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REVIEW ARTICLE

Is "functional end-to-end anastomosis" really functional? A review of the literature on stapled anastomosis using linear staplers

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Abstract
Purposes Anastomosis is one of the basic skills of a gastrointestinal surgeon. Stapling devices are widely used because stapled anastomosis (SA) can shorten operation times. Antiperistaltic stapled side-to-side anastomosis (SSSA) using linear staplers is a popular SA technique that is often referred to as "functional end-to-end anastomosis (FEEA)." The term "FEEA" has spread without any definite validation of its "function." The aim of this review is to show the heterogeneity of SA and conventional hand-sewn end-to-end anastomosis (HEEA) and to advocate the renaming of "FEEA."
Methods We conducted a narrative review of the literature on SSSA. We reviewed the literature on ileocolic and small intestinal anastomosis in colonic cancer, Crohn's disease and ileostomy closure due to the simplicity of the technique.
Results The superiority of SSSA in comparison to HEEA has been demonstrated in previous clinical studies concerning gastrointestinal anastomosis. Additionally, experimental studies have shown the differences between the two anastomotic techniques on peristalsis and the intestinal bacteria at the anastomotic site.
Conclusions SSSA and HEEA affect the postoperative clinical outcome, electrophysiological peristalsis, and bacteriology in different manners; no current studies have shown the functional equality of SSSA and HEEA. However, the use of the terms "functional end-to-end anastomosis" and/or "FEEA" could cause confusion for surgeons and researchers and should therefore be avoided.

Keywords Functional end-to-end anastomosis · Stapled anastomosis · Linear stapler

Introduction

Many automatic anastomotic techniques have been applied to the field of gastrointestinal surgery [1, 2]. Antiperistaltic stapled side-to-side anastomosis (SSSA) is sometimes referred to as, "functional end-to-end anastomosis (FEEA)" [3, 4]. The term "functional end-to-end" is difficult to understand in relation to this anastomotic technique.

This nonsystematic narrative review was conducted to evaluate the currently available literature on SSSA for right-side colon cancer, ileostomy closure and Crohn's disease. This anastomotic method is technically convenient and is usable regardless of the presence of disparity in the size of the intestinal tract. In this respect, stapled anastomosis is compatible with laparoscopic surgery, which has a long duration time in comparison to open surgery. As a result, its use has spread worldwide at the same time as laparoscopic surgery and the development of reliable and precise staplers. In some gastrointestinal articles, the term antiperistaltic SSSA may be used to refer to, "functional end-to-end anastomosis (FEEA)". The term, "functional end-to-end anastomosis (FEEA)" is often used in the field of laparoscopic surgery. However, a sense of incongruity is felt regarding the phrase, "functional end-to-end."

The term "functional end-to-end anastomosis (FEEA)" was first reported by Steichen [5]. In the article, the superiority of this method was mentioned using pathological specimens of anastomoses constructed using the stapled

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side-to-side method and comparing them to hand-sewn end-to-end anastomoses. The functionality of the anastomotic method, with regard to anastomotic peristalsis and the transport of the intestinal contents was not evaluated in the article.

In the 1980s, the utility of antiperistaltic SSSA was verified clinically and in experimental studies. As a result, this method rapidly gained popularity in the 1990s. In recent years laparoscopic surgery resulted in the development of surgical instruments such as the surgical stapler. Mechanical anastomosis methods have greatly advanced since the 2000s. With the expansion of surgical techniques and without any scientific proof of a real "function", the term "FEEA" appears to be misleading.

The aim of this review is to give the readers precise information regarding the pertinent literature on mechanical stapling anastomosis in ileocolic anastomosis. The article is not intended to provide a systematic review of "FEEA". This review includes a critical assessment of the pertinent literature and a discussion on the mixed reviews and experimental articles on the technique.

Methods

We performed a search of the PubMed database using the search terms: "stapled anastomo*" and/or "functional end-to-end" and/or "side-to-side anastomo*" and "ileocolic anastomo,*" and/or "ileostomy closure" and focused on articles that reported the use of SA for colon cancer and/or Crohn's disease and ileostomy closure.

Results

The theory and practice of anastomosis

Goulder et al. described the basic theory and practice of anastomosis in 2012. The important factors in gastrointestinal anastomosis are meticulous technique, good blood supply, and a lack of tension [6]. The choice of the anastomotic method is influenced by the diameter of the bowel ends, edema, available time and equipment, and pathology [6]. Anastomoses can be classified as follows: [1] end-to-end or side-to-side, [2] isoperistaltic or antiperistaltic, and [3] stapled or hand-sewn. Hand-sewn anastomosis has been used for more than a century. Various hand-sewn anastomosis techniques have been invented and developed over time and have been passed down in institutions and departments. Other surgical techniques, such as stapled anastomosis, are developed in a similar manner, which makes the assessment of these surgical techniques difficult.

The history of the development of stapled side-to-side anastomosis

Stapled side-to-side anastomosis (SSSA) using a linear cutter stapler was first reported by Steichen [5]. Antiperistaltic SSSA, which was based on the then current antiperistaltic SSSA technique, was initially presented with figures to illustrate its technique. It has been referred to in the literature as "functional end-to-end anastomosis (FEEA)." Steichen et al. mentioned that the anastomotic method had a "good function," similar to anatomical end-to-end anastomosis, but did not note compare the function to that achieved with anatomical end-to-end anastomosis. This article demonstrated the superiority of stapled anastomosis in comparison to the hand-sewn method with the use of pathological specimens in an equine experimental model.

In the 1970–1980s, the expression "functional end-to-end" was rarely present in scientific articles on gastrointestinal surgery. Anastomosis using staplers was referred to as, "stapled anastomosis" [7]. A PubMed database search using the search term "functional end-to-end," only located three articles that were published prior to 1990 [5, 8, 9]. However, gastrointestinal anastomosis using linear staplers was validated using clinical retrospective studies [7, 9] and experimental animal models [10]. Several case series and small randomized controlled trials (RCTs) compared stapled and hand-sewn gastrointestinal anastomosis in the 1970–1980s and showed no difference in the incidence of anastomotic leakage and postoperative morbidity [6, 7, 11–13].

In the early 1990s, with the beginning of laparoscopic surgery, there were many articles from Western countries on antiperistaltic SSSA [14–16]. As laparoscopic surgery gained popularity, the term "FEEA" spread and the number of articles on stapled anastomosis increased. As a consequence, the term "antiperistaltic SSSA" was expanded to "FEEA", A large RCT was published in 1991, which included elective and emergency anastomoses that were performed throughout the gastrointestinal tract; however, this study could not demonstrate a difference in the clinical outcome (the incidence of leakage, overall morbidity and mortality) between stapled and hand-sewn anastomosis [17]. Briefly, the differences between stapled and hand-sewn anastomosis have been clarified, but the term "functional end-to-end anastomosis" appears to be misleading. The term "FEEA" does not appear to actually refer to a "function", and may thereby cause confusion.

Variations in the surgical technique of stapled side-to-side anastomosis (Table 1)

The stapling technique reported by Steichen et al. is used to open the resection stump, which is sutured in the

Table 1 Studies of various technique on stapled side-to-side anastomosis

Author	Year	Study design	*n*	For comparison	Endpoint	Results	*p* value
Liu Z	2014	Retrospective study	379	SSSA vs SESA	Operative time	140.4 vs 150.5 min	0.001
Ojima H	2015	Retrospective study	110	Closed vs opened	SSI	11.0 vs 53.8 %	<0.001
Tewari N	2005	Retrospective study	64	Isoperistaltic vs Antiperistaltic	Postoperative hospital stay	4.2 vs 5.8 days	N.A
					Expenditure	255 vs 500$	N.A

Stapled anastomosis was been compared according to (1) the side-to-side or end-to-side methods in ileocolic anastomosis, (2) the closed method or opened method, and (3) isoperistaltic or antiperistaltic methods in small retrospective studies

SSSA stapled side-to-side anastomosis, *SESA* stapled end-to-side anastomosis, *SSI* surgical site infection, *NA* not available

Table 2 Meta-analysis compared with SSSA and HEEA to evaluate anastomotic leakage

Author	Year	Anastomosis	Patients	*n* (stapled/hand-sewn)	Effect size (95 % CI)	*p* value
Choy P	2011	Ileocolic	Cancer	300/525	0.28 (0.10–0.75)[a]	0.01
Gong J	2013	Ileo-ileo	Ileostomy closure	1289/3100	−0.00 (−0.01 to 0.01)[b]	0.38
Loffler T	2015	Ileo-ileo	Ileostomy closure	267/263	0.87 (0.13–6.00)[c]	0.89
Guo Z	2013	Ileo-ileo	CD	444/435	0.48 (0.22–1.07)[a]	0.07
He X	2014	Ileocolic	CD	366/392	0.54 (0.32–0.93)[a]	0.03

Five meta-analyses of stapled anastomosis in which the incidence of anastomotic leakage was analyzed. Two studies showed (statistically) that stapled anastomosis is superior to the hand-sewn method with regard to the incidence of anastomotic leakage

SSSA stapled side-to-side anastomosis, *HEEA* hand-sewn end-to-end anastomosis, *OR* odds ratio, *RD* relative difference, *RR* risk ratio

[a] OR (95 % CI)

[b] RD (95 % CI)

[c] RR (95 % CI)

antimesentrium in a side-to-side manner with a linear stapler, and to close the two connected stumps with double stapling [5]. As previously reported, this method uses staplers to close the resection stump of the intestine on the antimesenteric side of the stapling line [18]. Because the intestinal tract is not largely open, this technique is quite aseptic. If an emergency operation to perform mechanical bowel preparation is not required, then this method can be adopted to perform a clean surgery. Ojima et al. referred to the former method as the "open method" and the latter method as the "closed method" [19], and reported that the open method was associated with a higher incidence of surgical site infection [19].

With regard to anastomotic peristalsis, both isoperistaltic [20] and antiperistaltic stapled side-to-side anastomosis have been previously reported [7, 18, 21]. However, there do not seem to be any previously reported articles regarding the comparison of stapled anastomotic peristalsis with ileocecal anastomosis. In the systematic review of stapled ileocolic anastomosis [22] and ileostomy closure [23], the study items did not distinguish between isoperistaltic and antiperistaltic anastomosis (Table 2).

The clinical assessment of stapled anastomosis in ileocolic anastomosis and ileostomy closure

Ileocolic anastomosis is used in the resection of right-sided colon cancer and is commonly performed in Crohn's disease, when a patient has an obstruction and/or intestinal fistula in the same lesion. A large RCT conducted in 1993 showed a significant reduction in the incidence of intraoperative fecal contamination with stapled anastomosis ($p < 0.02$) and a non-significant decrease in anastomotic leakage (hand-sewn, 8.3 %; stapled, 2.8 %, respectively) [24].

A meta-analysis comparing stapled ileocolic anastomosis to hand-sewn anastomosis was reported in 2011 [22]. The study showed that stapled anastomosis was associated with a lower incidence of postoperative anastomotic leakage episodes than hand-sewn anastomosis. The results of this meta-analysis should be interpreted with caution because the authors analyzed articles on colon cancer surgery and Crohn's disease.

In total, there have been five meta-analyses concerning the incidence of anastomotic leakage after SA [22, 23,

Table 3 Meta-analysis compared with SSSA and HEEA to evaluate bowel obstraction for ileostomy closure

Author	Year	*n* (stapled vs hand-sewn)	Effect size	*p* value
Gong J	2013	1357/3727	0.56 (0.44–0.72)[a]	<0.001
Loffler T	2015	330/319	0.53 (0.32–0.88)[b]	0.01

Two meta-analyses of stapled anastomosis in ileostomy closure in which the incidence of anastomotic bowel obstruction was analyzed. Both meta-analyses demonstrated (statistically) that stapled anastomosis was superior to the hand-sewn method in the correction of bowel obstruction

OR odds ratio, *RR* risk ratio

[a] OR (95 % CI)

[b] RR (95 % CI)

25–27] (Table 2). Only the studies on ileocolic anastomosis showed a statistically significant difference in the incidence of anastomotic leakage.

A retrospective study on ileocolic anastomosis in 3428 colon cancer patients was recently reported [28]. Although it was a retrospective study, a multivariate analysis showed that stapled anastomosis is the only risk factor for postoperative anastomotic leakage [28].

With regard to the incidence of other specific postoperative complications after ileocolic anastomosis, many articles have reported the superiority of stapled anastomosis in comparison to hand-sewn anastomosis. There appears to be a paucity of data regarding the other postoperative complications in ileocolic anastomosis [7, 18, 24, 29]. Sameshima et al. reported the superiority of SSSA to HEEA in ileocolic anastomosis with regard to the operative time and wound infection rate [4].

In an RCT, Wolmark et al. reported that SSSA is associated with a lower incidence of local recurrence in patients with colon cancer than HEEA [30]. Liu et al. compared the incidence of complications in SSSA and stapled end-to-side anastomosis [3]. The antiperistaltic SSSA group had a lower incidence of anastomotic error and a shorter operating time. Wolmark et al. concluded that antiperistaltic SSSA after right hemicolectomy for colon cancer is a safe and reliable anastomotic technique, which results in a favorable outcome in selected patients with right colon cancer [30].

With regard to postoperative bowel obstruction, two meta-analyses on ileostomy closure have been reported [23, 25]. Both studies showed statistically significant differences in the incidence of postoperative bowel obstruction after stapled ileostomy closure (Table 3). Stapled anastomosis was found to be superior to hand-sewn in ileostomy closure in relation to the incidence of postoperative bowel obstruction.

Stapled anastomosis for Crohn's disease (CD)

Non-surgical treatments for CD, such as molecular target therapy and nutritional therapy, have been developing. However, the rate of patients who require surgical treatment is extremely high [31]. Surgery is a non-curative treatment for CD, and many CD patients experience recurrence [21, 32–35]. The relationship of the anastomotic methods to recurrence has therefore been examined. The region of CD is skipped to extend the entire gastrointestinal tract. A relatively large number of cases require surgical treatment for ileocecal lesions. One RCT showed that there were no significant differences in the anastomotic leak rates of stapled and hand-sewn anastomosis groups [36]. Several subsequent RCTs and non-randomized studies demonstrated a reduction in the risk of anastomotic leakage [32, 37] and overall complications [21, 34] with stapled anastomosis in comparison to hand-sewn anastomosis. The reduced risk of reoperation for recurrent CD after stapled anastomosis has also been shown [21, 33, 34].

A systematic review which analyzed multiple prospective RCTs and retrospective studies of stapled ileocolic anastomosis in CD was reported in 2014 [27]. A review of three prospective RCTs, one prospective non-RCT, and four non-randomized retrospective studies showed the superiority, in terms of the overall incidence of postoperative complications, anastomotic leakage, symptomatic recurrence, and reoperation for recurrence [27].

The majority of evidence currently favors ileocolic SSSA in CD [21, 31–33] or suggests that hand-sewn and stapled anastomosis are equivalent [38]. No evidence favors HEEA.

Several recent studies by Kono et al. focused on stapled and hand-sewn hybrid anastomosis in CD [39–41]. Although the studies involved a limited number of patients, they showed that the construction of a supporting column using a linear stapler resulted in a good surgical outcome.

Experimental research on the "function" of stapled side-to-side anastomosis

There are few recent experimental studies on SSSA. The most recent article that we were able to find was published in 2010 [42]. Toyomasu et al. showed the recovery of intestinal peristalsis in conscious dogs using a myoelectrical approach. In the earlier postoperative period, myoelectrical observation showed differences between HEEA and SSSA; however, no differences were observed at 4 weeks after surgery [42]. Intestinal motility after SSSA was also previously studied using myoelectrograms [43, 44]. On the other hand, other studies have demonstrated that antiperistaltic SSSA alters small-bowel motility to a greater

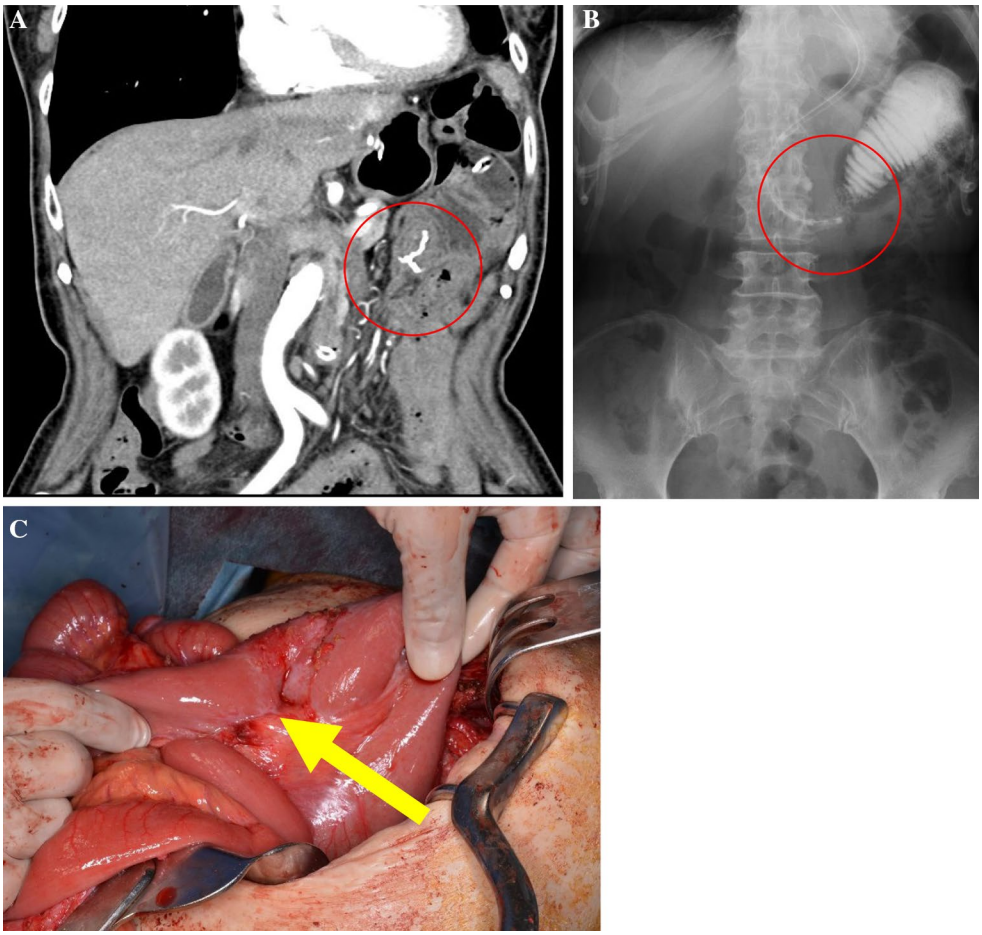

Fig. 1 The imaging and intraoperative photographs of a case of bowel obstruction after antiperistaltic stapled side-to-side anastomosis. **a** A computed tomography scan shows a caliber change near the stapled anastomotic site. **b** Radiography with contrast also shows bowel obstruction after the placement of an ileus tube. **c** An intraoperative photograph shows torsion of the mesenterium or adhesion at the anastomotic site

degree than HEEA [44], and myoelectrical propagation does not regenerate after SSSA, even after prolonged healing [43]. According to the published experimental research on SSSA, there may have been a difference in the peristaltic function after SSSA and "FEEA" in the earlier postoperative period. However, the two respective anastomotic methods may result in the same level of function at several months after surgery.

Two published studies compared the amount of peritoneal bacterial contamination after SSSA and HEEA [42, 45]. One study showed no significant difference between SSSA and HEEA [45]. However, a study using quantitative bacterial cultures indicated that antiperistaltic SSSA was associated with a trend toward bacterial growth [44].

Few studies have reported the function of SSSA. However, based on the results of several experimental studies, SSSA could not be considered equal to HEEA in terms of bacteriological and myoelectrical function.

Case report

A 68-year-old woman suffered from esophageal GIST and underwent laparotomy. Four years later, she suffered from postoperative strangulation ileus, and she underwent partial small intestinal resection with antiperistaltic SSSA reconstruction. On postoperative day 10, she again suffered from ileus. Conservative treatment failed to improve the patient's ileus and laparotomy was performed. A computed tomography scan (Fig. 1a) and radiography with contrast from the ileus tube (Fig. 1b) demonstrated torsion of the mesenterium and adhesion at the anastomotic site (Fig. 1c) caused small bowel obstruction. It is considered that HEEA has an intestinal prograde motion and does not cause torsion of the mesenterium. However, we do not consider SSSA to be inferior to the hand-sewn method. However, SSSA has the potential to cause bowel obstruction due to the torsion of the mesenterium [46] or adhesion at the anastomotic site.

The surgeon has to consider these characteristics when selecting an anastomotic method.

Conclusion

There is no reason why SSSA should not be adopted in place of HEEA for ileocolic or small intestinal anastomosis. The previous experimental and clinical reports confirm that the two are comparable surgical techniques. However, because no articles have clearly demonstrated the functional equality of ASSSA and HEEA, we may have to refrain from using the term "functional end-to-end anastomosis" and/or "FEEA" in ileocolic anastomosis and ileoileostomy. Finally, we advocate that this anastomotic method simply should be referred to be as "stapled (anatomical) side-to-side anastomosis".

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Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest in association with this study.

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