KJTCVS
The Korean Journal of Thoracic and Cardiovascular Surgery
https://doi.org/10.5090/kjtcs.2020.53.4.233
pISSN: 2233-601X eISSN: 2093-6516
Korean J Thorac Cardiovasc Surg.2020;53(4):233-241

Collective of current Review, Lecture

The Optimal Pyloric Procedure: A Collective Review

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ARTICLE INFO
Received May 6, 2020
Revised June 2, 2020
Accepted June 10, 2020

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†This article was presented at the 6th Esophageal Cancer Symposium (lecture on November 16th, 2019, Samsung Medical Center, Seoul, Korea).

Vagal damage and subsequent pyloric denervation inevitably occur during esophagectomy, potentially leading to delayed gastric emptying (DGE). The choice of an optimal pyloric procedure to overcome DGE is important, as such procedures can lead to prolonged surgery, shortening of the conduit, disruption of the blood supply, and gastric dumping/bile reflux. This study investigated various pyloric methods and analyzed comparative studies in order to determine the optimal pyloric procedure. Surgical procedures for the pylorus include pyloromyotomy, pyloroplasty, or digital fracture. Botulinum toxin injection, endoscopic balloon dilatation, and erythromycin are non-surgical procedures. The scope, technique, and effects of these procedures are changing due to advances in minimally invasive surgery and postoperative interventions. Some comparative studies have shown that pyloric procedures are helpful for DGE, while others have argued that it is difficult to reach an objective conclusion because of the variety of definitions of DGE and evaluation methods. In conclusion, recent advances in interventional technology and minimally invasive surgery have led to questions regarding the practice of pyloric procedures. However, many clinicians still perform them and they are at least somewhat effective. To provide guidance on the optimal pyloric procedure, DGE should first be defined clearly, and a large-scale study with an objective evaluation method will then be required.

Keywords: Esophageal surgery, Vagus nerve, Pylorus, Pyloromyotomy, Endoscopy

Introduction

Esophagectomy often results in the simultaneous resection of both sides of the vagus nerve. The loss of function of the stomach (or neo-esophagus) and pylorus, leading to delayed gastric emptying (DGE) [1,2], makes it difficult for patients to eat food; thus, surgeons are challenged to address this complication and efforts to facilitate nutritional support by additional pyloric procedures have a long history [3]. As the secondary complications of DGE include malnutrition, aspiration pneumonia, or even death, adding a pyloric procedure seems warranted.

However, it has been pointed out that pyloric procedures can themselves cause complications, including bile reflux, dumping syndrome, pylorus leakage/perforation, and delayed surgical time. In addition, it has been argued that additional pyloric procedures should not be performed, as their effect cannot be guaranteed. In 1998, Collard et al. [4] reported that the gastric conduit function recovered by itself after esophageal surgery and sometimes showed a contractile movement close to normal. This trend was more pronounced when the whole stomach was used as a conduit, rather than a tube. Another study based on long-term measurements of the neo-esophagus reported that gastrointestinal movement was unaffected by the anastomosis site (neck or chest) or the tract diameter [5]. A study that used gastric manometry and videofluoroscopy to identify the movement of the gastrointestinal tract after esophageal surgery revealed that the transposed stomach was a fairly dynamic organ and showed active movement in response to erythromycin [6].

In light of this variety of claims, a meta-analysis by Urschel et al. [7] in 2002 indicated that early postoperative gastric outlet obstruction (GOO) after esophagectomy occurred less often when pyloric drainage (PD) procedures were performed, but it had little effect on other early and late outcomes. In other words, pyloric procedures can improve GOO, but the supporting evidence was insufficient and other clinical parameters were not improved. There-

https://doi.org/10.5090/kjtcs.2020.53.4.233

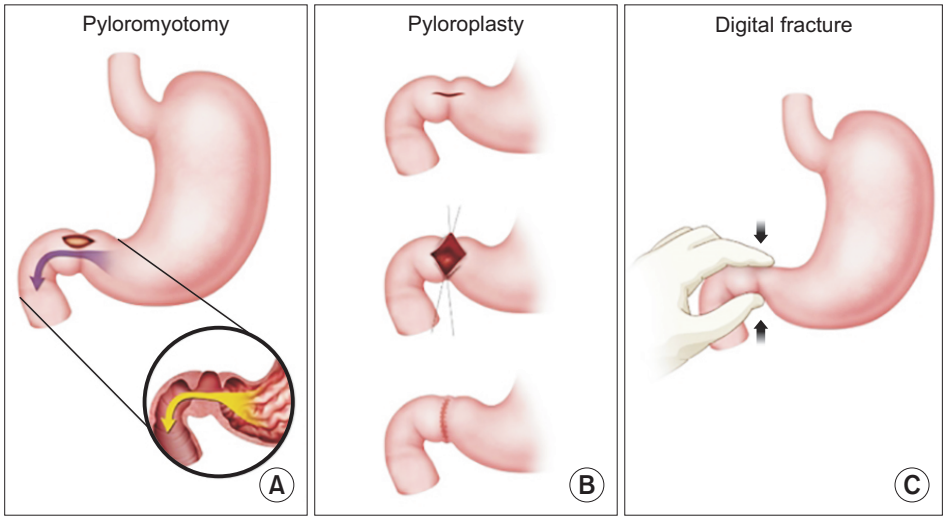

Fig. 1. Surgical pyloric procedures. The Ramstedt's pyloromyotomy can be summarized as an extra-mucosal longitudinal division of the pyloric muscle without sutures (A). The method of opening the pylorus longitudinally and suturing it transversely is called the Heineke–Mikulicz method (B). Digital or finger fracture is a method in which a surgeon applies pressure to the pyloric muscle using the fingers without the aid of other surgical instruments (C).

fore, the author could not answer the question of "What is the optimal pyloric procedure?"

Modern surgical techniques for the esophagus have evolved considerably from conventional to minimally invasive surgery, including video-assisted thoracoscopic surgery (VATS) and robot-assisted thoracoscopic surgery (RATS). However, there is still a lack of consensus on the optimal pyloric procedure. Therefore, this study aimed to describe the various pyloric procedures that are performed after esophageal surgery and to investigate the optimal pyloric procedure through an in-depth analysis of related studies.

Pyloric procedures

Surgical pyloric procedure

Pyloromyotomy (Fig. 1A)

Ramstedt [8] performed the first pyloromyotomy (PM) for what is now called idiopathic hypertrophic stenosis in 1912 [8]. The Ramstedt's PM can be summarized as an extra-mucosal longitudinal dividing of the pyloric muscle without sutures [9]. Specifically, a superficial incision is made longitudinally above the avascular area of the pyloric muscle. The muscle fibers are then fractured to expose the underlying mucosa. Finally, the gastric mucosa bulges upward into the incision. Historically, PM was performed under laparotomy, but it was adapted to laparoscopy [10-13]. Recently, new and less invasive methods have been described, including a report stating that gastric per-oral endoscopic PM was a useful and safe method [14-17].

Pyloroplasty (Fig. 1B)

Pyloroplasty (PP) was first performed in 1886 by Dr. Heineke for the treatment of an obstructive pyloric mass [18]. Shortly thereafter, Mikulicz [19] reported a similar operation applied to a bleeding duodenal ulcer. Because of the similar timing of these 2 reports, the method of opening the pylorus longitudinally and closing it transversely is called the Heineke–Mikulicz method. The PP of Finney [20] was described in 1902, but is strictly a gastroduodenostomy. The Heineke–Mikulicz and Finney PPs are the most common techniques for the treatment of peptic ulcer disease. A recent study on laparoscopic Heineke–Mikulicz PP reported that 86% of patients showed improvement in gastric emptying, with normalization observed in 77% of cases; moreover, the gastric emptying half-time decreased from 175 to 91 minutes [21]. In addition, a study in which gastric electrical stimulator implantation was performed simultaneously with PP for the treatment of gastroparesis in 27 patients reported a 71% improvement in total symptom scores and normalization of gastric emptying in 60% of cases [22]. Like PM, PP has also evolved from laparoscopic to robot-assisted techniques and various clinical methods are simultaneously performed, rather than attempting to improve symptoms with a single procedure. Some reports have described new methods of PP that simplify existing surgical methods [23].

Digital fracture (Fig. 1C)

Pyloric digital fracture (DF) or finger fracture is a method in which a surgeon applies pressure to the pyloric muscle using the fingers without the aid of other surgical instruments. Since there is no direct muscle damage, the

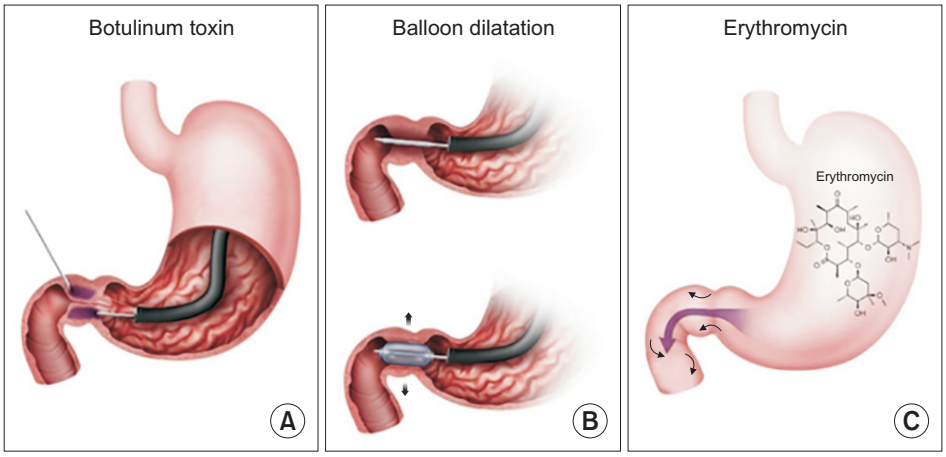

Fig. 2. Non-surgical pyloric procedures or medications. Botulinum toxin injection can be performed intraoperatively or through an endoscopic procedure after surgery, so it is an attractive alternative to surgical pyloric procedures (A). Endoscopic balloon dilatation is an effective method to expand the narrowed pylorus to the desired diameter and length by expanding a balloon through an endoscope (B). Erythromycin is a motilin agonist that can stimulate the gastric conduit to improve gastric emptying (C).

function of the pyloric sphincter is thought to gradually recover; thus, this method is performed with the expectation that complications such as bile leakage, perforation, and dumping syndrome will be minimized relative to other pyloric procedures. Records in 1882 indicate that Loreta [24] first attempted digital dilatation of a pyloric orifice during gastric surgery [24]. In a recent study, Kim et al. [25] performed finger disruption of the pylorus in 257 esophagectomy patients in 2008. The procedure was explained as simply a pinching or crushing of the pylorus to break the pyloric ring. In 2010, Deng et al. [26] described their DF method as (1) clarification of the pyloric canal, and (2) pinching of the pyloric anterior wall with the first and index fingers perpendicular to the pyloric sphincter with (3) 10–20 seconds of pressure. Several studies have assessed DF along with other pyloric procedures; however, research only on DF or on new DF methods is limited.

Non-surgical pyloric procedures or medications

Botulinum toxin injection (Fig. 2A)

Botulinum toxin (BT) blocks the release of acetylcholine into the neuromuscular junction to inhibit muscle contraction, including that of the pyloric sphincter. Not only is this effect similar to that of surgical pyloric procedures, but the effects of the toxin disappear over time, thus preventing permanent impairment of pyloric function. In addition, since BT can be performed through an endoscopic procedure after surgery, it is an attractive alternative to surgical pyloric procedures. Various papers have described the effects of BT [27-29]. Most reported a shorter operation time and superior outcomes to those of other existing pyloric procedures; however, Eldaif et al. [27] reported increased reflux symptoms and a requirement for postoperative interventions with BT.

Endoscopic balloon dilatation (Fig. 2B)

Endoscopic balloon dilatation (EBD) is an effective method for DGE after esophagectomy to expand the narrowed pylorus by the desired diameter and length by expanding a balloon through an endoscope, with fewer side effects. In 2008, Kim et al. [25] reported successful balloon dilatation in 21 patients with DGE among 157 patients undergoing esophagectomy. DGE improved after balloon dilatation in all patients. In 7 of 19 patients, the DGE rate significantly improved (30%–88%). There were no complications related to the procedure. In 2011, Lanuti et al. [30] reported the results of balloon dilatation in 98 GOO patients among 436 patients undergoing esophagectomy with a gastric conduit. Among the 38 patients in whom EBD was performed, the success rate was 95%, without evident complications.

Erythromycin (Fig. 2C)

Erythromycin is a motilin agonist that can stimulate the gastric conduit to improve gastric emptying. Both oral and intravenous erythromycin are effective in accelerating gastric emptying in esophagectomy patients. A 1996 study by Burt et al. [31] reported that the mean percent of radiolabeled meal retained in the stomach was reduced by more than 50% following the injection of erythromycin lactobionate (200 mg in 50 mL saline) into 24 patients who underwent esophagogastrectomy. The rate of gastric emptying was also significantly higher in the erythromycin group [31]. In 2002, Nakabayashi et al. [32] conducted a study of 23 esophagectomized patients. Significantly increased pyloric and antral motility were observed at 12 and 24 months postoperatively. The esophagectomized patients

https://doi.org/10.5090/kjtcs.2020.53.4.233

showed DGE, but erythromycin significantly accelerated gastric emptying [32].

Comparative studies and expert reviews

Determining the optimal pyloric procedure is difficult. If the same operation is performed in similar patients and evaluated in the same way, results close to the correct answer will be obtained. However, the following difficulties exist. First, there is considerable diversity in patients among studies. Differences in patients' race, diet, disease (malignant or benign), and daily activity can affect food intake and subjective DGE or GOO symptoms, which are difficult to evaluate. Second, there is variety in the surgical options, including the surgical method (open, VATS, or RATS), approach (neck+abdomen, thorax+abdomen, or neck+thorax+abdomen), conduit (stomach, colon, or jejunum), and route (subcutaneous, sub-sternal, or post-mediastinal). These variations result in different clinical outcomes. Third, several methods exist to evaluate DGE or GOO including subjective symptoms, endoscopy, radiopaque markers, gastric scintigraphy, questionnaires, and barium studies. Moreover, as the function of esophageal conduits changes over time after surgery, different results may be obtained depending on the evaluation period [4,6,26]. Finally, endoscopic techniques (EBD, BT, and even PM) [14-16,30,33,34] can be used for DGE or GOO, with different outcomes. As such, there is difficulty in controlling for these numerous variables to identify the optimal pyloric procedure. Therefore, high-quality studies had difficulties in drawing conclusions. With the goal of overcoming these difficulties, we will classify the published studies in chronological order according to whether they are in favor of or against the pyloric procedures and describe the core findings and limitations of each.

Studies in favor of pyloric procedures (Table 1)

In 1991, Fok et al. [35] published a prospective randomized trial of 200 esophageal cancer patients. The entire stomach was used as a conduit and the PP and no-PD groups included 100 patients each. Gastric emptying tests showed times of 6.6±7.5 and 24.3±31.5 minutes in the PP and no-PD groups, respectively ($p<0.01$). More patients in the PP group were able to tolerate a solid diet at normal or increased amounts than were patients in the control group in the early postoperative weeks ($p<0.01$). In addition, the no-PD group had difficulty eating even up to 6 months after surgery. Therefore, the authors recommended PP for Asians undergoing esophagectomy for esophageal cancer and whole stomach reconstruction.

In 2002, Urschel et al. [7] performed a meta-analysis including 9 randomized controlled trials with 553 patients. Operative mortality, esophagogastric leaks, pulmonary morbidity, PD complications, fatal pulmonary aspiration, and GOO were compared in the groups with and without PD. Less GOO was reported in the PD group (relative risk, 0.18; $p=0.046$) but the other parameters did not differ significantly. Although there was not a significant difference, a semi-quantitative review showed a trend favoring PD for the late outcomes of gastric emptying, nutritional status, and GOO symptoms. Regarding bile reflux, a non-significant trend favoring the no-drainage group was observed.

Deng et al. [26] published a report on DF in 2010. The retrospective study had a limited number of patients. However, PD was performed by the relatively simple DF method and the study is significant in that objective methods such as manometry, a questionnaire, and gastric scintigraphy were used to evaluate gastric emptying. This study found that performing DF improves the initial DGE.

In 2014, Antonoff et al. [36] published a retrospective study comparing various pyloric procedures. Most patients used gastric tubes as a conduit in cases of esophageal cancer. Most patients underwent PP or PM (197 patients), while 44 patients underwent digital dilation (DI) of the pylorus and BT simultaneously, and the number of patients was the same in the no-PD group. The method of evaluating gastric emptying was not described in detail; however, a comparison of postoperative complications and intervention showed a higher rate of aspiration in the no-PD group. DI+BT resulted in more complications than PP or PM.

Eldaif et al. [27] also analyzed 322 patients retrospectively in the same year. Most patients with esophageal cancer underwent a gastric conduit via various surgical methods including the Ivor Lewis, McKeown, or transhiatal techniques. The patients were divided into BT, PM, and PP groups according to the PD method. A contrast medium study was used to evaluate gastric emptying, and complications were compared according to each pyloric procedure. Mortality, postoperative dilation of the pylorus, and reflux occurred significantly more often in the BT group. Thus, the authors concluded that intrapyloric BT should not be used as an alternative to standard PD.

Studies against pyloric procedures (Table 2)

In 1995, Zieren et al. [37] published a randomized controlled study comparing PP and no PD. Although they ob-

Table 1. Studies supporting pyloric drainage

Year	Authors	Design, comparison, patients	Surgery	Evaluation	Results	Conclusions
1991	Fok et al. [35]	RCT; PP vs. no PD; PP (n=100), no PD (n=100); esophageal cancer	Whole stomach; extra-mucosal PP	Radioisotope	Gastric emptying; 6.6 min (PP)<24.3 min (no PD); solid, normal, or increased diet; more tolerable in PP	PP is recommended.
2002	Urschel et al. [7]	Meta; 9 RCTs; n=553	Heterogeneity (whole stomach vs. gastric tube, cervical vs. intrathoracic, various PP)	Heterogeneity (contrast study, etc.)	Less GOO in PD (RR, 0.18; p=0.046); no differences in mortality, esophageal leaks, and pulmonary/PD complications	PD reduces early GOO.
2010	Deng et al. [26]	Retro; DF vs. no PD; DF (n=48), no PD (n=30)	Cervical anastomosis; stomach; digital fracture; single surgeon	Manometry (during operation); questionnaire (POD #10); gastric scintigraphy (POD #14)	DGE: 13% (no PD), 0% (DF); emptying time: 130 min (no PD), 90 min (DF)	DF can prevent early DGE.
2014	Antonoff et al. [36]	Retro; PP/PM vs. no PD vs. DI vs. DI+BT; PP/PM (n=197), no PD (n=44), DI (n=8), DI+BT (n=44); esophageal cancer	Gastric tube (99%); transthoracic (56%); transhiatal (44%); 6 surgeons	Not described	Leakage: 5% (PD), 7% (no PD), 11% (DI+BT); postoperative intervention: 3% (PD), 16% (no PD), 7% (DI+BT); aspiration: 2% (PD), 11% (no PD), 5% (DI+BT)	No PD results in more aspiration. DI+BT showed more complications than PP/PM.
2014	Eldaif et al. [27]	Retro; BT vs. PM vs. PP; BT (n=78), PM (n=45), PP (n=199); esophageal cancer (86%)	Gastric conduit; heterogeneity (Ivor Lewis, McKeown, or transhiatal)	Contrast study (POD #5–7)	Reflux: 33% (BT), 12% (PM), 13% (PP); mortality: 12% (BT), 7% (PM), 3% (PP); postoperative dilation of pylorus: 24% (BT), 5% (PM), 1% (PP)	BT is not recommended as a pyloric procedure.

RCT, randomized controlled trial; PP, pyloroplasty; PD, pyloric drainage; Meta, meta-analysis; GOO, gastric outlet obstruction; RR, relative risk; Retro, retrospective study; DF, digital pyloric fracture; POD, postoperative day; DGE, delayed gastric emptying; PM, pyloromyotomy; DI, digital dilation; BT, botulinum toxin injection.

Table 2. Studies against pyloric drainage

Year	Authors	Design, comparison, patients	Surgery	Evaluation	Results	Conclusions
1995	Zieren et al. [37]	RCT; PP vs. no PD; PP (n=52), PD (n=55)	Stomach; cervical; extra-mucosal PP	Contrast study	Symptom/radiologic emptying; no difference; severe gastrointestinal symptom in PP; mortality (n=1; due to PP)	No PP is recommended.
2007	Lanuti et al. [33]	Retro; PM vs. no PD; PM (n=159), no PM (n=83)	Heterogeneity (Ivor Lewis, transhiatal, thoracoabdominal)	Contrast study (POD #4–7); endoscopy	GOO: 18% (PM), 10% (no PM), p=0.08; respiratory failure: 4% (PM), 8% (no PM), p=0.2; mortality: 2.5% (PM) vs. 2.4% (no PM), p=0.96	Routine PD may be unwarranted.
2007	Palmes et al. [38]	Retro; PP vs. PM vs. no PD; PP (n=34), PM (n=118), no PD (n=46)	Stomach; Ivor Lewis (94%)	Contrast study (POD #4); endoscopy (postoperative 12 mo)	Leakage: 12% (PP), 15% (PM), 17% (no PD); aspiration pneumonia: 3% (PP), 4% (PM), 7% (no PD); risk factors of reflux esophagitis: PP+PM (RR, 2.5; p=0.003)	PP+PM should be omitted.
2009	Cerfolio et al. [29]	Retro; PP, PM, no PD vs. BT; PP (n=28), PM (n=71), no PD (n=54), BT (n=68); esophageal cancer	Gastric tube and Ivor Lewis operations (100%); BT (during operation); single surgeon	Contrast study (POD #4)	Operation time: 4.3 (PP), 3.9 (PM), 3.5 (no PD), 3.3 (BT); DGE/bile reflux: PP (96%, 38%), PM (93%, 20%), no PD (96%, 9%), BT (59%, 6%); pneumonia/aspiration: 32% (PP), 14% (PM), 22% (no PD), 13% (BT)	BT is recommended (less operation time, DGE, reflux, complications).
2010	Nguyen et al. [39]	Retro; PP vs. no PD; PP (n=31), no PD (n=109)	Minimally invasive surgery (100%)	Contrast study; subjective symptoms	DGE, leakage: 6%, 9.6% (no PD), 3%, 9.7% (PP); operation time: 222 min (no PD), 360 min (PP); esophagitis; 6% (no PD), 4% (PP)	PP can be omitted during minimally invasive surgery.
2011	Lanuti et al. [30]	Retro; PM vs. no PD; PM (n=179), no PD (n=257); cancer+benign	Heterogeneity (Ivor Lewis, McKeown, transhiatal, etc.); various surgeons	Contrast study; subjective symptoms	GOO: 28% (PM) vs. 18% (no PD), p=0.01; no difference regarding clinical outcomes; except for hospital stay and nasogastric insertion	PM may not be routinely warranted.
2012	Bagheri et al. [28]	RCT; PP vs. BT; PP (n=30), BT (n=30); esophageal cancer	Stomach; cervical anastomosis	Contrast study (POD #7); isotope scan (POD #21)	Normal emptying: 80% (BT) vs. 70% (PP), p=0.446; normal gastric discharge: 93% (BT) vs. 76% (PP), p=0.355	BT may be used instead of PP (simple, effective, and complication-free method).
2018	Fritz et al. [40]	Retro; no comparison; no PD (n=170)	Gastric tube; Ivor Lewis	Clinical signs	Complications: leakage (24%), GOO (17%), pneumonia (27%), DGE (17%)	PD may be unwarranted in Ivor Lewis operation.

RCT, randomized controlled trial; PP, pyloroplasty; PD, pyloric drainage; Retro, retrospective study; PM, pyloromyotomy; POD, postoperative day; GOO, gastric outlet obstruction; RR, relative risk; BT, botulinum toxin; DGE, delayed gastric emptying.

https://doi.org/10.5090/kjtcs.2020.53.4.233

served no difference in clinical symptoms and radiologic emptying between the two groups, the authors concluded that PP was not recommended because 1 patient with PP had severe digestive symptoms and another died of PP-related complications.

In 2007 and 2011, Lanuti et al. [30,33] published retrospective studies comparing PM and no PD. Gastric passage was evaluated through a contrast study. The 2007 study observed no statistically significant differences in GOO, respiratory failure, and mortality rates, but concluded that "routine PD may be unwarranted." The results of the 2011 study demonstrated a significantly higher occurrence of GOO in the PM group, but did not prove a correlation between GOO and clinical outcomes. In addition, although the authors concluded that PM may not be routinely warranted in the 2011 study, they explained that a limitation of the paper was that PD was performed depending on the subjective judgment of the surgeon and there was the possibility of differences in conduit size and route, as well as incomplete PM.

In 2007, Palmes et al. [38] published a study comparing PP, PM, and no PD. Most patients underwent Ivor Lewis operation. The short- and long-term results were objectively evaluated using contrast study and endoscopy. Esophageal leakage and aspiration pneumonia were the most common in the no PD group. However, the authors concluded that, after including PP and PM in the same category of PD, PD (PP+PM) should not be performed due to the significantly higher incidence of reflux esophagitis in the PD group.

In 2009, Cerfolio et al. [29] published a similar retrospective study, but included results from BT injections. Their study involved patients operated on by a single surgeon using a single surgical method, with objective evaluation conducted through a contrast study. The authors concluded that BT has the advantage of shorter operating time, lower DGE, bile reflux, and pneumonia/aspiration than was found for PP, PM, and no PD and that BT could be an effective alternative to PD.

In 2010, Nguyen et al. [39] published a retrospective study comparing PP and no PD in patients who underwent minimally invasive esophagectomy. DGE and esophagitis were more common in the no-PD group, the leakage rates were similar, and the operation time was shorter in the no-PD group. The authors concluded that PP can be omitted during minimally invasive surgery, but the evidence for this is insufficient. Moreover, the large difference in the number of patients in each group (PP: n=31 versus no PD, n=109) made comparisons difficult.

In 2012, Bagheri et al. [28] published a randomized controlled study comparing PP and BT. Although there was no statistically significant difference in the emptying rate or gastric drainage, the authors recommended BT because it is simple, effective, and complication-free. In 2018, Fritz et al. [40] published a retrospective study without a control group. Ivor Lewis operations were performed using a gastric tube and the authors concluded that PD may not be warranted because the complication rate did not differ significantly from that of historical PD studies.

Other expert reports and recommendations

Authors who support drainage have recommended that PD (either PP or PM) be implemented based on statistically significant differences. However, those who oppose PD have done so not because PD showed statistically poor results, but rather because omitting the procedure led to no statistically significant difference. Moreover, conduit movements sometimes improved by themselves and positive results were reported from postoperative endoscopic procedures. Both sides of this argument have limitations; thus, it is difficult to unilaterally accept the claims of either group.

Other expert reviews have also described this difficulty. In 2014 and 2105, respectively, Gaur and Swanson [41] and Arya et al. [42] published review articles on optimal pyloric procedures based on analyses of 4 and 6 studies, respectively. Gaur and Swanson [41] reported that PD showed no statistically significant impact on DGE, but had positive effects on leakage and pulmonary complications. However, the heterogeneity between studies was so severe that it was difficult to draw a solid conclusion. Arya et al. [42] reported that PD reduced the occurrence of DGE, but that the difference was not significant. Moreover, a meaningful conclusion could not be drawn owing to the severe heterogeneity in DGE definitions and evaluation methods between studies.

The results of the studies to date lack sufficient decisive evidence to change existing policies regarding pyloric procedures. Therefore, rather than defining an optimal pyloric procedure, additional systematic research is needed to achieve a consensus on the definitions and evaluation methods for DGE or GOO. For example, it is reasonable to refer to the DGE definition from the International Study Group of Pancreatic Surgery [43]. Moreover, as several objective methods have been introduced and used, an expert group should officially determine which evaluation method should be used.

Conclusion

Recent advances in interventional technology and minimally invasive surgery have led to an increasing number of questions about the practice of pyloric procedures. However, many clinicians still perform these procedures and they are at least somewhat effective. To provide guidance on the optimal pyloric procedure, DGE should first be defined clearly, and then a large-scale study with an objective evaluation method is required.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Funding

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2017R1C1B5015969).

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