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·基础研究·

基于磁压榨技术的无创化胃造瘘的大鼠模型研究

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摘 要

背景与目的：胃造瘘术是普通外科常见手术，传统胃造瘘术创伤大，已逐步被内镜下胃造瘘、X线下胃造瘘术取代，但实施过程需要内镜系统或X线机辅助，且操作较为繁琐。基于应用磁压榨技术行无创化胃造瘘的设想，本研究采用自行设计加工的胃造瘘磁体装置，在大鼠模型上验证该设想的可行性和安全性。

方法：根据大鼠消化道解剖特点和尺寸自行设计加工适合于大鼠胃造瘘的钕铁硼子母磁体，电子万能试验机测试子母磁体的磁力学曲线。10只SD大鼠麻醉后经口置入子磁体至胃内，在大鼠左上腹部放置母磁体，子母磁体自动吸合，腹部X线明确磁体相吸情况。术后单笼饲养，观察大鼠存活状况、磁体脱落时间、磁体留置期间并发症发生情况。术后2周处死动物，获取造瘘口标本，肉眼及光镜下观察造瘘口形成情况。

结果：设计和生产出的子母磁体均为圆柱状，采用N42烧结钕铁硼加工而成，表面电镀镍防护处理。子磁体直径5 mm、高3 mm，母磁体直径6 mm、高5 mm，子母磁体质量分别为0.410 g和1.035 g。子母磁体在零距离时最大吸力达4.36 N，磁体吸力随位移增加而逐渐减小。10只大鼠麻醉后均成功经口置入子磁体至胃内，在大鼠左上腹部放置母磁体后，子母磁体迅速相吸，腹部X线检查显示磁体对位吸合良好。术后大鼠均存活，子母磁体留置期间，未出现磁体移位、子母磁体分离等意外事件，所有实验动物无消化道梗阻、腹腔感染等并发症。术后10~13 d子母磁体脱落，胃造瘘通道建立。术后2周开腹观察可见造瘘口处胃壁和腹壁粘连愈合牢固，腹腔无渗液及粘连。获取造瘘口标本肉眼可见瘘口形成良好，HE及Masson染色光镜下观察可见瘘口组织结构层次清晰。

结论：基于磁压榨技术的胃造瘘磁体设计巧妙、易于加工、成本低，该方法建立无创化大鼠胃造瘘操作简单，安全可行，造瘘口各层组织愈合良好。下一步可开展与人体解剖特点更接近的大动物实验验证其可行性并评价造瘘口形成的长期效果。未来优化磁体设计和操作路径后，该技术有望在临床试用开展。

关键词 胃造口术；磁力学；磁压榨技术；大鼠

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Noninvasive gastrostomy based on magnetic compression technique: an experimental study in rat models

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Abstract

Background and Aims: Gastrostomy is a common operation in general surgery. Traditional gastrostomy has been gradually replaced by endoscopic gastrostomy and X-ray gastrostomy due to the great surgical trauma. However, the implementation process requires the assistance of endoscopic system or X-ray machine, and the procedure is complicated. Based on the assumption of performing a noninvasive gastrostomy by magnetic compression technique, this study was conducted to verify the feasibility and safety of this assumption in rat models using a self-designed and developed magnet device for gastrostomy.

Methods: According to the anatomical characteristics and size of rat digestive tract, the parent and daughter magnets made from Ndfeb and suitable for rat gastrostomy were designed and produced. The magnitude of the magnetic force between the parent and daughter magnets was tested by electronic universal testing machine. In 10 SD rats, the daughter magnet was inserted into the stomach through mouth after anesthesia and the parent magnet was placed in the left upper abdomen. After the two magnets automatically latched onto each other, the attraction status was confirmed by abdominal X-ray. After operation, the rats were raised in a single cage, the survival status, time of magnet detachment, and complications during magnets retention were observed. The animals were sacrificed 2 weeks after the operation, and the gastrostomy specimens were obtained to observe the formation of the gastrostomy under naked eye and light microscope.

Results: Both the self-designed and produced parent and daughter magnets were cylindrical shaped and made from N42 sintered Ndfeb, with nickel plating on the surface. The diameter and height of the daughter magnet were 5 mm and 3 mm, and the diameter of the parent magnet were 6 mm and 5 mm, respectively. The mass of the daughter magnet and parent magnet were 0.410 g and 1.035 g respectively. The maximum adhesive force of the parent and daughter magnets was 4.36 N in direct contact, and the magnetic force of the magnets decreased with the increase of displacement. The daughter magnets were successfully inserted into the stomach of all the 10 rats after anesthesia. After the parent magnets were placed in the left upper abdomen of rats, the daughter and parent magnets were rapidly attracted to each other. Abdominal X-ray examination showed that the magnets stuck in right position. All rats survived after operation. During the period of retention of the parent and daughter magnets, there were no accidents such as magnetic displacement and separation of the magnets occurred, and no complications such as digestive tract obstruction and abdominal infection occurred in all experimental animals. The magnets were detached and the gastrostomy channel was established 10 to 13 days after operation. Two weeks after the operation, the adhesion between stomach and abdominal wall around the fistula stoma was firmly healed, and there was no exudation and adhesion in the abdominal cavity. The specimens of the fistula stoma were obtained, naked-eye observation found that the fistula stoma was well formed, and the tissue structure of the fistula was clear under HE and Masson staining and light microscope.

Conclusion: The magnet device for gastrostomy based on magnetic compression technique is cleverly designed, easy to process and low cost. The establishment of non-invasive gastrostomy in rats by this

method is simple, safe and feasible, and the tissues of each layer of the fistula can heal well. The next step is to carry out experiments in large animals that are more similar to human anatomy to verify its feasibility and evaluate the long-term effects of the fistula formation. Clinical trials of this technique are expected in the future after optimization of the design of magnets and the operating procedure.

Key words　Gastrostomy; Magnetics; Magnetic Compression Technique; Rats

CLC number: R656.6

胃造瘘术是普通外科常见手术，主要用于解决因各种疾病导致的长期不能经口进食而胃肠道功能正常的患者的营养问题[1-2]。对于短期不能经口进食者可给予鼻胃管实施肠内营养，如长期留置鼻胃管可导致鼻腔及咽部黏膜损伤、食管糜烂出血，同时严重影响患者生活质量，大部分患者无法耐受长期留置鼻胃管[3]。胃造瘘术可避免留置鼻胃管带来的诸多并发症，传统胃造瘘术创伤较大，目前已被一些微创操作如X线透视下经皮胃造瘘术、经皮内镜下胃造瘘术所取代[4-7]。磁压榨技术（magnetic compression technique，MCT）是新兴的外科技术，可用于消化系统管腔吻合重建[8-11]、消化道病理性瘘修补[12-13]、血管吻合[14-16]，还可用于气管食管瘘动物模型制备及修补装置的设计[17-18]，具有微创、操作简单、效果可靠等诸多优势。本实验在前期研究基础上，提出了利用磁压榨技术建立胃造瘘的设想，并以大鼠为动物模型对该设想进行了实验验证，取得良好的实验结果，现报告如下。

1　材料与方法

1.1　磁体设计加工

用于大鼠胃造瘘的磁体包括子磁体（daughter magnet，DM）和母磁体（parent magnet，PM）两部分。根据大鼠及胃的解剖特点，自行设计适当大小及形状的子母磁体。子母磁体均为圆柱体，子磁体直径5 mm、高3 mm；母磁体直径6 mm、高5 mm，均采用N42烧结钕铁硼加工而成，磁体表面电镀镍。子磁体质量0.410 g，母磁体质量1.035 g（图1）。

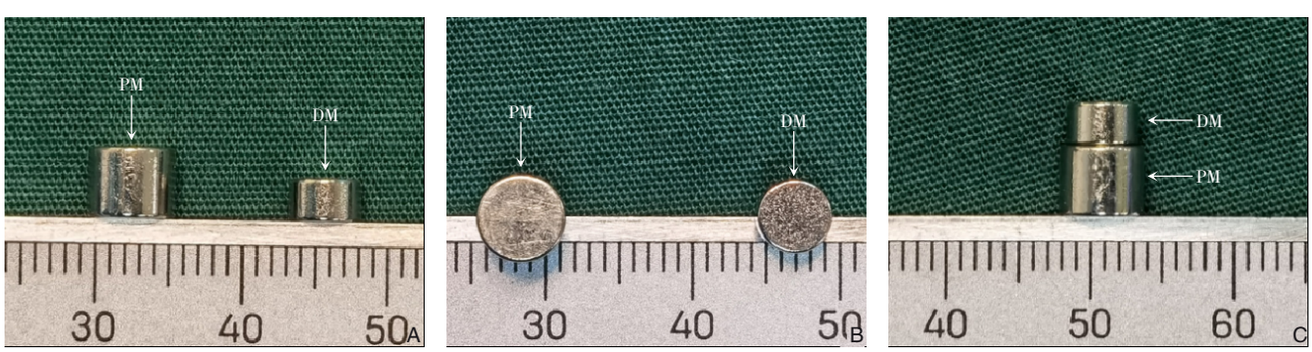

图1　用于大鼠胃造瘘的子母磁体　A：子母磁体侧面图；B：子母磁体底面图；C：子母磁体吸合状态

Figure 1　Parent and daughter magnets for gastrostomy in rats　A: Lateral view of the parent and daughter magnets; B: Bottom view of the daughter and parent magnets; C: Bonding state of daughter and parent magnets

1.2　子母磁体磁力学性能测试

利用电子万能试验机（型号UTM6202，深圳三思纵横科技股份有限公司）对子母磁体的磁力学性能进行测试。结果显示子母磁体距离为零时，磁力为4.36 N。随着两磁体间的距离增加，磁力逐渐减小，子母磁体的磁力位移曲线见图2。

　

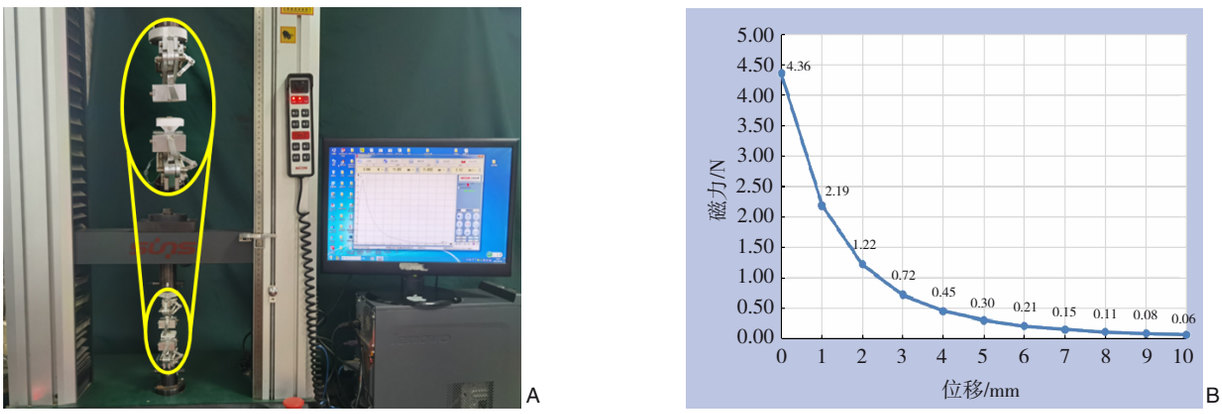

图2 磁力位移曲线测试图 A：磁力位移曲线测试示意图；B：子母磁体间的磁力位移曲线

Figure 2 Magnetic force displacement test curve A: Schematic diagram of magnetic force displacement test curve; B: Magnetic force displacement curve between parent and daughter magnets

1.3 实验动物

10只SD大鼠，雌雄各半，体质量200~250 g，由西安交通大学实验动物中心提供。本实验经西安交通大学生物医学伦理委员会审查后批准（审批号：XJTULAC2020-1360），整个实验过程符合动物实验伦理要求。本实验为创新性实验的可行性验证，故不设对照组，10只SD大鼠全部纳入磁压榨造瘘组。

1.4 手术操作及术后管理

所有大鼠术前不禁食饮，3%戊巴比妥钠（0.1 mL/100 g）腹腔注射麻醉。麻醉满意后仰卧位固定于小动物手术操作台上，左上腹部剃毛。取头高位60~70°，钛合金组织镊夹持子磁体经口腔置入子磁体至食管，然后用小儿胃管将其推送入胃内，把母磁体放置于左上腹部，子母磁体可自动吸合，手术操作即完成。术后立即行腹部X线明确子母磁体位置（图3）。术后单笼饲养，自由进食水。造瘘口形成后，子磁体与母磁体可自行脱落至体外，观察并记录各大鼠磁体脱落时间。术后2周处死大鼠，获取造瘘口标本，肉眼及镜下观察造瘘口形成情况。

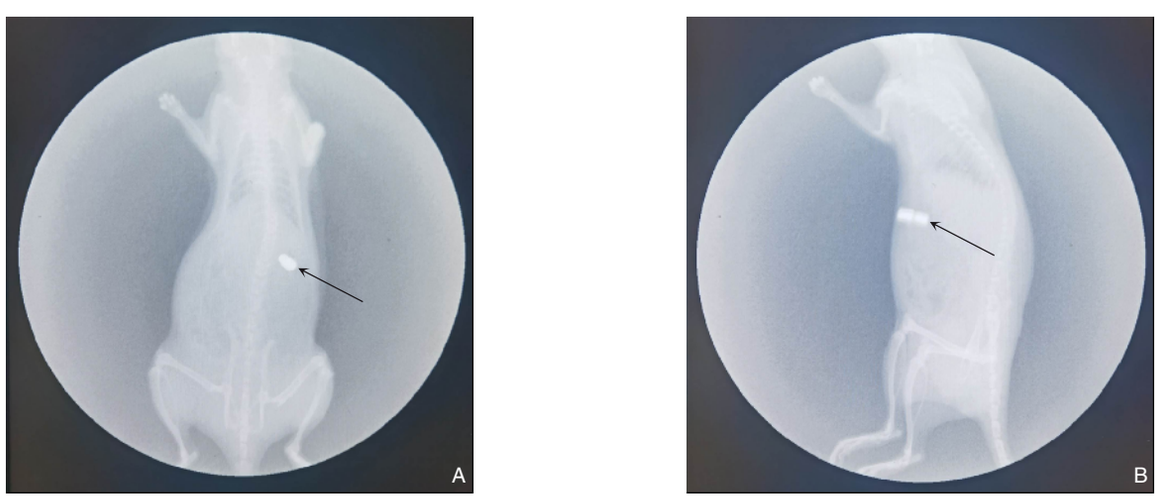

图3 X线下观察磁体对位吸合状态（箭头所指为子母磁体） A：正位片；B：侧位片

Figure 3 X-ray observation of the magnet on the position of the state (the arrow indicating the parent and daughter magnets) A: Anteroposterior radiograph; B: Lateral radiograph

2　结　果

10 只 SD 大鼠均顺利完成胃内子磁体的置入，在大鼠左上腹部皮肤外放置母磁体后，子母磁体自动相吸。X 线下可见子母磁体吸合良好。术后大鼠均存活，术后 10~13 d 子母磁体自行脱落至体外，胃造瘘口建立。在子母磁体留置期间，未出现磁体移位、子母磁体分离等意外事件，所有实验动物无消化道梗阻、腹腔感染等并发症。术后 2 周处死大鼠，开腹可见胃壁与腹部粘连牢固，造瘘后周围腹腔无粘连，获取造瘘口标本，可见造瘘通道形成良好（图 4）。HE 及 Masson 染色光镜下观察组织结构层次清晰（图 5）。

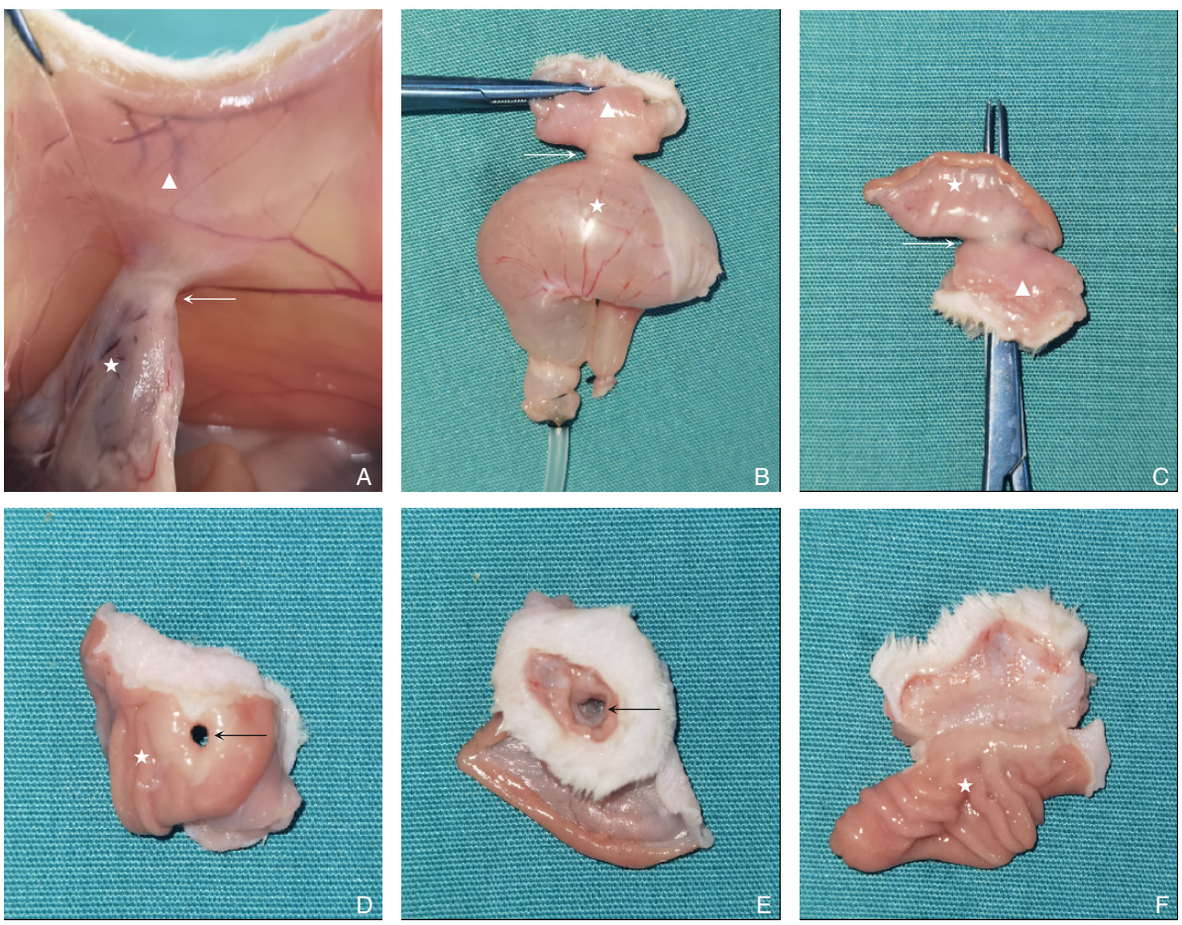

图 4　肉眼观察造瘘标本　A：开腹可见胃造瘘处胃壁与腹壁粘连牢固，周围无粘连；B：胃内充满水后观察造瘘通道；C：血管钳探查造瘘通道畅通性良好；D：胃侧观察所见造瘘口；E：皮肤侧观察所见造瘘口；F：沿造瘘通道纵向剖开所见造瘘通道（图中黑色箭头所指为造瘘口，白色箭头所指为造瘘通道，三角所示为腹壁，星号所示为胃）

Figure 4　The gastrostomy specimen observed by naked eye　A: After laparotomy, firm sticking of the gastric wall and abdominal wall at gastrostomy, without surrounding adhesions; B: Observation of the gastrostomy channel after filling the stomach with water; C: Exploration of the gastrostomy channel with vascular forceps showing smooth and patent lumen; D: View of the gastrostomy on gastric side; E: View of the gastrostomy on the skin side; F: Longitudinal incision of the gastrostomy along the fistula channel (the black arrow indicating the gastrostomy stoma, the white arrow indicating the gastrostomy channels, the triangle indicating the abdominal wall, and the asterisk indicating the stomach)

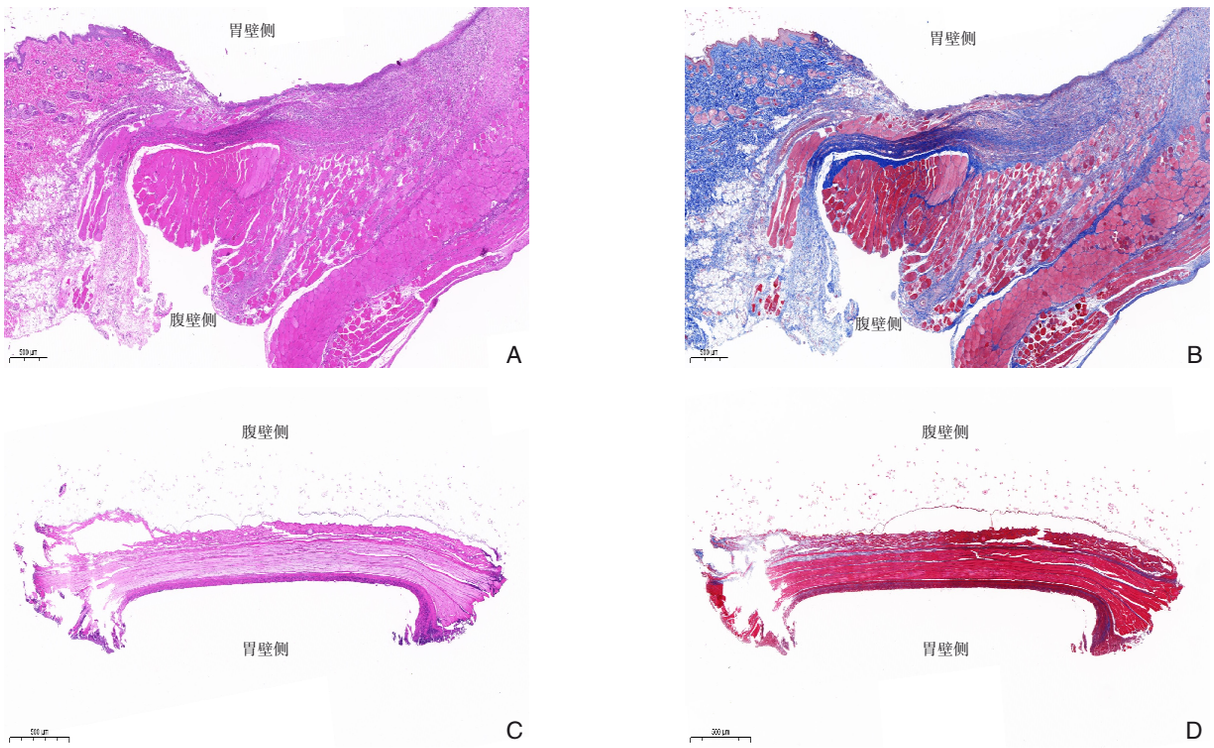

图5 光镜下所见造瘘通道组织学结构 A：造瘘口标本HE染色（HE×20）；B：造瘘口标本Masson染色（Masson×20）；C：子母磁体间的压榨坏死组织HE染色（HE×30）；D：子母磁体间的压榨坏死组织Masson染色（Masson×30）

Figure 5 The histological structure of the fistula channel under light microscope A: HE staining of the gastrostomy fistula specimen (HE×20); B: Masson staining of gastrostomy fistula specimen (Masson×20); C: HE staining of the necrotic tissue between the parent and daughter magnets (HE×30); D: Masson staining of the necrotic tissue between the parent and daughter magnets (Masson×30)

3 讨 论

磁外科是利用特殊设计的磁性医疗器械或设备，将磁性物质间“非接触性”磁场力转化为临床诊疗中能够发挥特定功能的力，从而完成组织压榨、器官锚定、管腔导航、间隙扩张、可控示踪、定向驱动等功能的新兴综合性技术学科[19]。磁外科相关技术可用于减戳孔腔镜手术[20-22]、辅助ESD术[23-25]、介入手术磁导航[26]等等。磁压榨技术是利用2个或2个以上磁体（或数个磁体与数个顺磁性材料）之间的磁性吸引力，通过开腹（胸）手术、腔镜手术、内镜操作、介入操作等来实现脏器的连接再通、组织的压榨闭合、管腔内容物的限流等，从而实现对临床疾病进行诊断和治疗的目的[27]。磁压榨吻合（magnetic compression anastomosis，MCA）是一种出色的吻合技术，可以在不打开腹部的情况下进行各种类型的吻合术[28]。子母磁体持续压榨的过程中，磁体间的受压组织发生缺血→坏死→脱落，而压榨旁组织则发生粘连→修复→愈合的病理变化[29-30]。利用这一特点，笔者提出利用磁压榨技术建立胃造瘘的实验设想，通过动物实验验证了该技术的可行性。具体来讲，磁压榨技术用于胃造瘘具有以下优点：(1) 本次实验以大鼠作为动物模型，手术操作简单，手术时间短；通过选择合适尺寸的子磁体，可顺利完成子磁体的胃内置入过程；在人体，可使患者通过吞磁的方式解决子磁体的胃内置入过程；(2) 手术操作近乎无创化，因手术操作无需开腹，不会造成腹腔粘连，可减少腹部手术并发症的发生；(3) 造瘘通道通畅性良好，瘘口组织各结构层次清晰，胃壁与腹壁粘连牢固可靠，可有效减少腹腔渗漏等问题；(4) 利用磁压榨技术完成胃造瘘无需胃镜、X线等大型医疗设备支持，临床上在床旁即可完成，简单易行。

该实验利用SD大鼠作为动物模型具有成本低、易于饲养和管理的优点，但也存在着一定的缺陷。受大鼠食管解剖特点影响，子磁体尺寸较小，导致子母磁体间磁力受限，模型制备时间较

长，如采用大动物（如犬、猪等）作为模型，可采用磁力更大的磁体，从而获得更大的压榨力，以缩短造瘘时间。再者，该实验缺乏对造瘘口形成后的长期观察，造瘘口径的稳定性需要通过更长时间的观察来进行评价。

本研究通过大鼠模型初步验证了磁压榨技术在胃造瘘中的可行性，但在临床实际应用过程中应考虑到采用合适直径的磁体，避免造瘘口通道过大或过小，同时子母磁体持续压榨过程中患者会产生一定的疼痛，应进行镇痛治疗。

本实验以SD大鼠为模型动物，结果表明利用磁压榨技术可实现无创化胃造瘘，造瘘效果确切。根据人体解剖特点，通过进一步对磁体设计及操作过程的优化，该技术有望应用于临床。

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