

NARRATIVE REVIEWS

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A Modern Magnetic Implant for Gastroesophageal Reflux Disease

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A magnetic implant for the treatment of gastroesophageal reflux disease (GERD) was Food and Drug Administration–approved in 2012 and has been extensively evaluated. The device is a ring of magnets that are placed around the gastroesophageal junction, augmenting the native lower esophageal sphincter and preventing reflux yet preserving lower esophageal sphincter physiologic function and allowing belching and vomiting. Magnetic force is advantageous, being permanent and precise, and forces between magnets decrease with esophageal displacement. Multiple patient cohorts have been studied using the magnetic device, and trials establish consistent, long-term improvement in pH data, GERD symptom scores, and proton-pump inhibitor use. A 5-year Food and Drug Administration trial demonstrated that most patients achieved normal pH scores, 85% stopped proton-pump inhibitors, and GERD health-related quality of life symptom scores improved from 27 to 4 at 5 years. Seven studies have compared magnetic augmentation with laparoscopic Nissen fundoplication and demonstrated that the magnetic device achieved comparable efficacy with regard to proton-pump inhibitor cessation, GERD symptom score improvement, and heartburn and regurgitation scores. However, to date there have been no randomized, controlled trials comparing the 2 techniques, and the study cohorts are not necessarily comparable regarding hiatal hernia size, severity of reflux, body mass index scores, or esophagitis scores. Dysphagia incidence was similar in both groups. Reoperation rates and safety profiles were also comparable, but the magnetic device demonstrated significant beneficial differences in allowing belching and vomiting. The magnetic device is safe, with the main adverse event being dysphagia with an approximate 3%–5% chronic incidence. Device removals in clinical trials have been between 0% and 7% and were uneventful. There have been no erosions, perforations, or infections in FDA clinical trials; erosions have rarely been noted in practice. Magnetic augmentation of the lower esophageal sphincter is a safe and effective operation for GERD, and should be considered a surgical option for those seeking a fundic-sparing operation, particularly those with parameters consistent with study cohorts. Additional randomized, controlled trials are underway.

“The magnet’s name the observing Grecians drew, from the magnetic region where it first grew.”

“The magnetic force is animate, or imitates a soul; in many respects it surpasses the human soul while limited to an organic body”.

- William Gilbert, 1544–1603

(English scientist and the “Father of magnetism”)

Suppose you could go back in time to 1956; Code et al¹ of the Mayo Clinic had just recently discovered the lower esophageal sphincter (LES), and in Switzerland, Nissen² had just described his eponymous surgical fundoplication. These advances proved to be essential, yet who would have predicted that some 60 years later the proper role of the LES and the exact mechanism of pathologic gastroesophageal reflux disease (GERD) would still be debated, and that Nissen fundoplication would remain the standard surgical technique for medication-refractory GERD despite its substantial adverse event profile? Regarding antireflux surgery, there have been many attempts to displace Nissen surgical fundoplication because of its associated side effects (eg, inability to belch or vomit, gas-bloat, flatulence), including various alternative surgical procedures (eg, Hill, Collis, Belsey),³ later followed by various innovative endoscopic techniques (eg, radiofrequency energy delivery to the LES, endoscopic fundoplication, injectables).^{4,5} Now, most recently, magnetic sphincter augmentation has emerged as a legitimate surgical contender to Nissen, based on comparable clinical and pH outcomes and a comparable safety profile.^{6–10}

Magnetic sphincter augmentation of the LES was conceived to address the limitations of fundoplication surgery, while helping to shed new light on the pathogenesis of reflux disease.⁶ Alternative endoscopic and minimally invasive surgical antireflux therapies have

Abbreviations used in this paper: BMI, body mass index; FDA, Food and Drug Administration; GEJ, gastroesophageal junction; GERD, gastroesophageal reflux disease; HRQOL, health-related quality of life; LES, lower esophageal sphincter; PPI, proton-pump inhibitor.

Most current article

Keywords: Gastroesophageal Reflux; Nissen Fundoplication; Proton Pump Inhibitors.

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recently taken on new importance as proton-pump inhibitor (PPI)-based medical therapy of GERD has come under fire because of potential associated side effects including community-acquired pneumonia, *Clostridium difficile* colitis, osteoporosis and hip fracture, chronic kidney disease, dementia, and myocardial infarction. These associations are reported from observational, retrospective, epidemiologic studies and although their exact importance remains to be elucidated, there currently exists a “therapy gap” for patients with GERD either symptomatically insufficiently controlled with PPI medication, or concerned about potential PPI side effects and unwilling to undergo Nissen surgery.¹¹⁻¹³

Magnets and the Magnetic Device

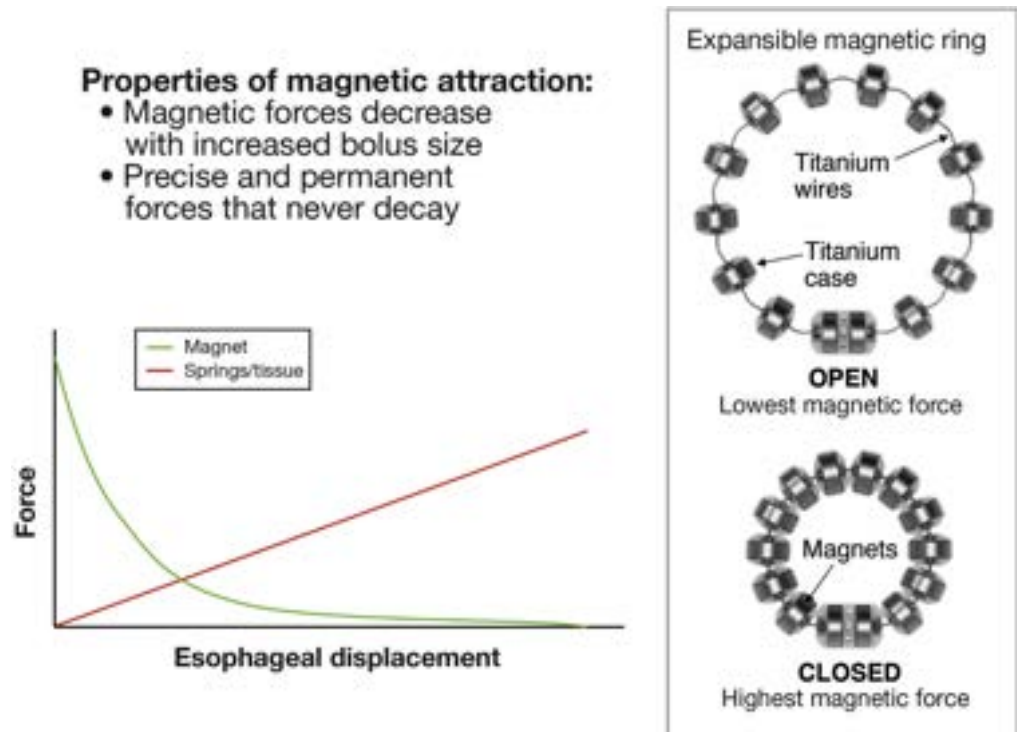
The use of magnets to address a defective reflux barrier is not an obvious first choice of materials, but in many respects magnetic forces are ideal: (1) magnetic forces are precise; (2) magnet forces are permanent and last into perpetuity; and (3) unlike any other type of material (eg, elastic materials, tissue) magnetic forces decrease with esophageal displacement, entailing less resistance the larger the food bolus. With any other type of material, resistance increases with larger bolus size (Figure 1).^{6,7} The magnetic device used today, and Food and Drug Administration (FDA)-approved in March 2012, is an expansible ring of individual magnet cores, placed in titanium cases, and separated with titanium wires to form an annular shape (Figure 1).

The design of the device was specifically developed based on the physiologic demands of the esophageal

sphincter and the peristaltic function of the esophageal body. Critical design considerations included the following: (1) The magnetic forces (number, size, shape, and position of the magnets) have to be strong enough to augment the native reflux barrier preventing inappropriate esophagogastric junction opening and pathologic reflux, yet weak enough to allow for consistent normal food bolus passage, and also to allow for normal venting of the stomach, (ie, allow for belching and vomiting). (2) In addition the distance between the magnetic cases (length of the connecting wires) has to allow for retraction of the magnets every time (too great a distance and the magnets would not reapproximate).⁶ (3) Lastly, the magnets have to be able to withstand the magnetic force within a magnetic resonance scanner, because magnetic resonance scanners contain powerful magnetic forces that can reverse the polarity of the relatively weaker forces in the implanted device. The current device is conditionally approved by the FDA for magnetic resonance scanners that are 1.5 T or less.¹⁴

The individual magnets are neodymium-iron-boron, hermetically encased and sealed within a 5.8-mm diameter, 4.3-mm width, commercially pure titanium case. Each magnetic bead, within its case, is connected by individual titanium wires that allow adjacent beads to be displaced relative to each other for a maximal fixed distance of 3.6 mm. When the device is in its closed position, each case rests against its adjacent cases analogous to a Roman arch, preventing esophageal compression. In this position the magnets are in the closest proximity to each other and exhibit the highest force (0.39 N); when the magnets are fully separated at the maximum expansion of all of the individual wires the

Figure 1. Magnetic attraction in the form of an expansible ring is ideally suited to the dynamic area of the GEJ. The properties of magnets provide a precise and permanent force to augment the LES. Unlike the use of springs or tissue to reinforce the antireflux barrier, magnetic force decreases with esophageal displacement.



magnetic force is at its lowest (0.07 N) (Figure 1). Although the attraction force between magnets exponentially decreases with separation distance, at no stage of the displacement does the magnetic force ever reach zero, because the lowest force between magnets at maximum displacement is sufficient to return the device to a closed (all cases touching) position. Collectively, this displacement of 1 or more pairs of adjacent beads allows the magnetic bracelet to expand radially to various circumferences, based on the size and total number of beads implanted (Figure 2). The device is capable of nearly doubling its diameter when all of the beads are separated. Devices composed of 13–17 magnetic beads are currently marketed.^{6–8,15}

The magnetic device is designed to allow for normal eating; when a patient swallows a food or liquid bolus the pressure of the peristaltic wave (ie, >20 mm Hg) is high enough to break 1 or more of the magnetic bonds between adjacent beads allowing the food bolus to pass through the enlarged diameter of the device (Figure 3). The connecting wires allow the first pair of adjacent beads to separate up to the maximum distance of 3.6 mm; when the maximum distance between the first pair of beads is achieved the next pair of beads then separates, and this process continues until the inside diameter of the esophagus is sufficient to allow the food bolus to pass into the stomach. Not all of the beads necessarily separate with each swallow; bead separation can also be partial. Unique to the design, is that the magnetic attraction force that must be overcome to allow separation of the beads is the same regardless of the number of beads contained in the device. The radial displacement of the device and the esophagus is transient; as the food passes the residual magnetic attraction returns the beads to the closed position. Note that the device allows venting in response to belching and vomiting forces, mimicking normal physiology.^{6–10}

Several trials have demonstrated that the device does not affect resting or residual LES pressures; this is caused by the lack of device compression in the region of the

gastroesophageal junction (GEJ).^{7–9} Rather the magnetic device works by augmenting the native LES, preventing effacement and LES shortening when challenged by increases in gastric pressure or gastric volume, thereby preventing transient barrier loss. The device also likely increases functional LES length and favorably impacts the compliance and gastric yield characteristics of the GEJ.^{6,7,16}

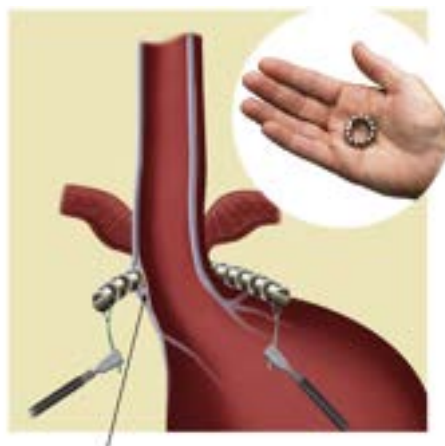
The device is laparoscopically placed around the region of the GEJ, without dissection of the gastric fundus. Using a minimal dissection technique, the diaphragm and a small window of distal esophagus are exposed and a sizing tool is used to measure the outer diameter of the esophagus. An appropriately sized device is selected to loosely fit around the esophagus (in the closed position), taking care to avoid esophageal compression, and tunneled under the posterior vagus nerve for anchoring to avoid migration (Figure 2). The 2 ends of the device are fitted together using the last 2 magnetic cores and the device is freely left in place without suturing. Hiatal hernias are repaired as needed at the time of surgery. Along with magnetic augmentation of the sphincter, a LES positioned in the thorax should always be restored to an intra-abdominal position and any hiatal defect should be surgically corrected, providing a comprehensive restoration of the antireflux barrier. Within the initial weeks postimplantation, the device becomes covered in a fibrous capsule. This helps contain the device in position, but uniquely still allows movement of the individual magnetic cases, analogous to balls moving in a sock. The surgery is typically accomplished in less than 30 minutes, with same-day discharge on a normal diet and without need for antibiotics. More detailed descriptions of the surgical technique have previously been published.^{7–10}

Food and Drug Administration Labeling and Clinical Trials

The magnetic sphincter device (LINX Reflux Management System, Torax Medical, Inc, Shoreview, MN)

Magnetic sphincter device dimensions

Model	Closed diameter (mm)	Open diameter (mm)
13 bead	13.6	25.3
14 bead	14.9	27.8
15 bead	16.2	30.4
16 bead	17.5	32.9
17 bead	18.7	35.8



Device placement, note "window" created between posterior vagus and esophagus to anchor device.

Figure 2. The magnetic sphincter is available in a range of sizes. The magnetic device is prevented from migrating (until fibrous encapsulation occurs) by surgically anchoring the device between the posterior vagus and the esophagus.

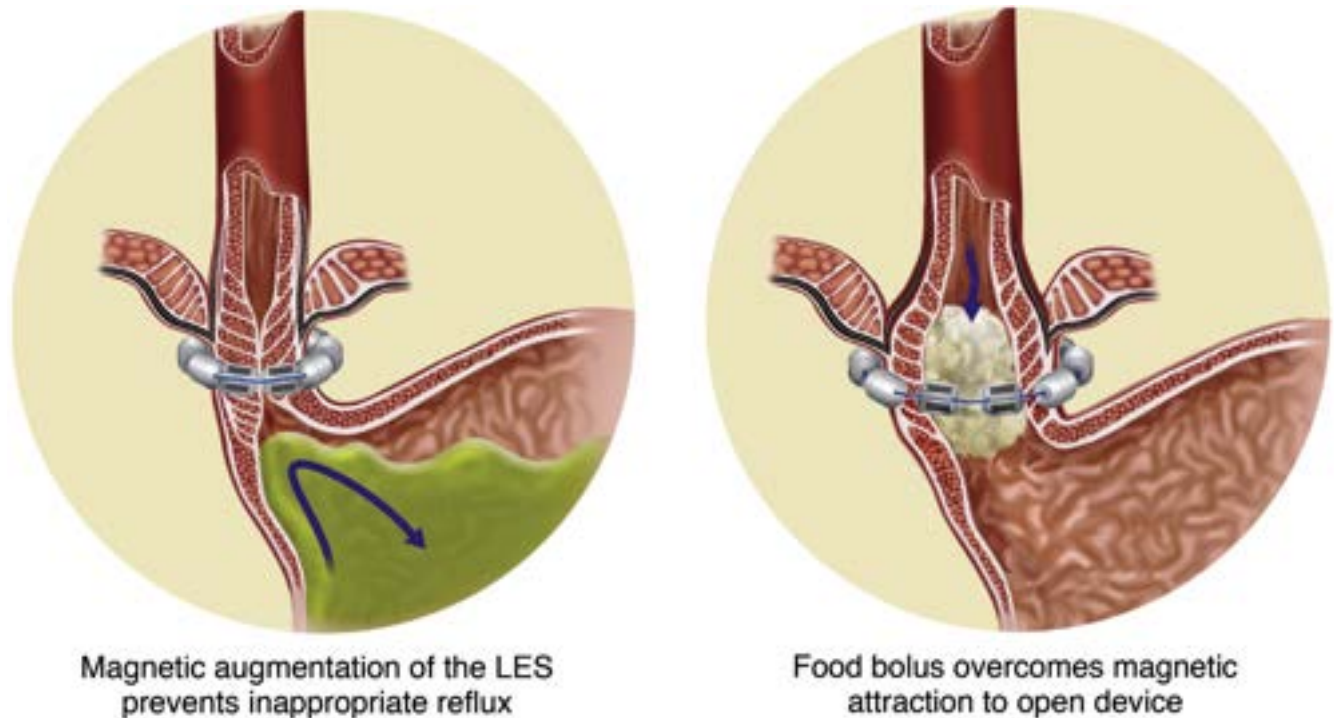


Figure 3. The magnetic sphincter prevents inappropriate reflux, but opens to allow normal esophageal function, such as swallowing, belching, and vomiting. Not all of the magnetic beads separate with each swallow.

was FDA-approved on March 22, 2012, based on extensive preclinical data, and premarket approval trials reported at multiple time points through 5 years.^{8-10,15,17,18} Currently, the device has the following FDA indication: “The magnetic reflux management system is a laparoscopic, fundic-sparing, anti-reflux procedure indicated for patients diagnosed with GERD, as defined by abnormal pH testing, and who are seeking an alternative to continuous acid suppression therapy (ie, PPIs or equivalent) in the management of GERD.”¹⁵ Patients with motility disorders are contraindicated for the procedure.

Including the FDA trials, the magnetic augmentation procedure has been studied in multiple distinct GERD patient cohorts, reported at various time-points, with assorted outcomes data available for analysis. Results for quality of life scores, discontinuation of PPIs, reduction in esophageal acid exposure, and resolution of moderate/severe regurgitation have been consistent, reproducible, and durable across all studies (Figure 4; not all published studies reported on all outcomes; trials reported at multiple time-points are graphed only at the final published time-point).^{10,18-25} Additionally, 7 studies have compared magnetic augmentation with laparoscopic fundoplication.²²⁻²⁸

Clinical Data: Food and Drug Administration–Approval Trial

The FDA pivotal approval trial was a large, non-randomized, single-arm, multicenter study (13 US

centers; 1 European center), involving both academic and community settings. Patients served as their own control subject for statistical analysis, but the study was uncontrolled with regard to an external control group. One hundred patients with GERD were enrolled and followed for 5 years. To enter the study, patients were required to have at least 6 months of GERD with classic symptoms of heartburn and/or regurgitation, a partial response to PPI therapy (partial improvement in GERD health-related quality of life [HRQL] scores), and pathologic acid exposure as documented by an abnormal pH score without medications. Exclusion criteria included a hiatal hernia >3 cm, Barrett’s esophagus, a major motility disorder or ineffective esophageal motility, body mass index (BMI) >35, or erosive esophagitis more than Los Angeles grade B. Ninety-eight patients completed the study at 3 years (96 with pH data at 1 year), and 85 patients completed the study at 5 years.^{9,10}

Patients were discharged on the same day or the next day, no antibiotics were used, and patients were encouraged to resume a normal diet as soon as possible after the procedure. The primary endpoint of reduction in esophageal acid at 1 year was measured as either esophageal pH normalization (total % time pH <4 was <4.5%) or at least a 50% reduction in esophageal acid exposure, based on an intent-to-treat analysis. This endpoint was met by 64% of patients, with 58% demonstrating normalization of pH scores. Median total acid exposure time was reduced from 10.9% at baseline, to 3.3% at 12 months. At 3 years 92% of subjects had at least a 50% reduction in GERD-HRQL scores; the median total score decreased from 27 at baseline off PPIs, to 2 at

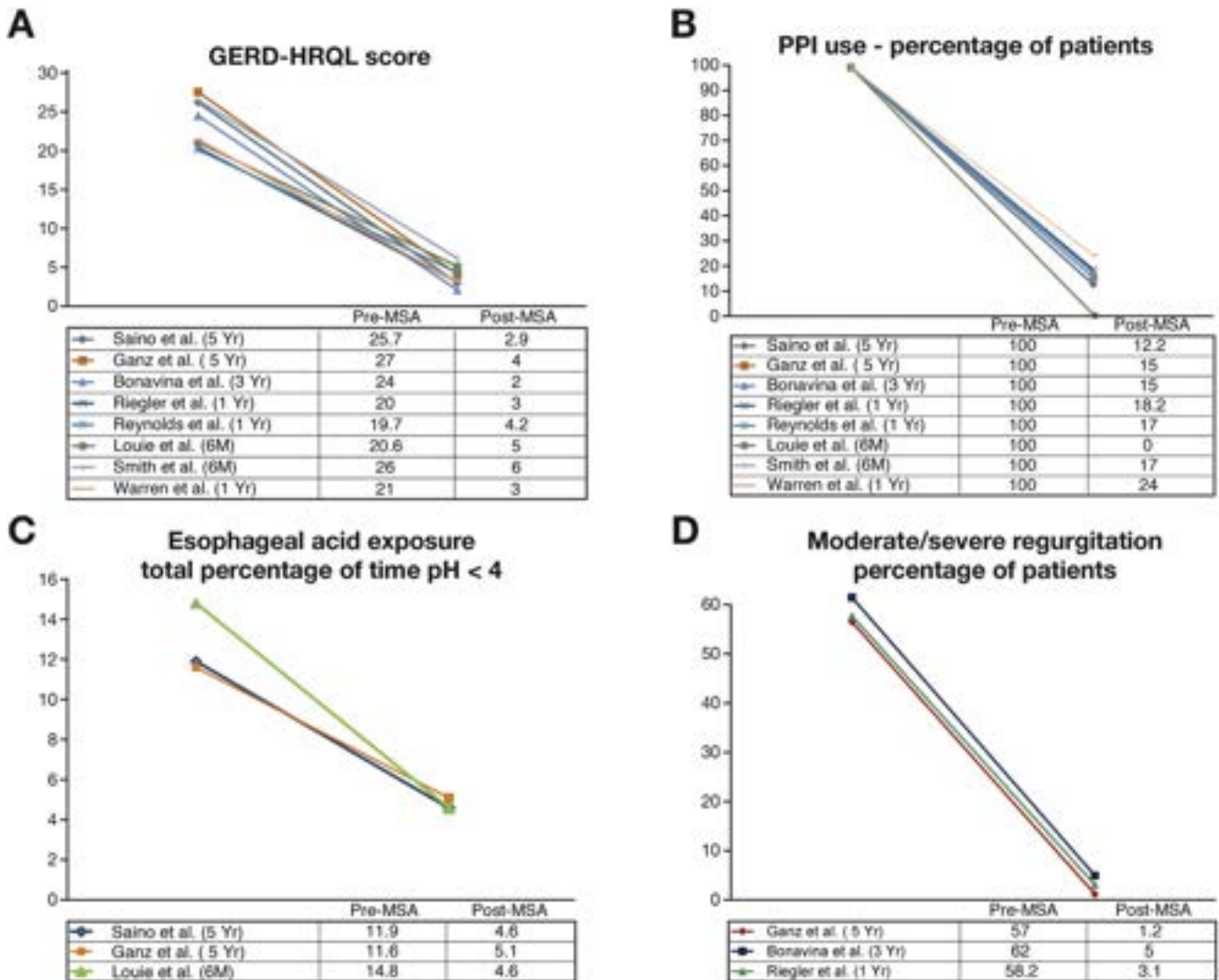


Figure 4. The magnetic sphincter has consistently provided improvement across key clinical outcomes from multiple studies for (A) GERD-HRQL, (B) PPI discontinuation, (C) reduction in esophageal acid exposure, and (D) elimination of moderate/severe regurgitation. MSA, magnetic sphincter augmentation.

3 years of follow-up off PPIs (compared with 11 at baseline on PPIs). There was complete cessation of PPI use in 87% of subjects at 3 years; of the 13% who still required PPIs, all reported taking the medication at a reduced frequency.⁹

At 3 years, the procedure was safe with no perioperative or intraoperative complications. There were no differences between academic or nonacademic centers and little evidence for a learning curve because initial cases did as well as later cases. The main adverse event in the 3-year report was dysphagia; this was seen in 68% of subjects postoperatively, decreasing to 11% at 1 year, 5% at 2 years, and 4% at 3 years. Esophageal dilation was carried out in 19 patients with 16 reporting improvement. Visible esophagitis was seen in 40% of patients at baseline, improving to only 12% at 1 year and 11% at 2 years. De novo esophagitis (Los Angeles grade A only) was seen in 4% at year 2. Ninety-eight percent of patients reported the ability to belch, and all of those reporting the need to vomit, could vomit. There was no

statistically significant change in any manometric parameter, from baseline.⁹

Six patients experienced a serious adverse event and the device was removed in 4 of these 6: a total of 3 patients had persistent dysphagia that resolved on removal of the device and 1 patient had persistent nausea that persisted despite device removal. Two of the 6 patients had postoperative nausea and vomiting that required hospitalization; they recovered with conservative therapy. Two additional patients had their devices removed not because of adverse events, but rather for reflux disease management; 1 for persistent reflux and 1 for persistent chest pain. Of the 6 patients with device removals, 3 of the 6 went on to have uneventful Nissen fundoplication surgery.⁹

The 5-year report of the same cohort (85 patients available) was recently published, focusing on long-term GERD quality of life scores, patient satisfaction, regurgitation scores, PPI use, and safety.¹⁰ At 5 years, 83% of patients had at least a 50% reduction in GERD-HRQL

scores, improving from 27 at baseline to 4 at 5 years, and 89% had at least a 50% reduction in PPI use. At the 5-year mark 85% of subjects reported complete cessation of PPI use. Moderate-severe regurgitation improved from 57% at baseline to 1.2% at 5 years, and patient dissatisfaction improved from 95% before treatment to 7.1% at the close of the study. Healing of esophagitis occurred in 76.5% by the end of the study and 5% of patients developed de novo esophagitis. All patients reported the ability to belch (or vomit if needed). Bothersome gas-bloat was present in 52% at baseline, improving to 8.3% at the end of the study. At 5 years bothersome dysphagia was reported in 6%, and 1 additional device was removed in a patient with persistent dysphagia, for a total of 7% device removals. There were no device erosions, migrations, malfunctions, abscesses, or infections noted, and no new safety risks emerged compared with the 3-year report. The study concluded that augmentation of the LES using the magnetic device resulted in sustained and significant efficacy in the treatment of patients with reflux dissatisfied with PPIs, with long-term safety documented, and that the procedure should be considered as a first-line surgical option.¹⁰

Additional Food and Drug Administration-Regulated Prospective Trial

Bonavina et al^{7,8} reported 1- and 2-year results from a separate 44-patient initial FDA feasibility trial, Lipham et al¹⁷ reported 4-year results from the same cohort, and Saino et al¹⁸ reported 5-year results. This was a 4-center, nonrandomized single-arm study (2 United States and 2 Europe) in which patients acted as their own control subjects, which also was presented to the FDA in support of device approval. The inclusion and exclusion criteria were similar to the FDA pivotal trial. Acid exposure decreased from a mean of 11.9% to 2.4%, and pH scores normalized in 90% of patients at the 2-year mark. At 1 year there were no statistically significant changes in any manometric parameter for the group overall, although in 9 patients with baseline hypotensive LES pressures, there was a significant increase postoperatively. GERD-HRQL scores significantly improved and 86% of patients were completely off PPI therapy at 2 years. Postoperatively 43% of patients experienced mild dysphagia but this resolved in most by 2 years. Two patients had their device removed for persistent dysphagia. At the 4-year mark an additional patient had the device removed for ongoing GERD and went on to Nissen surgery. At 3 years, 80% of patients continued to demonstrate normal pH scores, 80% of patients remained off PPIs, and the mean GERD-HRQL score was 3.3 (baseline, 25.7). At 5 years 75% of patients were available for study; the GERD-HRQL score was 2.9, and 87.8% of patients reported complete cessation of PPIs. Twenty of the 44 patients underwent pH testing at 5

years and of these 17 of 20 either had normal pH scores or a >50% reduction in acid exposure times. There were no additional device removals and no reported device erosions, migrations, or malfunctions.^{7,8,17,18}

Additional Prospective Case Series

Bonavina et al¹⁹ reported a 100-consecutive patient, single-center (Milan, Italy), prospective, single-arm, nonrandomized study in 2013 with similar inclusion and exclusion criteria. The median follow-up period was 3 years. GERD-HRQL scores improved from 24 at baseline off PPIs to 2 at last follow-up. Normalization or >50% reduction in acid exposure time was seen in 80%, and 85% reported complete cessation of PPI use. There were no erosions or migrations of the device and 3% of subjects had the device removed for dysphagia or persistent GERD.

Schwameis et al²⁹ reported a small 23-patient, short-term, prospective, nonrandomized study in Vienna, Austria. There were significant reductions in GERD-HRQL scores and 71% of patients completely discontinued PPIs. There were no postoperative pH data reported. There were no operative complications and persistent dysphagia was noted in 1 of 23 patients.

Reynolds et al²⁰ reported a prospective observational study of 67 patients who underwent magnetic sphincter placement at 2 California institutions from 2012–2013 with a median follow-up of 5 months. The only reported outcome was the GERD-HRQL score, which decreased to 4 postoperatively (baseline not reported), and 77% of patients were completely off PPIs at last follow-up. Eighty-three percent of patients reported initial postoperative dysphagia, but only 4% reported dysphagia at 12 weeks of follow-up.

Smith et al²¹ reported a 66-patient case series from the Mayo Clinic, with patients followed for a mean of 5.8 months. At time of last follow-up, 92% of patients were satisfied with their disease management and 83% had completely stopped PPIs. Dysphagia was identified in 20% of patients, but improved over time.

Magnetic Sphincter Versus Laparoscopic Nissen Fundoplication Comparison Trials

Seven studies have compared magnetic sphincter augmentation with laparoscopic Nissen fundoplication. Overall, clinical outcomes have been comparable between the 2 types of antireflux surgical procedures. However, to date there have been no randomized, controlled trials comparing the 2 techniques, and the study cohorts are not necessarily comparable regarding hiatal hernia size, severity of reflux, BMI scores, or esophagitis scores (Table 1, Figure 5).^{22–28}

Louie et al²² performed a retrospective, case-control study comparing 34 patients who underwent magnetic

Table 1. Comparison Summary of MSA and LF

Lead author	Study design	N = MSA/LF	Follow-up	GERD-HRQL results	PPI results	Side effects
Sheu	Single-center, case-controlled matched for age, gender, and hiatal hernia size	12/12	7 months	NA	NA	A trend toward decreased adverse gastrointestinal symptoms of bloating, flatulence, and diarrhea was seen after MSA compared with LF (0% vs 33%); dysphagia requiring endoscopic dilation was more frequent after MSA (50% vs 0%)
Riegler	Multicenter, prospective, concurrent enrollment	202/47	1 year	Improved from 20.0 to 3.0 for MSA and 23.0 to 3.5 for LF	PPI discontinuation: 82% MSA and 63% LF	Gas/bloating less after MSA (10%) compared with LF (32%); ability to vomit was greater after MSA (91%) compared with LF (44%)
Louie ^a	Retrospective, case-control of consecutive patients (similar reflux and hernia size)	34/32	MSA, 6 months; LF, 10 months	Improved from 20.6 to 5.0 for MSA vs 22.8 to 5.1 for LF	All MSA (0 of 24) remained off PPIs; 1 of 32 LF on PPI despite normal postoperative testing	MSA resulted in improved gas and bloating and enabled belching in 67% compared with none of the LFs
Reynolds	Single-center, propensity score analysis	50/50	1 year	Similar GERD-HRQL postoperative (4.2 MSA and 4.3 LF)	PPI use after surgery 17% MSA and 8.5% LF	No severe gas/bloating after MSA compared with 10.6% LF; unable to belch (9% MSA and 26% LF); unable to vomit (4% MSA and 21% LF); postoperative dysphagia was similar (46.8% MSA and 44.7% LF)
Warren	Multicenter, propensity score analysis	114/114	1 year	GERD-HRQL scores improved preoperative to postoperative; MSA 21–3 and LF 19–4	Resumption of daily PPIs higher for MSA (24%) vs LF (12%)	MSA had greater ability to belch (96 vs 69%) and vomit (95 vs 43%) with less gas bloat (47 vs 59%)
Asti	Single-center, propensity score analysis	135/103	1–7 years	Not statistically different	Not statistically different	Not statistically different for dysphagia and gas bloat

LF, laparoscopic fundoplication; MSA, magnetic sphincter augmentation; NA, not applicable.

^aReported pH results: pH normalized in both groups; DeMeester score (14.2 MSA vs 5.1 LF) and % of time pH <4 (4.6 MSA vs 1.1 LF).

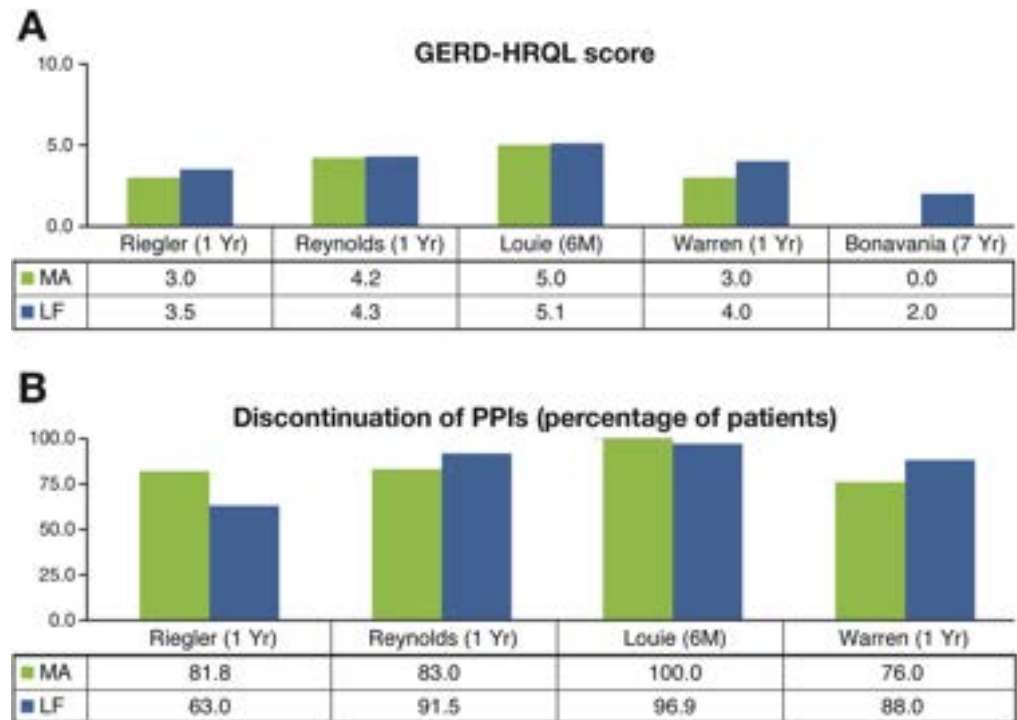


Figure 5. (A) Postoperative GERD-HRQL scores were comparable between magnetic augmentation (MA) and laparoscopic Nissen fundoplication (LF) and ranged from 0–5.0 after MA, compared with 3.5–5.1 after LF. (B) Discontinuation of PPIs was comparable between the treatments ranging from 76%–100% after MA and 63%–96.1% after LF.

sphincter augmentation with 32 patients who had laparoscopic fundoplication, at a single institute. At baseline, the groups were similar in reflux characteristics and hernia size; patients with hernias >3 cm in size were excluded. All of the patients were symptomatic despite PPI use. At 6 months of follow-up for the magnetic augmentation patients and 10 months of follow-up for the fundoplication patients, both groups demonstrated similar improvements in GERD-HRQL scores and there were no significant differences in heartburn or regurgitation scores. Ambulatory pH scores normalized in both groups, but were significantly lower for the fundoplication group (acid exposure time decreased from 14.8% to 4.6% in the magnetic augmentation group and from 13.5% to 1.1% following fundoplication). Dysphagia was initially worse in the fundoplication group, but by 6 months both groups' dysphagia scores returned to baseline and there were no differences in dysphagia between groups. The magnetic sphincter procedure allowed belching in 67% of patients compared with 0% in the fundoplication group, which Louie attributed to "super-normal" fundoplication effects.

Sheu et al²⁶ performed a small case-control trial comparing 12 magnetic sphincter patients with a case-matched cohort of 12 fundoplication patients at 1 institute. The patients were matched for age, gender, reflux severity, BMI, and hernia size, and followed for a mean of 7 months. Patients with hernias >3 cm in size were excluded. Following surgery, there was no difference in symptom control between the 2 groups (75% of the magnetic sphincter patients and 83% of the fundoplication patients had complete resolution of GERD symptoms). Dysphagia incidence was similar between the 2

groups but persistent dysphagia was more common in the magnetic device cohort, as was the need for endoscopic dilation. Dilation resolved all but 1 case of dysphagia in the magnetic device cohort.

Reynolds et al²³ performed a single-center, retrospective, controlled analysis of 1-year outcomes comparing 50 magnetic augmentation patients with 50 propensity-matched laparoscopic Nissen cases. Patients with hernias >3 cm in size were excluded. At 1-year postoperatively, both groups had similar GERD-HRQL scores, and similar rates of cessation of PPI use. Significantly more fundoplication patients were unable to belch or vomit, and there were also more cases of severe gas-bloat in the fundoplication group. The incidence of dysphagia and the number requiring dilation was similar in both cohorts. There were 2 postoperative complications in the fundoplication group; there were no complications, and no device migrations or removals in the magnetic augmentation group.

Reynolds et al²⁷ published a second, retrospective, nonrandomized, controlled study from the same institution, comparing 52 GERD patients who underwent magnetic augmentation with 67 laparoscopic Nissen fundoplication patients, and followed for 1 year. At study end, GERD-HRQL scores were similar for both cohorts (4.3 for the magnetic group and 5.1 for the Nissen group), and 85% of the magnetic patients had completely stopped PPIs versus 92% of Nissen patients, differences that were not significant. There was significantly less gas-bloat, and greater ability to belch and vomit for the magnetic augmentation group. Postoperative dysphagia was reported in 46% of the magnetic group and 56% of the fundoplication group, and the dilation requirements

were similar for both. The fundoplication group reported 5% severe dysphagia, and there was no severe dysphagia in the magnetic group. There were 2 complications in this study, both in the magnetic augmentation group; 1 patient had intractable vomiting that resolved with conservative management and a second patient had a food impaction that required endoscopic removal.

Warren et al²⁸ published a large, 3-center, propensity-matched trial that compared 201 patients with GERD treated with magnetic augmentation with 214 patients treated with laparoscopic Nissen fundoplication. Before the propensity-matched analysis, the groups were similar in age, gender, and baseline GERD-HRQL scores; however, the Nissen group had higher BMI scores, more preoperative dysphagia, and a higher percentage of hiatal hernia. At 1-year 354 patients (169 magnetic group; 185 Nissen group) had complete follow-up data. The propensity-matched analysis included 114 subjects treated with the magnetic device and 114 treated with Nissen fundoplication. Both groups demonstrated significant improvement in GERD-HRQL scores and satisfaction rates compared with baseline, with no difference between them. Fewer patients in the magnetic group achieved complete PPI cessation (76% vs 88%); however, more patients in the magnetic device group reported they would undergo the procedure again (93% vs 83%). The magnetic device group had greater ability to belch (96%) than the Nissen group (69%), and had significantly less gas-bloat (47% vs 59%). There was more mild dysphagia in the magnetic group (44% vs 32%; $P = .04$), but less severe dysphagia (1% vs 5%; $P = .55$). Two in the magnetic device group underwent reoperation; 1 had the device removed because of continued reflux symptoms with conversion to Nissen fundoplication, and the other patient had the device removed for erosion. In the Nissen group, 2 patients underwent reoperation for reoccurrence of hiatal hernia and symptomatic GERD.

Riegler et al²⁴ compared magnetic augmentation with laparoscopic Nissen surgery via a prospective, multi-center registry with concurrent enrollment. There were 202 magnetic sphincter patients versus 47 laparoscopic Nissen patients evaluable 1-year postoperatively. The fundoplication group was older and had a higher frequency of large hiatal hernias and Barrett's esophagus. The median GERD-HRQL score was 3.0 in the magnetic device group and 3.5 in the fundoplication group at 1-year follow-up (baseline was 20.0 and 23.0, respectively), both significantly improved. Complete cessation of PPIs was seen in 81.8% in the magnetic group, and 63.0% of the fundoplication group at 1 year; moderate or severe regurgitation improved from 58.2% at baseline in the magnetic group to 3.1%, compared with 60% baseline improving to 13.0% postfundoplication. These latter 2 outcomes were significantly better in the magnetic group. Excess gas and bloating were significantly lower, and ability to belch and vomit if needed, were significantly higher in the magnetic group. Reoperation rates

were similar in both groups (4.0% for the magnet group vs 6.4% for fundoplication). Riegler et al²⁴ concluded that magnetic sphincter augmentation was as effective as Nissen surgery and had similar safety and reoperation rates.

Asti et al²⁵ compared magnetic sphincter augmentation with Toupet fundoplication from an observational cohort of 238 consecutive patients using a propensity-score-matched method. All patients had a minimum of 1-year follow-up with some patients followed as long as 80 months. Both groups demonstrated significant improvement in quality of life scores, comparable PPI discontinuation, comparable side effects, and comparable reoperation rates. Asti et al²⁵ concluded that both surgical procedures were safe and both provided significant and comparable improvement in GERD quality of life over an extended period of follow-up.

Safety Analysis

In 2015, Lipham et al³⁰ provided a safety analysis of the first 1000 patients implanted with the magnetic sphincter device, from all available sources including the FDA Manufacturer and User Facility Device Experience Database (MAUDE), published medical literature, and data derived from the manufacturer of the device (Torax Medical, Inc).³¹ At the time of the analysis, there was a median implant duration of 274 days, at 82 institutions. Event rates were 0.1% for intraoperative/perioperative complications, there was a 1.3% hospital readmission rate, 5.6% need for esophageal dilation, and a 3.4% reoperation rate for device removal. All of the removals were elective and nonurgent with no complications related to device removal, and the main reason for device removal was persistent dysphagia. The pathogenesis of dysphagia is not known but may possibly relate to an exuberant fibrotic reaction postoperatively. There are no known predictors of response to dilation and no preferred dilation method has been published. There were no device migrations or device malfunctions; there was 1 reported erosion for a rate of 0.1%. The hospital readmissions were for dysphagia, chest pain, nausea, or vomiting. The authors concluded that magnetic sphincter augmentation had a low risk profile, and that the overall device removal rate was relatively low.³⁰

Comments

The main alternative for GERD patients dissatisfied with PPIs either because of ongoing symptoms, side effects, or cost, has traditionally been surgical fundoplication described by Nissen 60 years ago. Fundoplication surgery has recently been demonstrated to be as effective as chronic PPI therapy, but Nissen surgery requires permanent anatomic alterations and is associated with a significant side effect profile including gas-bloat, flatulence, and inability to belch or vomit, negatively

impacting quality of life scores.³² Using the gastric fundus as a wrap creates a “tightly” augmented LES that reduces the total number of reflux episodes to below what is considered normal. This results in a technique that is highly effective at preventing reflux but also prevents the normal venting of swallowed air. The inability to vent (belch) and the reduced number of normal reflux episodes after fundoplication surgery contributes to the side effects of bloating and flatulence.²² As a result of the pronounced side effect profile related to Nissen surgery, the popularity of this procedure has been declining in recent years, and there seems to be no net benefit over PPI therapy to warrant its use in the typical PPI GERD patient.^{13,32,33}

The magnetic sphincter augmentation procedure was designed to obviate many of the issues associated with Nissen surgery by replacing gastric tissue with an expansible ring of magnets, allowing for sparing of the fundus, mimicking normal LES function, and allowing more physiologic swallowing of food and venting of air. Studies of the magnetic device include long-term trials out to 5 years, performed with FDA oversight, along with multiple comparison studies to Nissen fundoplication using propensity-matched analyses to allow direct comparison of outcomes between the 2 procedures. After a decade of trials the device risks and benefits of magnetic augmentation are now well accepted, and are comparable with Nissen surgery, albeit with significantly less gas-bloat and preserved ability to belch and vomit. Because there were some differences at baseline between the reported Nissen and magnetic sphincter cohorts in some of the studies a randomized trial comparing the magnetic device with Nissen surgery might be ideal, although there are some potential limitations to such an approach including the inability to “blind” the surgeons. In addition, unlike the magnetic device, Nissen surgery has permanent consequences.³⁴ To randomize a patient to a permanent, irreversible surgical procedure, when the benefits of a reversible magnetic augmentation procedure are comparable and well established may not be feasible.

To date there have been 18 published studies regarding the magnetic augmentation device, among them well-executed prospective, multicenter, long-term

(1–5 year), patient self-controlled trials with rigorous follow-up and prespecified success criteria. These studies demonstrate excellent pH control with greater than 50% of patients normalizing pH scores at 1 year and 5 years, and significant improvements in symptom scores and PPI usage, compared with baseline, at the 5-year interval. These findings are consistent across all published trials. Although the lack of a control group makes these trials susceptible to a short-term placebo effect with regard to early assessment of the subjective variables, it should be noted that the sustained objective elimination of pathologic esophageal acid exposure in most patients at 1 year and 5 years (normal pH scores), and the long-term nature of the follow-up helps corroborate the treatment effect.^{9,10,18} The totality of clinical data shows significant improvement across all parameters measured, including esophageal acid exposure, heartburn, regurgitation, PPI use, and GERD quality of life scores. Also, the procedure is reversible and spares the fundus, thus preserving additional treatment options (eg, Nissen) in the event of failure. A randomized, controlled trial of magnetic augmentation versus PPI use is currently underway, which should help clarify results of the uncontrolled trials.

The device is safe across all studies with dysphagia the most common complaint. The incidence of dysphagia and need for esophageal dilation is comparable with Nissen fundoplication. Dysphagia is common immediately following the magnetic augmentation procedure and improves with time, with about 3%–5% of patients experiencing persistent dysphagia, presumably related to exuberant scar tissue that forms around the device preventing adequate expansion. In cases that do not respond to dilation, device removal typically resolves the dysphagia and patients can then have fundoplication surgery. The device removal rate is about 3%.¹⁷

The device erosion rate is less than 1%, without associated perforations. Patients with erosions have to date been nonurgent with uneventful device removals.^{17,30} This is materially different from the experience with an older reflux implant (ie, the Angelchik prosthesis). The magnetic sphincter device was engineered to address the design flaws of the Angelchik. The

Magnetic sphincter vs angelchick prosthesis



Figure 6. The magnetic sphincter augments the reflux barrier by expansible magnetic force, not bulk and rigidity as with the Angelchik prosthesis. The volume of the Angelchik was approximately 50 mL versus 1.2 mL for the magnetic sphincter.

magnetic sphincter augments the reflux barrier by expansible magnetic force, not bulk and rigidity, as with the Angelchik device. Indeed, the volume of the Angelchik was approximately 50 mL as compared with 1.2 mL for the magnetic sphincter (Figure 6). Furthermore, the magnetic sphincter responsively opens for food bolus transit and, because of the nature of magnets, exhibits progressively less force the larger the food bolus. In contrast, the Angelchik was a rigid, elastomer, doughnut-shaped device that affected a fixed diameter around the esophagus allowing for little to no device distention with food bolus transit. As a result of this nonconforming nature, the erosion and migration rate for the Angelchik occurred earlier after implant and at a higher rate than the magnetic sphincter device.^{35,36} Therefore, past experiences with the Angelchik should have no significant bearing on the magnetic sphincter procedure.

In conclusion, magnetic sphincter augmentation is proven to be effective and safe in the treatment of GERD and should be considered a surgical option for patients dissatisfied with medical management and considering surgical therapy, particularly for those seeking a fundic-sparing operation, and with reflux parameters consistent with study cohorts.

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Conflicts of interest

The author discloses no conflicts.