磁吻合技术在小儿外科领域中的应用

刘仕琪¹, 赵静儒², 高亚³, 胡兵⁴, 潘永康⁵, 方莹⁶, 任晓霞⁶, 王博^{7*}

1. 西京学院医学院, 西安 710123;
2. 西北妇女儿童医院, 西安 710061;
3. 西安交通大学第二附属医院小儿外科, 西安 710004;
4. 四川大学华西医院消化内镜中心, 成都 610041;
5. 西安市儿童医院新生儿外科, 西安 710043;
6. 西安市儿童医院消化内科, 西安 710043;
7. 西安交通大学第一附属医院肝胆外科, 西安 710061

* 联系人, E-mail: bobwang77@126.com

2019-12-27 收稿, 2020-02-07 修回, 2020-02-10 接受, 2020-02-11 网络版发表

国家自然科学基金(81470896, 81700545, 30830099, 81127005, 51275387)、陕西省卫生和计划生育委员会自然科学基金(2014D85)、陕西省自然科学基金基础研究计划(2017JQ8021)和陕西省科技资源开放共享平台项目(S2016TFPT0024)资助

摘要 新生儿消化道闭锁或狭窄是常见的先天性结构畸形疾病, 需要手术治疗. 长段型先天性食管闭锁(long-gap esophageal atresia, LGEA)伴或不伴有气管-食管瘘(tracheoesophageal fistula, TEF)与难治性食管狭窄(refractory esophageal stricture, RES), 是临床治疗的难题. 前者临床治疗周期长, 部分患儿甚至因食管壁张力较大导致吻合口撕裂、吻合口瘘等并发症. 术后吻合口狭窄是先天性食管闭锁(congenital esophageal atresia, CEA)行开胸或经胸腔镜手术后常见并发症. 大多数食管狭窄病例经内镜下扩张手术可缓解病情, 但有部分病例虽经多次内镜下扩张仍反复出现瘢痕性狭窄而需要再次开胸手术切除狭窄段瘢痕组织并重新进行食管吻合, 再次手术后仍面临再狭窄的可能, 严重影响患儿喂养和生长发育. 磁吻合(magnetic compressive anastomosis, MCA)技术通过磁体间压榨作用使受压组织坏死脱落, 同时局部相邻组织结构层次准确对位, 实现黏膜-黏膜层良好愈合, 从而形成较理想的吻合效果. 临床研究中, 采用MCA技术有助于实现盲端距离 ≤ 3 cm的LGEA一期吻合, 并为食管吻合术后发生吻合口严重狭窄并发症提供一种可行的微创治疗选择. 此外, MCA技术还可用于肠造口术后恢复远端肠管排便功能的一种可靠方法. 对于儿童先天性直肠闭锁畸形, 传统方法需要经后矢状入路切开骶尾部盆底组织, 对患儿盆底解剖结构损伤较大. 由于不可避免地切断直肠后方的盆底肌群与神经纤维, 故并发症较多, 部分患儿术后排便功能受到很大影响. MCA可以保留盆底肌、直肠扩张肌与神经丛等解剖结构, 排除了手术创伤因素对术后排便功能的影响. 对于部分病情复杂的先天性消化道发育畸形患儿, MCA技术是一种效果可靠的临床治疗方法, 基于临床应用的适用于儿童消化道吻合的系列磁性医疗器械可作为儿童外科疾病手术器械的有益补充.

关键词 小儿外科, 消化道畸形, 食管闭锁, 直肠肛门闭锁, 狭窄, 磁吻合

先天性食道闭锁(congenital esophageal atresia, CEA)伴或不伴有气管-食管瘘(tracheoesophageal fistu-

la, TEF)发病率约为1/3000, 是初生婴儿死亡的重要原因之一. 无论是传统手术, 还是近几年开展的胸腔镜手

引用格式: 刘仕琪, 赵静儒, 高亚, 等. 磁吻合技术在小儿外科领域中的应用. 科学通报, 2020, 65: 1264-1273

Liu S Q, Zhao J R, Gao Y, et al. Application of magnetic compression anastomosis technique in pediatric surgery (in Chinese). Chin Sci Bull, 2020, 65: 1264-1273, doi: 10.1360/TB-2019-0881

术, 均不可避免地造成胸部组织损伤, 尤其是对盲端距离较远的长段型先天性食管闭锁(long-gap esophageal atresia, LGEA)患儿, 需分期进行食管延长术、胃代食管或结肠代食管手术治疗, 术中或术后并发症多。其中, 吻合口狭窄是最常见的并发症, 部分难治性食管狭窄(refractory esophageal stricture, RES)患儿疗程长且效果欠佳, 甚至陷入再手术、再狭窄的恶性循环当中, 严重影响患儿生长发育和生活质量。直肠闭锁(rectal atresia, RA)是一种较少见的消化道畸形, 可源于先天性直肠闭锁畸形(congenital anorectal malformations, CAM), 也可以由出生后发生广泛坏死性小肠结肠炎而导致结肠炎性闭锁。RA与肛门闭锁常需分期手术, 尤其是行二期手术过程中, 经后矢状位入路导致盆底与直肠肛门周围肌群及神经损伤严重, 部分患儿甚至出现排便功能障碍, 创伤大、疗程长且并发症多, 严重影响患儿生长发育与生活质量。传统手术方法已不能满足病情复杂的消化道闭锁或狭窄疾病的治疗。基于磁场作用力的磁吻合(magnetic compressive anastomosis, MCA)技术为治疗儿童消化道疑难病例提供了一种崭新的途径, 不仅可以避免传统手术造成的巨大创伤, 而且可能显著减少术中、术后并发症, 具有非常好的应用前景。本文对MCA治疗先天性消化道闭锁畸形及术后反复发生吻合口狭窄等并发症的治疗进展进行介绍。

1 无缝线MCA技术

磁外科(磁外科学)领域中最最重要的一个研究方向是MCA技术, 这是一种基于永磁材料具有磁场的物理特性, 利用极性相反的一对磁体在磁场作用下相互吸引, 从而将需要吻合的空腔器官衔接在一起的技术。通过对挤压在磁体之间的组织产生持续稳定的压力, 受压组织缺血坏死。与此同时, 旁边相邻的组织重新愈合并连接, 磁体通过人体自然腔道排出体外, 最终实现空腔脏器吻合^[1]。由于此项技术免除了传统的手工缝针、缝线, 巧妙利用了磁场作用力使相邻组织重新愈合, 避免了传统缝合针线的异物反应及吻合质量受限于术者缝合技术水平的弊端, 学习曲线短, 吻合口并发症减少, 使通过传统手工缝合易造成严重组织创伤, 或因解剖位置原因难以手工缝合的空腔器官吻合手术得以在微创条件下完成。该方法不仅可以避免传统手术造成的副损伤, 而且可以减少术中、术后并发症的发生, 具有非常好的应用前景。目前MCA技术已在小儿外科领域

取得了不错的成绩。

2 MCA技术小儿外科临床应用发展历史

在磁性材料研发方面, 日本长期居于世界领先地位, 也是最早将磁性材料应用于小儿外科领域研究的国家^[2,3]。1977年, 日本神户医学院的外科专家首先报道了利用 Fe_3O_4 磁性材料吻合家犬食管及血管获得成功^[4], 从而开启了MCA技术应用于外科手术的先河。但 Fe_3O_4 具有磁能积较低、易氧化且耐腐蚀性差, 以及磁性材料表面处理技术尚未成熟等缺陷, 磁性材料进入临床应用受到限制。20世纪90年代, 苏联Bulynin等人^[5]首次将磁性材料应用于儿童食管狭窄病例临床治疗并取得较理想的治疗效果。随着稀土合金磁性材料与表面处理技术的日益成熟, 磁外科发源地日本神户儿童医院的Takamizawa等人^[6]于2007年报道利用MCA技术治疗CEA术后反复发生食管狭窄的男婴并获得良好治疗效果。由此, MCA在小儿外科领域的应用开始进入快车道。我国MCA技术应用于小儿外科虽然起步较晚, 但发展亦呈现良好趋势^[1,7-11]。

3 适用于MCA技术的磁性材料选择

3.1 MCA技术常用磁性材料比较

铁氧体最早应用于磁外科手术, 但因其耐腐蚀性差、磁能积低、发展缓慢, 其应用受到限制。目前已经应用于临床并可长期植入人体的磁性材料主要有钕-铁-硼(Nd-Fe-B)和稀土钐-钴(Sa-Co)合金2种永磁材料^[12-15]。Sa-Co合金永磁材料虽有较高磁能积和较好生物相容性, 但因价格昂贵, 其使用受到限制。Nd-Fe-B合金材料不仅物理性能较好, 易于切割和铸压成型, 耐腐蚀, 经过钝化及镀膜等表面处理后具有较好的生物相容性, 而且价格低廉, 因而得以广泛应用于工业生产、国防装备和医疗设备等各个方面。

3.2 Nd-Fe-B磁性材料理化性质与生物安全性

永磁材料产生的磁场为静态磁场, 不存在电磁辐射。文献^[6,15-19]报道用于治疗人体组织器官疾病的植入式Nd-Fe-B和Sa-Co合金永磁体表面磁通密度峰值<550 mT, 远低于美国斯坦福直线加速中心(Stanford Linear Accelerator Center, SLAC)与美国能源部(United States Department of Energy, DOE)提出的职业接触磁场暴露限量 ≤ 1000 mT的标准, 且磁性材料表面磁场强

度随距离增加而迅速衰减,因此医用永磁性材料产生的磁场强度是安全的。

第三代稀土永磁Nd-Fe-B是目前世界上磁性最强的永磁体,是以Nd₂-Fe₁₄-B金属间化合物为基础构成的金属合成物,原子间具有复杂的四方晶系晶体结构,具有高饱和磁化强度和单轴各向异性。由于材料中含有大量的钕和铁,易于氧化和腐蚀,在植入人体前,通过物理和化学方法进行表面镀膜等处理以增强Nd-Fe-B磁体的耐腐蚀性非常关键。目前,由Nd-Fe-B制成的各种不同规格的磁性植入材料在人类牙科手术^[20,21]中的应用已有30余年历史。此外,Nd-Fe-B还被应用于胃肠道无缝线吻合^[22-24]、冠状动脉搭桥^[25,26]及肝移植手术后胆道梗阻^[27,28]等微创治疗。

4 MCA临床应用是小儿外科技术发展的需要

目前,成人外科有着品种丰富、型号齐全的各类吻合器械,利于外科手术的标准化^[29]。由于各种原因,应用于小儿外科手术的医疗器械及相关技术水平发展明显滞后于成人外科,缺乏吻合口质量标准化的外科手术器械(如胃肠吻合器),因此儿童消化道吻合仍依赖于传统的手工缝合方法,对于一些手术部位较深且空间狭小器官的吻合难度较大。随着新型高磁性能材料在生物学领域应用的不断发展,以及机械加工技术的进步,陆续出现了成功应用MCA进行小儿消化道吻合的相关报道^[23]。研发适用于儿童消化道吻合的磁外科手术器械无疑是促进小儿外科临床技术发展的有益补充。

5 MCA治疗新生儿CEA畸形

5.1 新生儿长段型CEA治疗困境

新生儿CEA伴或不伴有TEF均需手术治疗,否则患儿因无法喂养而死亡。近80年来,外科技术的进步促使CEA患儿死亡率明显下降^[30]。传统开胸手术与近年开展的胸腔镜手术,对于盲端距离<2 cm的Ⅲb型CEA治疗效果较好,但对于Gross Ⅲa型CEA(盲端距离>2 cm),手术后吻合口瘘及狭窄等并发症发病率仍较高且严重;对于盲端距离≥3 cm的长段型CEA治疗则非常困难,并对外科医生有一定挑战性,术中结扎TEF后难以一期吻合食管盲端,因而需要分期进行食管延长术^[31]、胃代食管或小肠、结肠代食管术等^[32-34],疗

程长达数月至数年,术后吻合口瘘、狭窄、感染等并发症多,部分患儿甚至陷入再手术、再狭窄的恶性循环,严重影响生长发育且增加家庭与社会负担^[35-38]。多年来,大量临床实践表明,传统治疗方法已经无法满足临床需要。

5.2 MCA实现CEA微创治疗

目前国外采用MCA技术治疗新生儿长段型CEA病例报道中,主要用于不伴有TEF的Gross I型CEA患儿(约占6%)治疗。对于盲端距离接近3 cm的长段型Gross I型CEA,采用传统手术缝合方法难以一期吻合食管,通过胃造瘘于远端食管盲端植入一磁体,近端食管盲端内借助消化内镜辅助植入另一磁体,通过磁体的磁场作用力实现食管盲端互相接近并最终达到吻合的目的,从而避免患儿遭受胸外科手术造成的创伤(图1(a)和(c))。2001~2004年,Zaritzky^[13]选择了5例长段型EA患儿,其中3例伴有TEF的婴儿经过外科手术结扎瘘管,2例为I型食管闭锁患儿,均采用MCA方法实现食管吻合,术后随访2年多未发现吻合口瘘或狭窄等并发症的发生。由此可见,利用MCA技术延长食管盲端并最终完成吻合是治疗此类严重EA患儿的一个可选方法。我们^[9]曾采用MCA治疗3例LGEA合并TEF(Gross Ⅲa型)患儿,术前根据食管造影发现近端食管盲袋位置高达第二胸椎水平,术中证实盲端距离达3 cm,无法一期吻合,遂采用术中消化内镜辅助下在近端盲袋内植入一磁环,同时将远端食管结扎并修补TEF后植入另一对应磁环后行荷包缝合,中间留置一胃肠减压管穿过磁环中央孔,两食管盲端通过磁环间作用力相互吸引且受力分布面积大,组织张力均匀,从而避免既往常规缝合的缝针缝线由于食管自身弹性回缩而导致吻合口撕裂的弊端(图1(b)和(c))。手术4~5周后完成吻合,经口取出磁环,避免了分期手术所造成的创伤,但此方法目前尚缺乏盲端距离>3 cm LGEA临床治疗经验。

5.3 MCA技术分期治疗LGEA

在LGEA治疗过程中,由于传统的胃代食管或结肠代食管手术的并发症较多,MCA技术为治疗远距离EA病例提供了一种更符合生理特征的利用自身原位食管连续性重建方法。在一期手术结扎TEF并行胃造瘘以解决肠内营养问题的同时,分别通过探条定期延长食管盲端。盲端距离≤2 cm时,在内镜辅助下分别经口和胃

图1 (网络版彩色)MCA治疗CEA侧位示意图。(a) MCA实现CEA(Gross I型)微创治疗: 附带导管的磁体在食管中的位置; (b) MCA治疗Ⅲa型CEA; (c) MCA术后食管恢复通畅

Figure 1 (Color online) The lateral schematic diagram of MCA treatment for CEA. (a) Minimally invasive MCA treatment for CEA (Gross type I): The location of the magnet attached to a catheter in esophagus; (b) MCA treatment for CEA (Gross type III a); (c) restored esophageal patency after MCA treatment

造瘘管在近、远端闭锁食管腔内各置入一枚磁体, 利用磁体间持续作用力实现食管重建与通畅的目的, 这一方法有效缩短了治疗周期并减少了相关并发症^[39-41]。对于部分距离 ≤ 3 cm的Ⅲa型CEA, 可以在经胸结扎TEF的同时, 经口在近端食管盲端内植入一磁环, 另一配对磁环置入远端食管腔内并荷包缝合, 两磁环互相吸引靠拢实现食管吻合^[7,42]。这一方法优势在于实现了长段食管闭锁的一期吻合, 避免了分期手术或胃代食管、结肠代食管等方法的弊端, 明显改善患儿预后。

6 MCA技术实现食管狭窄微创治疗

6.1 难治性食管狭窄治疗困境

食管良性狭窄主要包括食管手术后吻合口狭窄、腐蚀性狭窄、反流性狭窄和放射性狭窄等, 其中吻合口狭窄最为常见。吻合口狭窄约90%以上发生于CEA术后, 目前传统治疗方法首选经消化内镜治疗, 主要方法有探条及球囊扩张^[43]、瘢痕切开、局部注射激素^[44,45]、丝裂霉素^[46,47]及食管内支架植入等^[48-52]。儿童进食时食物在狭窄部位以上堆积, 常因误吸而反复发生支气管肺炎甚至重症肺炎。多次内镜治疗无效的难治性食管狭窄往往需要再次开胸手术切除狭窄部位并重新吻合食管^[38], 但术后仍然存在再次狭窄的可能。采用MCA技术疏通狭窄部位可使患儿避免遭受再次开

胸手术的打击。

6.2 消化内镜辅助MCA技术实现食管术后吻合口狭窄微创治疗

2007年, 日本神戸儿童医院^[6]报道一例患有长段且未伴有TEF的CEA(Gross I型)男婴, 常规进行食管延长及吻合术后25月出现吻合口严重狭窄, 虽经多次球囊扩张, 但效果差; 术后第33月, Takamizawa等人^[6]利用MCA技术疏通患儿食管, 在消化内镜辅助下分别在食道狭窄部位上下端各放置一个磁体(磁场强度3200 G), 通过磁场吸引力持续压迫狭窄部位瘢痕组织, 34天后食管狭窄部位吻合完成, 磁体通过口腔取出体外; 治疗后患儿未再出现食管狭窄, 恢复良好。2011年, 日本Hidenori等人^[12]报道一位患者在出生后因CEA接受食管吻合术后反复发生吻合口严重狭窄, 反复多次进行内镜下扩张等治疗措施, 但效果较差, 食管梗阻并行胃造瘘病史长达19年, 严重影响正常发育和生活质量, 最终利用MCA方法在消化内镜辅助下于食管狭窄部位上下方分别植入磁体, 成功祛除了食管狭窄部位瘢痕组织, 食管恢复通畅, 随访2年未再发生狭窄。2014年, Zaritzky等人^[13]报道5例EA患儿在行食管吻合术后出现吻合口严重狭窄, 虽经反复球囊扩张, 却无明显疗效, 后来采用磁性材料制成的磁吻合装置, 通过微创技术植入梗阻部位远近端, 最终取得良好治疗效果。2018年, 我们^[9]采用气相沉积法氮化钛覆膜进行表面处理

增加磁环表面抗腐蚀性能,在消化内镜辅助下实现难治性食管狭窄微创治疗,并取得良好治疗效果(图2)。综上所述,消化内镜辅助MCA技术为食管狭窄提供了一种新的效果可靠的微创治疗方法。

6.3 消化内镜辅助MCA技术实现先天性食管狭窄微创治疗

儿童先天性食管狭窄(congenital esophageal stenosis, CES)是一种罕见的消化道发育畸形,发病率约为1/50000~1/25000^[53],常合并心血管畸形、食管闭锁、胆道闭锁及染色体异常^[54,55]。CES组织学分型有节段肌肉纤维肥厚型、气管支气管残留型及膜式狭窄3种类型,传统方法治疗CES根据狭窄类型的不同采取合适的治疗措施^[56]。CES治疗首选内镜下食管扩张术^[57],但若扩张效果不理想,则需要开胸或胸腔镜手术切除狭窄段^[58,59],术后仍可能存在再次狭窄,严重影响患儿生长发育。2019年,西北妇女儿童医院利用MCA技术为1例3岁CES患儿实施内镜辅助下磁体植入,成功祛除了狭窄部位的异常组织^[9]。术前经食管造影及CT检查排除狭窄部位气管软骨异位。利用MCA方法治疗CES过程与治疗食管吻合术后瘢痕性狭窄相似,通过消化道内镜和胃造瘘口分别向食管狭窄部位近、远端植入磁环,巧妙利用磁体间磁场作用力实现CES微创治疗,通过磁性材料在食管腔内对狭窄部位产生持续压榨作用,使之缺血坏死并自然脱落,有效祛除了局部增生的纤维肌性组织,实现了食管壁黏膜-黏膜的理想吻合,而且

在完成吻合任务后随着关瘘手术将磁体经胃造瘘口取出体外。术后吻合口通畅,随访6个月,患儿进食情况良好,身高与体重按正常发育规律增加,未发生并发症,治疗效果较好。此病例的成功为CES病例治疗提供了新的微创治疗方法。

7 MCA完成肠造瘘口吻合术

小肠或结肠造口是小儿外科为了解决患儿排便问题的常见手术方式,除了需终身造瘘的特殊病例外,绝大多数患儿均需择期接受关瘘手术。传统的关瘘手术采用原切口游离造瘘口肠管后利用手工缝合或吻合器钉合技术进行肠吻合,吻合口容易出现瘘或狭窄等并发症。采用MCA技术进行造瘘肠管吻合手术是一种新的关瘘方法,并已经获得美国食品和药物管理局批准可进行人体试验。阿根廷Toselli等人^[23]报道2例肠造瘘患儿接受MCA技术关闭造口的方法(图3),手术时间均少于20 min,术后24 h开始给予肠内营养,第4、5天肛门可见粪便排出。2例患儿分别于术后14和15天经造瘘口顺利取出磁体,无并发症发生。由此可见,采用MCA技术进行造瘘肠管吻合手术可作为一种安全、微创的方法用来逐步恢复远端肠管连通功能。

8 MCA技术治疗RA

低位RA较少见,但临床吻合手术难度较大,因新生儿盆腔狭小且缺乏适用于婴幼儿的直肠吻合器,面对此类病例临床最常采用经肛门脱出直肠吻合术。因

图2 (网络版彩色)食管吻合口严重狭窄MCA,消化内镜及X射线检查。(a) CEA术后食管造影显示吻合口严重狭窄(箭头);(b) 配对磁吻合环与胃管组合实物;(c) 经消化道内镜沿胃管向近端食管腔内置入磁体(箭头);(d) 术后第2天X射线检查显示两枚磁体对位良好(箭头);(e) 术后3周食管造影显示吻合口恢复通畅,无狭窄(箭头),磁体已自行脱落

Figure 2 (Color online) MCA treatment for severe esophageal anastomotic stricture, endoscopy and X-ray examination. (a) Esophagram showing severe anastomotic stricture post CEA operation (arrow); (b) matched magnetic anastomotic ring and gastric tube combination; (c) magnet was inserted into the proximal esophageal cavity along the gastric tube through gastrointestinal endoscopy (arrow); (d) X-ray examination on the second day after operation showed good alignment of the two magnets (arrow); (e) esophagogram showed anastomotic patency without stenosis three weeks after operation (arrow), and the magnets fell off automatically

图3 (网络版彩色)磁吻合肠造瘘口侧-侧吻合步骤示意图。(a) 小肠或结肠双腔造口距离皮肤5 mm深肠腔内分别置入对应磁体;(b) 磁体压迫造瘘口相邻肠管壁, 磁体牵引线固定在造瘘口外皮肤表面;(c) MCA完成造瘘口肠吻合, 并通过造瘘口回收磁体;(d) 远端肠管恢复通畅后关闭造瘘口(手工缝合或闭合器)

Figure 3 (Color online) The schematic diagram of the procedures of the magnamosis side-side anastomosis of enterostomy stoma. (a) The corresponding magnets were respectively placed into the double lumen stomas of the small intestine or colon 5 mm away from the skin; (b) the magnets compressed the adjacent intestinal walls of the stomas, and the magnet traction wire was fixed on the skin outside the stoma; (c) the side-side anastomosis of enterostomy stoma was completed by MCA, and the magnets were taken out through the stoma; (d) the stoma was closed after the distal intestinal tube patency was restored (manual suture or closure device)

术中不可避免地切断并损伤发育欠成熟的肛门内外扩约肌和神经纤维, 所以很容易导致排便异常等并发症, 影响患儿生长发育和生活质量. 将MCA技术应用于RA有一点偶然性, 因多篇文献报道磁性异物导致儿童消化道内瘘的情况^[60], Russell等人^[61]尝试利用MCA技术治疗1例直肠闭锁患儿, 先经结肠造瘘口放置一枚磁体于闭锁段直肠近端, 另一枚磁体经肛门植入直肠远端, 在磁场力作用下, 两枚磁体相互吸引并压榨闭锁段肠壁盲端, 最终实现肛门直肠解剖结构完整修复, 避免了肛门括约肌和相关神经纤维的损伤, 取得了良好疗效.

Zaritzky等人^[13]亦报道了2例利用磁性材料治疗患儿结肠狭窄的方法, 通过微创技术将磁吻合装置植入梗阻部位, 在磁场作用力下实现狭窄部位的吻合, 均取得良好治疗效果. 2018年, 我们^[8]利用MCA技术治疗1例因坏死性小肠结肠炎导致结肠多发闭锁的患儿, 在二期手术中于回盲部和远端闭锁结肠腔内分别放置一枚磁体, 术后第9天吻合口愈合后磁体自然脱落并随粪便排出体外, 成功保留了直肠与肛门扩约肌功能(图4), 术后随访一年排便功能正常, 身长与体重等生

长发育指标正常, 获得理想的治疗效果.

9 MCA技术在儿童消化道吻合手术中的局限性

绝大多数CEA病例需要急诊手术进行TEF修补, 对于距离合适的CEA, 可与TEF修补手术同时进行食管吻合. 因MCA技术目前仍处于临床前期研究阶段, 磁场强度与食管吻合口愈合的时间关系尚缺乏相关基础研究, 对于MCA食管吻合失败或并发症处理等未见文献报道. MCA技术缺乏多中心大样本随机对照研究, 该技术尚未完全成熟. 国外采用MCA技术治疗新生儿EA多用于不伴有TEF的I型食管闭锁(约占EA患儿的6%)非手术治疗, 对于存在TEF的大多数EA患儿, 仍需常规手术结扎瘘管, 故限制了该技术在EA疾病治疗中的广泛应用. 对于先天性小肠或结肠闭锁, 由于远端肠腔发育严重滞后, 与近端肠管直径差异太大, 且吻合完成后磁性材料排出较困难, 故MCA并不适合此类疾病的无缝线吻合. 目前MCA技术治疗肛门直肠闭锁畸形仍处于探索阶段. 我们在MCA治疗食管狭窄病例过程中发现,

图4 直肠闭锁MCA技术X射线检查。(a) 坏死性小肠结肠炎后直肠造影显示直肠低位闭锁(距肛门<3 cm); (b) 磁体分别置入闭锁肠管远近端, 对位良好; (c) MCA技术后磁体自行排出, 造影显示吻合口恢复通畅

Figure 4 X-ray examination of MCA for rectal atresia. (a) After necrotizing enterocolitis, rectal radiography showed low rectal atresia (less than 3 cm from the anus); (b) matched magnets were placed in the distal and proximal end of the atretic bowel, respectively, with good alignment; (c) magnets were discharged spontaneously after MCA, and radiography showed the patency was restored at anastomotic site

对于EA术后吻合口狭窄的患儿, 采用MCA技术疏通食管仍然存在再次狭窄的可能。

10 总结与展望

随着磁性材料科学与外科技术的共同协作发展, 研发适用于儿童消化道吻合的磁性吻合器械可作为小儿外科手术器械的有益补充。基于磁场作用力的MCA技术为小儿外科先天性消化道闭锁畸形或术后吻合口狭窄等疾病的治疗提供了一条崭新的途径, 尤其对于长段型CEA, 通过磁场作用力实现食管一期吻合可缩短部分患儿治疗周期。对于内镜多次扩张后仍多次复发的难治性食管狭窄, 采用消化内镜辅助的

MCA技术可以实现微创治疗目的, 并避免再次开胸手术的创伤, 且治疗效果显著, 对于复杂的食管闭锁或狭窄并发症是一种非常有前景的治疗方法。对于直肠闭锁畸形, 可以实现良好的吻合效果, 保护盆底及直肠扩张肌正常结构与功能, 避免了传统手术造成的创伤。但MCA技术有一定的适用范围, 如盲端距离超过3 cm的远距离CEA畸形, 因磁场作用力微弱, 难以达到吻合效果。随着磁外科技术临床推广应用并不断发展成熟, 相信在不久的将来, 必定会出现基于MCA技术适用于不同年龄和体重的儿童消化道吻合器械。MCA技术必将取得更大成就, 并为更多患病儿童带来更好的治疗效果。

参考文献

- Liu S Q, Lü Y, Yan X P. The current status and progress of constant magnetic field technique for digestive system anastomosis (in Chinese). *Chin J Gener Surg*, 2019, 34: 374–376 [刘仕琪, 吕毅, 严小鹏. 恒磁场技术实现消化道无缝线吻合的现状与进展. *中华普通外科杂志*, 2019, 34: 374–376]
- Koomen A R, Klopner P J. Healing of the oesophagus after total ligation with the Boerema button and a similar apparatus acting with magnetic force: An experimental study. *Arch Chir Neerl*, 1977, 29: 217–228
- Jansen A. De oesophagus-anastomose met behulp van magneetknopen. *Ned T Geneesk*, 1977, 121: 1309
- Obora Y, Tamaki N, Matsumoto S. Nonsuture microvascular anastomosis using magnet rings: Preliminary report. *Surg Neurol*, 1978, 9: 117–120
- Bulynin V I, Steshkin V I, Bulynin V V, et al. The restoration of esophageal patency in cicatricial strictures by using magnetic elements. *Grud Serdechnosudistaia Khir*, 1993, 3: 53–56
- Takamizawa S, Yamanouchi E, Muraji T, et al. MCRA of an anastomotic stenosis after esophagoesophagostomy for long gap esophageal atresia: A case report. *J Pediatr Surg*, 2007, 42: 769–772
- Liu S Q, Lü Y, Zhao J R, et al. Magnetic compression anastomosis for congenital esophageal atresia: 1 case report with a review of literature (in Chinese). *Chin J Pediatr Surg*, 2018, 39: 594–596 [刘仕琪, 吕毅, 赵静儒, 等. 磁吻合技术治疗新生儿远距离食管闭锁一例并文献复习. *中华小儿外科杂志*, 2018, 39: 594–596]
- Liu S Q, Zhao J R, Lü Y, et al. Magnetic compression anastomotic technique for rectal atresia after treating necrotizing enterocolitis: One case report with a review of literature (in Chinese). *Chin J Pediatr Surg*, 2019, 40: 755–757 [刘仕琪, 赵静儒, 吕毅. 磁吻合技术实现NEC治疗后直肠

闭锁无缝线吻合一例. 中华小儿外科杂志, 2019, 40: 755–757]

- 9 Liu S Q, Lü Y, Zhao J R, et al. Clinical efficacy of magnetic compression anastomosis for congenital esophageal atresia and stenosis (in Chinese). *Chin J Dig Surg*, 2019, 18: 581–586 [刘仕琪, 吕毅, 赵静儒, 等. 磁吻合技术治疗先天性食管闭锁与狭窄的临床疗效. 中华消化外科杂志, 2019, 18: 581–586]
- 10 Liu S Q, Lü Y. Recent advances of magnetic compression anastomosis technique for resophageal atresia and anastomotic strictures (in Chinese). *J Clin Ped Sur*, 2019, 18: 447–449, 455 [刘仕琪, 吕毅. 磁吻合技术治疗先天性长段食管闭锁与吻合口狭窄新进展. 临床小儿外科杂志, 2019, 18: 447–449, 455]
- 11 Liu S Q, Lü Y. Current status and recent advance of constant magnetic field technique for congenital esophageal and anorectal abnormalities (in Chinese). *Chin J Pediatr Surg*, 2019, 40: 664–667 [刘仕琪, 吕毅. 恒磁场技术治疗先天性食管与肛门直肠闭锁畸形的现状与进展. 中华小儿外科杂志, 2019, 40: 664–667]
- 12 Hidenori H, Eigorou Y, Yoshinori H, et al. Magnetic compression revision anastomosis of a severe anastomotic stenosis after esophagoesophagostomy for long gap esophageal atresia: A case report. *Gastroenterol Endosc*, 2011, 53: 2001–2005
- 13 Zaritzky M, Ben R, Johnston K. Magnetic gastrointestinal anastomosis in pediatric patients. *J Pediatr Surg*, 2014, 49: 1131–1137
- 14 Graves C E, Co C, Hsi R S, et al. Magnetic compression anastomosis (magnamosis): First-in-human trial. *J Am Coll Surgeons*, 2017, 225: 676–681.e1
- 15 Jang S I, Lee K H, Yoon H J, et al. Treatment of completely obstructed benign biliary strictures with magnetic compression anastomosis: Follow-up results after recanalization. *Gastrointest Endosc*, 2017, 85: 1057–1066
- 16 She Z F, Yan X P, Ma F, et al. Treatment of rectovaginal fistula by magnetic compression. *Int Urogynecol J*, 2017, 28: 241–247
- 17 Liu X M, Yan X P, Zhang H K, et al. Magnetic anastomosis for biliojejunostomy: First prospective clinical trial. *World J Surg*, 2018, 42: 4039–4045
- 18 Jang S I, Lee K H, Joo S M, et al. Maintenance of the fistulous tract after recanalization via magnetic compression anastomosis in completely obstructed benign biliary stricture. *Scand J Gastroentero*, 2018, 53: 1393–1398
- 19 Matsuura R, Ueno T, Tazuke Y, et al. Magnetic compression anastomosis for postoperative biliary atresia. *Pediatr Int*, 2017, 59: 737–739
- 20 Muller M. The use of magnets in orthodontics: an alternative means to produce tooth movement. *Eur J Orthodont*, 1984, 6: 247–253
- 21 George T M, Valiathan A, George A I, et al. Magnets in orthodontics. *J Pierre Fauchard Acad*, 1992, 6: 45–54
- 22 Rahman I, Patel P, Boger P, et al. Utilisation of magnets to enhance gastrointestinal endoscopy. *World J Gastroentero*, 2015, 7: 1306–1310
- 23 Toselli L, Martinez-Ferro M, Cervio G, et al. Magnetic compression anastomosis (magnamosis) for functional undiversion of ileostomy in pediatric patients. *J Laparoendosc Adv Surg Tech*, 2017, 27: 1314–1317
- 24 Machytka E, Bužga M, Zonca P, et al. Partial jejunal diversion using an incisionless magnetic anastomosis system: 1-year interim results in patients with obesity and diabetes. *Gastrointest Endosc*, 2017, 86: 904–912
- 25 Filsoufi F, Farivar R S, Aklog L, et al. Automated distal coronary bypass with a novel magnetic coupler (MVP system). *J Thorac Cardiovasc Surg*, 2004, 127: 185–192
- 26 Levi D S, Danon S, Gordon B, et al. Creation of transcatheter aortopulmonary and cavopulmonary shunts using magnetic catheters: Feasibility study in swine. *Pediatr Cardiol*, 2009, 30: 397–403
- 27 Liu X M, Li Y, Xiang J X, et al. Magnetic compression anastomosis for biliojejunostomy and pancreaticojejunostomy in Whipple's procedure: An initial clinical study. *J Gastroen Hepatol*, 2019, 34: 589–594
- 28 Jiang X M, Yamamoto K, Tsuchiya T, et al. Magnetic compression anastomosis for biliary obstruction after partial hepatectomy. *Endoscopy*, 2018, 50: E144–E145
- 29 Chen L, Bian S B. Choice and reasonable application of staplers for gastrointestinal surgery (in Chinese). *Chin J Gastrointest Surg*, 2013, 16: 601–604 [陈凇, 边识博. 胃肠手术中吻合器的选择及合理使用. 中华胃肠外科杂志, 2013, 16: 601–604]
- 30 Zimmer J, Eaton S, Murchison L E, et al. State of play: Eight decades of surgery for esophageal atresia. *Eur J Pediatr Surg*, 2019, 29: 39–48
- 31 Stoll C, Alembik Y, Dott B, et al. Associated anomalies in cases with esophageal atresia. *Am J Med Genet*, 2017, 173: 2139–2157
- 32 Zhang H W, Liu F L, Zeng Z D. Application of one-stage gastric transposition for long-gap esophageal atresia in neonates (in Chinese). *J Clin Ped Sur*, 2017, 16: 588–591 [张宏伟, 刘丰丽, 曾战东. 一期胃代食管术治疗新生儿长段型食管闭锁的疗效分析. 临床小儿外科杂志, 2017, 16: 588–591]
- 33 Bradshaw C J, Sloan K, Morandi A, et al. Outcomes of esophageal replacement: Gastric pull-up and colonic interposition procedures. *Eur J Pediatr Surg*, 2018, 28: 22–29
- 34 Garritano S, Irino T, Scandavini C M, et al. Long-term functional outcomes after replacement of the esophagus in pediatric patients: A systematic literature review. *J Pediatr Surg*, 2017, 52: 1398–1408
- 35 Upadhyaya V D, Gangopadhyaya A N, Gupta D K, et al. Prognosis of congenital tracheoesophageal fistula with esophageal atresia on the basis of gap length. *Pediatr Surg Int*, 2007, 23: 767–771

- 36 Bakal U, Ersoz F, Eker I, et al. Long-term prognosis of patients with esophageal atresia and/or tracheoesophageal fistula. *Ind J Pediatr*, 2016, 83: 401–404
- 37 Koziarkiewicz M, Taczańska A, Jasinska-Jaskula I, et al. Long-term complications of congenital esophageal atresia—single institution experience. *Ind Pediatr*, 2015, 52: 499–501
- 38 Azakpa A L, Moulot O M, Ehua M, et al. Reoperation of anastomotic stricture after oesophageal atresia Repair: An uncommon event. *Afr J Paediatr Surg*, 2017, 14: 34–36
- 39 Zaritzky M, Ben R, Zylberg G I, et al. Magnetic compression anastomosis as a nonsurgical treatment for esophageal atresia. *Pediatr Radiol*, 2009, 39: 945–949
- 40 Lovvorn H N, Baron C M, Danko M E, et al. Staged repair of esophageal atresia: Pouch approximation and catheter-based magnetic anastomosis. *J Pediatr Surg Case Rep*, 2014, 2: 170–175
- 41 Dorman R M, Vali K, Harmon C M, et al. Repair of esophageal atresia with proximal fistula using endoscopic magnetic compression anastomosis (magnamosis) after staged lengthening. *Pediatr Surg Int*, 2016, 32: 525–528
- 42 Bruns N E, Glenn I C, Craner D R, et al. Magnetic compression anastomosis (magnamosis) in a porcine esophagus: Proof of concept for potential application in esophageal atresia. *J Pediatr Surg*, 2019, 54: 429–433
- 43 Landisch R M, Foster S, Gregg D, et al. Utilizing stricture indices to predict dilation of strictures after esophageal atresia repair. *J Surg Res*, 2017, 216: 172–178
- 44 Morikawa N, Honna T, Kuroda T, et al. High dose intravenous methylprednisolone resolves esophageal stricture resistant to balloon dilatation with intralesional injection of dexamethasone. *Pediatr Surg Int*, 2008, 24: 1161–1164
- 45 Manfredi M A. Endoscopic management of anastomotic esophageal strictures secondary to esophageal atresia. *Gastrointest Endosc Clin North Am*, 2016, 26: 201–219
- 46 Chapuy L, Pomerleau M, Faure C. Topical mitomycin-C application in recurrent esophageal strictures after surgical repair of esophageal atresia. *J Pediatr Gastr Nutr*, 2014, 59: 608–611
- 47 Berger M, Ure B, Lacher M. Mitomycin C in the therapy of recurrent esophageal strictures: Hype or hope? *Eur J Pediatr Surg*, 2012, 22: 109–116
- 48 van der Zee D, Hulsker C. Indwelling esophageal balloon catheter for benign esophageal stenosis in infants and children. *Surg Endosc*, 2014, 28: 1126–1130
- 49 Okata Y, Hisamatsu C, Bitoh Y, et al. Efficacy and histopathological esophageal wall damage of biodegradable esophageal stents for treatment of severe refractory esophageal anastomotic stricture in a child with long gap esophageal atresia. *Clin J Gastroenterol*, 2014, 7: 496–501
- 50 Lange B, Sold M, Kahler G, et al. Experience with fully covered self-expandable metal stents for anastomotic stricture following esophageal atresia repair. *Dis Esophagus*, 2018, 31: 1–7
- 51 Alberca D L P F, Navalon R M, Egea V J. Management of refractory esophageal stenosis in the pediatric age. *Rev Esp Enferm Dig*, 2016, 108: 627–636
- 52 Rico F R, Panzer A M, Kooros K, et al. Use of polyflex airway stent in the treatment of perforated esophageal stricture in an infant: A case report. *J Pediatr Surg*, 2007, 42: E5–E8
- 53 Romero M E, Ravetta P, Patino G C, et al. Congenital esophageal stenosis: Diagnosis and treatment. Cases review. *Arch Argent Pediatr*, 2018, 116: e110–e114
- 54 Suzuhigashi M, Kaji T, Noguchi H, et al. Current characteristics and management of congenital esophageal stenosis: 40 consecutive cases from a multicenter study in the Kyushu area of Japan. *Pediatr Surg Int*, 2017, 33: 1035–1040
- 55 Zhang B B, Dong K R. Advances in the treatment of congenital esophageal stenosis (in Chinese). *Chin J Pediatr Surg*, 2018, 39: 308–311 [张宾宾, 董焄然. 先天性食管狭窄的治疗进展. *中华小儿外科杂志*, 2018, 39: 308–311]
- 56 Rastogi R, Majid A, Singh V P, et al. Congenital esophageal stenosis: A rare case of childhood dysphasia. *J Gastrointest Dig Syst*, 2016, 6: 407–409
- 57 Ksia A, Kechiche N, Mekki M, et al. Balloon dilatation in congenital esophageal stenosis. *J Neonat Surg*, 2017, 6: 90
- 58 Saka R, Okuyama H, Sasaki T, et al. Thoracoscopic resection of congenital esophageal stenosis. *Asian J Endosc Surg*, 2017, 10: 321–324
- 59 Kim S H, Kim H Y, Jung S E, et al. Clinical study of congenital esophageal stenosis: Comparison according to association of esophageal atresia and tracheoesophageal fistula. *Pediatr Gastroenterol Hepatol Nutr*, 2017, 20: 79–86
- 60 Naji H, Isacson D, Svensson J F, et al. Bowel injuries caused by ingestion of multiple magnets in children: A growing hazard. *Pediatr Surg Int*, 2012, 28: 367–374
- 61 Russell K W, Rollins M D, Feola G P, et al. Magnamosis: A novel technique for the management of rectal atresia. *BMJ Case Rep*, 2014, 2014: 1–3

Summary for “磁吻合技术在小儿外科领域中的应用”

Application of magnetic compression anastomosis technique in pediatric surgery

Shiqi Liu¹, Jingru Zhao², Ya Gao³, Bing Hu⁴, Yongkang Pan⁵, Ying Fang⁶, Xiaoxia Ren⁶ & Bo Wang^{7*}

¹ Medical College, Xijing University, Xi'an 710123, China;

² Department of Pediatrics, the Northwest Women's and Children's Hospital, Xi'an 710061, China;

³ Department of Pediatric Surgery, the Second Affiliated Hospital, Xi'an Jiaotong University, Xi'an 710004, China;

⁴ Director of Endoscopy Center, West China Hospital, Sichuan University, Chengdu 610041, China;

⁵ Department of Neonatal Surgery, the Children Hospital of Xi'an City, Xi'an 710043, China;

⁶ Department of Gastroenterology, the Children Hospital of Xi'an City, Xi'an 710043, China;

⁷ Department of Hepatobiliary Surgery, the First Affiliated Hospital, Xi'an Jiaotong University, Xi'an 710061, China

* Corresponding author, E-mail: bobwang77@126.com

Malformation of digestive tract is common in neonates. Esophageal atresia (EA) comprises a group of congenital abnormalities defined by discontinuity of the esophagus. EA with communication with the trachea is known as tracheoesophageal fistula (TEF). For the repair of EA, it is needed to establish an anastomosis between two structures that may be significantly spaced apart, such as in long-gap EA (with a gap >3 cm). The repair across a long-gap can induce tension on the anastomosis, leading to dehiscence, anastomotic leak, or procedure failure. In neonatal patients with long-gap EA with TEF, the complications of significant gastroesophageal reflux, or anastomotic leaks and severe refractory esophageal stricture after surgery are common, which remains challenging for pediatric surgery. There are multiple options for lengthening and approximating the ends in long-gap EA such as myotomies, Gough flap, or the Foker technique. The treatment of long gap EA usually requires thoracotomy or thoracoscopy to place traction sutures on each esophageal in multiple stage operations, the treatment period of which is long. Esophageal stricture is the most common complication following EA repair. Refractory esophageal anastomotic stricture after repair of EA in infants is a challenging surgical problem. In general, these strictures can be successfully managed using endoscopic techniques including bougie and balloon dilation, stenting, and chemotherapeutic agents. If these techniques are unsuccessful, treatment options are limited to surgical resection of the strictured segment and reanastomosis, or esophageal replacement. Magnetic compression anastomosis (MCA) has been introduced for several decades. Recently, rare-earth magnets have been employed to create solid anastomosis for long-gap EA and refractory esophageal stricture in children. In MCA, a sutureless anastomosis of the gastrointestinal tract can be formed using two magnetic Harrison rings. Magnetic compress has been shown to be effective for the treatment of long-gap EA in children. MCA can be conducted during the same stage surgery of ligating the TEF with customized magnetic rings. Under the magnetic force, the two magnetic rings pull along the gastric tube to achieve anastomosis. Once the postoperative permanent suction of these two pouches is instituted, spontaneous growth can be awaited. MCA has been shown to be effective in anastomosis of stomach, small bowel and colon in both experimental and clinical cases. The magnets are most commonly made of neodymium-boron or samarium-cobalt, which can display strengths significantly greater than those of ferrite. Magnetic compression has been used to treat biliary strictures in adult patients who have undergone liver transplantation, as magnetic connectors for coronary surgery, and for the functional undiversion of ileostomy in pediatric patients. Reports also describe the use of magnetic compression in restoring patency of anastomotic strictures of the alimentary tract in patients who have undergone surgery for esophageal, gastric, and rectal cancer. Yamanouchi and colleagues have published many papers on their experience with Samarium cobalt magnets. They even used them to treat recurrent anastomotic strictures after initial MCA. It has been reported that in conditions such as congenital oesophageal atresia or rectal atresia in children, and also is a safe, minimally invasive way to gradually refunctionalize the excluded distal bowel after previous diverting ostomy. MCA using mated magnets with their interposed compressed tissue may result in serosa-to-serosa apposition. At present, MCA for the treatment of EA patients is restricted to gross type A (without TEF) and anastomotic stenosis without thoracotomy. Magnamosis offers a minimally invasive technique for repair of this congenital anomaly. This is particularly helpful in those patients who cannot undergo initial or repeat thoracotomy or thoracoscopy due to anatomic considerations or overall severity of illness. Transluminal digestive tract anastomosis using the constant magnetic field is reliable and feasible as a minimally invasive technique to treat congenital esophageal and anorectal abnormalities. Magnamosis is technically feasible for esophago-esophageal anastomoses. In anorectal malformations with favorable anatomy, this procedure may avoid an operative repair such as posterior sagittal reconstruction. We propose that magnamosis can be considered as an alternative for the treatment of rectal atresia in certain children.

pediatric surgery, digestive tract malformation, esophageal atresia, anorectal atresia, stricture, magnetic compression anastomosis

doi: [10.1360/TB-2019-0881](https://doi.org/10.1360/TB-2019-0881)