. At these temperatures, cell membrane integrity is lost, and the loss of cytoplasm results in desiccation of the tissues **(30).**

In addition, synchronous protein denaturation results as stabilizing hydrogen bonds are broken. As the tissue temperature subsequently decreases, hydrogen bonds reform but in a different configuration. This so-called ‘‘coagulum’’ is the ‘‘biological glue’’ that enables vessel walls to adhere to one another **(31).**

An essential requirement in achieving these tissue effects is the ability of the electrosurgical instrument to apply even contact to the tissue and with adequate compressive force. Compression of the vessel ensures that blood flow is interrupted and the potential heat sink effect of the moving liquid is removed **(30).**

Furthermore, compression of the vessel brings the coagulum of the opposing vessel walls into close proximity so that hydrogen bonds can reform with resultant vessel sealing **(32).**

An awareness of the risk of lateral spread is essential, irrespective of the energy source used during laparoscopy, with the amount of lateral thermal spread proportional to the duration of instrument activation. Hence, lateral thermal spread will be detected at increasing distances from the primary surgical site for as long as the energy source is activated **(32).**

Therefore, the specter of lateral thermal spread during conventional bipolar electrosurgery has been a quandary for the surgeon who must use personal experience and visual cues to estimate the time of device

activation necessary for vessel sealing whilst being mindful of the risk of collateral tissue damage. The delivery of electrical energy by advanced bipolar ESUs is highly pulsatile, allowing for tissue cooling during activation in an attempt to minimize lateral thermal spread **(33).**

These proprietary ESUs also use computer-controlled tissue feedback response systems that monitor tissue impedance and/or temperature in order to continuously adjust the current and voltage generated by the unit. Hence, with graspers designed to enhance mechanical pressure delivery and electrosurgical energy optimized to improve the tissue effects at the lowest possible power settings, advanced bipolar technology combines optimal thermal and mechanical properties to seal vessels **(33).**

The advanced bipolar ESUs also either automatically switch off or alert the surgeon via an audio signal when the desired tissue effect has been achieved, thereby avoiding prolonged activation, increased tissue temperatures, excessive charring, and adherence of tissue to the instrument jaws and minimizing lateral thermal spread **(34).**

However, despite promising laboratory and animal studies, it has yet to be shown in clinical trials that these safeguards actually result in a reduction in electrosurgical injury due to lateral thermal spread **(34).**

Nevertheless, the optimized mechanical force and electrical energy delivered to the tissues by advanced bipolar devices has been rewarded by the US Food and Drug Administration with approval to seal vessels up to 7 mm in diameter **(33).**

Currently available advanced bipolar technologies include LigaSure (Covidien, Mansfield, MD;), EnSeal (Ethicon Endo-Surgery, Cincinnati, OH;), and PlasmaKinetic System (PKS; Gyrus ACMI, Southborough, MA;). Each of these technologies is different although all are approved to seal vessels up to 7 mm in diameter. Each system also offers a range of devices that vary in aspects of their design **(33).**

LigaSure, the first commercially available vessel sealing system (1998), has recently been improved with the introduction of the ForceTriad generator, which performs 4000 measurements of tissue impedance per second compared with 200 measurements per second for the conventional LigaSure to provide real-time adjustment control of the energy output with significantly improved mean burst pressures and shorter sealing times **(35).**

The electrical output between the EnSeal instrument jaws is autoregulated using a proprietary electrode that contains millions of nanometer-sized conductive particles embedded in a temperature-sensitive material, which maintains the sealing temperature at around 100C **(35).**

PKS delivers a pulsed energy with continuous feedback control. In theory, the pulsatile delivery of energy allows tissues to cool between energy bursts, reducing tissue drying at the contact point and therefore resulting in less electrode sticking; the effectiveness of this strategy is yet to be proven in clinical trials **(36).**

Apart from rapid and efficient vessel sealing, most advanced bipolar devices are capable of tissue transection with an incorporated cutting mechanism. The cutting device is most commonly a retractable blade built into the jaws of the instrument. PKS Omni (Gyrus ACMI) has an accessory electrode incorporated into the instrument jaws to provide a specialized bipolar tissue-transection function **(36).**

The advantage of incorporating a cutting device into the vessel sealer is a reduction in ‘‘instrument traffic’’ during laparoscopy, which may translate to shorter operative times and a reduction in hospital costs **(37).**

However, a downside is that the instrument tips of these ‘‘hybrid devices’’ may be bulkier than conventional bipolar devices because of the additional cutting mechanism, potentially compromising their dissection capabilities. Modifications of these instruments have been produced with curved and/or pointed tips to assist with tissue dissection. Concerns that the smaller surface area of the electrodes could potentially affect the quality of vessel sealing are yet to be proven **(37).**

Despite attempts to improve the design of the instrument tips of advanced bipolar devices, many surgeons may also continue to use traditional curved monopolar scissors or conventional bipolar graspers for their superior dissecting capabilities. Ultrasonic Devices Not dissimilar in appearance to new-generation bipolar electrosurgical devices, ultrasonic laparoscopic energy sources are also able to seal vessels and transect tissues. Indeed, most of the tissue effects produced by ultrasonic devices are the same as those for bipolar devices **(38).**

However, these tissue effects are produced without the passage of electrical current through the patient or target tissue. Ultrasonic devices instead convert electrical energy to both mechanical and thermal energy via

ultrasonic vibrations to achieve tissue transection and vessel sealing. Combining these 2 modalities into a single device helps to decrease ‘‘instrument traffic’’ (as for advanced bipolar devices), with potential economic advantages **(38).**

Ultrasonic devices produce tissue effects by generating mechanical vibrations at over 20,000 cycles per second (i.e., above the audible range). The ultrasonic generator delivers alternating electrical current to the handpiece transducer where excitation in piezoelectrodes interspersed between metal cylinders converts electrical energy into mechanical energy by vibrating the cylinders at frequencies ranging from 23 to 55 kHz **(38).**

The shaft of the instrument, the active component of the device, is in contact with the cylinders and oscillates linearly at the same frequency. The tip of the shaft forms the nonarticulating jaw of the ultrasonic shears. The articulating jaw of the instrument provides a mechanism for grasping and holding tissue against the active non-articulating jaw so that the desired tissue effect can be achieved **(39).**

The ultrasonic generator varies the amount of mechanical energy applied to the tissue to achieve a particular effect. There are 2 generator settings available: ‘‘Max’’ and ‘‘Min.’’ The mechanical energy delivered to the tissue is greatest on the ‘‘Max’’ setting with larger oscillations of the shaft tip (fixed at 100 mm) and is suitable for rapid tissue transection; lateral thermal spread is less with this mode, but the hemostatic potential is poor. The oscillation distance of the ultrasonic shaft tip is smaller on the ‘‘Min’’ setting (adjustable down to 50 mm); the lower level of mechanical energy is ideal for vessel sealing, but there is an increased risk of lateral thermal spread with this mode **(39).**

Ultrasonic tissue transection occurs as a result of mechanical friction between the oscillating device shaft and the tissue. The surgeon has some control over this process, which is significantly shorter than for vessel sealing. For example, tissue transection will be more rapid (and less hemostatic) as the pressure applied by the articulating jaw is increased, due to greater resultant frictional and shearing forces **(40).**

The application of pressure perpendicular to the tissue plane with the oscillating tip (e.g., lifting the pedicle) will similarly facilitate tissue transection. In addition to mechanical friction, cavitation may also facilitate tissue transection **(40).**

Cavitation is a phenomenon that occurs during tissue vaporization, which is the same process that is observed in electrosurgery when cells explosively rupture as the cytoplasm boils. Cavitation occurs when steam released from vaporized cells expands preexisting tissue planes, thereby assisting dissection. Because of the local environment created by the oscillating tip, cavitation may occur at lower temperatures with ultrasonic devices than in electrosurgery **(40).**

As with advanced bipolar devices, ultrasonic vessel sealing results from desiccation, coagulation, and coaptation. However, the mechanism by which these effects are obtained is very different **(40).**

With electrosurgery, the alternating current oscillates intracellular molecules as the polarity of the cell changes. Consequently, electrical energy is sequentially converted to mechanical energy to thermal energy via intracellular frictional effects to yield the desired tissue effects. With ultrasonic energy, electrical energy is likewise converted to mechanical energy to thermal energy as the frictional force exerted on the tissues by the oscillating shaft tip results in sequential extracellular heating followed by intracellular heating **(41).**

So, for both bipolar and ultrasonic devices, thermal energy is responsible for the tissue desiccation, coagulation, and coaptation effects. The lateral thermal spread with ultrasonic devices is greatest during vessel sealing mode (i.e., desiccation and coagulation) and least with tissue transection mode (i.e., mechanical cutting and cavitation) **(41).**

The laparoscopic ‘‘ultrasonic scalpel’’ was first described in 1993 by Amaral with an ability to provide both vessel sealing and tissue transection. The Ultracision Harmonic Scalpel (Ethicon Endo-Surgery) was developed for commercial use and approved to seal vessels up to 3 mm in diameter **(41).**

The Harmonic ACE (Ethicon EndoSurgery;) was subsequently developed; its ‘‘active’’ jaw oscillates at a frequency of 55,000 cycles per second, and it gained Food and Drug Administration approval to seal vessels up to 5 mm in diameter **(41).**

Other examples of currently available laparoscopic ultrasonic devices include the AutoSonix (Covidien), Sonocision (Covidien;), and SonoSurg (Olympus America, Center Valley, PA). These devices operate at similar frequencies to the Harmonic ACE and seal vessels up to 5 mm in diameter with similar mean burst pressures **(42).**

The AutoSonix, Harmonic ACE, and Sonocision are single-use disposable instruments, whereas SonoSurg is reusable and autoclavable. Sonocision is a newly released cordless ultrasonic device. Purported advantages of ultrasonic vessel sealers included less tissue necrosis and charring, reduced lateral thermal spread, and less smoke generation compared with electrosurgery **(42).**

Because the tissue temperature resulting from ultrasonic vessel sealing (desiccation, coagulation, and coaptation) is less than 100C, tissue charring will be much less than with the higher temperatures generated by noncontact continuous waveform (vaporization) or noncontact interrupted waveform (fulguration) monopolar electrosurgery **(42).**

However, the tissue charring resulting from contact monopolar electrosurgery, conventional bipolar electrosurgery, and advanced bipolar electrosurgery (all producing desiccation, coagulation, and coaptation) is much less; the resultant tissue temperatures are similar to those for ultrasonic technologies **(25).**

In addition, the activation time for vessel sealing with ultrasonic devices is subjective (as for monopolar and conventional bipolar electrosurgery) because there is no tissue impedance/temperature cutoff or audio signal (available with advanced bipolar devices) to inform the surgeon when vessel sealing is complete **(25).**

Hence, although the risk of lateral thermal spread may be low with ultrasonic devices, higher tissue temperatures (proportional to the increased time of activation) mean that lateral thermal spread injury remains a risk. Interestingly, the Harmonic ACE is associated with greater increases in tissue temperature compared with the Ultracision Harmonic Scalpel **(25).**

The newly available Harmonic ACE1 (Ethicon Endo-Surgery;) uses ‘‘adaptive tissue technology’’ to regulate energy delivery according to tissue conditions and provides the surgeon with an audio signal of energy output; it is yet to be proven that lateral thermal spread is decreased with this device compared to the Harmonic ACE **(25).**

The smoke plume generated by ultrasonic vessel sealers is less than with other laparoscopic energy sources although the smoke plume from these devices may still significantly obscure the surgeon’s view. The tips of the Harmonic ACE are more effective for dissection than the Harmonic Scalpel but overall may have more limited dissection capability when compared with monopolar scissors and conventional bipolar forceps **(25).**

Comparison of Advanced Bipolar and Ultrasonic Vessel Sealing Technologies

The reasons for a surgeon’s preference for a particular laparoscopic energy source may be many and varied. A common reason for choosing a particular instrument is the surgeon’s own experience with that instrument that may have been preordained by a mentor during surgical training. Unfamiliar technologies often are not trialed **(26).**

Surgeons are also subjected to marketing strategies and even inducements. Indeed, device manufacturers sponsor many of the studies on energy sources published in the medical literature. To complicate matters further, it is generally not possible to compare vessel sealing data from different studies because study conditions may vary widely **(26).**

Hence, it is difficult for surgeons to make an objective, informed decision about the relative merits of different laparoscopic energy sources. The relative merits of advanced bipolar and ultrasonic devices **(27).**

These data are from recent studies that compared at least 1 of the advanced bipolar devices with an ultrasonic vessel sealer. Both bipolar and ultrasonic devices are effective at sealing vessels up to 5 mm in diameter, but only bipolar devices are approved to seal vessels 6–7 mm in diameter **(34).**

There are conflicting data on the ‘‘time to seal.’’ No firm conclusion can be drawn as to which class of device is the faster vessel sealer. For all laparoscopic energy sources (monopolar [contact mode], bipolar [conventional and advanced], and ultrasonic [vessel sealing mode]), the amount of lateral thermal spread and the risk of collateral tissue damage are proportional to the length of time of activation of the instrument **(34).**

In general, lateral thermal spread generally seems to be less with ultrasonic devices although the time of activation with this technology, and the resultant amount of lateral spread, are operator dependent. Interestingly, the residual temperature of the instrument tip after activation is less with bipolar devices **(35).**
As a general principle, tissue should not be grasped with any energy source immediately after activation. Particulate formation is less with ultrasonic devices although all laparoscopic energy sources produce a plume of smoke or steam **(35).**
In summary, there is insufficient evidence for one vessel sealing technology to be considered superior to the other. A detailed critical evaluation of comparative clinical, laboratory, and animal studies of all classes of laparoscopic energy sources is available elsewhere **(35).**
Devices have recently been developed that combine bipolar vessel sealing and bipolar tissue transection (PKS Omni, Gyrus ACMI), monopolar and bipolar electrosurgery (LigaSure Advance, Covidien;), and ultrasonic and bipolar technologies (Thunderbeat, Olympus America;) into a single instrument **(29).**

Although it is desirable to incorporate multiple functionalities into 1 handpiece so that ‘‘instrument traffic’’ can be minimized, it is important not to compromise the functionality of individual technologies for the sake of efficiency. A single laparoscopic energy source that can produce all the tissue effects available with individual energy sources may become a reality for the future laparoscopic surgeon **(29).**
Along with ultrasonic and electrosurgical modalities, the ‘‘ideal laparoscopic energy source’’ would also possess the capabilities of fine tissue grasping and sharp tissue dissection. The dissecting abilities of various laparoscopic forceps have been reported previously, but the dissecting abilities of the newer-generation bipolar forceps and the ultrasonic shears have yet to be evaluated **(29).**

References

1. Uranues S &Alimoglu O. (2005): Laparoscopic surgery of the spleen. Surg Clin North Am. 85 (1):75-90.
2. Misiakos EP, Bagias G, Liakakos T & Machairas A. (2017): Laparoscopic splenectomy: Current concepts. World J Gastrointest Endosc. 9 (9):428-37.
3. Habermalz B, Sauerland S, Decker G, Delaitre B, Gigot JF, Leandros E, et al. (2008): Laparoscopic splenectomy: the clinical practice guidelines of the European Association for Endoscopic Surgery (EAES). Surg Endosc. 22 (4):821-48.
4. Hao X, Dai K, He Y, Tao L & Yu H. (2020): Laparoscopic splenectomy via the spleen bed in combination with selective esophagogastric devascularization for patients with cirrhotic portal hypertension: a single-institution experience. Wideochir Inne Tech Maloinwazyjne. 15 (3):462-8.
5. Zhu JH, Wang YD, Ye ZY, Zhao T, Zhu YW, Xie ZJ, et al. (2009): Laparoscopic versus open splenectomy for hypersplenism secondary to liver cirrhosis. Surg Laparosc Endosc Percutan Tech. 19 (3):258-62.
6. Wang Y, Zhan X, Zhu Y, Xie Z, Zhu J, Ye Z. (2010): Laparoscopic splenectomy in portal hypertension: a single-surgeon 13-year experience. Surg Endosc. 24 (5):1164-9.
7. Cobb WS, Heniford BT, Burns JM, Carbonell AM, Matthews BD & Kercher KW (2005): Cirrhosis is not a contraindication to laparoscopic surgery. Surg Endosc. 19 (3):418-23.
8. Kawanaka H, Akahos3hi T, Kinjo N, Harimoto N, Itoh S, Tsutsumi N, et al. (2015): Laparoscopic Splenectomy with Technical Standardization and Selection Criteria for Standard or Hand-Assisted Approach in 390 Patients with Liver Cirrhosis and Portal Hypertension. J Am Coll Surg. 221 (2):354-66.
9. Somasundaram SK, Massey L, Gooch D, Reed J & Menzies D. (2015): Laparoscopic splenectomy is emerging 'gold standard' treatment even for massive spleens. Ann R Coll Surg Engl. 97 (5):345-8.
10. Tsamalaidze L, Stauffer JA, Permenter SL & Asbun HJ. (2017): Laparoscopic Splenectomy for Massive Splenomegaly: Does Size Matter?. J Laparoendosc Adv Surg Tech A. 27 (10):1009-14.
11. Casaccia M, Sormani MP, Palombo D, Dellepiane C & Ibatici A. (2019): Laparoscopic Splenectomy Versus Open Splenectomy In Massive and Giant Spleens: Should we Update the 2008 EAES Guidelines?. Surg Laparosc Endosc Percutan Tech. 29 (3):178-81.
12. Canda AE, Ozsoy Y & Yuksel S. (2009): Laparoscopic splenectomy using LigaSure in benign hematologic

diseases. Surg Laparosc Endosc Percutan Tech. 19 (1):69-71.

13. Romano F, Caprotti R, Conti M, Piacentini MG, Uggeri F, Motta V, et al. (2006): Thrombosis of the splenoportal axis after splenectomy. Langenbecks Arch Surg. 391 (5):483-8.

14. Andolfi C and Matthews JB (2019): Minimally Invasive Surgical and Image-Guided Interventional Approaches to the Spleen. In Shackelford's Surgery of the Alimentary Tract, 2 Volume Set (pp. 1603-1621). Elsevier.

15. Huang D, Tao M, Cao L, Wang X, Zheng S & Cao Y. (2019): Risk Factors and Anticoagulation Effects of Portal Vein System Thrombosis After Laparoscopic Splenectomy in Patients With or Without Cirrhosis. Surg Laparosc Endosc Percutan Tech. 29 (6):498-502.

16. Bai DS, Jin SJ, Xiang XX, Qian JJ, Zhang C, Zhou BH, et al., (2022): Robotic-assisted versus laparoscopic approach of Bai-Jiang-style vagus nerve-preserving splenectomy and azygoportal disconnection.

17. Makansi M, Hutter M, Theilen TM, Fiegel HC, Rolle U & Gfroerer S. (2021): Comparison of perioperative outcomes between laparoscopic and open partial splenectomy in children and adolescents. World J Gastrointest Surg. 13 (9):979-87.

18. Shamim AA, Zafar SN, Nizam W, Zeineddin A, Ortega G, Fullum TM, et al. (2018): Laparoscopic Splenectomy for Trauma. JSLS. 22 (4).

19. Lewis SM, Williams A. & Eisenbarth SC. (2019): Structure and function of the immune system in the spleen. Science immunology, 4(33), eaau6085.

20. You N, Li J and Zheng L. (2022): Bleeding control during complex laparoscopic surgeries of the spleen: current status and challenges. Chin Med J; 135: 2938–40.

21. Li J, You N, Deng C, Wu K, Wang L, Huang X, et al., (2018): Use of iodized oil and gelatin sponge embolization in splenic artery coiling reduces bleeding from laparoscopic splenectomy for cirrhotic portal hypertension patients with complicating hypersplenic splenomegaly: a comparative study. J Laparoendosc Adv Surg Tech A; 28: 713–20.

22. Zheng L, Deng C, Li J, Wang L, You N, Wu K, et al., (2018): Treatment of hemangioma of the spleen by preoperative partial splenic embolization plus laparoscopic partial splenectomy: a case report. Medicine;97:e0498.

23. Vilos GA and Rajakumar C. (2013): Electrosurgical generators and monopolar and bipolar electrosurgery. J Minim Invasive Gynecol; 20: 279–87.

24. Kingston AJ, Lyons SD, Abbott JA and Vancaillie TG. (2008): Principles and practical applications of electrosurgery in laparoscopy. J Minim Invasive Gynecol; 15: S6

25. Park CW and Portenier DD. (2012): Bipolar electrosurgical devices. In: Feldman LS, editor. The SAGES Manual on the Fundamental Use of Surgical Energy (FUSE). New York: Springer; 93–106.

26. Brill AI. (2008): Bipolar electrosurgery: convention and innovation. Clin Obstet Gynecol; 51: 153–8.

27. Advincula AP and Wang K. (2008): The evolutionary state of electrosurgery: where are we now? Curr Opin Obstet Gynecol; 20: 353–8.

28. Newcomb WL, Hope WW, Schmelzer TM, et al., (2009): Comparison of blood vessel sealing among new electrosurgical and ultrasonic devices. Surg Endosc; 23: 90–6.

29. Law KSK and Lyons SD. (2013): Comparative studies of energy sources in gynaecologic laparoscopy. J Minim Invasive Gynecol; 20: 308–18.

30. Katsuno G, Nagakari K and Fukunaga M. (2010): Comparison of two different energy-based vascular sealing systems for the hemostasis of various types of arteries: a porcine model-evaluation of LigaSure ForceTriadTM. J Laparoendosc Adv Surg Tech Part A; 20: 747–51.

31. Munro MG. (2013): Economics and energy sources. J Minim Invasive Gynecol; 319–27.

32. Bittner JG, Verela JE and Herron D. (2012): Ultrasonic energy systems. In: Feldman LS, editor. The SAGES Manual on the Fundamental Use of Surgical Energy (FUSE). New York: Springer; 123–32.

33. Bandi G, Wen CC, Wilkinson EA, et al., (2008): Comparison of blade temperature dynamics after

activation of Harmonic Ace scalpel and the Ultracision Harmonic Scalpel LCS-K5. J Endourol; 22: 333–6.

34. Clements RH and Palepu R. (2007): In vivo comparison of the coagulation capability of SonoSurg and Harmonic Ace on 4 mm and 5 mm arteries. Surg Endosc; 21: 2203–6.

35. Entezari K, Hoffmann P, Goris M, Peltier A and Van Velthoven R. (2007): A review of currently available vessel sealing systems. Minim Invasive Ther Allied Technol; 16: 52–57.

36. Lamberton GR, Hsi RS, Jin DH, Lindler TU, Jellison FC and Baldwin DD. (2008): Prospective comparison of four laparoscopic vessel ligation devices. J Endourol; 22: 2307–12.

37. Sutton PA, Awad S, Perkins AC and Lobo DN. (2010): Comparison of lateral thermal spread using monopolar and bipolar diathermy, the Harmonic Scalpel and the Ligasure. Br J Surg; 97: 428–33.

38. Kim FJ, Sehrt D, Pompeo A and Molina WR. (2012): Comparison of surgical plume among laparoscopic ultrasonic dissectors using a real-time digital quantitative technology. Surg Endosc; 26: 3408–12.

39. Person B, Vivas DA, Ruiz D, Talcott M, Coad JE and Wexner SD. (2008): Comparison of four energy-based vascular sealing and cutting instruments: a porcine model. Surg Endosc; 22: 534–8.

40. Hruby GW, Marruffo FC, Durak E, et al., (2007): Evaluation of surgical energy devices for vessel sealing and peripheral energy spread in a porcine model. J Urol; 178: 2689–2693.

41. Noble EJ, Smart NJ, Challand C, Sleigh K, Oriolowo A and Hosie KB. (2011): Experimental comparison of mesenteric vessel sealing and thermal damage between one bipolar and two ultrasonic shears devices. Br J Surg; 98: 797–800.

42. Govekar HR, Robinson TN, Stiegmann GV and McGreevy FT (2011): Residual heat of laparoscopic energy devices: how long must the surgeon wait to touch additional tissue? Surg Endosc; 25: 3499–3502.