Magnetic gastrointestinal anastomosis in pediatric patients

Mario Zaritzky, Ricardo Ben, Krystal Johnston

Abstract

Background/Purpose: To describe 17 patients who underwent magnetic, non-surgical gastrointestinal (GI) anastomoses.

Methods: Patients with GI obstruction, stenosis, or atresia were treated with image-guided and/or endoscopically placed discoid magnet pairs or catheter-based bullet-shaped magnet pairs.

Results: Anastomosis was achieved in 7 days in an 11-year-old with gastric outlet obstruction due to metastatic colon cancer. Anastomosis was achieved in 8 and 10 days in 2 patients (age 2.0 years and 3.4 years) who had rectocolonic stenosis. Re-anastomosis was achieved in an average of 6 days (range 3 to 7 days) in 5 patients (age 6 months to 5.9 years) with severe recurrent postsurgical esophageal stenosis refractory to dilatation. Primary esophageal anastomosis was achieved in an average of 4.2 days (range 3 to 6 days) in 9 patients with esophageal atresia (Type A or Type C surgically converted to Type A) with a gap length of 4 cm or less. The average age of these esophageal atresia patients was 3 months (range 23 days to 5 months).

Conclusion: Minimally invasive magnetic placement was feasible and achieved anastomosis in all patients.

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Compression devices to facilitate intestinal anastomoses have achieved intermittent popularity in the medical literature. The first description of compression anastomosis in an animal model was put forth by Denans in 1826; his device was composed of metal rings. The Murphy button, introduced in 1892, also consisted of metal rings held in place by a purse-string suture. In the mid-1980s, additional compression devices were introduced, which were composed of biodegradable rings and non-biodegradable rings with or without magnets included in the design. These devices were primarily used to create small or large bowel anastomoses.

In the 1970s, Hendren and Hale published clinical outcomes of magnet-induced growth in the treatment of esophageal atresia and high-pouch imperforate anus; magnetic bougienage allowed primary esophageal or rectal anastomosis without interposition of additional tissue. From 1995 to 2001, Cope published four papers describing gastrointestinal and cholecystogastric/jejunal anastomoses in animals. In 2005, Chopita et al published results of 15 patients who had malignant upper GI obstruction and who underwent successful magnetic compression gastrointestinal anastomosis. Additionally, Takao et al. published a case report of a patient with benign common bile duct obstruction who underwent cholecodochoduodenostomy by magnetic compression anastomosis. More recently, magnetic compression anastomosis treatment for biliary obstruction has been reported in case reports and small case series.

Gastrointestinal (GI) anastomoses are traditionally created by suture or staple methods. The goal of any anastomosis is to connect the two structures and allow sufficient healing to discourage anastomotic leak. If a safe, minimally invasive treatment technique were developed, it could become the preferred anastomotic treatment method. Therefore, creation of a functional magnetic compression anastomosis through minimally invasive techniques warrants appropriate investigation. The purpose of this analysis is to describe patients with GI obstruction, stenosis, or atresia who underwent magnetic, non-surgical GI anastomoses.

1. Materials and methods

Between June 2001 and December 2012, 17 pediatric patients were treated by magnetic compression anastomosis at a single center in Argentina (Table 1). Approval was obtained from the site’s Ethics Committee and informed consent was obtained from the parents or legal guardians.

1.1. Discoid magnet pairs

A circular discoid magnet pair (Cook Medical, Winston-Salem, NC; device not currently marketed) was used to treat GI obstruction in 8 patients. One patient had gastric outlet obstruction due to metastatic colon adenocarcinoma, 2 patients had rectocolonic...
The esophageal catheter used for anastomosis of primary esophageal atresia contained 2 lumens. One lumen had a 5 mm bullet-shaped NdFeB magnet at the tip and the second lumen facilitated suction of excess saliva from the upper pouch. The gastric catheter contained 3 lumens. One lumen had a 5 mm bullet-shaped NdFeB magnet at the tip, another lumen had a retention balloon to keep the device in place within the stomach, and one lumen permitted gastric feeding. Each catheter-based magnet contained a central opening for passage of 0.038 inch wire guide and had a magnetic power of 12,800 G (Fig. 2A, B, and C).

AP and lateral chest radiographs were obtained immediately after placement of the catheter-based magnets to verify appropriate catheter position and magnet alignment. Radiographs were obtained daily thereafter until magnetic coupling was demonstrated. When anastomosis was achieved, the proximal end of the inner esophageal guiding catheter was cut, the retention balloon of the gastric catheter was deflated, and a wire guide was introduced and passed through the esophageal catheter, through the anastomosis, and through the gastrostomy port. The esophageal catheter was pushed distally toward the stomach while the gastric catheter was pulled away from the patient, thus removing the esophageal catheter, coupled magnets, and gastric catheter as a unit. The outer esophageal catheter was left in place for use as an orogastric tube.

2. Results

2.1. Discoid magnet pairs

Gastroenteric anastomosis was achieved in 7 days in an 11-year-old patient with gastric outlet obstruction due to metastatic colon cancer (Fig. 3A to F). Immediately, a 25 mm diameter partially covered duodenal stent was placed. One week after magnet removal, the patient required balloon dilatation for recurrent anastomotic obstruction caused by tumor ingrowth at an uncovered end of the stent. Importantly, the patient was able to ingest a normal diet until his death, which occurred 6 months after placement of the discoid magnets.

Colorectal anastomosis was achieved in 8 and 10 days in 2 patients who developed rectocolonic stenosis after surgical correction of Hirschprung’s disease. These patients were 2 years old and 3.4 years old, respectively, at the time of magnet therapy. In both patients, magnets were introduced through the existing colostomy. Both patients required anastomotic balloon dilatation 15 days after magnet removal and 1 patient also underwent prophylactic placement of a 28 mm diameter fully covered colonic stent. The colostomies were eventually taken down in both patients and neither patient experienced difficulty passing stool.

Esophageal re-anastomosis was achieved in an average of 6 days (range 3 days to 7 days) in 5 patients who previously underwent surgical correction of esophageal atresia but experienced severe recurrent postsurgical esophageal stenoses that were refractory to dilatation. These patients were aged 6 months to 5.9 years. Representative images from one of these patients are shown in Fig. 4A to E.

Table 1

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Indication for magnetic compression anastomosis</th>
<th>Type of magnet used</th>
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<tbody>
<tr>
<td>1</td>
<td>Gastric outlet obstruction (metastatic colon adenocarcinoma)</td>
<td>Discoid pair^a</td>
</tr>
<tr>
<td>2</td>
<td>Rectocolonic stenosis (post-Hirschsprung’s repair)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>3</td>
<td>Rectocolonic stenosis (post-Hirschsprung’s repair)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>4</td>
<td>Esophageal stenosis (post-surgical repair of esophageal atresia)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>5</td>
<td>Esophageal stenosis (post-surgical repair of esophageal atresia)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>6</td>
<td>Esophageal stenosis (post-surgical repair of esophageal atresia)</td>
<td>Discoid pair</td>
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<tr>
<td>7</td>
<td>Esophageal stenosis (post-surgical repair of esophageal atresia)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>8</td>
<td>Esophageal stenosis (post-surgical repair of esophageal atresia)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>9</td>
<td>Type A Esophageal atresia, unrepaired</td>
<td>Discoid pair^b</td>
</tr>
<tr>
<td>10</td>
<td>Type A Esophageal atresia, unrepaired</td>
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<td>12</td>
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<td>Type A Esophageal atresia, unrepaired</td>
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<td>14</td>
<td>Type A Esophageal atresia, unrepaired</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>15</td>
<td>Type C Esophageal atresia, esophagus unrepaired (tracheoesophageal fistula had been repaired)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>16</td>
<td>Type C Esophageal atresia, esophagus unrepaired (tracheoesophageal fistula had been repaired)</td>
<td>Discoid pair</td>
</tr>
<tr>
<td>17</td>
<td>Type C Esophageal atresia, esophagus unrepaired (tracheoesophageal fistula had been repaired)</td>
<td>Discoid pair</td>
</tr>
</tbody>
</table>

^a Discoid magnet pairs contained a 12 mm and a 14 mm diameter magnet with a magnetic power of 12,550 G.
^b Bullet-shaped catheter-based magnets were 5 mm in diameter with a magnetic power of 12,800 G.
Three of these patients also underwent prophylactic covered stent placement 2 weeks after placement of the discoid magnets. Stents were removed 2 months after placement.

2.2. Catheter-based bullet-shaped magnet pairs

Primary esophageal anastomosis was achieved in an average of 4.2 days (range 3 to 6 days) in 9 patients with previously unrepaired esophageal atresia. The average patient age in this group was 3 months (range 23 days to 5 months). Representative images from one of these patients are shown in Fig. 5A to D. No patient experienced an anastomotic leak. One patient developed sepsis (defined as fever and elevated white blood cell count) 48 h after magnet placement. In this case, the catheter-based magnets were removed, the patient was successfully treated with antibiotics, and the catheter-based magnets were replaced to complete the magnetic treatment. Eight patients developed anastomotic strictures that required dilatation and 2 of these patients with intractable esophageal stenosis also underwent placement of 10 mm diameter fully covered biliary stents after dilatation. One patient (who underwent several dilatations and stent placement) ultimately required surgical re-anastomosis.

Three esophageal atresia patients were lost to long-term follow-up. All 6 patients with long-term follow-up data are ingesting normal residue diets for their age. At the time of this writing, the oldest patient is over 12 years old. Several patients in this group demonstrate common comorbidities associated with esophageal atresia. Two patients have gastroesophageal reflux disease (GERD) and tracheomalacia. Three patients have esophageal dysmotility requiring treatment and 3 patients have asthma or recurrent pulmonary infections. None of the patients have scoliosis or rib deformities. Of note, 1 patient (17 months old at the time of writing) carries concurrent diagnoses of GERD, tracheomalacia, esophageal dysmotility, and asthma/recurrent pulmonary infection. This patient is at the 15th growth percentile for age at the time of publication.

3. Discussion

Temporary, minimally invasive magnet placement achieved GI anastomosis in all 17 patients in this series. Discoid magnet pairs were placed under fluoroscopic and endoscopic guidance. Catheter-based bullet-shaped magnet pairs were placed and monitored under radiographic guidance. Anastomoses were created in the esophagus, the gastric outlet, and the colon/rectum and all were accomplished between 3 and 10 days after magnet placement.

In animals, the integrity of small intestinal or gastroenteric magnetic anastomoses have been shown to be equivalent to or better than sutured [18] and stapled [18,19] anastomoses. An animal study demonstrated a slightly higher average burst pressure for magnetic
compression duodenocolonic anastomoses when compared to stapled anastomoses [20], while another animal study demonstrated a significantly higher burst pressure for magnetic compression jejuno-jejunal anastomoses compared to sutured anastomoses [21]. It is unlikely that a randomized controlled trial will be devised in humans to compare magnetic and sutured or stapled anastomoses, but it is important to recognize that the suture and staple techniques most commonly used in GI surgeries may not be the optimal choice. Further, magnetic compression anastomoses do not leave behind permanent foreign bodies like sutured and stapled anastomoses.

An animal study of magnetic colorectal anastomoses described magnet placement through a hybrid natural orifice transluminal endoscopic surgery (NOTES) procedure [22]. Both side-to-side and end-to-side anastomoses were created in these animals. Two animals developed asymptomatic anastomotic stenosis, but without further intervention, at 30-day follow-up, both anastomoses were easily crossed with the endoscope.

Eleven patients in this series required anastomotic dilatation, including eight patients who had esophageal atresia and were treated with catheter-based magnets. However, stenosis following magnetic compression anastomosis is not necessarily related to the catheter-based device. For example, Takamizawa et al. described a patient who underwent surgical repair of esophageal atresia, had recurrent postsurgical esophageal stenosis refractory to dilatation, and was treated with one magnet suspended on a nylon thread and one magnet introduced through the mouth [23]. Because these magnets did not attract, larger magnets were introduced in the same fashion two months later; reanastomosis was achieved but the patient still required several balloon dilatations over the subsequent three months. In contrast, the catheter-based magnets in the present study all functioned appropriately and achieved magnetic coupling in all patients.

Postoperative esophageal stenosis is also common after surgical intervention. Outcomes of surgical esophageal atresia repair can vary

Fig. 3. An 11-year-old patient with gastric outlet obstruction due to metastatic colon cancer. (A) Pyloric obstruction is demonstrated endoscopically. (B) Endoscopic placement of the first discoid magnet distal to the pylorus. (C) Second discoid magnet in position in the stomach. (D) Initial radiologic image after magnets placed. (E) Radiologic image showing coupling of the magnets. (F) Radiologic image after prophylactic stent placement.
by center (i.e., surgeon experience with the chosen surgical
technique) and can be influenced by the presence and degree of
underlying comorbidities. Postoperative esophageal stenoses occur in
27% to 44% of patients who undergo Type A esophageal atresia repair
[24–26]. Nevertheless, the overall rate of anastomotic stenosis in the
present study was particularly high (64.7%, 11/17); this rate can be
addressed by revision of magnet design and/or magnet power. Further
investigations are needed to refine the technique and to develop a
suitable alternative to open surgical or laparoscopic repair.

Seven patients in this series underwent stent placement after
magnetic compression anastomosis, including five patients who had
stenst placed in the esophagus. Since there are no currently approved
pediatric esophageal stents, tracheobronchial and fully covered biliary
stenst have been used in the treatment of pediatric esophageal
stenosis. One group recommends consideration of tracheobronchial
stent placement in the treatment of all recurrent severe pediatric
esophageal strictures [27]. In adults, a study investigating magnetic
gastroenteric anastomosis followed by routine stent placement was
terminated prematurely due to a serious adverse event (i.e., stent-
related perforation and sepsis leading to death) [28]. These
investigators noted that magnetic compression itself was feasible and
safe, but concluded that the requirement for subsequent stent
placement caused unnecessary risk. However, the adult patients in
that study had a primary malignant diagnosis, and thus, represent a
different patient population than the pediatric patients with benign
pathology who are described in the present study. Even so, it would be

Fig. 4. A patient with recurrent postsurgical esophageal stenosis refractory to dilatation. (A) Endoscopic view of the distal discoid magnet placed through the gastrostomy.
(B) Radiographic image of the distal discoid magnet in position. (C) Addition of the proximal discoid magnet placed via the mouth. (D) Radiologic image showing coupling of the
magnets. (E) Endoscopic image showing the final anastomosis.
most beneficial if magnetic compression anastomoses did not require stent placement to maintain the anastomotic tract; however, since a stent is often necessary, the best type of stent (e.g., biodegradable, self-expanding, covered, or uncovered) and the appropriate duration of stent placement, two currently unknown factors, require further investigation.

In conclusion, minimally invasive magnet placement was feasible using either discoid or catheter-based bullet-shaped magnet pairs. Gl

![Radiologic images from a patient with esophageal atresia (Type A or Type C converted to Type A) and a gap length of 4 cm or less. (A) AP image demonstrating measurement of the esophageal gap. (B) Image verifying initial catheter-based magnet placement. (C) Image showing coupling of the magnets. (D) First esophagram after anastomosis.](image-url)
anastomosis was achieved in all patients. Further design refinements are necessary to reduce the rate of post-anastomotic stenosis, but magnetic compression anastomosis appears to be a promising new therapeutic option.

Acknowledgments

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References