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Review

Mechanical Stapling Devices for Soft Tissue Repair: A Review of Commercially Available Linear, Linear Cutting, and Circular Staplers

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Abstract: Stapling devices have emerged as a widespread and effective option for soft tissue surgery, offering promising outcomes for patients by reducing complication rates and surgery time. This review aims to provide an exhaustive analysis of commercially available alternatives in the market, incorporating insights from market analysis, patent landscape, and the existing literature. The main focus lies in identifying and evaluating the most widely adopted and innovative stapling devices, including linear, linear cutting, circular, and powered staplers. In addition, this review delves into the realm of bioabsorbable staples, exploring the materials utilized and the surgical fields where these advanced staples find applications. To facilitate easy comprehension, the gathered information is presented in tables, highlighting the essential parameters for each stapling device. This comprehensive research about stapling devices is intended to aid healthcare practitioners and researchers in making informed decisions when choosing the most appropriate instrument for specific surgical procedures.

Keywords: staplers; surgical stapler; linear; circular; anastomosis; surgical instruments



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1. Introduction

In this work, surgical staplers, which are internal use devices employed to deliver staplers to tissues inside the body during surgery for removing part of an organ, cutting through and sealing organs, and creating connections between structures, are covered.

Modern surgical staplers are designed to be disposable, with a maximum number of firing actions, as well as cartridges and other products used for surgical stapling. Today's staples have a rectangular cross-section and become "B" shaped when compressed against the anvil of the stapler to reduce the risk of ischemia, allowing blood to flow through them to the tissue edges. The specific geometry has been developed to ensure hemostasis and to allow sufficient vascularization of the tissue, supporting wound healing [1].

Three major types of stapling devices used both in open and laparoscopic surgery can be identified: linear, linear cutting, and circular. Linear instruments form a straight staple line and may or may not include a blade, while circular instruments have staples set in a crown shape and always include a blade. The ever-increasing diffusion of laparoscopy and robotic surgery led to the diffusion of stapling devices dedicated to endoscopic techniques; linear and circular stapling devices are employed mostly in gastrointestinal procedures such as complex gastrectomies, bariatric treatments, and colorectal oncological resections.

Devices have been compared in terms of procedure duration, hospital stay, wound infection, anastomotic leakage, and anastomotic structures.

The outcome of the repair made by staples or suture techniques has attracted much interest in the scientific community. Recently, the mechanical behavior of repairs made with staples, sutures, and hybrid methods (staple and suture together) was evaluated carefully, showing that staples can resist high loads but are less deformable and rigid than handsewn sutures. This suggests safer employment in the case of small defects or diastasis, where the presumed tissue displacement is minimal. A hybrid repair improves its efficiency, becoming crucial in case of larger defects where the expected tissue displacement is maximal [2].

Although being more complex to operate and resulting in longer procedure times, in several studies covering gastric, bariatric, and colorectal surgery, linear staplers appeared to be preferred in clinical use due to their lower rate of anastomosis leakage and anastomosis strictures, with a sensible reduction in patients' postoperative morbidity [3–6].

Regardless of its specific configuration, a surgical stapler is always characterized by an actuation handle: the surgeon can operate the device manually through a sequence of squeezing a handle or sliding a knob. The effective function of stapling, cutting, and ejecting the staples is performed by the loading unit: two jaws are coupled in different ways to act, one as a cartridge loader for the staples and the other as an anvil to allow the closing of the staples. In the case of circular staplers, the anvil jaw is detachable, granting its insertion into the anastomosis site. The actuation handle and the loading unit are usually connected to each other: the input from the surgeon is translated into the mechanical or electro-mechanical firing system through the use of various keyed shafts [7]. Additional pins can be inserted into the jaws or be comprised into the loading unit to serve as alignment or safety devices, ensuring the correct compression of the tissue before firing or avoiding retention after staple delivery.

Each device is completely in accordance with the aims of surgical stapling, which consist, from a medical point of view, of creating an adequate lumen, preserving adequate vascularization, preventing tension in tissues, avoiding leakage, providing hemostasis, and ensuring mechanical reliability [8].

Non-absorbable staples are the ones most widely used in clinics thanks to their low artifact production in CT and their non-magnetic behavior, which causes minimal distortions in MRI. Titanium is the leading material, both pure or in alloys, thanks to its high resistance and lighter weight compared to stainless steel. Furthermore, titanium is corrosion-resistant but, most importantly, anti-allergic, and it can also be employed in patients suffering from chromate-nickel allergies [1,9].

The general design of stapling devices includes an anvil, a cartridge assembly to support an array of staples, a mechanism to push the cartridge close to the anvil, an alignment pin for capturing tissue between the cartridge and the anvil, and a firing mechanism for ejecting the surgical staples. The firing process is guided by a sequence of pressing the handle: the first press grants tissue compression and allows the surgeon to verify the correct alignment of the jaws, while the second press releases the staples. A button placed on the stapler permits the opening of the jaws at the end of the operation, setting the tissue free and allowing the reloading process.

The main particularity of cutting staplers is the addition of a blading element that allows for making a resection in the middle of the rows of staples. Instead, for endo cutting staplers, the instrument is composed of a disposable articulating end effector comprising the cartridge, the anvil, and a disposable handling unit containing the firing mechanism and the safety control system. The circular staplers have the same components with the particularity of a circular anvil and arrangement of the staples with a blading element. The powered stapling devices have the distinction of a powered actuation, meaning that the firing mechanism is controlled by an electro-mechanical system that gains energy from a battery. Figure 1 shows a description and representation of each type of device.

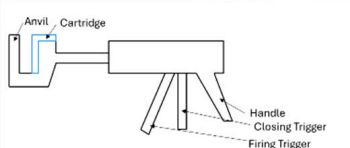
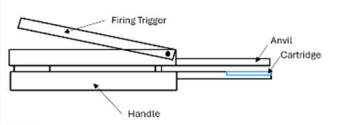
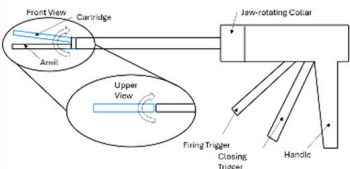
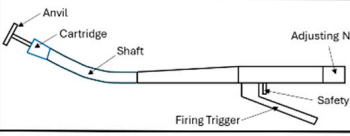
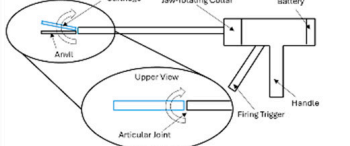
	General description	Schematic representation
Linear Stapler	This device is a surgical device with control buttons on the handle to prevent accidental firing. It typically features a retention pin or lever for manual or automatic actuation. The device includes buttons for aligning the cartridge, positioning tissue, and opening jaws for tissue release and reloading after the operation.	
Linear Cutting Stapler	This device features a sliding knob for activation, aligning and firing the blade simultaneously with stapling. The cutting line is intentionally shorter for safety. A release button disengages the cartridge after firing, and a safety tag covers the blade to prevent accidental firing during reloading.	
Linear Endo Stapler	This device has an articulating end effector attached through a rotating locking system. After correct alignment, the handle is pushed to close jaws over tissue. A side button unlocks the firing mechanism, and continuous handle pressure delivers staples while the blade moves forward, gradually compressing and cutting the tissue.	
Circular Stapler	This device consists of a detachable anvil and a handling part with a trocar for the cartridge, cutting element, rotary knob for jaw control, and an operating handle. The process involves opening the rotary knob to extract the anvil, detaching it for tissue insertion, and then assembling it with the cartridge by rotating the knob until an indicator confirms sufficient tissue compression.	
Powered Stapler	This device features battery-driven actuation, eliminating manual control. The firing mechanism is powered by a battery, operating an electro-mechanical system that controls the cutting element and the cartridge..	

Figure 1. Description of key components for each type of device. The cartridge is highlighted in blue.

Absorbable Staples

The use of absorbable staples is mainly spreading in dermal suturing and in performing ligations [10–15]. Currently, considering the bariatric, gastrointestinal, vascular, and thoracic surgery fields, which are the main fields of application of staplers, the only commercially available absorbable staple is Medtronic Polysorb [16–18], while other bioreabsorbable magnesium and zinc alloys are still a matter of research. Although studies claim to match the clinical requirements for a secure anastomosis, their technology is yet to be implemented by manufacturers on a production scale [19,20].

Another field of application for staplers is deep dermal suturing. In particular, in plastic surgery, the use of staplers has been adopted and provides wound healing outcomes that are better than those of conventional suturing [15].

Staplers are also used in orthopedics to secure soft tissues to bone [21–23]. Few applications have been found comprising staples in the process of suturing soft tissues in meniscal or rotator cuff repair, the latter involving scaffold placement [24,25].

When comparing devices of each type, a variety of features must be considered since each manufacturer proposes its own combination of specifications. In this work, all available characteristics of surgical staplers will be presented to compare the available alternatives for the three different classes of staplers.

2. Materials and Methods

The first step was the analysis of the current surgical stapling market through ECRI Institute archives, which allowed us to identify the main competitors on the global scene (Ethicon (Johnson & Johnson, New Brunswick, NJ, USA) endo-Surgery and Covidien (Medtronic, Minneapolis, MN, USA)). The Italian market was then assessed using information accessed from Ministry of Health reports. In light of the Italian public health system's data, Panther Medical (Beiqijia, Beijing, China) and Sinolinks (Zhonglou Zone, Changzhou, China) were taken into consideration for the analysis.

After choosing the manufacturers, their websites were consulted, and all the available technical documentation was extracted. The main parameters to make a comparison were identified as staple line length for linear devices, staple line diameter for circular devices, open and closed staple height, the maximum number of firings in case of reloadable devices, the maximum number of rows of staples placed on each side of the suturing line, and length of the shaft in case of Endo-related devices.

Each device was identified both by its commercial name and by its product code, allowing for a better univocal identification. To further explore the design and the functioning mechanism of each product, some of the patents have been assessed through OrbitExpress online (www.questel.com) with the search query shown in Table 1 (the search was done in January 2021). Among the 416 retrieved results, 216 have been included based on their International Patent Classification, these being A61B-017/068, A61B-017/072, or A61B-017/115, classes specifically dedicated to surgical staplers. Patents have been scanned on the basis of title and abstract and on the basis of their latest available and granted version, resulting in 38 included documents. The decisional process is described in Figure 2. For all other devices, it was not possible to identify the patent documentation because of a lack of correspondence between commercial and technical denominations or because of intellectual property restrictions and trade secrets. Finally, specifications coming from the FDA medical devices database, which were assessed using manufacturers' names and product codes as keywords for the query, were recorded.

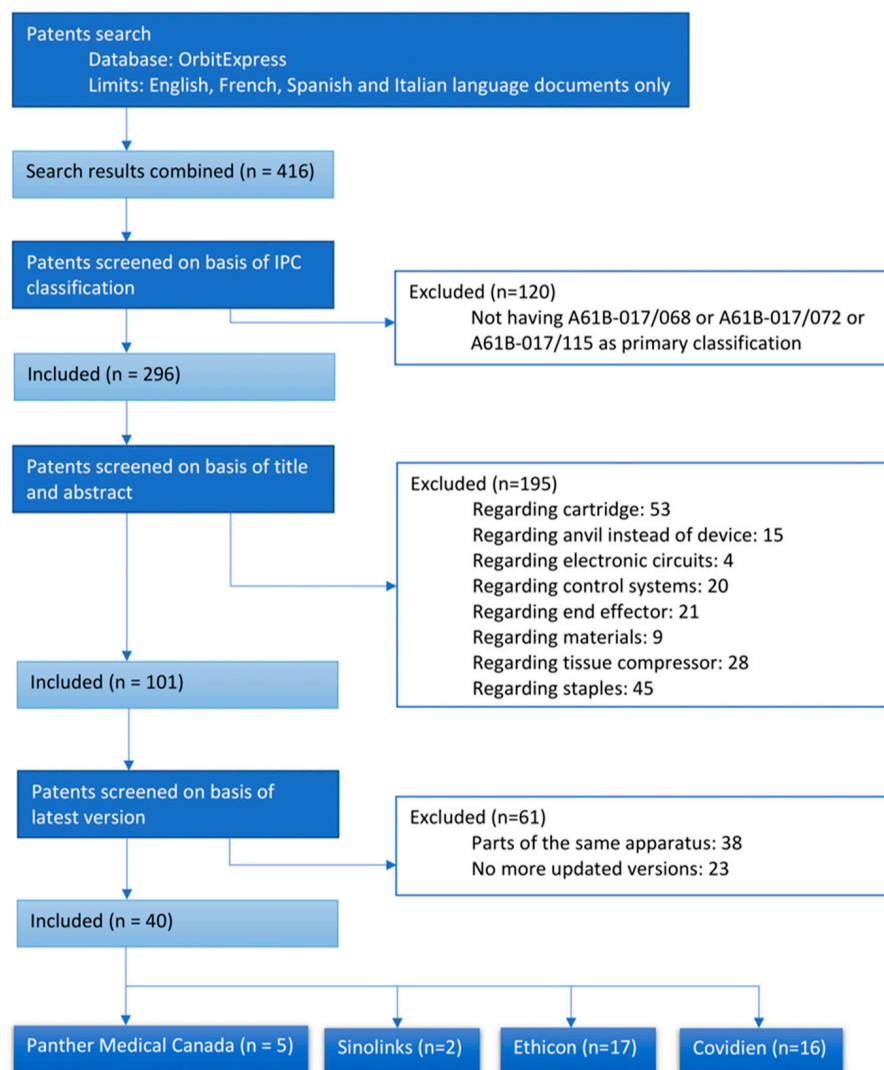


Figure 2. Patent inclusion flowchart.

Table 1. Patent search queries using OrbitExpress Questel software.

Keywords	Surgical stapler or stapler or stapling device or stapling apparatus or endo stapler or circular stapler or linear stapler or cutting stapler
Assignee	Ethicon Endo-Surgery or Covidien or Panther Medical or Sinolinks
Classification	A61B-017/068 or A61B-017/072 or A61B-017/115
Publication Country	WO or US or EP

3. Results

In this section, the information collected about the different classes of staplers was divided into subsections to organize the findings better. The crucial characteristics of the staplers were organized in tables to summarize. When some information was not available on the website an n.a (not available) was reported.

3.1. Linear Staplers

Linear devices are employed mostly in gastrointestinal procedures [26]. Other uses of linear staplers are abdominal surgery, gynecology, vascular surgery, and pediatric surgery.

Table 2 summarizes the principal characteristics of linear staplers in commerce by manufacturer. In particular, the commercial name and product code are reported according to the manufacturer. Other features that are reported include the staple line length, with values ranging between 30 mm and 60 mm for all manufacturers, while 45 mm and 90 mm sizes are proposed by everyone except Ethicon. Staple height depends on the cartridge mounted on the stapler: values vary from 2.5 mm proposed by Ethicon and Covidien for vascular applications to 4.8 mm for all the manufacturers for thicker tissues. For applications with a medium thickness, 3.5 mm is the chosen value, with only Sinolinks and Ethicon offering 3.8 mm and 3.85 mm alternatives. The height of the closed staple is quite standardized: 1.5 mm is ensured by all manufacturers, and 2 mm is available in every catalog except from Sinolinks, which offers a 1.8 mm alternative. Several rows placed by the instruments are also standardized—only Covidien and Ethicon propose a version of the stapler specific for vascular applications, which grants a height of 1mm but requires three rows of staples instead of two. The exceeding row is determined to be useful in providing a secure anastomosis and avoiding blood leakage issues.

Several studies in the literature analyzed the effects of linear stapler suturing and handsewn methods [26–28]. In a review, Choy et al. [27] compare linear stapled versus handsewn methods for ileocolic anastomosis. The authors analyzed different outcome measures like clinical and radiological anastomotic leakage, anastomotic stricture, hemorrhage, and time. Their results showed that stapled functional end-to-end ileocolic anastomosis is associated with fewer anastomotic leaks than handsewn anastomosis and should be considered the gold standard.

A meta-analysis of Gong et al. [26] analyzes stapled vs. hand suture closure of loop ileostomy. The authors affirm that stapled loop ileostomy reversal is superior to hand sutures in reducing postoperative small bowel obstruction, operation time, and hospital stay, and therefore, stapled side-to-side anastomosis should be considered the preferred technique.

According to the study of Giaccaglia et al. [9], in which three linear staplers of different companies were compared, small differences emerged between the devices regarding anastomotic pressure resistance and tensile strength. Many studies have confirmed the advantages of using linear staplers over circular staplers. Regarding a study on 213 patients with gastric cancer who underwent laparoscopic total gastrectomy, although mean operation time in the linear stapler group was longer than the circular stapler group, using linear staplers, anastomosis leakages and costs related to anastomosis were lower, and anastomosis stenosis did not occur. These advantages led scientists to prefer linear staplers in laparoscopic total gastrectomy [6].

Linear staplers are more effective than circular staplers in laparoscopic gastrojejunal (GJ) anastomosis in morbid obesity surgery [3].

Table 2. Linear stapler characteristics.

Brand	Commercial Name	Code	Staple Line Length [mm]	Staple Height [mm]	No. of Rows	Closed Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
PANTHER HEALTHCARE	Linear Stapler	FLSLF30	30.0	3.50 4.80	2	1.5 2.0	It can be reloaded up to 7 times for a total of 8 firings in a single procedure.	n.a	(Panther Healthcare, Open Linear Staplers) [29]
		FLSLF45	45.0						
		FLSLF60	60.0						
		FLSLF90	90.0						
SINOLINKS	Disposable Linear Stapler	DLS B	30.0	3.80 4.80	n.a	1.5 1.8	n.a	In gastrointestinal surgery, they are used for closure of the stump or incision in digestive tract reconstruction and viscera resection. Features: - DLS C: Three rows of staples provide better hemostasis. - DALS A: Two-stage closure for easy tissue adjustment. - DLS A: Manual integrated tissue positioning needle and flexible operation.	(Sinolinks, Linear Staplers)
		DLS C							
		DALS A							
		DLS A							
SINOLINKS	Disposable Linear Stapler	DLS B	45.0	3.80 4.80	n.a	1.5 1.8	n.a	In gastrointestinal surgery, they are used for closure of the stump or incision in digestive tract reconstruction and viscera resection. Features: - DLS C: Three rows of staples provide better hemostasis. - DALS A: Two-stage closure for easy tissue adjustment. - DLS A: Manual integrated tissue positioning needle and flexible operation.	(Sinolinks, Linear Staplers)
		DLS C							
		DALS A							
		DLS A							
SINOLINKS	Disposable Linear Stapler	DLS B	60.0	3.80 4.80	n.a	1.5 1.8	n.a	In gastrointestinal surgery, they are used for closure of the stump or incision in digestive tract reconstruction and viscera resection. Features: - DLS C: Three rows of staples provide better hemostasis. - DALS A: Two-stage closure for easy tissue adjustment. - DLS A: Manual integrated tissue positioning needle and flexible operation.	(Sinolinks, Linear Staplers)
		DLS C							
		DALS A							
		DLS A							
SINOLINKS	Disposable Linear Stapler	DLS B	90.0	3.80 4.80	n.a	1.5 1.8	n.a	In gastrointestinal surgery, they are used for closure of the stump or incision in digestive tract reconstruction and viscera resection. Features: - DLS C: Three rows of staples provide better hemostasis. - DALS A: Two-stage closure for easy tissue adjustment. - DLS A: Manual integrated tissue positioning needle and flexible operation.	(Sinolinks, Linear Staplers)
		DLS C							
		DALS A							
		DLS A							
COVIDIEN	DST Series™ TA™ Stapler	TA30V3S	30.0	2.50 (vascular version) 3.50 4.80	3 2 2	1.0 1.5 2.0	It can be reloaded up to 7 times for a total of 8 firings in a single procedure.	The version with a staple height of 2.5 mm is for vascular applications.	(Medtronic, TA™ Stapler with DST Series™ Technology) [30]
		TA3035S							
		TA3048S							
COVIDIEN	DST Series™ TA™ Stapler	TA4535S	45.0	3.50 4.80	2	1.5 2.0	It can be reloaded up to 7 times for a total of 8 firings in a single procedure.	n.a	(Medtronic, TA™ Stapler with DST Series™ Technology) [30]
		TA4548S							
COVIDIEN	DST Series™ TA™ Stapler	TA6035S	60.0	3.50 4.80	2	1.5 2.0	It can be reloaded up to 7 times for a total of 8 firings in a single procedure.	n.a	(Medtronic, TA™ Stapler with DST Series™ Technology) [30]
		TA6048S							
COVIDIEN	DST Series™ TA™ Stapler	TA9035S	90.0	3.50 4.80	2	1.5 2.0	It can be reloaded up to 7 times for a total of 8 firings in a single procedure.	n.a	(Medtronic, TA™ Stapler with DST Series™ Technology) [30]
		TA9048S							
ETHICON	PROXIMATE® Reloadable Staplers	TX30V	30.0	2.50 (vascular version) 3.50 4.80	3 2 2	1.0 1.5 2.0	Max firings: 8	It has applications throughout the alimentary tract and in thoracic surgery. The vascular version has applications in internal tissue, which can easily be compressed to 1mm in thickness and to ligate pulmonary vessels.	(Ethicon, PROXIMATE Reloadable Linear Stapler) [31]
		TX30B							
		TX30G							
ETHICON	PROXIMATE® Reloadable Staplers	TX60B TX60G	60.0	3.85 4.80	2	1.5 2.0	Max firings: 8	It has applications throughout the alimentary tract and in thoracic surgery.	(Ethicon, PROXIMATE Reloadable Linear Stapler) [31]

Linear Staplers with Bioresorbable Staples

Among all the manufacturers, only Covidien and CooperSurgical (Trumbull, Connecticut, Stati Uniti) include linear staplers mounting absorbable staples. The device of Covidien, TA Premium Polysorb (see Table 3), has the same design and functioning as traditional linear staplers. The available staple length is declared to be 55 mm. Each cartridge is intended to deliver a double staggered row of staples with a closed staple height that can be either 1.5 mm or 5 mm, depending on the staple filament width. The proposed device by CooperSurgical, INSORB[®], contains 20 individual, horseshoe-shaped staples with the following features: the staple is nominally 5 mm long × 3.5 mm wide × 0.7 mm thick. The staple is composed of an absorbable copolymer of predominantly polylactide and a lesser component of polyglycolide [32]. A study that compares the use of INSORB[®] and Subcuticular Skin Closure showed that the two treatment arms did not appear to differ [15,33].

Table 3. Linear staplers with absorbable characteristics.

Brand	Commercial Name	Code	Staple Line Length [mm]	Filament Width [mm]	No. of rows	Closed Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
COVIDIEN	TA Premium Polysorb	013501L 013505L	55.0	0.060 0.170	2	1.5 4.3 5.0	n.a	The device uses reabsorbable staples made of Lactomer.	(Covidien Polysorb)

During the search for bioresorbable staplers, a promising device for staple line reinforcement was found. In particular, FOREseal is made of polysaccharidic polyglycuronate biopolymers (highly purified fractions from calcium alginates) originating from seaweeds. It creates an interface between the staples and the organ wall and then forms a hemostatic, healing bioadhesive gel through the release of its calcium ions. The preliminary study on pancreatic parenchyma highlighted that the use of this new device to reinforce the staple line during pancreatectomy was well tolerated [33] and showed promising results for lung staple line reinforcement [34].

In a study conducted in France on six hundred sixty-four patients regarding the dermal suture, it was seen that the suture with semiautomatic stapler is a potential alternative to the one with conventional thread, and regarding patient scar assessment scale score at 3 months or after 18 months, the medium operating time and complication rates were equivalent. Instead, the average suture time and occupational exposure to blood were significantly lower in the stapler [9]. A study conducted on 176 patients confirmed the effectiveness of bioresorbable staples, showing a decreased incidence of composite wound complications with subcuticular staple closure versus traditional staple closure in patients undergoing cesarean section [35].

Another study conducted on 150 patients who underwent distal pancreatectomy affirms that the use of bioresorbable staples, in particular absorbable Lactomer staples for distal pancreatic resection, can be a safe alternative to the standard closure technique [18].

3.2. Linear Cutting Staplers

Linear cutting staplers are employed in open surgery to seal and resect tissues at the same time. The device allocates two or four rows of staggered staples while making a resection in the middle of the rows through the blading element.

Table 4 reports the main characteristics of linear cutting staplers. Panther Medical and Sinolinks offer the same staple line lengths of 60 mm, 80 mm, and 100 mm, while Covidien (part of Medtronic) offers 64 mm, 84 mm, and 104 mm staple line lengths, and Ethicon (part of Johnson & Johnson) proposes different lines of devices varying from the 45 mm staple line length of ENDOPATH[®] ETS Articulating Linear Cutters to the 102 mm of PROXIMATE[®] Linear Cutters series. Ethicon ENDOPATH was used in a novel technique that avoids entry to the chest cavity and minimizes the use of electrocautery on the diaphragm [36].

Panther Medical and Sinolinks provide cartridges having the same staple height of 3.8 mm or 4.8 mm, Covidien provides a 2.5 mm option for vascular purposes, while Ethicon offers a variety of sizes covering an interval from 2.6 mm to 4.4 mm depending on the considered series of devices and on the application. As can be seen in Table 3, all producers ensure the stapler reloading a maximum of seven times, resulting in a maximum of eight firings during the same operation. Only the Ethicon brand proposes two devices reaching 12 maximum firings. The Ethicon endo-Surgery Linear Cutter was adopted for gracilis muscle flap splitting in facial reanimation, allowing for a perfect resection of the gracilis muscle [37].

The closed staple height is 1.5 and 2 mm for 3.8 and 4.8 mm staple height, respectively, but it reaches a minimum of 1 mm for Ethicon and Covidien cartridges with vascular purposes. Ethicon also offers a 1.8 mm option for medium-thickness tissue application. Covidien linear cutting staplers DST series GIA have been used to prevent blood loss during cesarean delivery [38].

Recently, Meditulp developed a Novel Asymmetrical Linear Stapler (NALS). In comparison with the other linear cutting staplers, on the resected organ side, there is a single row of titanium fasteners located farthest from the endocutter in the stapler device. Thanks to the new design, the stapler can provide tissue for a frozen section biopsy at the true resection margin without the titanium fasteners injuring the tissue [39].

Standard Bariatrics (Cincinnati, OH, USA) has developed a novel linear stapler called Standard Titan to perform a sleeve gastrectomy with a single stapler firing. This device aims to decrease technical and mechanical failure by eliminating junctions along the staple line, decreasing tissue manipulation and operative time while optimizing gastric tissue compression [40].

The performance of the linear cutter stapler (Ethicon Endo-Surgery Linear Cutters) for muscle transferring was tested by Nasir [37]. The results showed a very clear and precise division of the muscle edges; the titanium clips prevent muscle fibril separation, resulting in an easy and safe procedure even after splitting the muscle [37]. The advantages of Ethicon Endo-Surgery Linear Cutters were also reported in a new approach for cutting and closing the pancreas during pancreatojejunostomy with positive results [41] and to perform cervical esophagogastric anastomosis using the triangulating stapling technique [42].

Only one study in the literature reported on the performance of the NALS device developed by Meditulp (Cheongju-si, Chungcheongbuk-do, Republic of Korea). In particular, the NALS stapler was evaluated in the examination of animal lung tissue after the procedure of resection. In comparison with the same typology of staplers, the NALS device showed no squeezing artifact at the resection margin on microscopic examination, and all of the alveolar structures for evaluation were preserved [39]. However, no other information was found on this new linear cutter stapler, and a modification was reported to improve the pathologic evaluation of the true surgical margin after the use of the Ethicon ENDOPATH stapler [43].

Linear cutting staplers are widely used in gastrointestinal surgery. The study carried out by Cheng et al. [44] on 10 patients who underwent laparoscopic total gastrectomy highlighted a safe and effective procedure with the linear cutting stapler [44].

In addition, the efficacy of this type of stapler in a new procedure for anastomosis between the ileum and colon was evaluated and continues to show promising results [39].

Another surgery in which linear cutting staplers are well established consists of laparoscopic sleeve gastrectomy (established standard of care), the most common bariatric procedure. In particular, the stapler is used to resect the lateral portion of the stomach [40]. In comparison with the other two staplers adopted in this surgery, Standard Titan highlighted the mechanical benefits of withstanding higher burst pressure with the notable advantage of single-load functionality. Clearly, the new single staple load eliminates staple line junctions without sacrificing the integrity of staple formation along the staple line [40].

Table 4. Linear cutting stapler characteristics.

Brand	Commercial Name	Code	Staple Line Length [mm]	Staple Height [mm]	No. of Rows	Close Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
PANTHER HEALTHCARE	Linear Cutter Stapler	SSAB-60	60.0	3.8 4.8	2	1.5 2.0	It can be reloaded up to 7 times for a total of 8 firings in a single procedure.	n.a	(Panther Healthcare) [45]
PANTHER HEALTHCARE	Linear Cutter Stapler	SSAB-80	80.0	3.8 4.8	2	1.5 2.0			(Panther Healthcare) [45]
PANTHER HEALTHCARE	Linear Cutter Stapler	SSAB-100	100.0	3.8 4.8	2	1.5 2.0			(Panther Healthcare) [45]
SINOLINKS	Disposable Linear Cutter Stapler	DLC B-60	63.0	3.8 4.8	n.a	n.a	n.a	Used for removing and suturing organs in gastrointestinal surgery and general surgery.	(Sinolinks, Disposable Linear Cutter Stapler)
SINOLINKS	Disposable Linear Cutter Stapler	DLC B-80	83.0	3.8 4.8	n.a	n.a			(Sinolinks, Disposable Linear Cutter Stapler)
SINOLINKS	Disposable Linear Cutter Stapler	DLC B-100	103.0	3.8 4.8	n.a	n.a			(Sinolinks, Disposable Linear Cutter Stapler)
COVIDIEN	GIA™ Stapler with DST Series™ Technology	GIA6025S GIA6038S GIA6048S	66.0	2.5 3.8 4.8	4	1.0 1.5 2.0	It can be reloaded for a total of 8 firings.	n.a	(Medtronic, GIA™ Stapler with DST Series™ Technology) [46]
COVIDIEN	GIA™ Stapler with DST Series™ Technology	GIA8038S GIA8048S	86.0	3.8 4.8	4	1.5 2.0	It can be reloaded for a total of 8 firings.	n.a	(Medtronic, GIA™ Stapler with DST Series™ Technology) [46]
COVIDIEN	GIA™ Stapler with DST Series™ Technology	GIA10038S GIA10048S	106.0	3.8 4.8	4	1.5 2.0	It can be reloaded for a total of 8 firings.	n.a	(Medtronic, GIA™ Stapler with DST Series™ Technology) [46]
COVIDIEN	GIA™ Stapler with Iri-Staple™ Technology	(Thin/medium) GIA60TMS GIA60TMC (Medium/thick) GIA60MTS GIA60MTC (Extra thick) GIA60XTS GIA60XTC (Thin/medium) GIA80TMS GIA80TMC (Medium/thick) GIA80MTS GIA80MTC (Extra thick) GIA80XTS GIA80XTC	60 80	2.4 2.7 3.0 3.5 4.0 4.5 5.0	3	n.a	It can be reloaded for a total of 8 firings.	Features: - Stronger staple line leak pressure compared to two-row staplers. - Less stress on tissue during compression and clamping. - A stepped cartridge face and varied-height staples that may provide greater perfusion to the staple line. - Consistent performance over a broad range of tissue thickness.	(Medtronic, GIA™ Stapler with DST Series™ Technology)
ETHICON	Ethicon Surgery Linear Cutters	NTLC55 SR55	55.0	4.4	6	1.5 1.8 2.0	It can be reloaded for a total of 12 firings.	It has applications in gastrointestinal, gynecologic, thoracic, and pediatric surgery for transection, resection, and the creation of anastomoses and can be used with staple line or tissue buttressing materials.	(Ethicon, Linear Cutters) [47]
ETHICON	Ethicon Surgery Linear Cutters	NTLC75 SR75	75.0	4.4	6	1.5 1.8 2.0			(Ethicon, Linear Cutters) [48]

Table 4. Cont.

Brand	Commercial Name	Code	Staple Line Length [mm]	Staple Height [mm]	No. of Rows	Close Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
ETHICON	PROXIMATE® Linear Cutters	TVC55 TLC55 TCT55	57.0	2.6 3.8 4.5	4	1.0 1.5 2.0	It can be reloaded for a total of 8 firings.	It has applications in gastrointestinal, gynecologic, thoracic, and pediatric surgery for transection, resection, and the creation of anastomoses and can be used with staple line or tissue buttressing materials.	(Ethicon, PROXIMATE® Linear Cutters) [49]
ETHICON	PROXIMATE® Linear Cutters	TLC75 TCD75 TCT75	77.0	3.8 4.2 4.5	4	1.5 1.8 2.0			(Ethicon, PROXIMATE® Linear Cutters) [49]
ETHICON	PROXIMATE® Linear Cutters	TLC10 TCT10	102.0	3.8 4.5	4	1.5 2.0			(Ethicon, PROXIMATE® Linear Cutters) [49]
ETHICON	ENDOPATH® ETS Articulating Linear Cutters (laparoscopic stapler)	ATS45-TR45W ATS45-6R45G ATS45-TR45G	45.0	2.5 3.5 4.1	4 (TR45G) 6 (TR45W or 6R45B)	1.0 1.5 2.0	It can be reloaded for a total of 8 firings.	It has applications in multiple open or minimally invasive general, gynecologic, urologic, thoracic, and pediatric surgical procedures for transection, resection, and/or creation of anastomoses.	(Ethicon, ENDOPATH™ ETS Articulating Linear Cutter) [50]
STANDARD BARIATRICS	Standard Titan	n.a	230	n.a	n.a	1.2 2.2	n.a	The device is designed to help achieve a more consistent and symmetrical performing sleeve gastrectomy. Furthermore, the company may provide a staple line reinforcement with GORE® SEAMGUARD®, a bioabsorbable staple line reinforcement.	(Standard Bariatrics, Standard Titan) [51]

Linear Cutting Staplers with Bioresorbable Staples

Covidien is the only manufacturer to provide a linear cutting stapler having the same design as those described in the previous paragraph but mounting absorbable staples (see Table 5). Poly GIA 75 places two double staggered rows of staples while a knife divides the tissue in between; the staple line length is declared to be 75 mm, and with a staple section width of 0.060 mm, it is possible to reach a closed staple height of 1.5 mm. Covidien also produces Premium Poly CS 57, specifically intended to be used in C-section suturing processes, mounting Polysorb absorbable staples. The design resembles that of linear staplers: the squeezing of a handle activates the firing and cutting mechanism, placing two rows of staples while a knife blade operates a resection between them.

Table 5. Linear cutting staplers with bioresorbable staple characteristics.

Brand	Commercial Name	Code	Staple Line Length [mm]	Filament Width [mm]	No. of Rows	Closed Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
COVIDIEN	Poly GIA™ 75	030775	75.0	0.060	2	1.5	n.a	The device uses reabsorbable staples made of Lactomer.	(Medtronic, Poly GIA™ 75)
COVIDIEN	Premium Poly™ CS	05140 05170	57.0	0.140 (thinner tissue) 0.170 (thicker tissue)	2	1.5	n.a	The device uses reabsorbable staples made of Lactomer.	(Medtronic, Premium Poly GIA™ 75)

For over 30 years, the standard of care for hysterotomy in the gravid uterus has been the Premium Poly CS stapler. Premium Poly CS stapler was developed for fetal surgery in the 1980s; the benefits of this stapler included simple use, hemostasis, membrane sealing, and fewer adverse effects upon future reproduction than metallic staplers [52].

Church et al. [53] compared the performance of a bipolar electrocautery device, the LigaSure Impact (Medtronic), and an ultrasonic dissection device, the Harmonic ACE + 7 Shears (Ethicon part of Johnson & Johnson), with the Premium Poly CS Stapler. As a result, the Harmonic ACE could create a hysterotomy that healed comparably to the CS Stapler after repair [53].

3.3. Endo Linear Cutting Staplers

The Endo linear cutting staplers are specialized medical instruments with a crucial role in various surgeries, particularly in gastrointestinal, colorectal, and thoracic procedures. In addition, the use of these devices has been reported for pregnant patients who have undergone surgery, with a low rate of complications reported [54].

The device features an adjustable articulating element controlled by a lever located on the upper part of the shaft. Most manufacturers allow for a 22° range of movement in one direction and 23° in the other, providing a total articulation movement of 45°.

In this work, Table 6 outlines the main characteristics of the Endo linear staplers. In detail, Panther Medical, Sinolinks, and Covidien offer a consistent triplet of shaft length options, ranging from 6 cm to 26 cm. However, Ethicon stands out with shaft length options of 34 cm and 44 cm and an additional 32 cm alternative specifically designed for vascular applications. On the other hand, the staple line length varies depending on the cartridge in use, with the standard options being 30, 45, and 60 mm, except for Sinolinks, which ensures staple line lengths of 31, 46, and 61 mm. Ethicon's PVE35A model offers a specific staple line length of 35 mm, tailored for vascular applications, as evidenced above, which explains the difference in comparison to other models. Except for Ethicon, which presents a range of values from 2.6 mm for the vascular cartridge to 4.2 mm for the thick tissue cartridge, the open staple height is relatively standardized among manufacturers. The Endo GIA linear cutting stapler is reported to be used in vascular applications [55].

Each manufacturer employs a varying number of staple rows for their devices. Sinolinks and Ethicon use three rows on each side of the cutting line, whereas Panther Medical and Covidien opt for two rows on each side of the blade. This results in a total of four lines. To prioritize safety and prevent blood leakage while ensuring successful anastomosis, the staple line length exceeds the cutting line length by at least 5 mm. All the devices under consideration guarantee a 45° degree of reached articulation.

Endoscopic linear cutting staplers have garnered considerable attention and discussion within the scientific community due to their remarkable applications across various types of endoscopic surgeries. In particular, The Endo GIA™ linear stapler has proven to be highly effective and superior to its competitors, specifically in gastric laparoscopy surgery, surpassing products like ETS flex™. This superiority is attributed to its outstanding materials, durability, and reusability after multiple surgeries, resulting in improved clinical outcomes. Notably, it exhibits exceptional efficacy in reducing excessive blood loss and minimizing human errors during procedures [4].

Endoscopic staplers are adopted for the treatment of patients with advanced lung emphysema. In particular, Akil et al. [56] evaluated the surgical performance of a traditional Endo linear stapler compared to a powered stapling system, reporting no difference in the amount of postoperative air leakage, the consecutive length of chest tube drainage, and the time of surgery [56].

In addition to this, some authors have further highlighted the innovative applications of Endo GIA™ linear staplers in pancreaticoduodenectomy and total pancreatectomy, addressing the challenges faced by many surgeons in these complex surgeries. Its use in these procedures offers significant benefits, including reduced bleeding, enhanced surgical precision, shorter operative times, and ultimately, decreased postoperative morbidity and mortality rates [57].

With regard to other manufacturers, Ethicon offers a range of device instruments specifically designed for minimally invasive surgical procedures, including gastrointestinal, vascular, and thoracic procedures, in comparison to Covidien products. In particular,

recent studies have emphasized the remarkable efficacy of powered vascular staplers (PVS) in intricate surgical procedures, such as thoracoscopic anatomical surgery, where endoscopic staplers play a critical role in transecting vessels, bronchi, and lung tissue. The ECHELON FLEX™ (Ethicon PSE45A) powered articulating linear instrument stands out as the preferred choice for closing targeted bronchi, consistently leading to highly satisfactory clinical outcomes. Its advantage becomes evident in the context of limited surgical space, making it significantly advantageous over other commercially available powered vascular staplers. The ECHELON FLEX™ has proven its superiority and ease of use, offering equivalent levels of effectiveness and security. By integrating the ECHELON FLEX™ into surgical procedures, the overall complexity of the operation is reduced, and the potential for intraoperative complications is minimized [58,59].

Notably, the use of Ethicon powered staplers has been associated with lower rates of transfusion, as evident in comparison with Medtronic manual staplers. Moreover, recent studies have compellingly supported the use of the ECHELON FLEX™ for pulmonary artery stapling, showcasing its promise in preventing tissue damage and intraoperative bleeding during pulmonary artery transection procedures [60].

On the other hand, some authors' reports have compellingly showcased the efficacy of the Panther and Sinolink families of linear staplers in laparoscopic total gastrectomy for cancer treatments. Among these breakthroughs, the intracorporeal construction of the anastomosis stands out, where endoscopic linear staplers have emerged as the preferred reconstruction method among esteemed surgeons worldwide, surpassing circular staplers in popularity and reliability. The overwhelming preference for linear stapled anastomosis over circular stapled anastomosis stems from its numerous advantages and simplified execution. Notably, the linear approach is widely regarded as being easier to perform, making it an attractive choice for surgeons seeking optimal outcomes and reduced surgical complexity [61,62].

Table 6. Endo linear cutting stapler characteristics.

Brand	Commercial Name	Code	Shaft Length [cm]	Staple Line Length [mm]	Staple Height [mm]	No. of Rows	Close Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
PANTHER HEALTHCARE	Universal Endo Linear Cutter	CEAC			2.5					(Panther Healthcare) [63]
		30	6	30	3.5				It can be reloaded for a total of 25 firings.	
		45	16	45	4.2	4	n.a			
		60	26	60	4.8					
				5.0						
PANTHER HEALTHCARE	Endo Linear Stapler and P2G Cartridges	CADF-30T							Features: Dog bone-shaped staple buckets enhance tissue stability and provide improved staple formation in thick tissue.	(Panther Healthcare) [63]
		CADF-30N								
		CADF-45T								
		CADF-45N								
		CADF-45S				2.5				
		CADF-45D	6	30	3.5					
		CADF-45R	16	45	4.2		n.a	n.a		
		CADF-60T	26	60	4.8					
		CADF-60N				5.0				
		CADF-60N								
CADF-60S										
CADF-60D										
CADF-60R										
SINOLINKS	Disposable Endoscopic Linear Cutter, GEN I and GEN II	DEC A/B							It has applications in thoracic surgery, abdominal surgery, pediatric surgery, and gynecologic endoscopy procedures for transection, resection, and/or creation of anastomoses.	(Sinolinks, Endoscopic linear stapler)
		60		31	2					
		160	26	46	2.5	6	1.5	It can be reloaded for a total of 25 firings.		
		260		61	3.5		1.9			
				4.8						

Table 6. Cont.

Brand	Commercial Name	Code	Shaft Length [cm]	Staple Line Length [mm]	Staple Height [mm]	No. of Rows	Close Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
COVIDIEN	Multifire Endo TA™ 30 Staplers and Reloads	n.a	n.a	30	2.5 (vascular) 3.5	3	n.a	It can be reloaded 7 times for a total of 8 firings.	n.a	(Medtronic, Multifire Endo TA™) [64]
COVIDIEN	Endo GIA™ Universal Staplers with Tri-Staple	SIG30AVM SIG30AVT SIG45AXT SIG60AXT	n.a	30 45 60	2.0 2.5 3.0 3.5 4.0	3	n.a	n.a	n.a	(Medtronic, Endo GIA™ Ultra Universal Staplers) [64]
COVIDIEN	Endo Gia™ Ultra Universal Stapler	EGIAUSHT EGIAUSTD EGIAUXL	6 16 26	30 45 60	2.0 2.5 3.5 4.8	6	0.75 0.88 1.5 2.25 3.0	n.a	n.a	(Medtronic, Endo GIA™ Ultra Universal Staplers) [65]
ETHICON	ECHELON FLEX™ ENDOPATH™ Staplers	EC45A EC45AL EC60A LONG60A	34 44	45 60	2.6 3.6 3.8 4.1 4.2	6	1 1.5 1.8 2 2.3	n.a	It has applications in multiple open or minimally invasive general, gynecologic, urologic, thoracic, and pediatric surgical procedures. It can be used with tissue buttressing materials. The instrument may also be used for transection and resection of liver parenchyma (hepatic vasculature and biliary structures), pancreas, kidney, and spleen.	(Ethicon, Echelon Flex Endopath) [66]

3.4. Circular Staplers

Specialists use them for end-to-side, end-to-end, and side-to-side anastomoses. The applications of circular staplers involve the anastomosis of the proximal colon with the distal colon during colostomy, laparoscopic distal gastrectomy, and gastrojejunal anastomosis in Roux-en-Y gastric bypass [67–73]. Circular staplers also play an increasingly important role in vascular anastomoses [74]. The instrument is composed of a detachable anvil and a handling part, the last comprising a shaft that allocates the stapling cartridge and cutting element, a wing nut for opening and closing, and a handle to perform the firing and cutting operation [75]. This class of devices' cartridges contain a circular knife and a crown of staples of different heights that are available in a range of diameters to adapt to the dimension of the lumen to suture.

Table 7 shows the principal characteristics of circular staplers, sorting devices according to their producers and identifying them both through their commercial name and through their univocal product code. Panther Medical offers a device with a 26 cm shaft and cartridges with 21 mm, 24 mm, 26 mm, 29 mm, 32 mm, and 34 mm diameters. No information on the shaft length has been found for Sinolinks. Still, it is known that their staplers are available in 17 mm, 19 mm, 21 mm, 23 mm, 25 mm, and 27 mm diameters. Covidien offers 22 cm and 35 cm shafts with diameters of 21 mm, 25 mm, 28 mm, 31 mm, and 33 mm. Finally, Ethicon circular staplers have 26 and 37 cm shafts with 21 mm, 25 mm, 29 mm, and 33 mm diameters. As can be seen in Table 7, all manufacturers, except for Sinolinks, for which data were not available, provide cartridges allocating two rows of staples whose height depends on the chosen diameter; only Covidien uses its technology Tri-Staple, with three rows of different height staples. Circular staplers' cartridges contain

a circular knife and a crown of staples of different heights, and they are available in a range of diameters to adapt to the dimension of the lumen. Staple height varies in a wide range depending on the considered manufacturer, going from 3 mm of EEA™ circular stapler with Tri-Staple™ technology to 5.5 mm of Ethicon circular staplers. Close staple heights also vary in the data, including a range that goes from 1.4 mm for Panther Medical to 3mm for Ethicon circular staplers. Ethicon circular staplers with product codes beginning with CDHA and ECS-A provide the maximum closed staple height, indicating they are specifically intended for use in deeper, thicker bowels.

Despite the widespread use of staplers, surgeons are still in search of the most suitable technique to perform surgery. Circular staplers are typically used in colorectal anastomosis, gastrojejunal anastomosis, and other procedures. In the meta-analysis of Milone et al. [73], the literature regarding the use of circular and linear stapler techniques for gastrojejunostomy was analyzed. The results showed that by analyzing the overall anastomotic complications, there was a significantly lower rate of complications in the linear stapler technique compared to the circular stapler one. Other studies in the literature showed similar results. Edholm et al. [76] found that linear staplers, unlike circular staplers, are associated with short operative times, reduced wound infection risks, and shorter lengths of stay.

Mazaki et al. [77] compared the pressure resistance of triple-row circular stapler (EEA™ circular stapler with Tri-Staple™ technology, 28 mm Medium/Thick, Covidien) and double-row circular stapler (EEA™ circular stapler with DST series™ technology, 28 mm, 4.8 mm, Covidien) in a porcine model, reporting that the pressure resistance of the triple-row circular stapler is higher compared to DCS, suggesting that the triple-row circular stapler may reduce the rate of anastomotic leakage [77].

Strassner et al. (2023) [78] evaluated the performance of the Tri-Staple technology (Medtronic) with two-row staplers (Ethicon), comparing them in terms of perfusion, withstanding tension and intraluminal pressure, and reduced damage to the staple line during removal. The results of the tests show that Tri-Staple technology shows a median leak pressure that was 73% higher, better perfusion preservation, a 20% higher failure force, and a median removal force 78% lower than the double-row stapler [78].

Table 7. Circular stapler characteristics.

Brand	Commercial Name	Code	Shaft Length [cm]	Diameter [mm]	Staple Height [mm]	No. of Rows	Close Staple Height [mm]	Staple Quantity	Surgery Application and Relevant Info	Reference
PANTHER HEALTHCARE	Disposable Circular Stapler	FCSME21	26.0	21.0	4.5	2	1.4-2.2 (range)	n.a	n.a	(Panther Healthcare, Circular Stapler) [79]
		FCSME24		24.0						
		FCSME26		26.0						
		FCSME29		29.0						
		FCSME32		32.0						
		FCSLWAF21		21.0						
		FCSLWAF25		25.0						
		FCSLWAF29		29.0						
		FCSLWAF32		32.0						
		FCSLWAF33 (Extra Long)		33.0						
SINOLINKS	Disposable Circular Stapler	DCS H 17	n.a	17.0	4.5	n.a	2.0	n.a	It has applications in gastrointestinal surgery. Used for the whole digestive tract for end-to-end, end-to-side, and side-to-side anastomoses.	(Sinolinks, Disposable Circular Stapler)
		DCS H 19		19.0						
SINOLINKS	Disposable Circular Stapler	DCS A/E/F21	n.a	21.0	4.8	n.a	2.0	18		(Sinolinks, Disposable Circular Stapler)
		DCS A/E/F23		23.0				18		
		DCS A/E/F25		25.0				20		
		DCS A/E/F27		27.0				22		
SINOLINKS	Disposable Circular Stapler	DCS A/E/F29	n.a	29.0	4.8	n.a	2.0	24		(Sinolinks, Disposable Circular Stapler)
		DCS A/E/F31		31.0				28		
		DCS A/E/F33		33.0				5.2		

Table 7. Cont.

Brand	Commercial Name	Code	Shaft Length [cm]	Diameter [mm]	Staple Height [mm]	No. of Rows	Close Staple Height [mm]	Staple Quantity	Surgery Application and Relevant Info	Reference
COVIDIEN	EEA™ Stapler with DST Series™ Technology	EEA21	22.0	21.0	3.5	2	n.a	18	It has applications in bariatric, colorectal, and general surgery.	(Medtronic, EEA™ Circular Stapler with DST™ Series Technology) [80]
		EEA25		25.0						
COVIDIEN	EEA™ Stapler with DST Series™ Technology	EEA31	35.0	31.0	4.8	2	n.a	22		(Medtronic, EEA™ Circular Stapler with DST™ Series Technology) [80]
		EEA33		33.0						
COVIDIEN	EEA™ Stapler with Tri-Staple Technology	TRIEEA28MT	n.a	28.0	31.0	3	n.a	n.a	n.a	(Medtronic, Suturatrice Circolare EEA™ con Tri-Staple™ Technology) [81]
		TRIEEA28XT								
		TRIEEAXL28MT								
		TRIEEAXL28XT								
		TRIEEA31MT								
		TRIEEA31XT								
		TRIEEAXL31MT								
		TRIEEAXL31XT								
		MT								
		3.0								
3.5										
4.0										
4.0										
4.5										
5.0										
XL										
3.0										
3.5										
4.0										
ETHICON	Ethicon Circular Stapler	CDH21A	26.0	21.0	5.5	2	1.5	16	n.a	(Ethicon, Circular Stapler) [82]
		CDH25A		25.0						
		CDH29A		29.0						
		CDH33A		33.0						
ETHICON	Ethicon Circular Stapler	ECS21A	37.0	21.0	5.5	2	1.5	16	n.a	(Ethicon, Circular Stapler) [83]
		ECS25A		25.0						
		ECS29A		29.0						
		ECS33A		33.0						
ETHICON	ETHICON™ Circular Stapler	ECS21B	37.0	21.0	5.2	2	1.5	20	It has applications in surgery fields such as bariatric, colorectal, and thoracic surgeries to perform esophagectomy, gastric bypass, left colectomy, lower anterior resection, and sigmoidectomy procedures.	(Ethicon, Circular Stapler) [84]
		ECS25B		25.0						
		ECS29B		29.0						
		ECS33B		33.0						

Over the years, researchers and surgeon specialists performed different studies to assess which type of stapler was the most suitable for different surgery procedures. Gastrojejunostomy is one of the most analyzed techniques for anastomosis. Typically, two different types of staplers' outcomes are compared, and the authors consider linear and circular staplers' techniques for the outcome comparison [3,68–73,76].

Other studies analyze the safety and efficacy of laparoscopy gastrectomy in patients with gastric cancer using linear stapler and circular stapler techniques [85]. Circular staplers were also used for restorative surgery for rectal cancer [86].

A variant of this class of device is hemorrhoidal staplers, which work exactly as circular staplers but have different diameters and employ different cartridges, ensuring a lower closed staple height. Table 8 below displays the different manufacturers that offer staplers for this specific purpose. The disposable hemorrhoidal stapler by Sinolinks has diameters of 32 mm and 34 mm; Covidien has the EEA™ hemorrhoid and prolapse stapler with DST Series™ technology that has a diameter of 33 mm, the same as Ethicon PROXIMATE® PPH3 Hemorrhoidal Circular Stapler Set; and Golden Stapler has the PPHD Single-Use

Hemorrhoidal Circular Stapler line, with diameters of 32 mm, 34 mm, and 36 mm. The staple height is different in each of the four staplers: 3.8 mm for Sinolinks staples, 3.5 mm and 4.8 mm for Covidien staples, 4 mm for Ethicon, and finally, 4.3 and 4.5 for Golden Stapler. The number of rows of staggered staples, as the closed staple height, is also listed in Table 8.

Table 8. Hemorrhoidal stapler characteristics.

Brand	Commercial Name	Code	Diameter [mm]	Staple Height [mm]	No. of Rows	Closed Staple Height [mm]	Staple Quantity	Surgery Application and Relevant Info	Reference
SINOLINKS	Disposable Hemorrhoidal Stapler	DHS B-32 DHS B-34	32.0 34.0	4	2	1	32 34	It has applications in hemorrhoid surgery for the selective resection of the mucosa along the dentate line.	(Sinolinks, Disposable Circular Stapler) [87]
SINOLINKS	Disposable Hemorrhoidal Stapler	DHS C-32 DHS C-34	32.0 34.0	4	2	1	32 34		
COVIDIEN	EEA™ Hemorrhoid and Prolapse Stapler with DST Series™ Technology	HEM3335	33.0	3.5 4.8	4	n.a	n.a	It has applications in hemorrhoid surgery.	(Medtronic, EEA™ Hemorrhoid and Prolapse Stapler Set) [88]
ETHICON	PROXIMATE® PPH Hemorrhoidal Circular Stapler Set	PPH03	33.0	4.0	2	0.75 1.50	28	It has applications in hemorrhoid surgery.	(Ethicon, PROXIMATE™ PPH Hemorrhoidal Circular Stapler Set) [89]
GOLDEN STAPLER	Single-Use Hemorrhoidal Circular Stapler	PPHD32 PPHD34 PPHD36	32.5 34.5 36.5	4.3 4.3 4.5	2	0.8 2.0	32 34 36	It has applications in hemorrhoid surgery.	(Golden Stapler, Single Use Hemorrhoidal Circular Stapler) [79]

3.5. Powered Stapling System

Both linear and circular powered stapling systems are commercially available (see Table 9). For linear systems, today, Ethicon and Covidien are the only manufacturers on the market offering powered surgical staplers. Ethicon has two powered stapling systems, one being the ECHELON CIRCULAR™ Powered Stapler (ECPS) already mentioned in the previous section. The other one is the ECHELON FLEX™ Powered Vascular Stapler (PVS) (Ethicon, Echelon Flex Powered Vascular Stapler) [90].

The PVS has a powered actuation, meaning that the firing mechanism is no more controlled by the swing of a knob or the compression of a spring but through a battery providing power to an electro-mechanical system maneuvering the cutting element if present and the cartridge. The stapler has a curved anvil tip, an introducer-like cartridge body tip, and active articulation with high articulation angles to facilitate access in surgical procedures with small surgical spaces or difficult-to-reach vessels.

Medtronic Covidien Signia™ Stapling System (SIG) is relatively more complex. Not only does it have powered actuation, but the articulation, opening, and closing of the end effector are also powered through electrical motors. The compression of the tissue is sensed thanks to a strain-gage transducer located on the shaft, providing indications to the surgeon through a display.

Regarding circular powered stapling solutions, Ethicon produces the ECHELON CIRCULAR™ Powered Stapler (ECPS) (Ethicon, Echelon Circular Powered Vascular Stapler) [91].

This represents the powered variant of the already-discussed ETHICON™ Circular Stapler product and shares most of its technical specifications, such as lumen diameter (available in four sizes), staple rows, open staple leg length, and closed staple height. The iDrive™ staplers provided by Covidien showed superior performance in terms of access, visibility, and ease of placement in the deep pelvis [92].

Both the ECHELON FLEX™ Powered Vascular Stapler (PVS) and the Covidien Signia™ Stapling System (SIG) have been extensively validated by the scientific community. In particular, SIG was tested for video-assisted thoracic surgery by Shimada et al. [93], which also introduced a new procedure, named “sliding technique”, to optimize safe surgical margins with minimal stapler movement.

The advantages of PVS in comparison to manual endoscopy are highlighted in Roy et al. [94] for laparoscopic bariatric surgery, in Park et al. [95] for thoracoscopic lobectomy lung cancer, and video-assisted thoracic surgery lobectomy in Miller et al. [59].

In comparison to the non-powered alternatives, these studies showed, respectively, a decrease of 47% (3.05% to 1.61%) in terms of hemostasis-related complications, a decrease of 56% in terms of intraoperative blood loss, and a decrease of 47% in terms of bleeding complications. The PVS device has also been applied for scientific investigations on a novel physiologic lung model by Eckert et al. [96].

Some direct comparisons of PVS and SIG have been performed by Rawlins et al. [97] in laparoscopic sleeve gastrectomy. The authors report a lower observed incidence of hemostasis-related complications during the surgical admission in the ECHELON FLEX™ group in comparison with the SIG group (3 events vs. 11 events).

Regarding the ECHELON CIRCULAR™ Powered Stapler (ECPS), this has been proven to reduce the risk of anastomotic leakage rates in left-sided colorectal anastomosis from 11.8% to 1.7% in a single institution clinical study [98]. Postoperative anastomotic leaks were experienced in 2.4% of subjects in a cohort study of left-sided colorectal surgery performed by Herzig et al. [99]. Similarly, it has been successfully benchmarked against manual operation for left-sided colorectal resections by Pollack et al. [100] and Sylla et al. [101].

Table 9. Powered stapler characteristics.

Brand	Commercial Name	Code	Dimension [mm]	Staple Height [mm]	No. of Rows	Closed Staple Height [mm]	Firing Actions	Surgery Application and Relevant Info	Reference
COVIDIEN	Signia™ Stapling Platform	n.a	30 30 45	4.5	n.a.	n.a.	n.a	It adapts to different surgical conditions, properly adjusting the drive speed according to force measurements.	(Medtronic, Signia™ Stapling Platform) [102]
COVIDIEN	Signia™ Stapling Platform Small Diameter (8 mm shaft)	SIGSDS30CTV SIGSDS30CTVT SIGSDS45CTVT	30 30 45	n.a	n.a	n.a	n.a	Compatibility with all Medtronic handles.	(Medtronic, Signia™ Stapling Platform) [102]
ETHICON	FLEX™ Powered Vascular Stapler	PVE35A VASECR35 (Only for vascular/ thin tissue)	32	5.2	4	1.5 mm– 2.2 mm	It can be reloaded for a total of 12 firings.	It has applications in surgery fields such as general, gynecologic, pediatric, thoracic, and urologic to perform lung resection, nephrectomy, appendectomy, splenectomy, and oophorectomy procedures, as well as for vessel transection and stapling.	(Ethicon, Echelon Flex Powered Vascular Stapler) [90]
ETHICON	CIRCULAR™ Powered Vascular Stapler	CDH23P, CDH25P, CDH29P, CDH31P	23 mm, 25 mm, 29 mm, 31 mm	5.2	2	1.5 mm– 2.2 mm	n.a	It has applications in surgery fields such as colorectal, gastric, and thoracic to perform colorectal resections, gastrectomies, gastric bypass, and esophagectomies procedures.	(Ethicon, Echelon Circular Powered Vascular Stapler) [91]
COVIDIEN	iDrive™	n.a	n.a	n.a	n.a	n.a	n.a	The iDrive Ultra powered stapling device, with Endo GIA stapling reloads, provides precision in surgical stapling, enabling surgeons to position and keep the stapler exactly where they intend.	(Covidien, iDrive™)

4. Conclusions

Stapling devices have gained widespread adoption in various surgical fields, demonstrating excellent results in terms of surgical outcomes and reduced operation time. Manufacturers and the existing literature provide valuable information on the specific applications of each stapling device, with a range of staple cartridges tailored to different surgical targets. The variety of staple sizes, designed to accommodate diverse tissue thicknesses and lumen diameters, surgical spaces, ensures effective hemostasis while minimizing ischemia and tissue damage. However, it is important to acknowledge that stapling can disrupt the structural continuity of tissues, introducing stress and strain that may not be entirely physiological but still lead to favorable outcomes. Despite this, only a limited number of articles have explored the strength of anastomotic techniques involving stapling devices. It is important to highlight that staple configurations are under constant improvement, and the experimental tests to evaluate their performance are performed by different research groups, as reported in [78].

Therefore, further studies should focus on understanding the impact of adopting specific stapling devices, also in comparison with manual or mixed operations as documented in [2] regarding suture resistances, for different tissues and explore the potential influence of staple height and the number of staple rows on the overall surgical outcome. By undertaking such investigations, we can better optimize the use of stapling devices, tailor their applications to specific tissues, and potentially enhance the overall success and safety of surgical procedures. This research will contribute to the advancement of surgical techniques and the improvement of patient outcomes in the future.

This review aims to gather information from the literature published in previous years regarding surgical stapling devices. Furthermore, specific sections are dedicated to the use of bioresorbable staples to highlight where bioresorbable materials are used in this specific field of surgery. The use of bioresorbable devices in medicine has been increasing in the last few years, both in clinical and research settings. However, few devices adopt the usage of bioresorbable staples and only for specific fields of surgery. The collected information indicates a growing interest in new stapling devices using bioresorbable staples.

While this suggests the potential future of bioresorbable staples, their applicability across all surgical fields might be limited only to skin closure. Indeed, non-bioresorbable staples will remain the gold standard for applications that require permanent closure of internal organs, such as gastrointestinal procedures, abdominal surgery, gynecology, and vascular surgery.

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