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·文献综述·

主动脉根部–升主动脉段病变腔内修复的研究进展

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摘　要　主动脉根部–升主动脉段，由于其复杂的解剖结构及血流动力学湍流特点，使得在设计腔内移植物时，需考虑“主动脉瓣膜、双侧冠脉开口、主动脉窦部膨大、头臂干开口”等几个因素。因而被视为腔内修复最后的“禁区”，至今仍然无理想的腔内移植物能够用于此段病变的治疗，成为全球各大血管外科中心聚焦的前沿问题。现有研究方案包括 Endo-Bentall 法、Endo-Wheat 法以及“景氏瓣窗型”移植物腔内修复动物实验等，但是主要存在个体化局限性、冠脉支架的远期通畅率不明确和移植物感染等悬而未解问题。目前尚无完善的腔内移植物或腔内手术方案可解决主动脉根部–升主动脉段病变。鉴于目前此技术的局限性和有限的临床经验，这项技术应保留给高危患者，特别是那些拒绝开放干预的患者。笔者对目前现有的腔内修复累及主动脉根部及升主动脉病变方案做一综述。

关键词　主动脉疾病；血管内操作；移植物；综述

中图分类号：R654.3

Progress of endovascular repair of lesions involving aortic root/ascending segment

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Abstract　Aortic root/ascending segment, due to its complex anatomical structure and hemodynamic turbulence characteristics, requires consideration of several factors such as "aortic valve, bilateral coronary artery openings, aortic sinus dilation, and innominate artery opening" when designing endovascular grafts. Therefore, it is regarded as the final "forbidden zone" for endovascular repair, and to this day, there is still no ideal intraluminal graft available for treating lesions in this segment, becoming a forefront issue focused on by major vascular surgery centers worldwide. Current research strategies include the Endo-Bentall procedure, Endo-Wheat procedure, and "Jing's valved-fenestrated endografting" animal experiments, but significant challenges remain unresolved, such as individualization limitations, unclear long-term patency of coronary stents, and graft infections. Currently, there are no perfect endografts or endovascular surgical approaches to address lesions in the aortic root-ascending aorta segment. Given the

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limitations of the current technology and limited clinical experience, this technique should be reserved for high-risk patients, especially those who refuse open interventions. Here, the authors provide an overview of the currently available endovascular repair options involving the aortic root and ascending aorta lesions.

Key words Aortic Diseases; Endovascular Procedures; Transplants; Review

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累及主动脉根部及升主动脉的病变包括急性A型主动脉夹层、壁内血肿、穿透性动脉粥样硬化性溃疡和慢性动脉瘤样扩张等，开胸在体外循环下行Bentall或Wheat等传统开放手术（主动脉瓣和升主动脉置换，伴或不伴冠状动脉再植），仍然是对累及主动脉根部–升主动脉病变的治疗的“金标准”[1]，但是研究[2]表明约28%的患者存在外科开放手术的禁忌。尽管开放手术远期预后良好，但对于高龄、外科高风险、存在开放手术禁忌的患者来说，胸主动脉腔内修复术（thoracic endovascular aortic repair，TEVAR）作为开放手术的替代选择，正受到越来越多的关注[3]。近年来，随着平行支架技术、体外/原位开窗技术、带单/多分支腔内移植物的迅速发展，主动脉弓部、降主动脉内脏动脉区等曾经的腔内修复“禁区”，已逐步被攻克[4-5]。现如今，如何利用腔内技术攻克主动脉根部这一“禁区”，解决主动脉腔内手术的“最后5 cm”，已成为国内外各大血管外科中心聚焦的前沿。为了更好地了解这项技术的临床应用前景及意义，笔者对腔内修复主动脉根部–升主动脉病变的现有解决方案做一综述。

1 主动脉根部–升主动脉的解剖及血流动力学特点

主动脉根部包括左室流出道、主动脉瓣、主动脉瓣环、主动脉窦（冠脉开口）、窦管交界。窦管交界至主动脉弓发出头臂干间的这段升主动脉非常短，长度变化区间为（62.6±11.4）~（68.6±13）mm。升主动脉直接承受来自左室的高速脉冲血流，在心动周期中并非规则的层流，而是在主动脉窦中形成湍流，导致升主动脉直径在同一心动周期内变化可达2.70 mm[6]。升主动脉的解剖特点使得在设计腔内移植物时需考虑“主动脉瓣膜、双侧冠脉开口、主动脉窦部膨大、头臂干开口”等几个因素；血流动力学特点，对移植物的柔顺性及锚定的稳定性要求较高。

2 TEVAR在单纯累及升主动脉段病变的应用现状

对于一部分Debakey II型夹层，或升主动脉局限性溃疡、动脉瘤的患者，已有很多中心使用市场上现有的短覆膜支架，成功进行单纯累及升主动脉病变的全腔内修复[7-9]。Cook公司的Zenith Ascend device是目前报告过用于临床的升主动脉腔内移植物[10]。众多知名医疗器械生产厂家也在“抢滩登陆”，研发专用于升主动脉的支架。然而，由于相关文献多为小样本病例系列研究，可能存在研究偏倚，实际应用效果可能不及文献报道。并且所有升主动脉夹层腔内治疗的报道中，支架移植物的近端锚定区均位于窦管交界的远心端（距离高位冠脉开口2 cm以上），病变仅仅限于升弓部，未累及主动脉根部，这使得短覆膜支架有足够锚定区，且能与弓部腔内移植物“无缝链接”。但是，临床上绝大多数Stanford A型夹层同时累及主动脉根部。主动脉根部的解剖特性，仍然是全腔内修复主动脉病变的“瓶颈”。

3 经导管主动脉瓣植入术（transcatheter aortic valve implantation，TAVI）的启示

自Cribier等[11-13]证实TAVI可行性以来，其手术适应证已逐步由外科高危患者，扩大至中危患者，甚至是相对年轻（<60岁）的中低危患者，但面临的最大问题是介入瓣膜的持久性。研究[14]表明，TAVI瓣膜的寿命与外科手术生物瓣膜的寿命相当。那么，衔接介入瓣和血管腔内覆膜支架时，选择球扩式抑或自膨式瓣膜，将给移植物的整体释放方式带来不同选择。TAVI大多为经股动

脉或心尖入路植入移植物，也有中心经锁骨下动脉或经主动脉通路，这两种入路可以降低经心尖入路的致残率和病死率[15]。无论是带瓣膜移植物的释放方式，还是介入入路的选择，都为全腔内修复根部–升主动脉段病变带来启示。如何有效衔接升主动脉覆膜支架及 TAVI 瓣膜，是腔内血管外科界的“终极命题”，也将是未来 10~20 年主动脉外科的最大热点。

4　累及主动脉根部–升主动脉段的 Endo-Bentall 解决方案

2020 年 1 月，巴西圣保罗医院报告了世界首例“Endo-Bentall”手术[16]。这例患者是 64 岁的女性，6 年前因严重的主动脉狭窄，行开胸生物瓣换瓣手术，因升主动脉吻合口假性动脉瘤引发胸痛入院，评估后发现生物瓣失功，主动脉瓷化等系列问题。患者已不具备再次开胸手术的条件，遂进行腔内修复术。此例患者使用的是自制移植物（将近端球扩式 TAVI 瓣膜和远端自膨式覆膜支架组合而成）。在主动脉支架和瓣膜移行区设计内外各两根用于桥接的分支支架，重建左右冠状动脉，桥接支架均为商品化的替代支架（图 1）。经心尖入路植入支架和主动脉瓣复合体，经股动脉途径植入冠状动脉支架；术毕无内漏等并发症，随访 9 个月无心肌缺血。此技术首次成功衔接升主动脉覆膜支架与 TAVI 瓣膜，通过全腔内途径，完成了 Bentall 手术需要达到的目的，但仍存在以下问题：需提前个体化定制，保障双侧冠脉开窗位置准确；超选冠脉及桥接冠脉支架存在难度，可能延长手术时间甚至超选冠脉失败的技术瓶颈；冠脉支架的远期通畅率值得商榷。

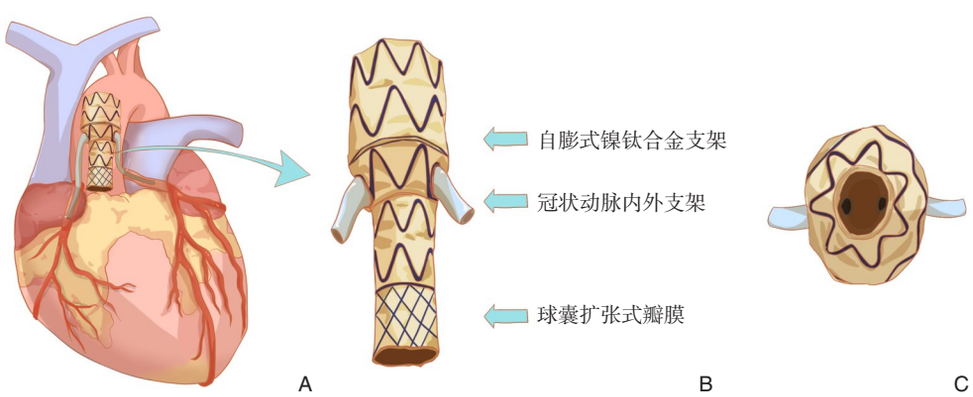

图 1　Endo-Bentall 解决方案示意图　A：Endo-Bentall 方案概念图解；B：Endo-Bentall 方案关键部位设计示意图；C：Endo-Bentall 方案俯视图

Figure 1　**Endo-Bentall solution schematic diagram**　A: Conceptual diagram of the Endo-Bentall solution; B: Schematic diagram illustrating the key component design of the Endo-Bentall solution; C: Top view diagram of the Endo-Bentall solution

5　累及主动脉根部–升主动脉段的 Endo-Wheats 解决方案

2014 年 Rylski 团队[17]提出了将直管型升主动脉覆膜支架和人工心脏瓣膜缝制在一起，实施 Endo-Wheat 方案，并完成了首例动物模型（图 2）。移植物由一个近端的经导管主动脉瓣组件和半覆膜支架移植物组成，介入瓣与覆膜支架之间存在“裸区”，即主动脉窦部双侧冠脉开口部位，无覆膜，可保障冠脉血流，升主动脉段覆膜支架可覆盖夹层破口（图 3）并且能够经心尖入路引流心包积液。该移植物有 3 个锚定区：主动脉瓣环区、窦管交界处的近端密封区、头臂干水平的远端密封区。此方案包括几个关键点：根据术中造影测量的主动脉各关键径线，分别选择合适的介入瓣和覆膜支架，在手术台上将二者缝合连接；双侧冠状动脉开口处为裸支架，保证冠脉血流灌注；为防止复合移植物移位，设置 3 个锚定区；经心尖入路一期修复[18]。无论是 Endo-Bentall 抑或 Endo-Wheat，均处于探索阶段，如果技术成熟将获得极大的临床应用价值[5,19–21]。

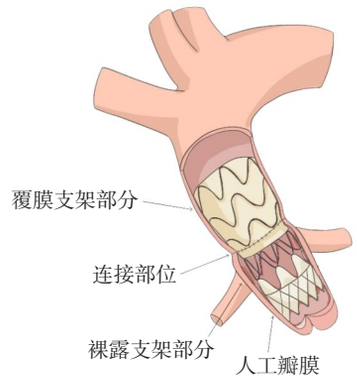

图2 Endo-Wheat解决方案示意图（根据术中造影分别选择合适的介入瓣和覆膜支架，在手术台上将二者缝合连接；双侧冠状动脉开口处为裸支架，保证冠脉血流灌注；设置3个锚定区；可经心尖入路一期修复）

Figure 2 Endo-Wheat solution schematic diagram (Based on intraoperative angiography, suitable intervention valves and covered stents are selected, and they are sutured and connected on the operating table. The openings of the bilateral coronary arteries are left uncovered to ensure coronary blood flow perfusion. Three landing zones are established. The repair can be performed through a transapical approach in a one-stage procedure)

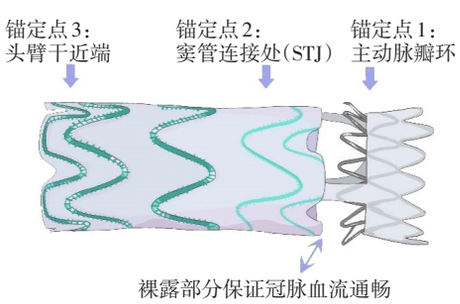

图3 主动脉瓣组件与半覆膜支架移植物拼接示意图（锚定点1：主动脉瓣环，通过瓣膜装置稳定支架移植物；锚定点2：窦管连接处，形成近端密封区；锚定点3：头臂干近端，形成远端密封区）

Figure 3 Schematic diagram of aortic valve component and semi-covered stent graft integration (Landing zone 1: Aortic valve annulus, stabilizing the stent graft through valve device; Landing zone 2: Sinotubular junction, forming a proximal sealing zone; Landing zone 3: Proximal end of the brachiocephalic trunk, forming a distal sealing area)

6 “景氏瓣窗型”移植物腔内修复根部病变动物模型研究

长海医院在2020年发表了研究[22-25]，对20头成年家猪进行了主动脉根部腔内重建的实验。自制移植物（景氏瓣窗型腔内移植物，图4）包括主体覆膜支架和分支覆膜支架（头臂干支架，增强锚定），将牛心包裁剪缝合到主体覆膜支架的内表面。根据术前CTA测量数据，在距离生物瓣膜底部10 mm处各开2个直径10 mm的窗口以保留冠状动脉。随访期有1例实验动物计划外死亡，原因是移植物感染。术后第2个月心脏超声随访发现2例轻度主动脉瓣反流（2/18，11.1%），每个月行CTA显示所有冠状动脉和头臂干均通畅，未发现腔内移植物移位。

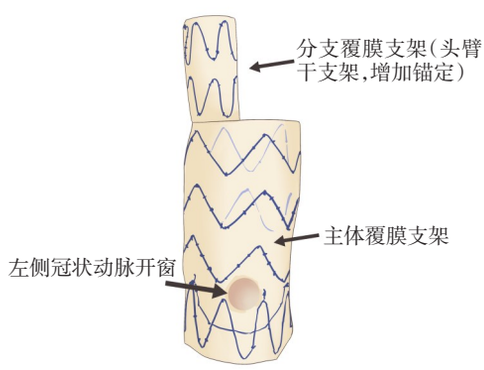

图4 一体化带瓣开窗分支型腔内移植物示意图

Figure 4 Schematic diagram of integrated valved-fenestrated-bifurcated endograft

7 展 望

目前尚无完美的腔内移植物或腔内手术方案可解决主动脉根部–升主动脉段病变[26]，虽然很多血管外科中心已在进行先期研究，但以案例报道或案例系列研究为主，证据等级较低，尚需样本量较大的队列研究以验证其安全性和有效性[27]。此外，现阶段对升主动脉夹层腔内治疗的探索属于超适应证治疗，必须综合考虑并严格把握治疗方案[28-29]。如何拼接腔内覆膜支架和介入瓣膜，是分体式移植物在台上现装，还是设计一体化移植物预装在同一输送器？如何保障双侧冠脉的远期通畅率？如何改进金属支架的属性，使之具有足够径向支撑力的同时，又能减少对根部组织的损伤[30-31]？存在问题尚多，但随着理论和技术的进

步，以及越来越多的带瓣支架移植物的研发，更多的外科高危患者或将从中受益。

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参考文献

[1] Fazzini S, Torsello G, Austermann M, et al. Aortic endograft and bridging stent-graft remodeling after branched endovascular aortic repair[J]. Vascular, 2021, 29(6): 808−816. doi: 10.1177/1708538120983698.

[2] Shi J, Liu LG, Wei X, et al. Back-table modified stent-graft for endovascular repair of ascending aorta[J]. J Endovasc Ther, 2021, 28(6):888−896. doi: 10.1177/ 15266028211028201.

[3] 陈梦泽, 李振江, 张鸿坤. 腔内治疗A型主动脉夹层的难点与突破[J]. 外科理论与实践, 2022, 27(4): 299−303. doi: 10.16139/j.1007−9610.2022.04.005.
Chen MZ, Li ZJ, Zhang HK. Endovascular repair of type A aortic dissection: difficulty and breakthrough[J]. Journal of Surgery Concepts & Practice, 2022, 27(4): 299−303. doi: 10.16139/j.1007−9610.2022.04.005.

[4] Czerny M, Schmidli J, Adler S, et al. Editor's choice-current options and recommendations for the treatment of thoracic aortic pathologies involving the aortic arch: an expert consensus document of the European association for cardio-thoracic surgery (EACTS) & the European society for vascular surgery (ESVS)[J]. Eur J Vasc Endovasc Surg, 2019, 57(2): 165−198. doi: 10.1016/j.ejvs.2018.09.016.

[5] Piffaretti G, Czerny M, Riambau V, et al. Endovascular repair of ascending aortic diseases with custom-made endografts[J]. Eur J Cardiothorac Surg, 2021, 59(4): 741−749. doi: 10.1093/ejcts/ezaa383.

[6] 赵玉玺, 冯家烜, 周建, 等. 升主动脉根部测量研究进展[J]. 介入放射学杂志, 2016, 25(11): 939−943. doi: 10.3969/j. issn. 1008−794X.2016.11.002.
Zhao YX, Feng JX, Zhou J, et al. Research progress in the measuring of ascending aortic root[J]. Journal of Interventional Radiology, 2016, 25(11): 939−943. doi: 10.3969/j. issn. 1008−794X.2016.11.002.

[7] Uchida T, Kuroda Y, Yamashita A, et al. Clinical experience of endovascular stent-graft treatment for stanford type A acute aortic dissection[J]. Kyobu Geka, 2019, 72(12):976−983.

[8] Xiao CB, Yu HX, Mao LF, et al. Surgical treatment of Stanford type A aortic dissection after thoracic endovascular aortic repair[J]. Chin J Surg, 2021, 59(6): 520−524. doi: 10.3760/cma.j.cn112139−20200827−00667.

[9] Baikoussis NG, Antonopoulos CN, Papakonstantinou NA, et al. Endovascular stent grafting for ascending aorta diseases[J]. J Vasc Surg, 2017, 66(5):1587−1601. doi: 10.1016/j.jvs.2017.07.064.

[10] Oderich GS, Pochettino A, Mendes BC, et al. Endovascular repair of saccular ascending aortic aneurysm after orthotopic heart transplantation using an investigational zenith ascend stent-graft[J]. J Endovasc Ther, 2015, 22(4): 650−654. doi: 10.1177/1526602815593537.

[11] Cribier A, Eltchaninoff H, Tron C. First human transcatheter implantation of an aortic valve prosthesis in a case of severe calcific aortic stenosis[J]. Ann Cardiol Angeiol (Paris), 2003, 52(3): 173−175. doi: 10.1016/s0003−3928(03)00062−3.

[12] Yamashita Y, Shimamura K, Maeda K, et al. Simultaneous aortic valve-in-valve and ascending stent grafting for prosthetic valve Stenosis and ascending flap[J]. Ann Vasc Dis, 2020, 13(4): 422−425. doi: 10.3400/avd.cr.20−00065.

[13] Kainth AS, Ring A, Williams MS, et al. Outcomes after endovascular reintervention for aortic interventions[J]. J Vasc Surg, 2022, 75(3):877−883. doi: 10.1016/j.jvs.2021.08.090.

[14] Rahman F, Resar JR. TAVI beyond 3 years: durability and predictors for survival[J]. Innovations (Phila), 2021, 16(5): 417−425. doi: 10.1177/15569845211017558.

[15] Tchetche D, de Biase C, Brochado B, et al. How to make the TAVI pathway more efficient[J]. Interv Cardiol, 2019, 14(1): 31−33. doi: 10.15420/icr.2018.28.2.

[16] Felipe Gaia D, Bernal O, Castilho E, et al. First-in-Human Endo-Bentall Procedure for Simultaneous Treatment of the Ascending Aorta and Aortic Valve[J]. JACC Case Rep, 2020, 2(3): 480−485. doi: 10.1016/j.jaccas.2019.11.071.

[17] Rylski B, Szeto WY, Bavaria JE, et al. Development of a single endovascular device for aortic valve replacement and ascending aortic repair[J]. J Card Surg, 2014, 29(3): 371−376. doi: 10.1111/jocs.12348.

[18] Kreibich M, Rylski B, Beyersdorf F, et al. Endo-Bentall for proximal aortic dissection: from conception to application[J]. Asian Cardiovasc Thorac Ann, 2021, 29(7): 697−700. doi: 10.1177/0218492320929211.

[19] Anwar MA, Hamady M. Various endoluminal approaches available for treating pathologies of the aortic arch[J]. Cardiovasc Intervent Radiol, 2020, 43(12): 1756−1769. doi: 10.1007/s00270−020−02561−y.

[20] Tsilimparis N, Drewitz S, Detter C, et al. Endovascular repair of

ascending aortic pathologies with tubular endografts: a single-center experience[J]. J Endovasc Ther, 2019, 26(4): 439-445. doi: 10.1177/1526602819852083.

[21] Wang CT, Regar E, Lachat M, et al. Endovascular treatment of non-dissected ascending aorta disease: a systematic review[J]. Eur J Cardiothorac Surg, 2018, 53(2): 317-324. doi: 10.1093/ejcts/ezx308.

[22] 侯钦茂. 主动脉夹层大动物模型构建及升主动脉夹层治疗的初步研究[D]. 上海: 中国人民解放军海军军医大学, 2018.
Hou QM. The primary research of building aortic dissection model on pig and the treatment of ascending aortic dissection[D]. Shanghai: PLA Navy Medical University, 2018.

[23] 李晓晔, 陆清声. 升主动脉夹层腔内治疗的研究进展[J]. 中国血管外科杂志: 电子版, 2021, 13(1):73-76. doi: 10.3969/j.issn.1674-7429.2021.01.018.
Li XY, Lu QS. Research progress of endovascular treatment of ascending aortic dissection[J]. Chinese Journal of Vascular Surgery (Electronic Version), 2021, 13(1):73-76. doi: 10.3969/j.issn.1674-7429.2021.01.018.

[24] 赵玉玺. 升主动脉扩张合并瓣膜疾病腔内微创治疗的新器具研究[D]. 上海: 中国人民解放军海军军医大学, 2021.
Zhao YX. Development of new devices for endovascular treatment of ascending aortic dilation combined with valvular disease[D]. Shanghai: PLA Navy Medical University, 2021.

[25] 鲍贤豪. 景氏瓣窗型腔内移植物系统的研制及动物实验研究[D]. 上海: 中国人民解放军海军军医大学, 2019.
Bao XH. Development of Jing's valved-fenestrated endograft system and its experimental study in animals[D]. Shanghai: PLA Navy Medical University, 2019.

[26] Haghiashtiani G, Qiu KY, Zhingre Sanchez JD, et al. 3D printed patient-specific aortic root models with internal sensors for minimally invasive applications[J]. Sci Adv, 2020, 6(35):eabb4641. doi: 10.1126/sciadv.abb4641.

[27] 张喆, 陈学明, 李晨宇, 等. 腔内治疗破口位于升主动脉的Stanford A型主动脉夹层[J]. 中国普通外科杂志, 2015, 24(12): 1649-1653. doi: 10.3978/j.issn.1005-6947.2015.12.002.
Zhang Z, Chen XM, Li CY, et al. Endovascular treatment for Stanford type A aortic dissection with entrance tear in ascending aorta[J]. China Journal of General Surgery, 2015, 24(12): 1649-1653. doi: 10.3978/j.issn.1005-6947.2015.12.002.

[28] Trimarchi S, Grassi V, Lomazzi C, et al. Endovascular type A aortic repair-When? [J]. J Card Surg, 2021, 36(5): 1742-1744. doi: 10.1111/jocs.15103.

[29] Prasad NK, Boyajian G, Gupta A, et al. Transcarotid approach for ascending aortic endovascular repair[J]. Ann Thorac Surg, 2021, 112(1):e17-19. doi: 10.1016/j.athoracsur.2020.10.063.

[30] Roselli EE, Idrees J, Greenberg RK, et al. Endovascular stent grafting for ascending aorta repair in high-risk patients[J]. J. Thorac Cardiovasc Surg, 2015, 149(1): 144-151. doi: 10.1016/j.jtcvs.2014.07.109.

[31] 罗明尧, 朱梦依, 方坤, 等. 合并严重冠心病的短锚定区主动脉弓降部疾病的腔内修复[J]. 中国普通外科杂志, 2017, 26(12):1536-1540. doi: 10.3978/j.issn.1005-6947.2017.12.005.
Luo MY, Zhu MY, Fang K, et al. Endovascular repair of proximal descending aortic disease with insufficient proximal landing zone in patients with concomitant severe coronary heart disease[J]. China Journal of General Surgery, 2017, 26(12): 1536-1540. doi: 10.3978/j.issn.1005-6947.2017.12.005.

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