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# 支架植入治疗儿童主动脉缩窄并高血压的可行性及近中期疗效

孙红林,管玉强,于培儒,李磊,杜庆霞,丁浩
(山东大学附属儿童医院(济南市儿童医院)心血管内科,山东 济南 250022)

**摘要:目的** 分析支架植入治疗儿童主动脉缩窄(coarctation of aorta, CoA)并高血压可行性及近中期疗效分析。**方法** 回顾分析 5 例(男 3 例、女 2 例,6~10 岁)CoA 并高血压患儿的临床特点、介入治疗、随访结果。**结果** 手术成功率 100%,术前主动脉压差 28.0 (25.5,33.0)mmHg(1 mmHg=0.133 kPa)降至术后 5.0(3.5,6.5)mmHg,术前主动脉横径 4.8(3.1,6.1)mm 扩张至术后 18.0(13.0,21.5)mm,2 例患儿需持续口服单一抗高血压药物,随诊 15 个月未再发现支架移位、主动脉夹层、主动脉再缩窄等并发症。**结论** 采用球囊扩张+支架植入治疗儿童 CoA 并高血压可取得即时及近中期疗效,但其远期效果仍需进一步随访观察。

**关键词:**主动脉缩窄;高血压;儿童;介入治疗;支架
**中图分类号:**R725.4 **文献标志码:**A

# Feasibility and short-to-medium-term efficacy of stent implantation for the treatment of aortic coarctation complicated by hypertension in children

SUN Honglin, GUAN Yuqiang, YU Peiru, LI Lei, DU Qingxia, DING Hao
(Department of Cardiovascular Medicine, Children's Hospital Affiliated to Shandong University (Jinan Children's Hospital), Jinan 250022, Shandong, China)

**Abstract: Objective** To evaluate the feasibility and short- to mid-term efficacy of stent implantation for the treatment of coarctation of the aorta (CoA) complicated by hypertension in children. **Methods** A retrospective analysis was conducted on five children (3 boys and 2 girls, aged 6-10 years) diagnosed with CoA and hypertension. The clinical characteristics, procedural details of interventional therapy, and follow-up outcomes were reviewed. **Results** The procedural success rate was 100%. The median trans-coarctation pressure gradient significantly decreased from 28.0 (25.5,33.0) mmHg (1 mmHg=0.133 kPa) preoperatively to 5.0(3.5,6.5) mmHg postoperatively. Concurrently, the median diameter at the coarctation site increased significantly from 4.8 (3.1, 6.1) mm to 18.0(13.0,21.5) mm after stenting. Two children required continued oral antihypertensive therapy with a single agent. During a median follow-up period of 15 months, no complications such as stent migration, aortic dissection, or recoarctation were observed. **Conclusion** Balloon-expandable stent implantation is a feasible and effective treatment for children with CoA and hypertension, demonstrating excellent immediate and short- to mid-term outcomes. However, long-term follow-up is necessary to confirm its sustained efficacy.

**Key words:** Coarctation of the aorta; Hypertension; Children; Interventional therapy; Stent

主动脉缩窄(coarctation of aorta, CoA)是一种较常见主动脉局限性狭窄,可发生于胸、腹主动脉任何部位,国内外统计约占先心病的 6%~8%,男:女比例(4~5):1。CoA 绝大部分发生于左锁骨下动脉远端的动脉导管附近,根据范围分为局限缩窄和管状狭窄两种,可引起上肢高血压,下半身低灌注低血压[1]。球囊扩张术+支架植入术治疗 CoA 多用于年长儿童及成年人,支架植入中位数年龄为 15.3

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**通信作者:**李磊。E-mail:talilei1981@163.com

岁[2]。但关于儿科人群近中期结果和随访的信息有限,本研究旨在跟踪儿童主动脉缩窄支架植入术的手术结果,并评估该手术对儿童的安全性和有效性。

## 1 资料与方法

### 1.1 临床资料

纳入山东大学附属儿童医院 2021 年 5 月至 2023 年 10 月诊断 CoA 并高血压患儿 5 例,其中男 3 例、女 2 例,6~10 岁,因发现高血压数天至数周不等入院。入院后上肢血压测量 3 次平均收缩压大于同性别、年龄和身高儿童血压的第 95 百分位,符合高血压诊断标准[3]。下肢血压低,上下肢血压差>20 mmHg(1 mmHg = 0.133 kPa)。完善检查,血常规、常规生化、抗核抗体、风湿免疫因子、血筛尿筛、高血压五项、颅脑磁共振均未见异常,体格检查上下肢血压差明显,足背动脉波动弱或未触及,心脏超声示 3 例左心室肌或室间隔增厚、胸腹部大血管超声均提示主动脉缩窄。进一步行心血管增强 CT(图 1),提示 4 例降主动脉局部缩窄、1 例胸主动脉管状缩窄(T9-T10 水平),均接受球囊扩张+覆膜支架植入术治疗。本研究获得山东大学附属儿童医院医学伦理委员会批准(SDFE-IRBIF-2025118),患儿家属均签署知情同意书。

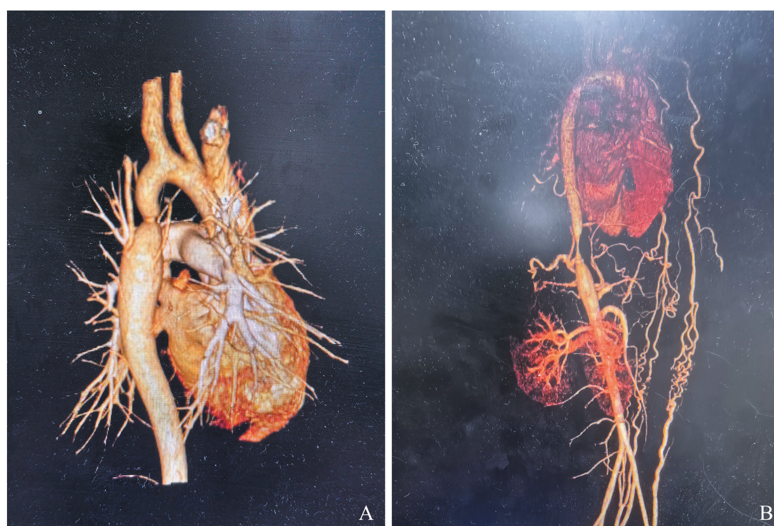


图 1 CT 示降主动脉局部狭窄(A)及胸主动脉管状缩窄(B)

Figure 1 CT shows localized stenosis of the descending aorta (A) and tubular coarctation of the thoracic aorta (B)

### 1.2 方法

#### 1.2.1 手术方法

5 例患者均在全身麻醉气管插管下行股动脉穿刺术,置入 5F 猪尾造影导管至主动脉缩窄段近端,测量缩窄部位主动脉压差,左侧位行升主动脉造影,4 例均为降主动脉峡部狭窄,1 例胸主动脉缩窄,并明确主动脉侧枝位置关系。了解有无侧枝循环,测量缩窄长度、近端直径、远端直径,所有患儿均选择 BIB PTA Catheter 球囊导管(美国纽迈德公司)及覆膜支架,支架的长度依据左锁骨下动脉和缩窄部位远端 15 mm 之间的距离而定,且要兼顾支架扩展后的缩短率,确保支架能完全覆盖狭窄段。球囊按主动脉缩窄近端直径,偶尔可加大 1~2 mm,装载覆膜支架时手套干燥,避免聚四氟乙烯薄膜层从支架脱落,装载支架的球囊导管递送到狭窄部位,以 2~4 个大气压压力扩张球囊、支架释放支架后再次行主动脉造影,确定扩张效果并测量支架两端压差。见图 2。

#### 1.2.2 术后处理

术后卧床 12 h,穿刺部位按压止血,常规心电监护、补液,口服阿司匹林肠溶片 3~5 mg/kg(最大量 100 mg),连续 6 个月,有高血压者继续口服抗高血压药物,术后 3 例出现胸痛、1 例出现腰痛,考虑扩展主动脉缩窄部位有内膜撕裂有关,3~5 d 自行缓解,疼痛剧烈时需复查心脏超声、胸部正位片,无殊可 48 h 后出院。

### 1.3 统计学处理

采用 SPSS 25.0 统计学软件。本研究样本量较小,采用 Shapiro-Wilk 检验效力极低,无法准确判断数据分布特征,因此使用 $M(P_{25}, P_{75})$ 进行数据描述,采用 Wilcoxon 秩和检验对术前、术后主动脉压差及横径进行比较;采用 Firedman $M$ 检验对术前、术后 1 d 和术后 1、3、6、15 个月相关数据进行统计分析,存在统计学差异时,进一步采用 Bonferroni 进行两两比较。检验水准 $\alpha = 0.05$。

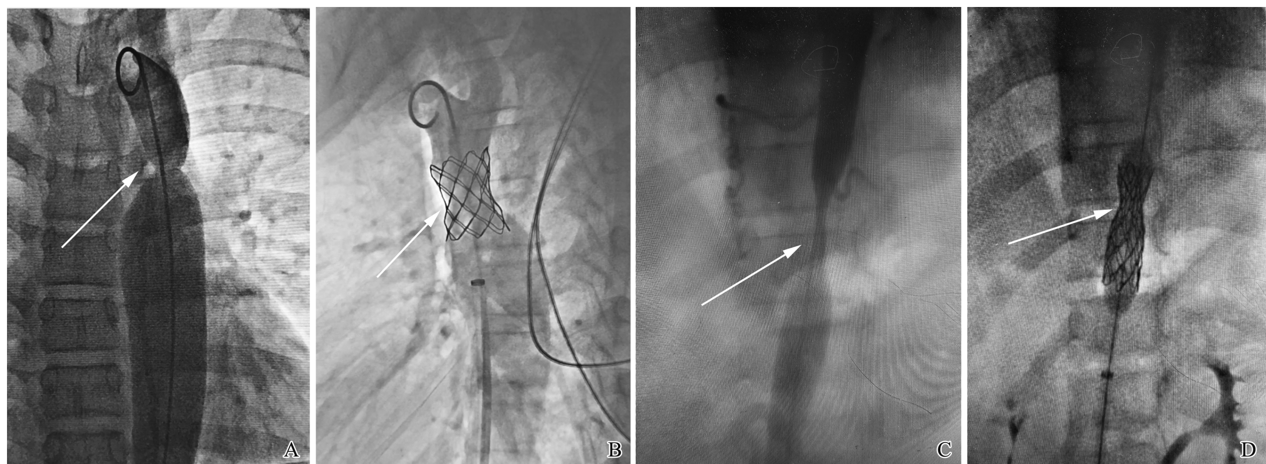

图2 术中造影和支架植入后
A、B:降主动脉缩窄造影及支架植入后；C、D:胸主动脉管状缩窄造影及支架植入后(箭头)。
Figure 2 During intraoperative angiography and after stent implantation
A,B: Post-angioplasty and stent placement for coarctation of the descending aorta; C,D: Status post angiography and stent implantation for tubular coarctation of the thoracic aorta (arrow).

## 2 结果

### 2.1 术后即刻结果

5例患者术后跨缩窄段压力差均≤20 mmHg，扩张后主动脉横径明显增大(表1)，术中无主动脉层、动脉瘤及破裂等并发症。

### 2.2 门诊随访结果

术后1、3、6、15个月随访，包括上下肢血压检测、胸部正侧位片、心脏超声、心电图等。随访复查CTA未出现再狭窄，支架形态、位置良好。5例血压恢复正常，上下肢压差均缩小(表2)。2例患儿需持续口服单一降血压药物，3例心室肌增厚恢复正常。

表1 支架植入后即刻效果
Table 1 Immediate outcomes after stent placement

| 病例 | 年龄/岁 | 体质量/kg | 输送鞘尺寸/*F* | 支架规格 | 主动脉动脉压差/mmHg | | 主动脉横径/mm | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 术前 | 术后 | 术前 | 术后 |
| 病例1 | 6 | 36 | 10 | CVRDCP8Z34 | 31 | 6 | 4.8 | 18.0 |
| 病例2 | 7 | 28 | 10 | CVRDCP8Z34 | 28 | 4 | 5.5 | 20.0 |
| 病例3 | 8 | 43 | 12 | CVRDCP8Z39 | 26 | 5 | 3.3 | 14.0 |
| 病例4 | 9 | 46 | 12 | CVRDCP8Z39 | 35 | 7 | 6.8 | 23.0 |
| 病例5 | 10 | 55 | 12 | CVRDCP8Z45 | 25 | 3 | 3.0 | 12.0 |
| $M(P_{25},P_{75})$ | | | | | 28.0 (25.5,33.0) | 5.0 (3.5,6.5) | 4.8 (3.1,6.1) | 18.0 (13.0,21.5) |
| $Z$ | | | | | -2.023 | | -2.023 | |
| $P$ | | | | | 0.043 | | 0.043 | |

表2 术后门诊随访结果
Table 2 Follow-up outcomes of postoperative outpatient

| 时间 | 上下肢压差/mmHg | 室间隔厚度/mm |
|---|---|---|
| 术前 | 62.00(60.50,65.00) | 1.10(1.00,1.15) |
| 术后1 d | 33.00(32.00,35.50)[a] | 1.10(1.00,1.15) |
| 术后1个月 | 34.00(31.50,37.00) | 1.00(0.90,1.05) |
| 术后3个月 | 34.00(32.50,35.00) | 0.90(0.80,0.95) |
| 术后6个月 | 38.00(34.50,39.00) | 0.77(0.75,0.80)[ab] |
| 术后15个月 | 36.00(34.00,37.00) | 0.75(0.72,0.78)[ab] |
| $\chi^2$ | 15.462 | 23.994 |
| $P$ | 0.009 | <0.001 |

注：[a] $P<0.05$ *vs.* 术前；[b] $P<0.05$ *vs.* 术后1 d。

## 3 讨论

主动脉弓在胎儿6~8周开始发育，左位主动脉弓由左侧第4弓动脉发育，而动脉导管则起源于第6弓动脉，在主动脉峡部汇合。二者发育异常则会导致缩窄，缩窄多是局限性的，处于动脉导管开口或动脉韧带水平，可分为导管前型(婴儿型)和导管后型(成人型)，部分可表现为主动脉弓及峡部的长段发育不良，所以根据范围可分为局限缩窄和管状狭窄两种[4-6]。当缩窄严重，左心室后负荷明显增高，

可表现为心肌肥厚、扩张以及严重的循环衰竭。即使后期解除缩窄,部分患者可能无法修复血管结构及功能上损伤,导致血管损害持续存在[7]。由于 CoA 存在导致下身器官供血不足,尤其肾脏缺血激活肾素-血管紧张素-醛固酮系统引起继发性高血压[6]。

CoA 是一种先天性心脏缺陷,严重者早期可出现死亡[8]。既往外科手术是首选方案,适用于各年龄段患者,包括:①缩窄部切除,主动脉对端吻合;②左锁骨下动脉与缩窄后主动脉吻合;③缩窄部切开补片加宽手术;④人工血管转流术或人工血管替换术。以前 3 种多见,但有很多不足之处:①术中及术后 3 个月内死亡率高,达 5.2%以上,死因包括心衰、酸中毒以及术中心脏停跳[9];②术后再缩窄,发生率 10%~33%[10];③动脉瘤形成,发生率 13%;④创伤较大,且住院时间长[11],上述 2~4 种情况随着术后时间延长有明显升高的趋势[12]。心导管介入技术应用于先天性心脏病治疗领域以来,为经导管非开胸矫治提供了重要途径,尤其在 CoA 的治疗中具有显著优势[13]。其适应证包括:①主动脉解剖结构适宜支架置入,且跨缩窄段收缩压差≥20 mmHg,或虽压差<20 mmHg 但伴有系统性高血压;②长段主动脉缩窄、峡部发育不良或主动脉弓发育不良;③外科术后再狭窄或主动脉瘤形成。鉴于支架可能限制血管生长,该技术更多适用于青少年及成人患者[14-15]。相关并发症包括:①主动脉夹层及动脉瘤:其发生率在术中及术后显著低于外科手术[16],Hámdan 等[17]及 Contrafouris 等[18]分别报道 34 例和 47 例患者发生率为 0%(0/34)和 4.2%(2/47),覆膜支架的应用可显著降低该类事件风险;②血管并发症如动静脉瘘、股动脉血栓或闭塞;③支架移位;④术中主动脉破裂,Suárez 等[19]报道发生率为 2.1%(1/48)。介入治疗普遍优势是创伤小,住院时间短,患儿可接受度高,适用于年长患儿,且 Berman 等[20]报道在婴幼儿治疗主动脉缩窄和肺动脉狭窄中支架植入术后取得满意效果。

但是,儿童 CoA 行球囊扩张支架植入术仍存在若干争议。①生长发育相关问题:CoA 患儿多数年龄较小,植入支架后,其直径固定,而随患儿生长发育主动脉内径逐渐增大,可能导致支架相对性狭窄,甚至需再次干预[21]。病理研究显示,支架术后再狭窄多发生于支架远端或近端,局部内膜及中膜增生并不明显,这与传统球囊扩张或外科术后再狭窄的机制有所不同。研究表明,对这类狭窄再次行球囊扩张是安全且有效的,扩张过程中可见新生内膜变形、延伸,仅伴轻微表面损伤及纤维蛋白-血小板聚集,该结果支持将支架植入术应用于低年龄患儿,并通过分期扩张策略以适应主动脉生长[13,16,20,22]。②内膜过度增生的风险:作为金属异物,支架植入可能刺激血管内膜过度增生,尤其在中小血管中更为显著。然而在主动脉这类大血管中,严重再狭窄的发生率相对较低[23]。有临床报道指出,术后规范口服阿司匹林可有效抑制内膜过度增生,降低再狭窄风险[24-25]。③对主动脉分支血管的影响:包括左锁骨下动脉、肋间动脉等重要侧支循环。动物实验及部分临床随访显示,支架植入后上述血管通常保持通畅,未观察到明显缺血表现[26],提示该治疗方式对分支血管血流影响较小,安全性较为可靠。

本研究 5 例患儿术前均经胸腹大血管增强 CT 检查确诊为 CoA,且未合并其他心内畸形。术中选用专为 CoA 设计的 NuMed BIB 球囊导管与 CP 覆膜支架系统。BIB 导管采用双球囊设计,能够使扩张力分布更为均匀,有助于降低支架释放过程中的移位风险并提高支架边缘贴壁效果,从而减少血管损伤[27]。CP 支架外表覆有聚四氟乙烯膜,可将动脉瘤阻隔在循环外,有效预防主动脉壁的损伤,降低主动脉夹层及动脉瘤等并发症的发生风险[28]。一项涵盖 56 例 CoA 患者的研究显示,采用覆膜支架治疗的成功率达 96.4%(54/56)[13],提示其相较于传统裸支架具有更高的安全性[29]。本研究 5 例患儿均取得预期手术效果。但由于本病发病率低,样本量有限且随访时间较短,今后需延长随访时间并通过多中心协作扩大样本量,进一步统计远期并发症发生率,包括再狭窄、动脉瘤形成及支架断裂等。

综上,经皮球囊扩张术+支架植入术治疗儿童 CoA 并高血压近、中期安全有效,优于单纯球囊扩张及外科手术,尤其覆膜支架、生长支架、生物可降解支架产生,将更广泛应用于临床。

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