World Journal of Gastroenterology

Online Submissions: http://www.wjgnet.com/1007-9327office
wjg@wjgnet.com
doi:10.3748/wjg.v16.i13.1610

World J Gastroenterol 2010 April 7; 16(13): 1610-1621
ISSN 1007-9327 (print)

REVIEW

Techniques for colorectal anastomosis

Yik-Hong Ho, Mohamed Ahmed Tawfik Ashour

Yik-Hong Ho, Mohamed Ahmed Tawfik Ashour, Discipline of Surgery, School of Medicine, James Cook University, Townsville, QLD 4811, Australia
Author contributions: Ho YH and Ashour MAT contributed equally to this review.
Correspondence to: Yik-Hong Ho, MD, FRCSEd, FRCS (Glasc.), FRACS, FICS, Professor and Head of Surgery, Discipline of Surgery, School of Medicine, James Cook University, Clinical School 1MB52, Angus Smith Dr, Douglas, Townsville, QLD 4811, Australia. yikhong.ho@jcu.edu.au
Telephone: +61-7-47961417 Fax: +61-7-47961401
Received: December 15, 2009 Revised: January 20, 2010
Accepted: January 27, 2010
Published online: April 7, 2010

Abstract

Colorectal anastomotic leak remains one of the most feared post-operative complications, particularly after anterior resection of the rectum with, the shift from abdomino-peritoneal resections to total mesorectal excision and primary anastomosis. The literature fails to demonstrate superiority of stapled over hand-sewn techniques in colorectal anastomosis, regardless of the level of anastomosis, although a high stricture rate was noted in the former technique. Thus, improvements in safety aspects of anastomosis and alternatives to hand-sewn and stapled techniques are being sought. Here, we review alternative anastomotic techniques used to fashion bowel anastomosis. Compression anastomosis using compression anastomotic clips, endoluminal compression anastomotic rings, AKA-2, biofragmental anastomotic rings, or Magnamosis all involve the concept of creating a sutureless end-to-end anastomosis by compressing two bowel ends together, leading to a simultaneous necrosis and healing process that joins the two lumens. Staple line reinforcement is a new approach that reduce the drawbacks of staplers used in colorectal practice, i.e. leakage, bleeding, misfiring, and inadequate tissue approximation. Various non-absorbable, semi or fully absorbable materials are now available. Two other techniques can provide alternative anastomotic support to the suture line: a colorectal drain and a polyester stent, which can be utilized in ultra-low rectal excision and can negate the formation of a defunctioning stoma. Doxycycline coated sutures have been used to overcome the post-operative weakness in anastomosis secondary to rapid matrix degradation mediated by matrix metalloproteinase. Another novel technique, the electric welding system, showed promising results in construction of a safe, neat, smooth sutureless bowel anastomosis. Various anastomotic techniques have been shown to be comparable to the standard techniques of suturing and stapling. However, most of these alternatives need to be accepted and optimized for future use.

Key words: Alternative anastomosis; Compression anastomotic clip; Compression anastomotic ring; Biofragmental anastomotic ring; AKA-2; Magnamosis (magnetic anastomosis); Matrix metallo-proteinase; Sutureless

Peer reviewer: Antonio Basoli, Professor, General Surgery "Paride Stefanini", Università di Roma-Sapienza, Viale del Policlinico 155, Roma 00161, Italy

Ho YH, Ashour MAT. Techniques for colorectal anastomosis. *World J Gastroenterol* 2010; 16(13): 1610-1621 Available from: URL: http://www.wjgnet.com/1007-9327/full/v16/i13/1610.htm
DOI: http://dx.doi.org/10.3748/wjg.v16.i13.1610

INTRODUCTION

Since the first reports of laparoscopic colectomy in the 1990's, this technique has matured into a well-developed mode of therapy. It has introduced the colorectal surgical world to the advantages, and the unique perspectives and concerns of minimal access surgery. Colorectal anastomotic leakage remains one of the most feared post-operative complications, particularly after anterior resection of the rectum, with the shift from abdomino-peritoneal resections to total mesorectal excision and primary

anastomosis. It is also associated with a higher local recurrence rate and lower long-term survival. Moreover, long-term functional outcome might be adversely affected by anastomotic leakage[1-4]. The importance of surgical technique is underscored by the wide variations of anastomotic leakage rates among surgeons. The frequency of anastomotic leakage ranges from 1% to 24%[5-7]. The rate of leakage is generally considered to be higher for elective rectal anastomosis (12% to 19%) than for colonic anastomosis (11%)[8-10].

PHYSIOLOGY OF GASTROINTESTINAL HEALING

Better appreciation of the principles of intestinal healing will lead to a better adoption of techniques to overcome the risk factors inherent to the laparoscopic approach and hence anastomotic dehiscence. The environment for wound healing is substantially different in an anastomosis, due to the presence of shear stress (secondary to intraluminal bulk transit and peristalsis), as well as the presence of aerobic and anaerobic bacteria.

The process of intestinal anastomotic healing can be arbitrarily divided into an acute inflammatory (lag) phase, a proliferative phase, and, finally, a remodeling or maturation phase. Collagen is the single most important molecule for determining intestinal wall strength, which makes its metabolism of particular interest for understanding anastomotic healing. After surgery, degradation of mature collagen begins in the first 24 h and predominates for the first four days. This is caused by the upregulation of matrix metalloproteinases (MMPs), which are an important class of enzymes involved in collagen metabolism. *In vivo* use of MMP inhibitors has been found to increase the strength of intestinal anastomoses by up to 48% at postoperative day three, which suggests that these enzymes are important in determining the risk of leakage. By postoperative day seven, collagen synthesis takes over, especially proximal to the anastomosis. After five to six weeks, there is no significant increase in the amount of collagen in a healing wound or anastomosis, though turnover and, thus synthesis, are extensive. The strength of the scar continues to increase progressively with time. The orientation and the cross-linking between collagen fibers maintain the tensile strength of the tissues[11,12].

Bursting pressure is used as a quantitative measure to grade the strength of an anastomosis *in vivo*. This pressure has been found to increase rapidly in the early postoperative period, reaching 60% of the strength of the surrounding bowel by three to four days and 100% by 1 wk[11]. In 1887, Halsted[13] discovered that the submucosa provides the GI tract with the majority of its tensile strength. The bulk of collagen is contained within this layer, along with blood vessels, lymphatics, and nerve fibers. Type I collagen predominates (68%), followed by type Ⅲ collagen (20%), and type V collagen (12%). The serosa is a thin layer of connective tissue that covers the muscularis propria. When creating an anastomosis, direct apposition of this layer minimizes the risk of leakage[14,15]. During the first postoperative days, anastomotic strength is limited, and hence the risk of wound failure is greatest, as collagen breakdown increases. Early anastomotic strength is therefore dependent on the suture- or staple-holding capacity of existing collagen, until a large amount of new collagen can be synthesized by both fibroblasts and smooth muscle cells. Postoperatively, anastomosis will be weak for one or two days until this occurs[16-19].

FASHIONING ANASTOMOSES

Over the past two decades, numerous different materials have been used to join one bowel end to another, including catgut, stainless steel, and newer monofilamentous and absorbable sutures. In the past 30 years, stapling devices have been embraced enthusiastically by the surgical community[11]. However, the choice of either technique in fashioning anastomoses is a matter of controversy among various schools[18].

Apart from inert substances, most foreign materials will evoke an inflammatory reaction in the human body and surgical sutures are no exception. It is now known that silk has the ability to evoke an inflammatory reaction that can persist for weeks after implantation. Substances such as polypropylene (Prolene), catgut, and polyglycolic acid (Dexon) evoke a milder response. There is little difference between absorbable and nonabsorbable sutures with respect to the strength of the anastomosis[11].

STAPLING

Surgical stapling devices were first introduced by Hültl, Humer (Budapest) in 1908; but their use has grown since the introduction of new and reliable disposable instruments in the past 30 years[11]. However despite comparable results in terms of mortality, anastomotic dehiscence, and wound infection, the rate of stricture at the anastomotic site is considerably higher with staples than with sutures: 8% *vs* 2%, respectively, for colorectal anastomosis[20].

Lim *et al*[21] confirmed the presence of foreign body reaction in stapled human GI anastomoses. The source of the foreign materials eliciting this reaction was the stapler cartridges.

The literature fails to demonstrate superiority of stapled over hand-sewn techniques in colorectal anastomosis, regardless of the level of anastomosis, although a high stricture rate was noted with the former technique.

The use of staplers for intraperitoneal anastomosis has been questioned[20]; Matos systematically reviewed (Cochrane Database) nine studies involving 1233 patients (622 stapled and 611 hand-sewn) and found that overall leaks were 13% *vs* 13.4%, clinical 6.3% *vs* 7.1%, radiological 7.8% *vs* 7.2%. There was insufficient evidence to demonstrate superiority of either technique[20]. The decision over which technique to use must be judged on the basis of previous experience, clinical circumstances, and available resources. Another systematic review showed that both techniques (stapler *vs* Hand-sewn) are effective,

and the choice may be based on personal preference[22]. Other prospective and randomized trials have shown different results. No significance intergroup difference was found in regard to time for anastomosis construction or occurrence of complications in colorectal anastomosis[23]. In addition, the routine use of stapling instruments for infraperitoneal colorectal anastomosis could not be recommended because of a higher incidence of mishaps and strictures, even though the operation took less time to perform and anastomotic leakage occurred less often[24].

Therefore, there is an ongoing search for an ideal method of anastomosis that would not only lower the incidence of dangerous complications, but also avoid the need for a defunctioning colostomy or ileostomy. Based on the aforementioned data, there is still controversy between surgeons.

It is therefore necessary to review all relevant studies and trials to resolve this issue. Multi-center, well-designed, randomized controlled trials are required to build a link between new technology and practice. As technology advances, the use of newer techniques should allow improvements in the quality of patient care.

COMPRESSION ANASTOMOSIS

Connecting sections of the intestine after the surgical removal of a diseased portion has been the subject of research and invention since the 19th century. The goal has been to find a method to eliminate the leakage associated with anastomosis. The principle of compression anastomosis consists of two opposing rings trapping the cut ends of the transected bowel with subsequent ischemia and eventual sloughing of the trapped bowel, thus releasing the rings into the fecal stream[25]. Despite its technical safety, it was not accepted[26].

The idea of compression anastomosis was first reported in 1826 by Denan, who conceived a sutureless bowel anastomosis that encompassed the inverting technique proposed by Lembert. The idea was to compress two bowel walls together and cause a simultaneous necrosis and healing process leading to the joining of the two lumens. In 1892, Murphy introduced a mechanical device known as "Murphy's button" that was used for years[27].

It comprises a pair of metal rings that hold circular segments of intestine together under continuous pressure; the rings are expelled several days after surgery. However, its clinical success was limited and the results were mediocre. Moreover, it was a metallic foreign body that remained in the lumen of the bowel for several days until it was spontaneously discharged from the body with the necrotic tissues[28].

In the 1980s a device comprising two magnetic rings was used for intestinal anastomosis, but this concept was not further pursued[29].

In 1984, Kanshin *et al*[30] developed the AKA-2 device (Seidel Medipool, Munich, Germany) for colorectal surgery. In 1985, Hardy *et al*[31] introduced the Valtrac biofragmentable anastomotic ring (BAR) (Davis and Geck/Cyanamid, Danbury, CT). Numerous publications, including prospective randomized controlled trials (RCTs), reported that the BAR was safe and efficacious in both emergency and elective surgery[31-39]. Both devices adopted the concept of compression anastomosis, and incorporated some of the basic features of Murphy's button. However, in contrast to the BAR, the AKA-2 ring is not absorbable and it is usually disconnected from the anastomosis after four to six days. In addition, it was made exclusively for transanal application[40].

Years later a novel device for performing compression anastomosis using the shape memory alloy (SMA) of nickel-titanium was introduced. The device is available both as a clip (Compression Anastomosis Clip or CAC, NiTi Medical Technologies, Netanya, Israel), and as a ring (Compression Anastomosis Ring or CAR, NiTi Medical Technologies). After approximately one week, the entire device, together with the necrosed tissue, detaches and is naturally expelled from the body[41-44]. A summary of the four main types of compression devices is presented in Table 1.

CLASSIFICATION OF DIFFERENT COMPRESSION DEVICES

Valtrac™ BAR

Valtrac™ BAR is composed of two segments containing absorbable polyglycolic acid (87.5%) and barium sulfate (12.5%). It comes in a size range (25, 28, 31, and 34 mm). The two components interdigitate on a central frame; a 6-mm gap is seen between the scalloped edges of the BAR in the open position, and a 1.5-mm, 2-mm, or 2.5-mm gap is made in the fully closed position to accommodate different thicknesses of bowel wall. This also limits the amount of tissue necrosis[45].

Each ring is securely placed into the cut bowel ends with the aid of a purse-string suture, and the device snapped shut. Between two and three weeks after the operation, the BAR rings fragment and are passed into the stool. This results in the production of a sutureless, inverted, serosa-to-serosa intestinal anastomosis[46]. The BAR has been used for construction of various types of anastomosis, including procedures involving the upper and lower GI tract. Prior to the development of the transanal applicator, early studies often excluded patients with low rectal anastomosis[47].

In a randomized control trail comparing BAR with stapling devices in extra-peritoneal mid-rectal anastomosis, surgeons did not consider the use of BAR to be more difficult than a stapled anastomosis. The time required to create a BAR anastomosis was slightly shorter than the time needed for a stapled anastomosis, although this was not statistically significant. The overall operating time, intraoperative blood loss, and postoperative complication rates were similar with both anastomotic techniques[48]. Correspondingly, there were no statistical differences in the complication rates between the BAR and a sutured anastomosis in elective and emergency procedures[48].

Table 1 Characteristics of the four main compression devices

	BAR	AKA-2	CAC	EndoCAR[27]
Absorbable	Yes	No	No	No
Application	Laparoscopy, laparoscopy, transanal	Transanal	Laparotomy, laparoscopy, hand-assisted lap	Laparotomy, laparoscopy, hand-assisted lap
Internal Lumen	11-20	25, 28, 31	8	One ring size (27 mm) replaces a number of competitive sizes (25-34 mm)
Average time to expulsion (d)	14-21	4-6	7	7-10
Type of surgery				
Elective/emergency	Yes/yes	Yes/yes	Yes/no	Yes/no
Foreign body reaction	No	Possible to metal pins	No	No
Tissue healing	Extensive fibrosis/may cause stricture	Extensive fibrosis/may cause stricture	Primary intention/no strictures reported	Primary intention/no strictures reported (recovery of multi-layer lumen structure)
Anastomotic index	Lumen capacity depends upon standardized ring size		Full lumen capacity within 8-12 wk	
Efficacy	Safe and secure and can be applied to achieve multiple anastomosis (in case requiring rapidity and security)			
Learning curve[1]	Technically difficult than the other three devices		Technically simple after education	
Cost[2]	About $600	NA	About $3	NA (however higher than conventional staples)
Tissue thickness accommodation	Selecting ring size to be compatible with diameter and thickness of bowel wall	Same as BAR	Only one size, shape memory alloy that accommodates varies tissue thickness. Unique thermo-mechanical properties and super elasticity	
Type of anastomosis	End-to-end, end-to-side, side-to-side		Side-to-side	End-to-end
Site of anastomosis	Suitable for intestinal, colonic and rectal anastomosis	Distal colon and rectal only	Intestinal, colonic and rectal anastomosis	

[1]Galizia *et al*[47] described a learning curve of nine patients for BAR anastomosis. A meta-analysis of over 500 cases in North America, Europe and Israel, 75% of surgeons rated the CAR[27] device to be very easy or easy to use[83]; [2]Cost-effectives depend upon a number of factors namely learning curve and post operative morbidity. However, as multiple staplers are used for construction of most colonic/rectal anastomosis, there might be a cost advantage for compression devices. BAR: Biofragmentable anastomotic ring; CAC: Compression anastomotic clip.

An initial study with large animal models (300 dogs and 31 pigs) presented a randomized analysis of 28 pigs, comparing sutured, stapled and BAR anastomosis. They found the "Burst" pressure at day 0 was highest with the BAR and equal at days seven and 16 in all three types of anastomosis. The authors stated that the BAR anastomoses were performed more easily and quickly than the other two anastomoses. Microscopic examination also revealed the least amount of tissue necrosis for the BAR anastomosis[46].

In 1987, Hardy *et al*[49] published results of the first 27 patients who had colorectal anastomoses using the BAR device. They reported no difficulties and all patients tolerated a regular diet before fragmentation of the rings.

In the 1990s, the device gained popularity and a number of prospective studies confirmed that the results with the device were satisfactory, although there were reports of intraoperative problems, such as failure of the purse-string suture, incorrect estimation of the diameter of the colon lumen, subsequent mucosal tears, and failure of the device to lock. Many of these might simply have been because of the operator's learning curve[33,50-53].

Based on the previously mentioned studies, possible limitations of the device include: (1) Failure of purse string sutures; (2) Incorrect estimation of colon lumen diameter; (3) Subsequent mucosal tears; (4) Failure of the device to lock (the bowel might be contused by closing maneuver from outside the gut); (5) Excessive snapping pressure could shatter the friable device; (6) fragmentation delay; (7) possibility of postoperative tenesmus and frequent stool passage before excretion of fragments; (8) bulky and uncomfortable device to deploy; and (9) potential risk of relative obstruction due to smaller inner diameter of the ring.

AKA-2

In 1984, Kanshin *et al*[30] developed the AKA-2 device (Seidel, Medipool) to address the transanal approach for compression anastomosis. The AKA-2 is composed of two rings: a base ring, which includes metal pins and metal springs, attached on a plastic ring (the "distal ring"), and a proximal plastic ring (the "proximal ring"). The rings are applied with a transanal applicator. The AKA-2 works on a similar principle to that of endoanal stapling devices, though the bowel edges are pressed together with intraluminal rings and held in place by metal pins. Circular blades cut the central cuff of bowel, and the metal pins ensure constant compression on the inverted bowel edges. The two plastic rings and the compressed resection margins separate from the anastomosis after four to six days and are expelled with the feces[46]. The technique had an advantage in that it created a good lumen size for stool passage.

There is only one report in English of the use of this device[40]; the majority of the literature being in Russian or German. A prospective audit presented the results of

442 patients undergoing colorectal surgery for benign and cancerous disease. There was a 5.4% overall complication rate, with 11 patients (2.5%) developing clinical features of an anastomotic leak, which is relatively low compared to other series using various anastomotic techniques[48,49,54,55]. Fourteen of the 442 patients died (3.2%), of which three cases were related to anastomotic leak (0.7%). Among 442 patients who underwent AKA-2 anastomosis only two patients developed a stricture[40].

The authors maintain that the advantage of this device is that it produces a good size lumen for the passage of feces. The plastic ring sizes are 25, 28, and 31 mm, respectively. In addition, necrosis of inverted resection margins is the only biological factor leading to the rejection of the plastic rings, which is an advantage in cases with delayed healing. However, early device exclusion raised the possibility of higher leak rate, as it is concurrent with the maximal breaking strength of anastomosis[46].

Compression anastomotic clip

Nitinol[60] (Nickel Titanium Naval Ordinance Laboratory), an alloy of nickel and titanium, is a temperature-dependent, shape-memory alloy (SMA) that has been used in the formation of compression anastomoses[56]. The metal is shaped under high temperatures, and when it is ice cooled (to less than 0℃), it loses its rigidity and becomes flexible. At or above room temperature, it resumes its preset configuration. It has been used mostly for vascular prostheses, orthodontic braces, and for internal fixation of bone fractures for its inherent advantage of controlled compression with a constant force[46].

The Nitinol CAC device (Niti Medical Technologies) has been approved by the food and drug administration (FDA) for use in GI surgery[41]. The device consists of a double-ring that, in the open and flexible state (at 0℃), has a diameter of 30 mm and an opening angle of 30 degrees. At body temperature, the rings return to their closed configuration and hold bowel tissue under a constant compressive force, regardless of the thickness of intervening tissue. This leads to ischemia of the entrapped bowel wall and the formation of a compression anastomosis. The internal diameter of the rings is 8 mm, and is pierced by a 5-mm blade built into the applicator to restore bowel continuity in the early period. The device is elastic, pliable, and easy to manipulate[46].

Initial reports on both animal and human studies using the CAC device to create a side-to-side anastomosis in upper and lower GI tracts revealed no signs of anastomotic stricture or leakage, with formation of a uniform, completely re-epithelialized anastomotic line[41]. There were no reported postoperative complications, and colonoscopic examination at six months demonstrated a satisfactory anastomosis[43].

The safety of this device has been documented in numerous animal studies[41,57], and the safety of the alloy has been demonstrated by its extensive uses in other medical procedures. The CAC was considered to be safe, simple, and effective in colon surgery in a study that evaluated the thermo-mechanical properties of the device[58].

In line with this conclusion, a randomized control trial studied the clinical effects of using the CAC device in small intestinal anastomosis proximal to the ileocecal valve. CAC anastomosis was performed in 33 out of 66 patients, with the other 33 patients being used as a control group for whom a stapled anastomosis was constructed. The main indication was gastric cancer in both groups. Anastomosis was fashioned to reconstruct a Roux-en-Y loop, entero-entrostomy, Billroth Ⅱ gastro-jejunostomy, and gastro-jejunostomy. The authors found no post-operative complications whatsoever in terms of leakage, obstruction, bleeding, or stenosis after six months of follow-up[59].

Clinical trials for SMA of nickel-titanium in intestinal anastomosis are scarce, and all of the clinical reports are of CAC from a single center that included only elective cases performed both by laparotomy and laparoscopically[42-44]. None of the patients who underwent surgery with CAC had a protective stoma. None of the patients reported so far in published clinical studies experienced a clinical leak and initial experience with a laparoscopic technique had similar results, thus precluding the learning curve among surgeons.

The consensus among the published studies was that microscopic examination of the CAC anastomosis showed minimal inflammation and no foreign body reaction, with very little scar tissue at the anastomotic line.

The specific advantages of the CAC include a one sized clip with a wide external diameter, preprogrammed round shape negating the need to forcefully close the rings and therefore diminish the risk of shattering the device. It exerts constant compression of the bowel ends, regardless of the intervening tissue thickness; coils exert a constant stress plateau at about 400 Mpa. The result is a smooth homogenous anastomosis formed by the gradual controlled necrosis of the tissue, limited by the coil perimeter while the external edges become sealed[46]. A drawback of this device is the need for suture closure of the insertion incisions made in the bowel wall.

Endoluminal compression anastomotic ring, EndoCAR[27]

The endoluminal compression anastomotic ring, EndoCAR[27] (spectrum of the shape memory alloy of nickel-titanium), utilizes two separate synthetic rings that are mounted on an instrument very similar to a circular stapler. An anvil containing one ring is fixed to the proximal bowel end, and the instrument with the other ring is inserted trans-anally for a rectal anastomosis. When engaged, the rings are locked together by Nitinol springs that exert the desired constant controlled pressure force (7.7 Newtons or 1.65 Pounds), and a circular knife resects the access tissue. As in the side-to-side device, a simultaneous necrosis-healing process takes place, and at the completion of this process (seven to ten days), the

Table 2 Compression anastomosis: clinical experience and complications

Study	Device	Emergency/elective	Anastomotic leakage	Obstruction	Stricture
Bubrick *et al*[34]	BAR	0/395	12 (3.2%)	18 (5%)	-
Cahill *et al*[35]	BAR	0/101	2 (2%)	4 (4%)	-
Corman *et al*[36]	BAR	0/222	6 (2.7%)	9 (4%)	2 (0.9%)
Gullichsen *et al*[37]	BAR	-	-	13 (16%)	-
Seow-Choen *et al*[39]	BAR	-	0	0	2 (10%)
Di Castro *et al*[49]	BAR	90/424	17	0	4 (1%)
Thiede *et al*[33]	BAR	0/1360	34 (2.5%)	-	-
Pahlman *et al*[38]	BAR	24/26	2 (4%)	3 (6%)	-
Ghitulescu *et al*[53]	BAR	23/136	7 (4.2%)	13 (7.9%)	3 (1.8%)
Kim *et al*[45]	BAR	101/515	5 (0.8%)	13 (2.1%)	1 (0.5%)
Wullstein *et al*[40]	AKA-2	70/372	11 (2.5%)	-	2 (0.5%)
Nudelman *et al*[43]	CAC	0/5	0	0	0
Nudelman *et al*[42]	CAC	0/30	0	0	0
Nudelamn *et al*[44]	CAC	0/10	0	0	0
Liu *et al*[59]	CAC	0/33	0	0	0

device is detached and expelled naturally. Furthermore, the longitudinally orientated metal prongs further fixate both bowel ends and prevent tissue slippage from axial movements. An advantage of this contemporary device is that there is no anastomotic-scarred lip inside lumen and a safe applier removal without fishtailing[60].

Two separate studies looked at bursting strength in a porcine model. Kopelman *et al*[57] measured a mean bursting strength of 247.7 mmHg (range 100-300 mmHg) in nine animals at time zero (immediately after the excision of the fashioned anastomosis). Furthermore Stewart *et al*[61] revealed a significantly higher bursting pressure after compression anastomosis in comparison with a conventional double stapling technique (103, 75.3 mmHg *vs* 3, 23 mmHg, respectively). Four of the nine compression anastomoses failed at the anastomotic line whereas nine of nine stapled anastomoses failed at the staple line (Fishers' exact test, $P < 0.01$). Bursting pressures measured at two weeks after the anastomosis revealed equal pressures (266, 32.2 mmHg and 230, 87.5 mmHg, respectively). Compression therefore seems to be capable of overcoming anastomotic weakness during the 'classical' lag-phase and to result in equal strength after detachment of the ring[62].

Kopelman *et al*[57] looked at the anastomotic index (ratio of the mean bowel diameter 5 cm proximal and distal to the anastomosis and on antero-lateral and posterior view), which was 0.81 (0.60-0.92) at two months.

An early clinical trial was performed in Israel using the EndoCAR[27] device to construct a left-side anastomosis. Four patients were enrolled. No device related complications were noted in these patients and no anastomotic leak reported (unpublished data). Based upon that experience, a pilot study was started in May 2007 in Uppsala (Sweden) and in Leuven (Belgium) to obtain clinical data in a consecutive group of 40 patients[62]. The recruited patients had either malignant or benign (diverticular) disease requiring resection with a high colorectal anastomosis (between 10 and 15 cm from the anal verge). Preliminary results from that pilot study showed that of the first ten patients, nine underwent high anterior resection, and left colectomy was performed on one patient. No leak age occurred in this first group of patients. No other data is available yet.

These promising results demonstrate that this device could be a revolutionary invention in colorectal practice; however, there are still doubts regarding its efficacy in low/ultralow rectal anastomoses. The location of the ring above the pelvic floor could induce persistent anal sensation (urge) and it is still unknown whether a spontaneous evacuation will occur in diverted patients.

Magnamosis

Controlled magnetic approaches have shown promise in biliary and vascular anastomoses (although the latter involves permanent implantation). A specially designed self-orienting device has been put into a trial to test the hypothesis of creating a magnetically mediated intestinal anastomosis using a temporary device that is expelled some time after creating the desired compression-necrosis effect (Department of Surgery, University of California, San Francisco)[63].

Two topologies were evaluated; namely the uniform and the gradient compression device. The study was conducted on 16 pigs with the creation of a side-to-side anastomosis. Half of these were created with the uniform device and the rest with the gradient. They also created hand-sewn and stapled side-to-side anastomosis for comparison. Devices were designed with surface fields of approximately 3000 Gauss (G). Preliminary experimentation had revealed that combinations of 3000/6000 G and 6000/6000 G uniformly caused necrosis and perforation within 48 h independent of device geometry. The results were promising, with the creation of successful patent anastomosis using the magnetic devices and no leaks reported[63].

The mechanical integrity of the magnetic anastomoses was not statistically significantly different from stapled or hand-sewn; however, there was a trend toward greater strength with the gradient type device and earlier patency. No evidence of stenosis was reported[63].

Table 2 presents the past clinical experience with

Table 3 List of reinforcement materials[64]

	Material	Stapler type	Company
Non-absorbable	ePTFE	Linear	W.L. Gore, Elkton, MD, USA
Semi-absorbable	Bovine pericardium (peristrips dry)	Circular linear	Synovis Life Technologies, Inc.
	Porcine small bowel (surgisis)	Linear	Cook Biotech Inc.
Absorbable	Polyglycolic acid:trimethylene carbonate (seamguard bioabsorbable)	Linear circular	W.L. Gore & Associates, Inc.
	Cellulose (Xcell)	Linear	Xylos Corp.
	Knitted calcium alginate (foreseal)	Linear	Laboratoires Brothier, Nanterre, France

compression anastomosis devices and their related complications.

BUTTRESSING OF INTESTINAL ANASTOMOSIS

Many staple devices are commercially available, however all the different types and models have inherent drawbacks that contribute to post-operative complications. Complications such as enteric leakage, bleeding, inadequate tissue approximation, and misfiring (technical failures) have been reported. However, complications related to colorectal anastomosis are the most devastating in terms of morbidity and mortality[64].

A new approach to reduce this is to use staple line reinforcement materials. Gastrointestinal reinforcement is well known, but its application in colorectal surgery is relatively new[65]. The application of buttressing materials is thought to moderate the tension of the stapler line because it acts as a neutralization plate. It reinforces the stapler line by sealing the gaps between staples and narrowing the spaces, thus reducing tearing of tissues, bleeding, and leakage[64]. Reinforcement materials can be applied exogenously to the staple line or incorporated into it. The material is composed of two regions, one that secures it to the stapler prior to activation, and is later discarded, and the other forms the seal. It has an adhesive surface and is readily packed in a sterile manner[65].

Reinforcement material can be non-absorbable, semi- or fully-absorbable. Studies have shown diminished incidence of leakage and stapler line failure in gastrointestinal and pulmonary surgery. Although all types of materials seem equally adequate in reducing staple line complications, the material itself can cause problems[65]. Therefore, the choice of material must be considered from a safety point of view, although there seems to be advantages of absorbable material over the other two types.

The effects of the materials in colorectal anastomosis have been tested in a small clinical pilot study by Franklin *et al*[66,67] using bio-absorbable seamguard (BSG) with a linear stapler. Published data revealed no bleeding, or apparent bleeding, at the staple line.

Several reports support the theoretical benefits of reinforcement materials in increasing the burst pressure[68-71]. It was also hypothesized that buttressing of stapler line can have a positive effect on tumor recurrence[66]. Although published studies showed a decrease in complications with these materials, no previous studies have shown significant results for reducing bleeding or leak rates at the stapler line. Thus, further research and investigations are required. Table 3 refers to the list of materials used as staple line adjuncts.

Non-absorbable materials

ePTFE: ePTFE is a very easy and quickly employed material composed of non-absorbable expanded polytetrafluoroethylene. It is constructed like a sleeve that can be slid over both arms of the stapling device negating the need for additional fixing to the stapler before firing. After firing, the material is released from the arms by pulling a ripcord. The potential benefits of this material include a low host response and biocompatibility. There are no reports of strip erosion or migration with this material, which evokes a minimal tissue inflammatory reaction. It provides thick tissue coverage for an extended period of time with no extra handling time required for its preparation and use. Its application suits open and laparoscopic procedures[72,73].

Semiabsorbable material

Bovine pericardium: This material is composed of bovine pericardium (peristrips dry). It is temporarily attached to the stapler with gel (which is applied to inner surface of both stapler arms), after which the stapler is positioned and locked over the strips. It can be applied on linear, as well as circular, staplers. The material is then incorporated by the host tissue after firing the stapler. Apart from increasing the burst pressure, this material demands relatively more handling time than other materials. However, it has the potential of to reduce the time required to stop staple line bleeding. Possible limitations include a high risk of animal source contamination, resulting in an inflammatory reaction to the xenomaterial (non-biocompatible). This makes it prone to erosion and migration[64]. Recently, its combination with Veritas technology results in remodeling of the material into indistinguishable host tissue.

Porcine small intestinal submucosa: This is a completely resorbable, acellular xenograft composed of

porcine small animal submucosa. It is suitable for anastomotic and non-anastomotic staplers. A potential advantage is that it provides a bioscaffold for tissue growth, inducing submucosal regeneration and also achieving an increase in burst pressure[74,75]. However, its efficacy in human staple-line reinforcement is undocumented.

Absorbable material

Polyglycolic acid:trimethylene carbonate: This is a synthetic fiber web that is composed of polyglycolic acid: trimethylene carbonate Maxon polymer. It is formed like a sleeve to be fitted over the stapler arms and released by pulling the suture that holds the sleeve in place. It can also be affixed as discs onto circular-type staplers. The material is strongly biocompatible, simple and easy to apply on the stapler and is non antigenic. It maintains its strength for four to six weeks and is fully resorbed after six months (hydrolytic and enzymatic reactions lead to the breakdown of the material)[76,77]. Overall, it minimizes staple-line bleeding, leakage, and operative time[78-80].

Cellulose: Cellulose (XylosT M Surgical Reinforcing Material. Xcell SDMC surgical film) was originally developed as a wound dressing. This dry sterile material is composed of a microbially-derived cellulose matrix having multilayered, three-dimensional structures. The cellulose is produced by *Acetobacter xylinum* bacteria and is processed into a resorbable form. Research is in progress to evaluate and construct it as a possible staple line reinforcing material in GI surgery[81].

Knitted calcium alginate: This material is composed of polysaccharidic polyglycuronates biopolymers (highly purified fractions from calcium alginates), originating from seaweeds. The device consists of preformed coated knitted bio-absorbable sheets held into the form of sleeves (one cartridge device, one anvil device) sized to fit snugly onto the forks of the surgical stapler. When applied to wet surfaces, the material becomes highly conformable and acquires bio-adhesive and sealant properties. It contains no additives or preservatives, and therefore no presoaking or rinsing is required as a preparatory step. The device is easy to handle and simple to apply, eliciting minimal foreign body response[82]. However, clinical trials are scarce.

OTHER FORMS OF ANASTOMOTIC SUPPORT

C-seal (polyganics)

The colorectal drain (C-seal) is applied with a circular stapler. It is a single use tubular device, closed at one end and composed of biodegradable synthetic material. It is a thin walled tube with an approximate diameter of 3 cm and an approximate length of 20 cm. This drain works as a shield covering the newly formed anastomosis, preventing contact between the bowel contents and the anastomosis. Degradation process starts gradually, and the material is expelled from the bowel after approximately 10-15 d. Its theoretical benefits lie in the ability to protect a low rectal anastomosis, preventing leakage. It can also be used as a staple line adjunct. It is microbiologically safe and is completely expelled after two weeks, negating the use of a protective defunctioning stoma in low rectal excision[83].

Polyester stent

Most recently, covered intraluminal stents have been successfully introduced to manage anastomotic leaks after esophagectomy and gastric bypass operations.

A randomized control trial in a large animal model addressed this issue in stapled colorectal anastomosis. The study found that placement of a covered polyester stent across a colorectal anastomosis prevents leak-related complications and supports healing of an anastomotic leak[84].

It consists of a polyflex self-expandable covered plastic stent (25 mm proximal flare and 12 cm long) and a delivery system. The outer layer is composed of braided polyester and the inner layer is silicone (no gaps in this layer). It is applied through a standard flexible colonoscope using a guide wire and a delivery system, and is deployed under fluoroscopic control after reconstruction of the end-to-end anastomosis. The components of the material allow it to adapt elastically to the lumen wall, exerting a well-balanced radial force. The silicone membrane provides a reliable leak occlusion, preventing ingrowth of granulation tissue; hence allowing stent repositioning or removal. Similarly to C-Seal, it negates the need for a diverting stoma in low rectal excision. However, the main disadvantage for the future of these types of stents is migration[84].

NOVEL TECHNIQUES

Doxycycline coated sutures

Experimental studies revealed that the strength of an intestinal anastomosis diminishes postoperatively reaching a nadir on the third postoperative day. This is mediated by the increased activity of MMP, causing local matrix degradation in the tissue surrounding the sutures. This activity is higher still in concurrent bacterial peritonitis, with subsequently greater deterioration of anastomotic strength. Several experimental studies showed that MMP inhibitors administered systemically alleviate postoperative weakening of intestinal anastomoses. Other studies have shown the beneficial effects of treatment with systemic MMP inhibitors, e.g. doxycycline, most notably on the critical third postoperative day[85-87].

Potent MMP inhibitors administered systemically can cause joint stiffness, swelling[88], and other toxic reactions[89]. Additionally, there are concerns about detrimental effects of broad-spectrum hydroxamate MMP inhibitors on secondary healing of cutaneous wounds[90], although these types of MMP inhibitors can increase tensile strength of primary skin wounds[91]. The less

potent MMP inhibitor doxycycline does not appear to delay wound closure[92]. Due to adverse systemic effects, local delivery of an MMP inhibitor in humans would be advantageous over systemic administration[93].

This hypothesis was studied by Pasternak *et al*[93] in 2008. They implemented a novel method for coating sutures with a cross-linked fibrinogen film and then bound the MMP inhibitor (doxycycline) into this film. The sutures were then used in a standard rat model for evaluating mechanical properties of colonic anastomosis three days after surgery. The breaking strength of the anastomosis was higher with the doxycycline-coated sutures than with the controls. This might inspire further studies involving pharmacological manipulation of intestinal healing by local drug delivery[93].

Electric "Welding" of soft tissues

Experience of the application of electric surgery for cutting tissues and hemostasis is about one hundred years long. It has been established that under certain conditions, it is possible to join incisions in different organs and soft tissues by a method based on heating the joint zone by a high-frequency current. Electric welding to join incisions of live tissues and organs during surgery was applied for the first time by the team of researchers of the E.O. Paton Electric Welding Institute of NASU in cooperation with the scientists and specialists of the experimental department of the Institute of Surgery and Transplantology (IS&T) of AMSU with participation of International Association (Welding) and financial support of CSMG Company, USA[94].

They developed a novel welding system that includes a power unit comprising a power source (High frequency coagulator) with an adaptive automatic control system and special software, bipolar welding tools (forceps, clamps and laparoscopes) connected to a power source, and special assembly devices. The control system is based on feedbacks. The tissue layers being joined are brought into contact over their surface layers by means of the welding tool. The surgeon clamps the tissue to be welded by the electrodes of the tool and switches on the welding current source. Upon completion of the process (i.e. thermal denaturation of albumin molecules), control program power is turned off. Clamped tissue is then released and process repeated until complete wound closure[94].

The device has been tested in multiple experimental trials and on more than 2000 patients in the clinics and hospitals of Kiev, Ukraine. The author maintains that the advantage of the device is in the formation of an attractive, neat, smooth thin welded anastomosis. In addition, it is a fumeless and odorless technology, causing no burns to surrounding tissues. The report demonstrates a reduction of blood loss and no organ deformation or stenosis. It also shortens the average operative time (20-40 min)[94].

CONCLUSION

Although alternatives to the conventional methods have been sought, many have been abandoned by the surgical community.

Compression anastomosis, although existing for decades, has not gained worldwide popularity. This concept seems to be difficult for surgeons to accept, as it includes relying on a device to create an anastomosis and letting it be spontaneously discharged from the body. Reinstitution of this concept using new technology, such as Nitinol, could be a potential replacement for the current available techniques. Controlled magnetic anastomosis is no exception to this. It is a promising novel technique for creation of a side-to-side anastomosis but requires to be optimized for future use.

The theoretical benefits of colorectal seals and the polyester stents as adjuncts to creating an end-to-end anastomosis could alleviate the need for a defunctioning stoma for lower rectal tumor resections. This is another concept that needs to be accepted and subjected to further research to optimize its use. In line with this, staple line reinforcement is an effective technique for reducing perioperative complications in stapled resection and anastomoses, with absorbable materials having a considerable advantage over semi or non-absorbable material(s). However, there has been little experience with absorbable staple line reinforcement materials.

A contemporary and sophisticated technique, such as electric tissue welding shows a promising future in modern surgical techniques. It is a revolutionary technique that still needs acceptance and research, utilizing greater patient samples in colorectal surgical practice.

Finally, overcoming the postoperative anastomotic weakness due to over activity of matrix metalloproteinases, and hence the risk of dehiscence, using doxycycline coated sutures should also be explored.

In summary, these various techniques fulfill the requirements of creating a safe anastomosis (overcoming the lag-phase, increasing the bursting pressure, and decreasing the rate of leakage, bleeding and stricture). They revealed great differences in avoiding dramatic complications that can occur with the conventional methods; an outcome that every colorectal surgeon would advocate. Surgeons need to widen their scope of practice, and further trials and research are required to overcome "dogmas" in traditional colorectal practice. Keeping abreast of technological advances is considered vital in every surgeons training and daily practice; failure to do so could lead to reduced quality of patient care.

REFERENCES

1 **Fowler DL**, White SA. Laparoscopy-assisted sigmoid resection. *Surg Laparosc Endosc* 1991; **1**: 183-188
2 **Phillips EH**, Franklin M, Carroll BJ, Fallas MJ, Ramos R, Rosenthal D. Laparoscopic colectomy. *Ann Surg* 1992; **216**: 703-707
3 **Jacobs M**, Verdeja JC, Goldstein HS. Minimally invasive colon resection (laparoscopic colectomy). *Surg Laparosc Endosc* 1991; **1**: 144-150
4 **Fleshman JW**, Nelson H, Peters WR, Kim HC, Larach S, Boorse RR, Ambroze W, Leggett P, Bleday R, Stryker S,

Christenson B, Wexner S, Senagore A, Rattner D, Sutton J, Fine AP. Early results of laparoscopic surgery for colorectal cancer. Retrospective analysis of 372 patients treated by Clinical Outcomes of Surgical Therapy (COST) Study Group. *Dis Colon Rectum* 1996; **39**: S53-S58
5 **Matthiessen P**, Hallböök O, Rutegård J, Simert G, Sjödahl R. Defunctioning stoma reduces symptomatic anastomotic leakage after low anterior resection of the rectum for cancer: a randomized multicenter trial. *Ann Surg* 2007; **246**: 207-214
6 **Enker WE**, Merchant N, Cohen AM, Lanouette NM, Swallow C, Guillem J, Paty P, Minsky B, Weyrauch K, Quan SH. Safety and efficacy of low anterior resection for rectal cancer: 681 consecutive cases from a specialty service. *Ann Surg* 1999; **230**: 544-552; discussion 552-554
7 **Matthiessen P**, Hallböök O, Andersson M, Rutegård J, Sjödahl R. Risk factors for anastomotic leakage after anterior resection of the rectum. *Colorectal Dis* 2004; **6**: 462-469
8 **Fielding LP**, Stewart-Brown S, Blesovsky L, Kearney G. Anastomotic integrity after operations for large-bowel cancer: a multicentre study. *Br Med J* 1980; **281**: 411-414
9 **Karanjia ND**, Corder AP, Bearn P, Heald RJ. Leakage from stapled low anastomosis after total mesorectal excision for carcinoma of the rectum. *Br J Surg* 1994; **81**: 1224-1226
10 **Pakkastie TE**, Luukkonen PE, Järvinen HJ. Anastomotic leakage after anterior resection of the rectum. *Eur J Surg* 1994; **160**: 293-297; discussion 299-300
11 **Mortensen NJ**, Ashraf S. Chapter 29 Intestinal Anastomosis In Section 5 Gastrointestinal Tract and Abdomen. September 2008. Available from: URL: http://www.acssurgery.com/acs/Chapters/CH0529.htm
12 **Syk I**, Agren MS, Adawi D, Jeppsson B. Inhibition of matrix metalloproteinases enhances breaking strength of colonic anastomoses in an experimental model. *Br J Surg* 2001; **88**: 228-234
13 **Halsted WS**. Circular suture of the intestine: an experimental study. *Am J Med Sci* 1887; **94**: 436-461
14 **de Hingh IH**, de Man BM, Lomme RM, van Goor H, Hendriks T. Colonic anastomotic strength and matrix metalloproteinase activity in an experimental model of bacterial peritonitis. *Br J Surg* 2003; **90**: 981-988
15 **Martens MF**, Hendriks T. Postoperative changes in collagen synthesis in intestinal anastomoses of the rat: differences between small and large bowel. *Gut* 1991; **32**: 1482-1487
16 **Hesp FL**, Hendriks T, Lubbers EJ, deBoer HH. Wound healing in the intestinal wall. A comparison between experimental ileal and colonic anastomoses. *Dis Colon Rectum* 1984; **27**: 99-104
17 **Khoury GA**, Waxman BP. Large bowel anastomoses. I. The healing process and sutured anastomoses. A review. *Br J Surg* 1983; **70**: 61-63
18 **Bissett IP**. Ileocolic anastomosis. *Br J Surg* 2007; **94**: 1447-1448
19 **Wise L**, McAlister W, Stein T, Schuck P. Studies on the healing of anastomoses of small and large intestines. *Surg Gynecol Obstet* 1975; **141**: 190-194
20 **Lustosa SA**, Matos D, Atallah AN, Castro AA. Stapled versus handsewn methods for colorectal anastomosis surgery. *Cochrane Database Syst Rev* 2001; CD003144
21 **Lim CB**, Goldin RD, Darzi A, Hanna GB. Characterization of materials eliciting foreign body reaction in stapled human gastrointestinal anastomoses. *Br J Surg* 2008; **95**: 1044-1050
22 **MacRae HM**, McLeod RS. Handsewn vs. stapled anastomoses in colon and rectal surgery: a meta-analysis. *Dis Colon Rectum* 1998; **41**: 180-189
23 **Cajozzo M**, Compagno G, DiTora P, Spallitta SI, Bazan P. Advantages and disadvantages of mechanical vs. manual anastomosis in colorectal surgery. A prospective study. *Acta Chir Scand* 1990; **156**: 167-169
24 **Fingerhut A**, Hay JM, Elhadad A, Lacaine F, Flamant Y. Supraperitoneal colorectal anastomosis: hand-sewn versus circular staples--a controlled clinical trial. French Associations for Surgical Research. *Surgery* 1995; **118**: 479-485
25 **Hardy KJ**. A view of the development of intestinal suture. Part II. Principles and techniques. *Aust N Z J Surg* 1990; **60**: 377-384
26 **Booth CC**. What has technology done to gastroenterology? *Gut* 1985; **26**: 1088-1094
27 **Murphy JB**. Cholecysto-intestinal, gastro-intestinal, entero-intestinal anastomosis, and approximation without sutures. *Med Rec N Y* 1892; **42**: 665-676
28 **Classic articles in colonic and rectal surgery**. Nicholas Senn 1844-1908. Enterorrhaphy; its history, technique and present status. *Dis Colon Rectum* 1985; **28**: 59-68
29 **Jansen A**, Keeman JN, Davies GA, Klopper PJ. Early experiences with magnetic rings in resection of the distal colon. *Neth J Surg* 1980; **32**: 20-27
30 **Kanshin NN**, Lytkin MI, Knysh VI, Klur VIu, Khamidov AI. [First experience with application of compression anastomoses with the apparatus AKA-2 in operations on the large intestine] *Vestn Khir Im I I Grek* 1984; **132**: 52-57
31 **Hardy TG Jr**, Pace WG, Maney JW, Katz AR, Kaganov AL. A biofragmentable ring for sutureless bowel anastomosis. An experimental study. *Dis Colon Rectum* 1985; **28**: 484-490
32 **Ye F**, Lin JJ. [Clinical application of biofragmentable anastomosis ring for intestinal anastomosis] *Zhejiang Daxue Xuebao Yixueban* 2006; **35**: 668-672
33 **Thiede A**, Geiger D, Dietz UA, Debus ES, Engemann R, Lexer GC, Lünstedt B, Mokros W. Overview on compression anastomoses: biofragmentable anastomosis ring multicenter prospective trial of 1666 anastomoses. *World J Surg* 1998; **22**: 78-86; discussion 87
34 **Bubrick MP**, Corman ML, Cahill CJ, Hardy TG Jr, Nance FC, Shatney CH. Prospective, randomized trial of the biofragmentable anastomosis ring. The BAR Investigational Group. *Am J Surg* 1991; **161**: 136-142; discussion 142-143
35 **Cahill CJ**, Betzler M, Gruwez JA, Jeekel J, Patel JC, Zederfeldt B. Sutureless large bowel anastomosis: European experience with the biofragmentable anastomosis ring. *Br J Surg* 1989; **76**: 344-347
36 **Corman ML**, Prager ED, Hardy TG Jr, Bubrick MP. Comparison of the Valtrac biofragmentable anastomosis ring with conventional suture and stapled anastomosis in colon surgery. Results of a prospective, randomized clinical trial. *Dis Colon Rectum* 1989; **32**: 183-187
37 **Gullichsen R**, Ovaska J, Rantala A, Havia T. Small bowel anastomosis with the biofragmentable anastomosis ring and manual suture: a prospective, randomized study. *World J Surg* 1992; **16**: 1006-1009
38 **Pahlman L**, Ejerblad S, Graf W, Kader F, Kressner U, Lindmark G, Raab Y. Randomized trial of a biofragmentable bowel anastomosis ring in high-risk colonic resection. *Br J Surg* 1997; **84**: 1291-1294
39 **Seow-Choen F**, Eu KW. Circular staplers versus the biofragmentable ring for colorectal anastomosis: a prospective randomized study. *Br J Surg* 1994; **81**: 1790-1791
40 **Wullstein C**, Gross E. Compression anastomosis (AKA-2) in colorectal surgery: results in 442 consecutive patients. *Br J Surg* 2000; **87**: 1071-1075
41 **Nudelman IL**, Fuko VV, Morgenstern S, Giler S, Lelcuk S. Gastrointestinal anastomosis with the nickel-titanium double ring. *World J Surg* 2000; **24**: 874-877
42 **Nudelman I**, Fuko V, Waserberg N, Niv Y, Rubin M, Szold A, Lelcuk S. Colonic anastomosis performed with a memory-shaped device. *Am J Surg* 2005; **190**: 434-438
43 **Nudelman I**, Fuko V, Rubin M, Lelcuk S. A nickel-titanium memory-shape device for colonic anastomosis in laparoscopic surgery. *Surg Endosc* 2004; **18**: 1085-1089
44 **Nudelman IL**, Fuko V, Greif F, Lelcuk S. Colonic anastomosis with the nickel-titanium temperature-dependent memory-shape device. *Am J Surg* 2002; **183**: 697-701
45 **Kim SH**, Choi HJ, Park KJ, Kim JM, Kim KH, Kim MC, Kim YH, Cho SH, Jung GJ. Sutureless intestinal anastomosis with

the biofragmentable anastomosis ring: experience of 632 anastomoses in a single institute. *Dis Colon Rectum* 2005; **48**: 2127-2132
46 **Aggarwal R**, Darzi A. Compression anastomoses revisited. *J Am Coll Surg* 2005; **201**: 965-971
47 **Choi HJ**, Kim HH, Jung GJ, Kim SS. Intestinal anastomosis by use of the biofragmentable anastomotic ring: is it safe and efficacious in emergency operations as well? *Dis Colon Rectum* 1998; **41**: 1281-1286
48 **Galizia G**, Lieto E, Castellano P, Pelosio L, Imperatore V, Canfora F, Pignatelli C. Comparison between the biofragmentable anastomosis ring and stapled anastomoses in the extraperitoneal rectum: a prospective, randomized study. *Int J Colorectal Dis* 1999; **14**: 286-290
49 **Hardy TG Jr**, Aguilar PS, Stewart WR, Katz AR, Maney JW, Costanzo JT, Pace WG. Initial clinical experience with a biofragmentable ring for sutureless bowel anastomosis. *Dis Colon Rectum* 1987; **30**: 55-61
50 **Di Castro A**, Biancari F, Brocato R, Adami EA, Truosolo B, Massi G. Intestinal anastomosis with the biofragmentable anastomosis ring. *Am J Surg* 1998; **176**: 472-474
51 **Chen TC**, Ding KC, Yang MJ, Chang CP. New device for biofragmentable anastomotic ring in low anterior resection. *Dis Colon Rectum* 1994; **37**: 834-836
52 **Forde KA**, McLarty AJ, Tsai J, Ghalili K, Delany HM. Murphy's Button revisited. Clinical experience with the biofragmentable anastomotic ring. *Ann Surg* 1993; **217**: 78-81
53 **Ghitulescu GA**, Morin N, Jetty P, Belliveau P. Revisiting the biofragmentable anastomotic ring: is it safe in colonic surgery? *Can J Surg* 2003; **46**: 92-98
54 **Detry RJ**, Kartheuser A, Delriviere L, Saba J, Kestens PJ. Use of the circular stapler in 1000 consecutive colorectal anastomoses: experience of one surgical team. *Surgery* 1995; **117**: 140-145
55 **Hansen O**, Schwenk W, Hucke HP, Stock W. Colorectal stapled anastomoses. Experiences and results. *Dis Colon Rectum* 1996; **39**: 30-36
56 **Barras CD**, Myers KA. Nitinol - its use in vascular surgery and other applications. *Eur J Vasc Endovasc Surg* 2000; **19**: 564-569
57 **Kopelman D**, Lelcuk S, Sayfan J, Matter I, Willenz EP, Zaidenstein L, Hatoum OA, Kimmel B, Szold A. End-to-end compression anastomosis of the rectum: a pig model. *World J Surg* 2007; **31**: 532-537
58 **Song C**, Frank T, Cuschieri A. Shape memory alloy clip for compression colonic anastomosis. *J Biomech Eng* 2005; **127**: 351-354
59 **Liu PC**, Jiang ZW, Zhu XL, Wang ZM, Diao YQ, Li N, Li JS. Compression anastomosis clip for gastrointestinal anastomosis. *World J Gastroenterol* 2008; **14**: 4938-4942
60 **Szold A**. New concepts for a compression anastomosis: superelastic clips and rings. *Minim Invasive Ther Allied Technol* 2008; **17**: 168-171
61 **Stewart D**, Hunt S, Pierce R, Dongli Mao, Frisella M, Cook K, Starcher B, Fleshman J. Validation of the NITI Endoluminal Compression Anastomosis Ring (EndoCAR) device and comparison to the traditional circular stapled colorectal anastomosis in a porcine model. *Surg Innov* 2007; **14**: 252-260
62 **D'Hoore A**, Hompes D, Folkesson J, Penninckx F, PAhlman L. Circular 'superelastic' compression anastomosis: from the animal lab to clinical practice. *Minim Invasive Ther Allied Technol* 2008; **17**: 172-175
63 **Jamshidi R**, Stephenson JT, Clay JG, Pichakron KO, Harrison MR. Magnamosis: magnetic compression anastomosis with comparison to suture and staple techniques. *J Pediatr Surg* 2009; **44**: 222-228
64 **Yo LS**, Consten EC, Quarles van Ufford HM, Gooszen HG, Gagner M. Buttressing of the staple line in gastrointestinal anastomoses: overview of new technology designed to reduce perioperative complications. *Dig Surg* 2006; **23**: 283-291
65 **Cheragwandi A**, Nieuwenhuis DH, Gagner M, Consten EC. An update of available innovative staple line reinforcement materials in colorectal surgery. *Surg Technol Int* 2008; **17**: 131-137
66 **Franklin ME Jr**, Ramila GP, Treviño JM, González JJ, Russek K, Glass JL, Kim G. The use of bioabsorbable staple line reinforcement for circular stapler (BSG "Seamguard") in colorectal surgery: initial experience. *Surg Laparosc Endosc Percutan Tech* 2006; **16**: 411-415
67 **Franklin ME Jr**, Berghoff KE, Arellano PP, Trevino JM, Abrego-Medina D. Safety and efficacy of the use of bioabsorbable seamguard in colorectal surgery at the Texas endosurgery institute. *Surg Laparosc Endosc Percutan Tech* 2005; **15**: 9-13
68 **Arnold W**, Shikora SA. A comparison of burst pressure between buttressed versus non-buttressed staple-lines in an animal model. *Obes Surg* 2005; **15**: 164-171
69 **Hagerman GF**, Gaertner WB, Ruth GR, Potter ML, Karulf RE. Bovine pericardium buttress reinforces colorectal anastomoses in a canine model. *Dis Colon Rectum* 2007; **50**: 1053-1060
70 **Morton JM**, Lucktong TA, Trasti S, Farrell TM. Bovine pericardium buttress limits recanalization of the uncut Roux-en-Y in a porcine model. *J Gastrointest Surg* 2004; **8**: 127-131
71 **Pinheiro JS**, Correa JL, Cohen RV, Novaes JA, Schiavon CA. Staple line reinforcement with new biomaterial increased burst strength pressure: an animal study. *Surg Obes Relat Dis* 2006; **2**: 397-399, discussion 400
72 **Murray KD**, Ho CH, Hsia JY, Little AG. The influence of pulmonary staple line reinforcement on air leaks. *Chest* 2002; **122**: 2146-2149
73 **Vaughn CC**, Vaughn PL, Vaughn CC 3rd, Sawyer P, Manning M, Anderson D, Roseman L, Herbst TJ. Tissue response to biomaterials used for staple-line reinforcement in lung resection: a comparison between expanded polytetrafluoroethylene and bovine pericardium. *Eur J Cardiothorac Surg* 1998; **13**: 259-265
74 **Kini S**, Gagner M, de Csepel J, Gentileschi P, Dakin G. A biodegradeable membrane from porcine intestinal submucosa to reinforce the gastrojejunostomy in laparoscopic Roux-en-Y gastric bypass: preliminary report. *Obes Surg* 2001; **11**: 469-473
75 **de la Fuente SG**, Gottfried MR, Lawson DC, Harris MB, Mantyh CR, Pappas TN. Evaluation of porcine-derived small intestine submucosa as a biodegradable graft for gastrointestinal healing. *J Gastrointest Surg* 2003; **7**: 96-101
76 **Van Winkle W Jr**, Hastings JC. Considerations in the choice of suture material for various tissues. *Surg Gynecol Obstet* 1972; **135**: 113-126
77 **Kangas J**, Paasimaa S, Mäkelä P, Leppilahti J, Törmälä P, Waris T, Ashammakhi N. Comparison of strength properties of poly-L/D-lactide (PLDLA) 96/4 and polyglyconate (Maxon) sutures: in vitro, in the subcutis, and in the achilles tendon of rabbits. *J Biomed Mater Res* 2001; **58**: 121-126
78 **Katz AR**, Mukherjee DP, Kaganov AL, Gordon S. A new synthetic monofilament absorbable suture made from polytrimethylene carbonate. *Surg Gynecol Obstet* 1985; **161**: 213-222
79 **Metz SA**, Chegini N, Masterson BJ. In vivo and in vitro degradation of monofilament absorbable sutures, PDS and Maxon. *Biomaterials* 1990; **11**: 41-45
80 **Farrar DF**, Gillson RK. Hydrolytic degradation of polyglyconate B: the relationship between degradation time, strength and molecular weight. *Biomaterials* 2002; **23**: 3905-3912
81 **Frankel VH**, Serafica GC, Damien CJ. Development and testing of a novel biosynthesized XCell for treating chronic wounds. *Surg Technol Int* 2004; **12**: 27-33
82 **Thomas P**, Massard G, Porte H, Doddoli C, Ducrocq X, Conti M. A new bioabsorbable sleeve for lung staple-line reinforcement (FOREseal): report of a three-center phase II clinical trial. *Eur J Cardiothorac Surg* 2006; **29**: 880-885

83 **The manufacture's IFU (information for use) literature.** Available from: URL: http://www.polyganics.com; http://www.nitisurgical.com/colonring.htm

84 **Tsereteli Z**, Sporn E, Geiger TM, Cleveland D, Frazier S, Rawlings A, Bachman SL, Miedema BW, Thaler K. Placement of a covered polyester stent prevents complications from a colorectal anastomotic leak and supports healing: randomized controlled trial in a large animal model. *Surgery* 2008; **144**: 786-792

85 **Syk I**, Agren MS, Adawi D, Jeppsson B. Inhibition of matrix metalloproteinases enhances breaking strength of colonic anastomoses in an experimental model. *Br J Surg* 2001; **88**: 228-234

86 **Agren MS**, Andersen TL, Mirastschijski U, Syk I, Schiødt CB, Surve V, Lindebjerg J, Delaissé JM. Action of matrix metalloproteinases at restricted sites in colon anastomosis repair: an immunohistochemical and biochemical study. *Surgery* 2006; **140**: 72-82

87 **Siemonsma MA**, de Hingh IH, de Man BM, Lomme RM, Verhofstad AA, Hendriks T. Doxycycline improves wound strength after intestinal anastomosis in the rat. *Surgery* 2003; **133**: 268-276

88 **Renkiewicz R**, Qiu L, Lesch C, Sun X, Devalaraja R, Cody T, Kaldjian E, Welgus H, Baragi V. Broad-spectrum matrix metalloproteinase inhibitor marimastat-induced musculoskeletal side effects in rats. *Arthritis Rheum* 2003; **48**: 1742-1749

89 **Peterson JT**. Matrix metalloproteinase inhibitor development and the remodeling of drug discovery. *Heart Fail Rev* 2004; **9**: 63-79

90 **Mirastschijski U**, Haaksma CJ, Tomasek JJ, Agren MS. Matrix metalloproteinase inhibitor GM 6001 attenuates keratinocyte migration, contraction and myofibroblast formation in skin wounds. *Exp Cell Res* 2004; **299**: 465-475

91 **Witte MB**, Thornton FJ, Kiyama T, Efron DT, Schulz GS, Moldawer LL, Barbul A. Metalloproteinase inhibitors and wound healing: a novel enhancer of wound strength. *Surgery* 1998; **124**: 464-470

92 **Hebda PA**, Whaley D, Kim HG, Wells A. Absence of inhibition of cutaneous wound healing in mice by oral doxycycline. *Wound Repair Regen* 2003; **11**: 373-379

93 **Pasternak B**, Rehn M, Andersen L, Agren MS, Heegaard AM, Tengvall P, Aspenberg P. Doxycycline-coated sutures improve mechanical strength of intestinal anastomoses. *Int J Colorectal Dis* 2008; **23**: 271-276

94 **Paton BE**. Electric welding of soft tissues in surgery "The Paton Welding Journal", number: 9. 2004r. Available from: URL: http://www.iaw.com.ua/english/publications/

95 **Kaidar-Person O**, Rosenthal RJ, Wexner SD, Szomstein S, Person B. Compression anastomosis: history and clinical considerations. *Am J Surg* 2008; **195**: 818-826

S- Editor Wang JL **L- Editor** Stewart GJ **E- Editor** Ma WH