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· 专题报道 ·

## 脊柱均匀短缩脊髓轴性减压术治疗脊髓栓系综合征合并脊柱侧凸的疗效分析

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**[摘要]** **目的** 探讨脊柱均匀短缩脊髓轴性减压术(HSAD)对脊髓栓系综合征(TCS)合并脊柱侧凸的治疗效果。**方法** 回顾性纳入2015年4月至2018年1月在海军军医大学(第二军医大学)长征医院骨科因TCS合并脊柱侧凸行HSAD治疗的6例患者,记录手术时间、术中失血量、并发症等资料。并于术前、术后行尿动力学检查评估逼尿肌反射、括约肌功能、功能膀胱容量和最大尿流率。**结果** 男3例、女3例,年龄为7~23岁,平均年龄为(15.7±6.9)岁,平均随访时间为(28±9)个月。其中5例患者伴大小便失禁,3例伴足下垂,4例伴下肢肌力下降,1例存在腰痛,1例合并髋关节脱位。6例患者手术时间为180~320 min,平均(261±63) min;术中失血量为650~1 100 mL,平均(925±167) mL。1例腰痛患者术后腰痛症状完全缓解,4例伴下肢肌力下降患者术后下肢肌力均有改善。1例患者因术后未行尿动力学检查未予统计;其余5例患者于术前、术后均接受尿动力学检查,其中4例术前尿道外括约肌过动、1例失调,术后2例尿道外括约肌协调、1例改善、2例过动。术前、术后功能膀胱容量分别为195.0(127.5, 233.5) mL、213.0(188.5, 251.5) mL,差异无统计学意义( $Z=-0.4$ ,  $P=0.70$ )。术前最大尿流率、残余尿量分别为7.3(1.4, 10.3) mL/s、130(106, 200) mL,与术后[10.3(5.6, 16.2) mL/s、30(6, 174) mL]相比差异均有统计学意义( $Z$ 均=-2.0,  $P$ 均=0.04)。5例患者术后膀胱逼尿肌肌力得到不同程度改善,最大尿流率增加,残余尿减少。**结论** TCS合并脊柱侧凸可以通过HSAD一期手术治疗,该手术可同时缓解脊髓轴向张力、矫正脊柱畸形、恢复脊柱和脊髓的协调性。患者术后下肢症状和膀胱功能均得以有效改善,同时避免了脑脊液漏、出血多和神经功能恶化等并发症。

**[关键词]** 脊髓栓系综合征; 脊柱侧凸; 脊柱均匀短缩; 脊髓轴性减压术

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### Homogeneous spinal-shortening axial decompression in treatment of tethered cord syndrome combined with scoliosis: a therapeutic effect analysis

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**[Abstract]** **Objective** To explore the therapeutic effect of homogeneous spinal-shortening axial decompression (HSAD) in patients with tethered cord syndrome (TCS) and scoliosis. **Methods** Six patients with TCS and scoliosis, who underwent HSAD in Orthopaedics Department of Changzheng Hospital of Naval Medical University (Second Military Medical University) from Apr. 2015 to Jan. 2018, were retrospectively included. The operation time, intraoperative blood loss and complications were recorded. Urodynamics examination was performed to evaluate the bladder function before and after surgery, including detrusor reflex, sphincter function, functional bladder capacity and maximal urination speed. **Results** There were three males and three females, aged 7-23 (mean 15.7±6.9) years old, with an average follow-up of (28±9) months. Five patients had incontinence, three had foot-drop, four had decreased lower limb muscle strength, one had low back pain, and one had congenital dislocation of the hip. The operation time was 180-320 min (mean [261±63] min), and the intraoperative blood loss was 650-1 100 mL (mean [925±167] mL). After surgery, the low back pain was completely relieved in one patient, and the muscle strengths of the lower extremities were improved in four patients. Five patients received

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urodynamic examination before and after surgery. Before surgery, four cases were evaluated as external sphincter overactivity and one case as uncoordinated sphincter activity; after surgery, two cases were evaluated as normal external sphincter activity, one case as coordinated external sphincter activity, and two cases as external sphincter overactivity. The functional bladder capacity of the five patients was 195.0 (127.5, 233.5) mL and 213.0 (188.5, 251.5) mL before and after surgery, respectively, and the difference was not significant ( $Z = -0.4$ ,  $P = 0.70$ ). The maximal urination speed and residual urine before surgery were 7.3 (1.4, 10.3) mL/s and 130 (106, 200) mL, respectively, and were significantly different from those after surgery (10.3 [5.6, 16.2] mL/s and 30 [6, 174] mL, respectively; both  $Z = -2.0$ , both  $P = 0.04$ ). In the five patients, the bladder detrusor muscle strength was improved to different extents, the maximal urination speed was increased, and the residual urine was reduced. **Conclusion** HSAD is an effective one-stage technique to relieve the TCS combined with scoliosis, and it can effectively relieve the axial tension of the spinal cord, correct the deformity of the spine and improve the coordination between spine and spinal cord. The lower limb symptoms and bladder function are improved after surgery, and complications such as cerebrospinal fluid leakage, bleeding, and deterioration of neurological function are avoided.

**[Key words]** tethered cord syndrome; scoliosis; homogeneous spinal-shortening; spinal axial decompression

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脊髓栓系综合征 (tethered cord syndrome, TCS) 是由于先天或后天因素导致脊髓或圆锥被束缚于腰骶段椎管内而导致的一系列神经损伤表现。原发性 TCS 多指终丝肥大 (直径  $>2$  mm) 牵拉圆锥低位 (低于  $L_2$ ); 继发性 TCS 多合并其他先天畸形, 如先天性脊柱裂、脊髓纵裂、硬脊膜内/外脂肪瘤等。TCS 临床症状复杂, 主要表现为下肢活动障碍、疼痛、会阴部感觉缺失、大小便功能障碍及脊柱畸形等。目前, TCS 常规手术方式为终丝切断栓系松解手术, 随访发现该术式可以缓解患者疼痛、改善下肢运动和感觉功能、防止膀胱功能恶化。

TCS 患者合并脊柱畸形是脊柱手术面临的重要挑战。据报道, 几乎所有 TCS 患者晚期均发生脊柱侧凸<sup>[1]</sup>。由于脊髓处于栓系状态, 在侧凸矫形过程中撑开牵拉可能加重栓系状态, 导致脊髓和神经损伤。因此, 传统的手术治疗一般分为 2 期, 首先行栓系松解手术, 然后二期行矫形手术。然而, 越来越多临床研究发现栓系松解术后神经并发症高达 30%, 且有 5%~50% 的患者出现再栓系<sup>[2-4]</sup>。同时, 2 次手术给患者带来更严重的身体和心理创伤, 也给家庭增加了经济负担。那么, 是否可以通过一次手术同时矫正畸形并解除栓系呢?

脊柱截骨术最早被用于治疗严重脊柱侧凸畸形。研究发现通过截骨缩短脊柱可以达到间接解除脊髓牵拉的目的, 脊柱截骨术可能是治疗脊髓栓系的有效手术方式<sup>[5-6]</sup>。但是, 单个节段截骨减压范围有限, 容易造成脊髓损伤。海军军医大学 (第二军医大学) 长征医院史建刚团队率先提出腰椎均匀短缩脊髓轴向减压的理念和手术方式可使腰段脊髓获得更大范围的减压, 同时避免截骨相关并发症,

对 TCS 具有良好的临床效果<sup>[7]</sup>。本研究拟探讨脊柱均匀短缩脊髓轴性减压术 (homogeneous spinal-shortening axial decompression, HSAD) 对 TCS 合并脊柱侧凸的手术效果。

## 1 资料和方法

**1.1 研究对象** 选择 2015 年 4 月至 2018 年 1 月在海军军医大学 (第二军医大学) 长征医院骨科脊柱外科因 TCS 合并脊柱侧凸行 HSAD 治疗的患者。TCS 诊断标准: 圆锥低于  $L_2$ , 终丝肥大 (直径  $>2$  mm)。纳入标准: (1) 诊断为 TCS; (2) 合并脊柱侧凸, 主弯 Cobb 角  $\geq 20^\circ$ ; (3) 能够耐受手术, 无心、肺等核心脏器严重疾患; (4) 随访至少 1 年。排除标准: (1) 主弯 Cobb 角  $<20^\circ$ ; (2) 合并其他严重疾病, 不能耐受手术。本研究通过海军军医大学 (第二军医大学) 长征医院医学伦理委员会审批。

**1.2 研究方法** 记录患者手术时间、术中失血量、并发症等。术前行腰椎 MRI、腰椎 CT 和全脊柱 X 线片检查, 并行腹部和心脏超声检查以排除严重器质性病变。于术前、术后和随访 3 个月时拍摄全脊柱正侧位 X 线片, 测量主弯 Cobb 角, 并于术前、术后行尿动力学检查评估逼尿肌反射、括约肌功能、功能膀胱容量和最大尿流率。

**1.3 手术方法** 所有纳入患者的 HSAD 手术均由史建刚教授主刀完成, 手术主要步骤 (以  $L_1 \sim L_5$  轴性短缩侧凸矫形为例) 如下: (1) 患者取全身麻醉下俯卧位, 切开皮肤及皮下组织, 沿棘突两侧骨膜下剥离骶棘肌。X 线透视定位无误后, 于  $L_1 \sim L_5$  双侧椎弓根各拧入 1 枚椎弓根螺钉。(2) 用咬骨

钳咬除 L<sub>1/2</sub> 棘突间韧带及韧带上下棘突止点的部分骨质,以利于短缩术后棘突相接触发生骨性融合。

(3)用骨刀凿除 L<sub>1</sub> 下关节突及大部分的 L<sub>2</sub> 上关节突。(4)剥离并切除 L<sub>1/2</sub> 之间的黄韧带,对椎管进行充分减压,避免压缩后皱褶的黄韧带压迫神经组织。(5)于一侧显露 L<sub>1/2</sub> 椎间隙及横突,用弧形骨膜剥离子逐渐显露椎间盘纤维环侧壁。切开椎间盘纤维环,分别用铰刀配合刮刀、髓核钳逐步清除椎间盘组织。(6)对侧做相同处理,用夯实器(脚踏)将后纵韧带及正后方纤维环压向椎间隙,并使用髓核钳将其取出。(7)同法处理 L<sub>2/3</sub>、L<sub>3/4</sub>、L<sub>4/5</sub> 节段,在两侧均安装连接杆后对各节段间缓慢均匀加压,加压至后方 L<sub>1</sub>~L<sub>5</sub> 棘突相碰。最后进行后方植骨和逐层缝合。

1.4 统计学处理 应用 SPSS 24.0 软件进行统计学分析。年龄、随访时间等计量资料以  $\bar{x} \pm s$  表示;由于样本量小,主弯 Cobb 角、尿流动力学参数均以中位数(下四分位数,上四分位数)表示,术前、术后比较采用配对样本 Wilcoxon 秩和检验。检验水准( $\alpha$ )为 0.05。

## 2 结果

2.1 患者基本资料与临床表现、手术效果 共纳入 6 例 TCS 合并脊柱侧凸患者,临床表现和手术效果见表 1。男 3 例、女 3 例,年龄为 7~23 岁,平均年龄为 (15.7±6.9) 岁,平均随访时间为 (28±9) 个月。4 例脊髓脊膜膨出,1 例脊柱裂伴硬膜外脂肪瘤,1 例终丝肥大,1 例合并脊髓纵裂,1 例合并髋关节脱位。6 例患者均合并腰弯。2 例圆锥位于 L<sub>5</sub>, 3 例圆锥位于 S<sub>1</sub>, 1 例圆锥位于 S<sub>2</sub>。6 例患者术前 1 年内均未行栓系松解术。5 例患者伴大小便失禁,3 例伴足下垂,4 例伴下肢肌力下降,1 例存在腰痛。6 患者手术时间为 180~320 min,平均 (261±63) min;术中失血量为 650~1 100 mL,平均 (925±167) mL。6 例患者中 3 例行 L<sub>1</sub>~S<sub>1</sub> 融合,2 例行 L<sub>1</sub>~L<sub>5</sub> 融合,1 例行 T<sub>12</sub>~L<sub>3</sub> 融合。所有患者均获得良好的后方融合,无翻修手术。1 例腰痛患者术后腰痛症状完全缓解,4 例伴下肢肌力下降患者术后下肢肌力均有改善。

表 1 6 例 TCS 合并脊柱侧凸患者临床表现和 HSAD 手术效果

Tab 1 Clinical characteristics and HSAD outcomes of six patients with TCS combined with scoliosis							
No.	Age (year)	Diagnosis	Conus	Main curve Cobb angle (°)			Surgery history
				Pre-operation	Post-operation	Follow-up	
1	22	MMC+lipoma	S <sub>1</sub>	20.6	4.2	3.6	None
2	23	Spinal bifida+epidural lipoma	L <sub>5</sub>	27.1	2.8	2.6	Meningeal repair+untethering
3	8	MMC+thick filum+sacral dysplasia	S <sub>1</sub>	27.1	8.4	6.7	Meningeal repair+untethering
4	7	Spinal bifida	L <sub>5</sub>	27.2	10	8.4	Meningeal repair+untethering
5	15	MMC+diastematomyelia+segmentation malformation	S <sub>1</sub>	26.7	10.6	10.4	None
6	19	MMC+segmentation malformation+CDH	S <sub>2</sub>	30.9	10.8	9.7	Meningeal repair+untethering

No.	Fusion segment	Surgery time (min)	Blood loss (mL)	Presentation	Outcome
1	L <sub>1</sub> -S <sub>1</sub>	286	1 000	Incontinence and constipation, left foot-drop	Bladder function improved, muscle strength increased
2	L <sub>1</sub> -L <sub>5</sub>	180	800	Incontinence and constipation, left leg muscle atrophy, muscle strength 4 <sup>-</sup>	Bladder function improved, muscle strength increased to 4 <sup>+</sup>
3	L <sub>1</sub> -S <sub>1</sub>	181	650	Incontinence and constipation, left leg muscle atrophy, muscle strength 4 <sup>-</sup>	Bladder function improved, muscle strength increased to 4 <sup>+</sup>
4	L <sub>1</sub> -L <sub>5</sub>	300	1 000	Incontinence and constipation, left leg muscle atrophy, muscle strength 3	Bladder function improved, muscle strength increased to 4
5	L <sub>1</sub> -S <sub>1</sub>	320	1 000	Back pain, right foot-drop, both leg muscle strength 3	Pain relieved, muscle strength increased to 4
6	T <sub>12</sub> -L <sub>3</sub>	300	1 100	Incontinence and constipation, left foot-drop, left hip dislocation	Bladder function improved

TCS: Tethered cord syndrome; HSAD: Homogeneous spinal-shortening axial decompression; MMC: Meningomyelocele; CDH: Congenital dislocation of hip

2.2 并发症 1 例患者术后出现右下肢肌力下降,经过保守治疗 1 个月后恢复。1 例患者伤口愈合延

迟。6 例患者均无脑脊液漏、深部感染和神经功能恶化等并发症。



2.3 影像学评估结果 术前冠状面主弯 Cobb 角为 20.6°~30.9°, 中位值为 27.1° (25.2°, 28.1°); 术后为 2.8°~10.8°, 中位值为 9.2° (3.9°, 10.7°), 与术前比较差异有统计学意义

( $Z=-2.2, P=0.03$ ); 随访3个月时为 2.6°~10.4°, 中位值为 6.7° (3.4°, 9.9°), 与术前比较差异有统计学意义 ( $Z=-2.2, P=0.03$ ), 侧凸矫正率为 75%。典型影像学结果见图 1。

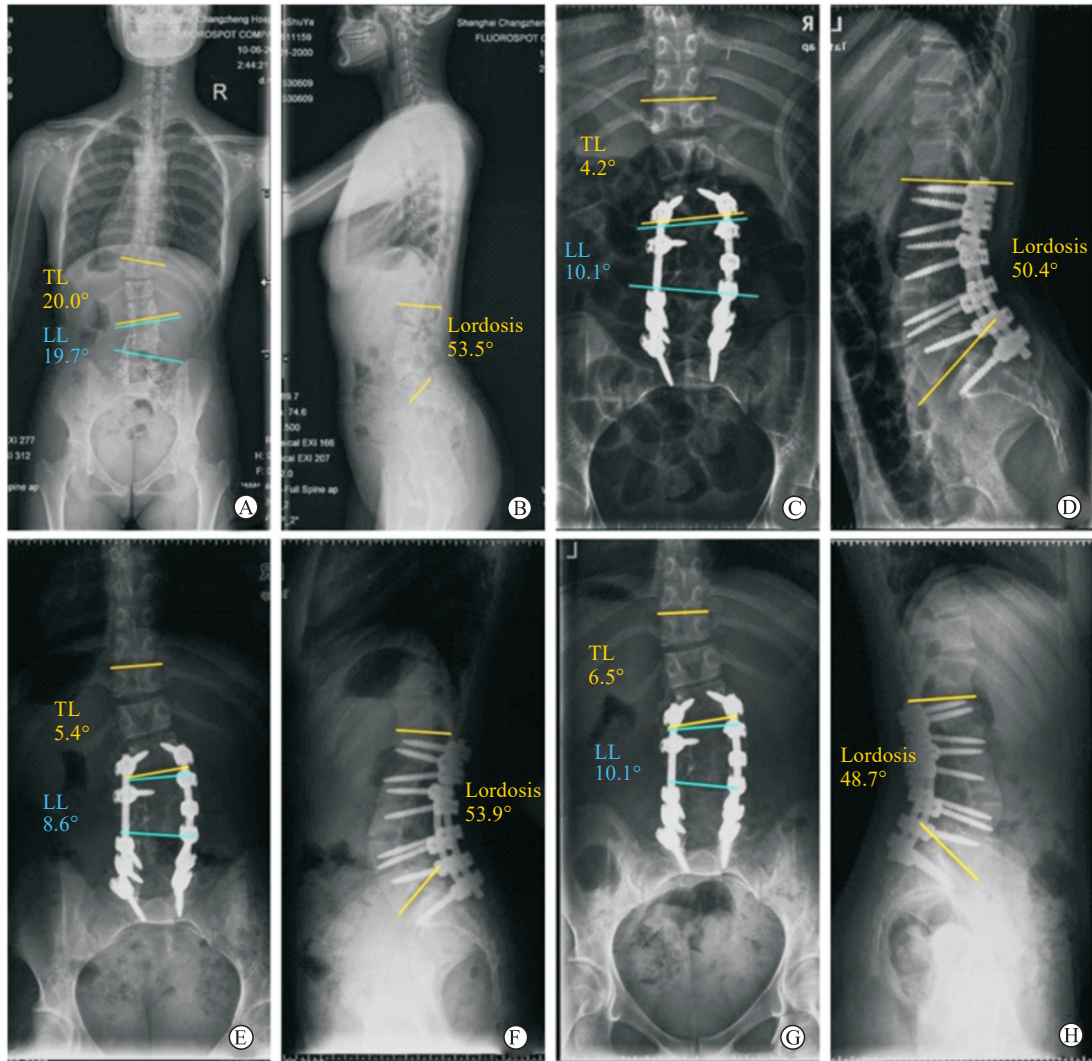


图 1 1例 TCS 合并胸腰弯畸形患者 HSAD 术前、术后及随访影像学资料

Fig 1 Imaging data of a TCS and thoracolumbar deformity patient before and after HSAD surgery and during follow-up A 15 years old male patient with diastematomyelia and segmentation malformation, undergoing L<sub>1</sub>-S<sub>1</sub> HSAD surgery. The main manifestations of spinal deformity were thoracolumbar (TL) scoliosis and lumbar (LL) scoliosis. A, B: Before surgery; C, D: Immediately after surgery; E, F: Three months after surgery; G-H: Thirteen months after surgery. A, C, E, G: Anteroposterior X-ray; B, D, F, H: Lateral X-ray. TCS: Tethered cord syndrome; HSAD: Homogeneous spinal-shortening axial decompression

2.4 尿动力学检查结果 1例患者因术后未接受尿动力学检查未予统计; 其余5例患者于术前、术后均接受尿动力学检查, 结果见表2。5例患者术后膀胱逼尿肌肌力得到不同程度改善, 最大尿流率增加, 残余尿减少。术前4例患者膀胱逼尿肌弱动, 1例无逼尿肌反射; 术后1例逼尿肌反射恢复, 2例改善, 2例过动。术前4例尿道外括约肌过动, 1例失调; 术后2例尿道外括约

肌协调, 1例改善, 2例过动。术前功能膀胱容量为 195.0 (127.5, 233.5) mL, 术后为 213.0 (188.5, 251.5) mL, 差异无统计学意义 ( $Z=-0.4, P=0.70$ )。术前最大尿流率为 7.3 (1.4, 10.3) mL/s, 术后为 10.3 (5.6, 16.2) mL/s, 差异有统计学意义 ( $Z=-2.0, P=0.04$ )。术前残余尿量为 130 (106, 200) mL, 术后为 30 (6, 174) mL, 差异有统计学意义 ( $Z=-2.0, P=0.04$ )。

表2 5例TCS合并脊柱侧凸患者HSAD术前、术后尿流动力学检查结果

Tab 2 Urodynamics of five patients with TCS combined with scoliosis before and after HSAD

No.	Detrusor		Urethral sphincter		FBC (mL)		Maximal urination speed (mL·s <sup>-1</sup> )		Residual volume (mL)	
	Before	After	Before	After	Before	After	Before	After	Before	After
1	Weak	Active	Over active	Over active	111.0	213.0	1.5	10.3	91	30
2	Weak	Normal	Over active	Coordinated	195.0	191.0	7.6	14.8	121	8
3	No reflex	Normal	Dysfunction	Coordinated	144.0	287.0	7.3	9.5	130	4
4	Weak	Over active	Over active	Over active	220.0	186.0	1.3	1.7	193	156
5	Weak	Over active	Over active	Improved	247.0	216.0	12.9	17.6	208	192

TCS: Tethered cord syndrome; HSAD: Homogeneous spinal-shortening axial decompression; FBC: Functional bladder capacity

### 3 讨论

**3.1 HSAD 的手术理念** 尽管栓系松解术是目前治疗TCS的常规手术方式,但是临床研究发现术后并发症发生率高,对膀胱功能的改善相比保守治疗也未获得更佳的效果<sup>[8]</sup>,这对传统终丝牵拉理论提出了质疑。本团队通过对较大样本TCS患者进行随访发现,神经损伤症状与患者生长发育高峰相关,患者脊柱快速生长后总是伴随神经症状出现或加重<sup>[9]</sup>。因此,本团队提出了脊柱、脊髓由于生长速度不同而出现不匹配、导致脊髓轴向牵拉损伤理论。该理论摒弃了终丝牵拉理论中终丝对圆锥的“点状”牵拉,提出了差异性发育造成的脊髓、神经根在较长范围内的整体轴性牵拉,强调每一节段脊柱和脊髓是一个相互制约的功能单元,栓系手术的目标是恢复脊柱和脊髓之间的协调性,而不是仅仅解决骨性结构或神经损伤的单一问题。通过切除椎间盘和部分关节突等后柱结构,减少每一节段椎管中脊髓的行走距离,恢复椎体和脊髓的轴向序列,此即HSAD。

HSAD治疗TCS有以下优势:(1)腰段脊髓均匀轴向减压,较截骨和栓系松解的减压范围广;(2)同时进行神经根松解,防止矫形过程中神经根损伤;(3)通过切除椎间盘和后柱结构可以同时进行侧凸矫形。

**3.2 HSAD与截骨手术效果比较分析** 截骨手术也是基于脊柱短缩、脊髓间接减压的一种手术方式。常用的截骨方式有关节突部分切除截骨、经椎弓根截骨和三柱截骨。目前文献报道的截骨位置一般选取L<sub>1</sub>,也有选择侧凸的顶椎,通常仅行单节段截骨治疗TCS,如侧凸较严重可行多节段混合截骨<sup>[6]</sup>。Hsieh等<sup>[10]</sup>研究发现,脊柱截骨手术

可以显著降低脊髓和腰骶神经的张力,而传统手术需松解至少90%的神经组织才能取得类似效果。多项研究均报道截骨手术治疗TCS取得了较好的临床效果,能够显著缓解下肢疼痛和运动障碍,部分缓解膀胱功能障碍<sup>[5-6]</sup>。韩国学者报道截骨手术治疗TCS合并脊柱侧凸,术后72%的神经症状能够得到不同程度改善,但未报道尿动力学的改善情况<sup>[11]</sup>。该研究中截骨手术治疗TCS合并脊柱侧凸手术时间较长,平均手术时间为544 min;并发症发生率也较高,约24%的患者术后出现肌力下降、脑脊液漏或尿路感染,其中1例患者术中失血量超过5 000 mL。本研究中6例患者的症状在术后均有不同程度改善,下肢肌力得到不同程度恢复,5例患者尿动力学改善,逼尿肌肌力增加,膀胱协调性恢复,残余尿减少。2例患者残余尿和最大尿流率改善相对不明显,可能与膀胱逼尿肌过动有关,提示膀胱功能仍处于恢复期,需要更长时间随访。相较于截骨手术<sup>[11]</sup>,HSAD手术时间明显缩短,平均手术时间为261 min,出血量少(925 mL vs 2 769 mL)。同时HSAD避免了脑脊液漏和其他神经损伤等并发症的发生。尽管截骨手术是治疗TCS的一种有效选择,但面临以下2个难题:(1)哪个节段截骨能够最大程度缓解脊髓紧张?(2)如何确定截骨程度能够获得最佳手术效果?由于截骨手术是单一节段短缩,因此,无法判定截骨手术能对腰段脊髓起到整体减压的效果。同时,动物实验研究发现,单一节段截骨超过20 mm会导致硬脊膜褶皱,减少脊髓和神经血供,导致电信号传导障碍<sup>[12]</sup>。

**3.3 栓系松解与矫形效果分析** 理论上,侧凸矫形手术会增加脊柱长度,从而加重栓系状态,导致神经损伤。Linthorst等<sup>[13]</sup>推荐对脊髓脊膜膨出患



者先行栓系松解,再行脊柱侧凸矫形。Reigel等<sup>[14]</sup>随访了262例行栓系松解术的脊髓脊膜膨出患者,发现松解术并不能缓解胸段栓系侧凸进展,但对腰段栓系侧凸有一定稳定作用。McGirt等<sup>[15]</sup>研究发现,Risser征0~2的患者栓系松解术后侧凸仍然会进展;而Risser征3~5、主弯Cobb角 $<40^{\circ}$ 的TCS患者,栓系松解术后侧凸不会进展。Huang等<sup>[11]</sup>通过一期截骨治疗TCS合并脊柱侧凸,侧凸矫正率为61%,患者术后无新发神经损伤。本研究中,6例TCS合并脊柱侧凸患者中侧凸矫正率为75%,也未出现新发神经损伤等并发症。由于栓系松解术具有较高的神经并发症和再栓系发生率,预防性栓系松解术临床获益有限。截骨手术和HSAD手术可以同时一期处理栓系和侧凸,减少手术创伤和神经并发症的发生,因此,笔者推荐青少年TCS合并脊柱侧凸患者行HSAD治疗。

综上所述,TCS合并脊柱侧凸可以通过HSAD一期手术治疗,可同时缓解脊髓轴向张力、矫正脊柱畸形、恢复脊柱和脊髓的协调性,患者术后下肢症状和膀胱功能可以得到有效改善,同时避免脑脊液漏、出血多和神经功能恶化等并发症的发生。

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