10 Fundamentals of Stapling Devices

Christina Souther and Kenric Murayama

10.1 History of Stapling

The design of the first surgical stapler with resemblance to our current devices is credited to Humer Hultl in 1908 [1–4]. Prior to Hultl's stapler, which applied four parallel lines of wire hooks [3, 4], Henroz had anastomosed dog bowel with metal rings in 1826, and John Murphy created the Murphy button in 1892 which again used rings to join structures [2]. Hultl's device, however, was similar to the staplers we use today. Hultl's reason for pursuing the development of a mechanical device for anastomosis was to control spillage of bowel contents in an effort to decrease infection; he intended to create a device that would make operations cleaner, faster, and easier to perform [2]. To produce the first surgical stapler, Hultl enlisted the assistance of Peter Fischer who created the product which Hultl had envisioned. His first device, although innovative, was noted to be heavy and difficult to use by its operators [2]. The stapler was also difficult to clean between uses. Major improvements were made in the 1920s by Aladar Petz, who used silver clips rather than thin steel wires [3, 4]. His "Petz clamp" was notably easier to maneuver especially during the application and removal of the device and was lighter than Hultl's version [2–4]. This stapler also fired parallel staple lines similar to Hultl's product.

In the 1930s, replaceable cartridges were developed by H. Friedrich so that multiple loads of staples could be fired in succession without preparing an entirely separate device [1]. The simultaneous application of staples and division of the stapled viscera was pioneered in the Soviet Union during the 1950s through the 1970s [2]. The Russian staplers also featured a staggered rather than a parallel staple line configuration which was found to increase hemostasis. Mark Ravitch is credited with bringing staplers to widespread use in the United States and also optimizing the devices by allowing customization based on tissue type and size [2]. He created multiple different cartridges which could be loaded onto the same stapler base allowing for immediate customization for variable tissues during a surgery. These cartridges differed both in staple size and length of staple line creating the ability to tailor the stapler to each specific tissue type and length of tissue involved. He also developed the circular stapler allowing for end-to-end stapled anastomosis creation [1, 5]. Leon Hirsch, who formed the United States Surgical Corporation in the 1960s, contributed to the streamlining of surgical stapler function by optimizing the structure of the stapler and creating disposable cartridges for easy and efficient loading of the staples [6].

C. Souther · K. Murayama (✉)
Department of Surgery, John A Burns School of Medicine, University of Hawaii at Manoa, Honolulu, HI, USA
e-mail: kenricm@hawaii.edu

F. Palazzo (ed.), *Fundamentals of General Surgery*, https://doi.org/10.1007/978-3-319-75656-1_10

10.2 Mechanics of Stapling

The majority of surgical staplers in use today form staples in a "B" shape when fired against the anvil [7]. The "B" shape of the staple was designed to hold tissue securely but to allow small vessels to pass through the staples allowing for adequate perfusion [8]. The stapling device first compresses the tissue to be stapled causing elongation of the tissue. Allowing time for full compression and elongation of the tissue is important for adequate staple line formation but compression for an extended period of time can lead to tissue damage [1, 7, 9]. These considerations are important especially when using the staplers that complete their compression when they are first closed. Other models do not fully compress the tissue until they are fired so the compression time cannot be altered as easily. Longer duration of compression prior to firing the stapler has been associated with fewer anastomotic leaks and more adequate hemostasis of the staple line [7]. However, adequate compression does not only depend on duration; it is also affected by patient characteristics such as overall systemic health, including nutritional status and vascular supply. The tissue makeup is also important for adequate stapling. The ratio of liquid to solid components of the tissue and the elasticity of the tissue play important roles as well [7]. Tissue with higher liquid content requires longer compression time to reduce the fluid at the site of stapling and allow the tissue to elongate evenly. The longer compression time also allows the staple to form a tighter "B" shape which has been associated with decreased bleeding at the staple line [10, 11]. Short tight staples are also thought to decrease the chance of forming a stricture at the site [7]; however prolonged compression may increase the risk of local ischemia. *In choosing a staple cartridge for a particular operation, the thickness of the tissue must be considered* (Table 10.1). Creating a staple that is too tall can lead to gaps between the staple and tissue ultimately resulting in anastomotic leaks or bleeding at the staple line [7, 10, 11]. However, a staple which is too short can lead to anastomotic leaks as well, due to excessive compression of the tissue leading to ischemia and subsequent breakdown of the anastomosis [7]. Another key feature of creating a robust stapled anastomosis is the lack of force placed on the staple line during creation [7, 8]. Sheer forces and torque can lead to tearing of tissue or misalignment of the staples leading to both immediate injury requiring immediate revision and also subtle damage that is not recognized until the postoperative period during which complications arise. Easy firing of the stapler is important to avoid placing additional force or tension on the staple line during its creation.

In open cases, to avoid applying additional force to the tissues, the anvil can be inserted first followed by the cartridge instead of attempting to align both ends simultaneously. Holding the stapler steady with one hand or having an assistant stabilize the tissues that will be approximated can help to avoid tearing. The other hand should be used to fire the stapler slowly and smoothly, avoiding jarring movements especially when reaching the end of the staple line. To open the stapler, the trigger must be pulled back, and the tissue must remain stabilized during this step so

Table 10.1 Staple height and tissue applications for common laparoscopic staplers

Tissue	Covidien		Covidien tri-staple	Ethicon		Stomach	Small bowel	Large bowel	Rectum
Thin-mesentery	Gray	2 mm	Gray	White	2.6 mm				
Thin-vascular	White	2.6 mm	Gold				X		
Medium	Blue	3.5 mm	Gold/Purple	Blue	3.6 mm	X	X	X	X
Medium-thick	Gold	3.8 mm	Purple	Gold	3.8 mm	X		X	X
Thick	Green	4.8 mm		Green	4.1 mm	X			X
Extra-thick			Black	Black	4.2 mm	X			

that inordinate force is not placed on the newly created staple line.

In laparoscopic cases, the staplers can be manipulated in multiple directions by articulation. Articulating the stapler prior to placing it in contact with tissues is ideal to avoid grasping the tissue with the stapler as it is adjusted. The laparoscopic staplers have a narrow end which acts as the anvil; this narrow end should be inserted through any window in the tissue (e.g., between an appendix and mesoappendix), and the larger side should be applied externally to avoid forcing the larger side of the stapler through a small opening.

10.3 Current Devices

Surgical staplers used today are largely disposable and have become much easier to operate. Most of the devices have both an open and a laparoscopic counterpart. Linear staplers are available with multiple types of handles and cartridge configurations, allowing for tension-free application in various settings. The linear staplers include both models which apply staple lines and divide the tissue between the staple lines during the firing (GIA staplers) and also models which apply a staple line without any severing of tissue (TA staplers) [8]. These staplers require the operator to divide the tissue sharply after firing the stapler. Both of these linear staplers are available in endomechanical versions as well for use in laparoscopy and thoracoscopy. A modification of the linear stapler is a curved staple load fired in the same way with a blade between the staple lines, allowing for control and division of tissues in difficult to reach areas, such as the rectum. The curve allows the stapler to be applied to a structure deep in the pelvis or in another narrow area without placing torque on the stapler and thus decreasing the risk for shear of the tissues [7].

Circular staplers have been developed mainly for the creation of end-to-end anastomoses. The circular staplers allow firing of staple lines circumferentially and also excise a ring of tissue allowing connection of the two lumens. Circular staplers are generally used near an end of the GI tract as the stapler itself must be inserted through the tubular viscera and aligned with a prepositioned anvil in the other end of the planned anastomosis but can also be inserted via an enterotomy. The introduction of circular staplers allowed for stapled anastomoses in areas where tissues are difficult to mobilize, making distal rectal stapled anastomoses possible and much more facile [7].

10.4 Applications of Surgical Staplers

The widespread use of surgical staplers over the last half century has led to adaptation of the technology for use in multiple organ systems and various modes of operation. The original staplers were created for use in gastrointestinal surgery, and much of the data regarding technical aspects of staple size choice and outcomes have been derived from the field of bariatric surgery [7, 10, 11]. Staplers are used frequently in bariatric surgery: linear staplers for division of the stomach in sleeve gastrectomy and jejunojejunal anastomoses in gastric bypass and circular staplers for gastrojejunal anastomoses in gastric bypass. Shorter staple heights are associated with lower postoperative bleeding rates when circular staplers are used for the gastrojejunal anastomosis [10, 11]. Special attention must be paid to the size of the staples used on the stomach due to the varying thickness of the stomach in different anatomic regions in contrast to the colon which tends to be more uniform in thickness. Longer staples are generally used in the distal stomach as the distal stomach tends to be thicker [7]. Long staple lines, although sometimes necessary, can cause additional complications, especially leaks [12, 13]. In addition, a higher number of intersections of staple lines are associated with a higher risk of leak [13]. This situation typically occurs when creating a stapled anastomosis between two segments of bowel which already have stapled ends. This increased risk can be mitigated by inverting one staple line into another [13].

Throughout the gastrointestinal tract, linear staplers can be used to divide the small bowel or colon without spillage of contents, and curved staplers with long handles can be used to reach deep into the pelvis to divide the distal sigmoid colon or rectum without placing tension on the colon or torque on the device. Circular staplers are used frequently for distal sigmoid or rectal anastomoses. Ideally a single staple load is used to divide bowel as the use of multiple linear staplers for the same anastomosis can result in higher rate of anastomotic leak [7], making the curved stapler that can traverse the rectum in one application safer.

Esophagectomies and the subsequent anastomoses can be performed using both linear and circular staplers. Emergent situations such as bleeding esophageal varices can be managed with stapling devices as well by obtaining hemostasis using staplers to divide the esophagus and control the bleeding, followed by reanastomosis using additional staplers after the enlarged veins have been controlled [14].

Division of the pancreas can be simplified with the use of a stapler, and this method is commonly used for sealing the remaining portion of the pancreas after distal pancreatectomy [15]. Appropriate choice of staple height [15] and adequate compression duration [7, 16] are important for the prevention of pancreatic fistula in these cases. The thickness of the pancreas has been found to independently predict formation of a pancreatic fistula after stapled distal pancreatectomy making the decision to use the stapler and the choice of cartridge significant [17].

Linear staplers can be used in open and laparoscopic hepatic resections both for the division of the liver parenchyma itself and also for vascular control for the segment undergoing removal [18, 19]. As in other organ systems, the thickness of the liver can affect the success of staple line. In vitro studies have suggested that the liver measuring more than 10 mm in thickness can have other important factors influencing risk of staple line failure including stiffness which does not seem to play a role in the liver which is not as thick [18]. Staplers have also been used to divide enlarged cystic ducts in biliary operations during which a clip cannot fit entirely across the duct [20].

Pulmonary surgery has benefited from the use of staplers in lung resections [5, 7]. However, the air distribution in the lungs can make the thickness of the tissue more variable than in other organs. Since additional air is located in the periphery of the lung, the compression time and pressure required during application of the stapler are lower than those required in more central portions of the lung which contain bronchial tissue and more blood to displace prior to firing the stapler [7]. Baseline pulmonary health must be considered when stapling lung parenchyma as the thickness can be affected by malignancies, fibrosis, and chemical damage, while bronchopleural fistulae are more likely in emphysematous lung parenchyma [7]. Overall, the stapling of lungs leads to better aerostasis than hand-sewn pulmonary resections [7]. Methods including folding over the edges of bronchi prior to anastomosis to decrease tension placed at the center of the staple line have been employed to improve the success rate of pulmonary stapling [21].

10.5 Current Controversies

Given that leaks or bleeding are dreaded complications of endomechanical devices, the staple lines can be reinforced by the use of several “buttressing” materials which can be absorbable or permanent. Many surgeons advocate for their use, but the need for reinforcement, as well as the method providing the most benefit, is widely debated. Some authors report no benefit in reinforcing staple lines [22]. In several studies, decreased leak rates and lower rates of bleeding have been seen after oversewing the staple line [23–26]. Some advocate using bovine tissue buttresses rather than simply suture reinforcements to the staple line [23–25]. There is some concern for stenosis which can occur when additional sutures are placed, so care should be taken when reinforcing staple lines to avoid decreasing the patency of the anastomosis [26].

10.6 Summary

The first surgical stapler designed by Hultl initially designed to control spillage of bowel contents and improve asepsis paved the way for the modern devices which make many operations easier to accomplish and increase their efficiency. Many organs can be divided and anastomosed using stapling devices, and a variety of modifications have been made to suit tissues of different character and size. Surgeons must pay close attention to mechanical aspects of staple application, including each patient's baseline health, comorbidities, and tissue composition, to fully obtain the benefits of these devices and avoid complications by using the tailored stapling products available for each clinical situation.

Take-Home Messages

- Tissue depth and composition must be taken into consideration when choosing staple size.
- It is important to avoid torque on the tissues when firing staplers.
- Surgeons should become familiar with stapling devices and their possible complications despite the relative ease of operating they provide.

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