REVIEW ARTICLE

Magnets for therapy in the GI tract: a systematic review

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In 1957, Equen et al[1] reported the retrieval of foreign bodies in the esophagus, stomach, and duodenum by using magnets. For many years afterward, the clinical role for magnets and magnetic technologies in the GI tract remained quiescent. However, recently there has been a resurgence of interest.

Advanced endoscopic therapeutic techniques such as natural orifice transluminal endoscopic surgery (NOTES) and endoscopic anastomosis creation have been developed as a minimally invasive alternative to surgery. Although these techniques reduce hospital stay, recovery time, and adverse events associated with conventional surgery, their wider uptake has been slow. This is in part due to the complex and demanding nature of the techniques, requiring a highly skilled operator. Difficulties often are encountered with tissue traction, anchoring, and accuracy of dissection as a result of a lack of triangulation of instruments and distal force transmission. The properties of magnets may present a technological solution to some these challenges. Their ability to exert untethered force over distance means magnets could be used in endoluminal resections and coupling and anchoring for single-incision laparoscopy as well as in NOTES procedures. In addition, applications to specific clinical indications have resulted in the advancement of magnetic compression anastomosis and sphincter augmentation, which are already clinically demonstrated.

The endoscopic and surgical communities have traditionally perceived magnets with justified scepticism because of the widely recognized perils of magnet ingestion. Early successes with innovative therapeutic uses of magnets allowed clinicians to view magnets differently, as a purposeful and promising technology. The widespread use of magnetic resonance imaging has helped to alleviate concerns regarding static magnetic fields, and there are no known adverse clinical implications to human exposure to static magnetic fields up to strengths of 2 Tesla.[2] This provides reassuring evidence to support the safety of magnetic devices for advanced endoscopic roles.

The aim of this review is to systematically examine the literature to identify emerging clinical roles for magnet-assisted GI endoscopic techniques and provide a clinician-orientated overview of magnetic forces that might inform future clinical use and ongoing research. Applications such as magnetic maneuverable capsule endoscopy[3] and magnetic foreign body removal[4] are considered outside the scope of this review, as are applications to single-port and traditional laparoscopic surgery. Magnetically tracked enteral tube placement[5-7] was considered in scope, although the application involves magnetic tracking by using sensors rather than relying on magnetic forces.

MATERIALS AND METHODS

The review protocol was registered on the PROSPERO international prospective database of systematic reviews (CRD42014009438).

Search methods

To identify the existing evidence base, a systematic search of multiple electronic literature databases was undertaken (PubMed and EMBASE) by using the following combination of relevant medical subject headings (MeSH): magnets (MeSH) *or* magnetics (MeSH) *and* endoscopy (MeSH) *or* endoscopes (MeSH). English language restrictions were applied. The search period was defined as the years 1992 to 2014, inclusively. The primary search strategy was supplemented by reference lists of retrieved articles, reviewers' suggestions, and the PubMed related articles feature. Two reviewers (P.C.M., T.P.C.) independently undertook title and abstract screens, with disagreements either resolved by consensus or arbitrated by a senior author.

Eligibility criteria

Inclusion criteria were defined as (1) clinically oriented procedures in animal models, human cadavers, or human

Abbreviations: ESD, endoscopic submucosal dissection; MAGS, Magnetic Anchoring and Guidance System; MeSH, medical subject headings; NdFeB, neodymium-iron-boron; NOTES, natural orifice transluminal endoscopic surgery.

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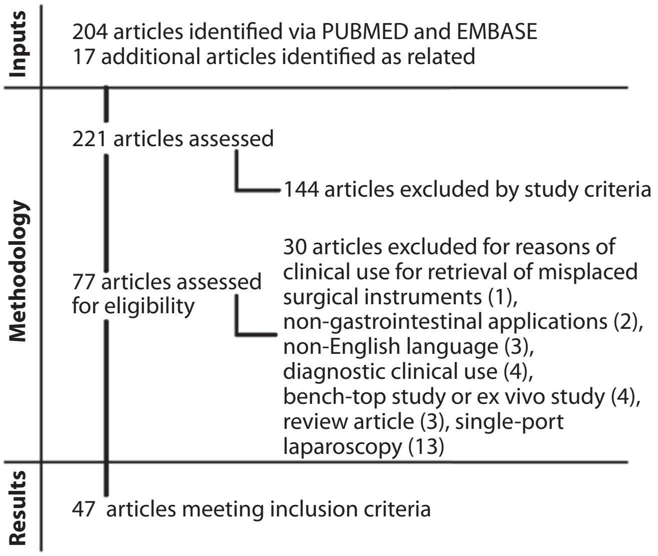

Figure 1. A modified Prisma (preferred reporting items for systematic reviews and meta-analyses) flow diagram depicting the systematic process undertaken by using the search strategy Magnets (MeSH) *or* Magnetics (MeSH) *and* Endoscopy (MeSH) *or* Endoscopes (MeSH).

participants; (2) interventional endoscopic procedures involving the GI tract; and (3) use of permanent magnet assistance. As previously noted, studies were excluded if they related to accidental ingestion of magnets with unintended clinical sequelae, metallic foreign body retrieval, diagnostic clinical applications (eg, magnetic endoscopic imaging, magnetic capsule navigation, magnetic resonance colonography), and endovascular applications. NOTES procedures were included, but single-port and traditional laparoscopic applications were excluded.

Outcomes of interest

Primary outcomes of interest were clinical parameters of feasibility, safety, and efficacy. Secondary outcomes of interest were technical features of magnet shape and design, navigation and deployment of magnets, and coupling.

Data extraction and categorization

Relevant data for these outcomes were retrieved from included studies. Results were categorized by research group (primary author affiliation), study model (clinical or animal), and clinical indication. Noted outcomes (eg, number of subjects, clinical outcome success, and complications) were recorded where available.

RESULTS

A total of 47 relevant studies were identified (Fig. 1). Distribution of study characteristics was 66% in-human clinical investigations (n = 31/47), 30% porcine model studies (n = 14/47), and 4% canine model studies (n = 2/47) (Fig. 2). The most frequently reported clinical role for magnet assistance was for compression anastomosis involving either intestinal or biliary anatomy, whereas the next most frequently described roles were for magnetic sphincter augmentation and magnetic anchoring and/or retraction (Table 1). Other clinical roles that have been reported include controlled luminal constriction (eg, to reinforce an incompetent lower gastroesophageal or anal sphincter) and preoperative endoluminal tumor marking for operative extraluminal localization (Table 1). Characteristics of retrieved studies highlight geographic variability and dependency patterns for research in the field. For example, all clinical reports of magnet-assisted biliary anastomosis applications are associated with Japanese or Korean institutions. The majority of animal model studies are represented by publications from institutions in the United States and Europe.

Magnet-assisted resection and dissection

Magnet-assisted retraction and endoscopic dissection have been demonstrated by a number of groups. Small, untethered clips or forceps are delivered into a lumen via a conventional flexible endoscope. Tissue is grasped and coupled via a proximal magnet to a second magnet external to the patient. This approach enables traction and counter-traction forces to be applied on tissue and a sense of instrument triangulation. These almost essential prerequisites for tissue dissection are inadequately provided for by existing endoscopes. Magnet assistance may be regarded as making challenging techniques such as endoscopic submucosal dissection (ESD) more feasible and accessible in addition to reducing procedure time and incidences of adverse events. The internal device can be maneuvered easily across the parietal peritoneum to provide freedom of positioning and retraction as necessary. An attractive feature of this arrangement is that once the intracorporeal magnet is in a desired position, the external magnet may confidently be left unattended, allowing clinicians to use their hands to control the endoscope.

One example of an extracorporeal electromagnet is the magnetic anchor–guided (MAG-ESD) system, which was shown to facilitate ESD in 25 patients with early gastric cancer[8] (Fig. 3). All procedures were performed successfully under with patients under conscious sedation with no perforations or severe uncontrollable bleeding. Multiple magnets were used in 16% (n = 2/25) of cases, highlighting the versatility of the concept, and there were no long-term sequelae of magnetic field exposure. It is noted that this study involved an external electromagnet rather than a permanent magnet, which facilitated greater control of the internal magnetic anchor. Recent work has sought to miniaturize the original external magnet.[9] Additional studies have indicated that retraction by using external permanent magnets may be feasible.[10,11]