

Constant magnetic field in treating congenital esophageal and anorectal malformation: a review

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ABSTRACT

Background Congenital esophageal and anorectal malformation are common in neonates. Refractory esophageal anastomotic stricture and abnormal defecation after surgical correction in infants are challenging surgical problems. Magnetic compression anastomosis (MCA) using mated magnets with their interposed compressed tissue may result in serosa-to-serosa apposition.

Data sources A literature search was performed to establish an algorithm for these accidents by the authors to identify relevant articles published from 1977 to 2019 in Google, Medline, ISI Web of Knowledge Ovid, CNKI and library document delivery, using search terms “magnetics”, “esophageal malformation”, “anorectal” and “perforation”. A total of 24 literatures were collected.

Results Magnamosis is technically feasible for alimentary tract anastomoses in pediatric patients. The magnets are most commonly made of neodymium–iron–boron and samarium–cobalt alloys, which have been employed to create solid anastomosis for long-gap esophageal atresia and refractory esophageal stricture without thoracotomy in children in recent years. Furthermore, magnamosis can be used for the functional undiversion of ileostomy. In anorectal malformations with favorable anatomy, this procedure may avoid an operative repair such as posterior sagittal reconstruction.

Conclusion Transluminal anastomosis of digestive tract using the MCA is a reliable, minimally invasive and feasible method to treat congenital esophageal and anorectal malformation.

lengthening should be performed in stages. Staged surgery is needed for children with high ARM; however, it has a long course of treatment and many complications, which seriously affect the growth and development of children. Traditional surgical methods are no longer sufficient for the treatment of congenital gastrointestinal malformation with complicated conditions.

Magnetic compression anastomosis (MCA) based on constant magnetic field (CMF) provides a new way to effectively treat congenital gastrointestinal malformations. MCA can avoid the huge trauma of traditional surgery and it also can significantly reduce complications during and after surgery, showing a promising application potential. This review summarizes the application and progress of CMF and MCA in treating esophageal and anorectal malformation.

Concept of constant magnetic field and magnetic compression anastomosis

CMF refers to the presence of a constant magnetic field around permanent magnets made of rare earth materials that will not change over time. MCA is a technology that uses a pair of magnets with opposite polarities to attract each other through the force of CMF, thus creating solid tissue anastomosis. CMF can generate continuous and stable pressure on the tissues between the magnets, causing tissue necrosis while achieving tissue anastomosis. With CMF, the organ and tissue anastomosis that is difficult to achieve using traditional manual sutures can be completed under minimally invasive conditions.

Development history of magnetic compression anastomosis

For more than 100 years, surgeons have been trying to find a more convenient and faster method of digestive tract anastomosis than manual sutures.^{3 4} The special cases of gastrointestinal damage and internal fistula caused by accidental swallowing of magnetic

INTRODUCTION

Congenital esophageal atresia (CEA) with or without tracheoesophageal fistula (TEF), and congenital anorectal malformations (ARMs) are common congenital gastrointestinal malformations. The incidence of CEA is about 1/3000,¹ and that of ARM is about 1/1500.² CEA and ARM are often combined with malformations in other organs, which is one of the important causes of newborn infant death. The treatment method includes traditional surgery and laparoscopic surgery; however, these surgeries inevitably cause a large amount of tissue damage, especially for children with long-gap esophageal atresia (LEA). For such children, esophageal



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foreign bodies in children have attracted the attention of surgeons.⁵⁻⁷ They used the CMF of magnetic materials to achieve anastomosis of the digestive tract.⁸ In recent years, with the continuous development of new materials and processing technologies in the field of biology, there have been reports on the successful application of MCA in digestive tract anastomosis, including intestinal ostomy, intestinal anastomosis, biliary obstruction, portal vein reconstruction and liver accessory duct anastomosis in liver transplantation.⁹⁻¹³ MCA provides a new way to treat difficult cases of anastomosis.

Magnetic material selection, magnetic field strength and biological safety

Magnetic material selection

At present, the permanent magnetic materials used in clinical practice mainly include the third-generation rare earth materials neodymium-iron-boron (Nd-Fe-B) and samarium-cobalt (Sa-Co) alloys.^{14,15} Nd-Fe-B is more widely used due to its low price, easy cutting and forming, and better physical properties (such as better corrosion resistance). It has excellent biocompatibility after titanium nitride coating.

Magnetic field strength and biological safety

The constant static magnetic field generated by permanent magnetic materials does not cause electromagnetic radiation. The occupational magnetic field exposure limit proposed by the Stanford Linear Acceleration Center and the Department of Energy of USA is ≤ 1000 mT. The surface magnetic flux density of Nd-Fe-B and Sa-Co alloy permanent magnets used for anastomosis of human tissues and organs is between 68 and 92 mT, which is far less than the proposed limit.¹⁶⁻¹⁸ Moreover, the magnetic field strength decreases rapidly with increasing distance. Therefore, the locally constant magnetic field generated by Nd-Fe-B and Sa-Co alloy permanent magnet is safe. Various types of magnetic implant materials made of Nd-Fe-B have been used in dental surgery and in coronary artery bypass grafting, and for minimally invasive treatment of biliary obstruction after liver transplantation.¹⁹⁻²⁶

Non-surgical treatment of neonatal esophageal atresia using constant magnetic field

For CEA with or without TEF, it is necessary to sever the odd vein to reveal the abnormal esophageal structure in both traditional thoracotomy and thoracoscopic surgery, which inevitably causes normal tissue and organ damage. For children with LEA, esophageal lengthening, gastroesophageal replacement or colonic esophageal replacement should be performed in stages. These surgical procedures are complicated, which may cause many complications, such as post-operative anastomotic fistula, stenosis and infection, and result in huge trauma and difficult recovery. In addition, a long course of treatment makes the children suffer from disease for a long period of time, which seriously affects their growth and development and increases the economic burden on families and society.

From 2001 to 2004, Zaritzky *et al*¹⁴ reported the use of CMF and N-Fe-P magnetic materials for CEA treatment in five children, and esophageal anastomosis was achieved in all patients. The average anastomosis time was 4.8 days. Among them, three patients complicated with TEF received surgery for fistula ligation. After a follow-up of more than 2 years, all patients recovered well. It can be seen that the use of CMF and magnetic materials can bring esophageal ends closer to each other, and finally achieve anastomosis.²⁷

For children with LEA, stage 1 anastomosis is likely to cause complications such as leakage or stenosis of the anastomosis due to excessive tension of the anastomosis. The staged surgery has a long treatment course. If magnets are placed at the distal and proximal ends of the esophageal cavity in the occlusion or obstruction section under endoscope, esophageal reconstruction and patency may be achieved under the continuous action of the CMF force between the magnets, which will likely shorten the treatment course and reduce complications. Several reports have verified the feasibility of this technique.^{15,28-30}

Minimally invasive treatment of esophageal anastomotic stenosis with constant magnetic field

Anastomotic stenosis is the most common complication after esophageal anastomosis. The traditional treatment method is balloon dilation under endoscope. If stenosis remains after multiple dilations, re-thoracotomy is needed. However, if CMF is used, re-thoracotomy can be avoided. In 2007, Kobe Children's Hospital in Japan reported a case of a baby boy with CEA but without TEF, who underwent routine esophageal lengthening and anastomosis.^{15,28-30} A severe anastomotic stenosis appeared 25 months after surgery. Multiple balloon dilations were performed but failed. Then, at 33 months after surgery, a pair of 15×5 mm (diameter×height) disc-shaped Sa-Co alloy magnets were placed at the upper and lower ends of stenosis. The CMF with a surface magnetic flux density of 320 mT (3200 G) was used. After 34 days, the stricturoplasty was completed and the magnets were removed through the mouth. After treatment, there was no recurrence of esophageal stenosis and the child recovered well. Similarly, Takamizawa *et al*¹⁷ reported five cases of patients with CEA that had severe anastomotic stenosis after esophageal anastomosis. The repeated balloon dilatation was ineffective in relieving the stenosis. However, they implanted a magnetic anastomosis device made of magnetic materials through minimally invasive technology and achieved good treatment results. Therefore, MCA based on CMF provides a new minimally invasive treatment for esophageal anastomosis.

Anti-gastroesophageal reflux (GER) with constant magnetic field

GER is a series of symptoms caused by reflux of gastric acid into the esophagus due to relaxation of the lower sphincter of the esophagus. For the traditional treatment of patients with severe GER, fundoplication is

needed, which is traumatic and has many complications. In order to overcome the shortcomings of traditional surgery, Bortolotti *et al* used CMF in the porcine GER model and obtained encouraging results.³¹ They placed two 5×20×1.5 mm magnets into the submucosa of the cardia sphincter. Under the force of CMF, cardia was closed, thus preventing the gastric contents from flowing back into the esophagus. Subsequently, two studies^{32 33} reported that patients with GER received implantation of a magnetic device made of a permanent magnetic material near the cardia in the lower part of the esophagus, and anti-reflux effects were achieved after enhancing the function of the lower sphincter of the esophagus by the CMF force of the magnets. Thus, CMF can avoid trauma and complications of traditional surgery and is more minimally invasive than laparoscopic fundoplication.

Constant magnetic field for esophageal diverticulum

Esophageal diverticulum with pain or obstruction usually requires thoracoscopy or thoracotomy, which are traumatic. Bouchard *et al* used MCA for minimally invasive treatment of four patients with esophageal diverticulum.³⁴ First, under endoscope, a magnet was placed in the esophageal diverticulum cavity, and then another magnet was placed in the esophageal cavity adjacent to the lower edge of the diverticulum. Under the force of CMF, the magnets were closely aligned together. After 10 days, there was complete necrosis of the diaphragm between the diverticulum and the esophagus. All four patients recovered well after surgery without any complications.

Constant magnetic field for congenital anorectal malformations

The high ARM requires three stages of surgery, of which the Peña procedure, which is the mid-course approach after the second-stage surgery, is currently the most commonly used anal plasty. It is unavoidable to cut off and damage the underdeveloped anal sphincter and the nerve fibers, which can easily lead to complications such as abnormal bowel movements, and affect the growth and development and quality of life of children. Russell *et al* treated an ARM child with CMF.³⁵ First, a magnet was placed at the proximal end of the rectum through the colostomy orifice, and then another magnet was implanted at the distal end of the rectum through the anus. Under CMF force, the two magnets attracted each other and squeezed the blind end of the intestinal wall of atresia. Eventually, a complete repair of the anatomical structure was achieved without damaging the anal sphincter and nerve fibers. Zartzky *et al*³⁶ also reported two cases of children with colorectal stenosis treated with magnetic materials. The magnetic anastomosis device was implanted into the stenosis site by minimally invasive technology, and the anastomosis of the stenosis site was achieved under the force of CMF. Based on these results, we suppose that for children with high ARM, if a magnet is implanted in the rectal blind end and a corresponding

magnet is placed on the skin surface of the anal point during rectal urethral fistula repair, anal forming will be completed by the CMF force between magnets. However, how to ensure that the CMF acts on the contraction center of the anal sphincter is a difficult problem, and there is currently no relevant treatment experience. In the future, MCA may become a new method for minimally invasive treatment of ARM and stenosis.

Limitations and prospects of constant magnetic field in treating digestive tract malformations

At present, MCA based on CMF force is only applicable to the first-stage anastomosis of type I esophageal atresia without TEF. This type of case only accounts for 6% of the total number of CEA cases. In addition, there is no MCA suitable for TEF repair, which limits its application in CEA treatment. The vast majority of children with CEA require emergency surgery for TEF repair. For CEA with less than 3 cm distances, esophageal anastomosis can be performed at the same time of TEF repair. There are not many such reports at present. At present, the relationship between the strength of CMF force and the healing time of esophageal anastomosis has only been reported in a few studies. There is no report on the failure of esophageal anastomosis or the treatment of complications under MCAF.

MCA is not suitable for congenital small intestine or colon atresia due to the severe lag in the development of the distal intestinal lumen, the big difference in diameter between small intestine or colon and the proximal intestine, and the difficulty in removing magnetic materials after the anastomosis. At present, the treatment of ARM with MCA is still under exploration. Conclusively, MCA can be used for minimally invasive anastomosis of the esophagus with the support of endoscopic techniques in some CEA cases. MCA is a promising treatment for complex digestive system malformations.

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