

临床论著

骨盆入射角与腰椎前凸角匹配度对强直性脊柱炎后凸畸形矫形术后矢状面平衡的影响

罗建周, 吴太林, 杨子立, 李 究, 黄政基, 罗振娟, 段春光, 陶惠人

(深圳大学总医院脊柱骨病科 518000 深圳市)

【摘要】目的:探讨骨盆入射角与腰椎前凸角匹配度(pelvic incidence and lumbar lordosis mismatch, PI-LL)对强直性脊柱炎(ankylosing spondylitis, AS)后凸畸形矫形术后脊柱骨盆矢状面平衡的影响。**方法:**回顾性研究 2010 年 1 月~2019 年 10 月本团队行改良经椎弓根椎体截骨术治疗的 85 例 AS 后凸畸形患者,男 75 例,女 10 例;年龄 37.1 ± 8.8 岁(20~67 岁),其中 63 例行单节段截骨矫形,22 例行双节段截骨矫形。脊柱全长侧位片上测量术前、术后(3~4 周)及末次随访时脊柱骨盆矢状面参数:骨盆入射角(pelvic incidence, PI)、骨盆倾斜角(pelvic tilt, PT)、骶骨倾斜角(sacral slope, SS)、腰椎前凸角(lumbar lordosis, LL)、PI-LL、截骨角(osteotomized vertebral angle, OVA)和矢状面躯干偏移(sagittal vertical axis, SVA)。术前及末次随访时采用脊柱侧凸研究学会-22(Scoliosis Research Society-22, SRS-22)问卷和 Oswestry 功能障碍指数(Oswestry disability index, ODI)评估患者的肢体功能和生活质量。末次随访时 $SVA > 5\text{cm}$ 为脊柱矢状面失衡, $PT > 25^\circ$ 为骨盆矢状面失衡。通过 Pearson 相关系数分析术后 PI-LL 与末次随访 SVA 和 PT 的相关性,并运用受试者操作特征(receiver operating characteristic, ROC)曲线和最大约登指数计算术后 PI-LL 的阈值,获得 PI-LL 的最佳匹配度。根据术后 PI-LL 是否满足最佳匹配度分组,分析不同术后 PI-LL 对末次随访脊柱骨盆矢状面序列的影响。运用线性回归分析腰椎 OVA 与 PI-LL 矫正值的线性关系,计算线性回归方程。**结果:**85 例 AS 患者术后平均随访 30.8 ± 6.3 个月(24~84 个月),末次随访时 LL(-31.6°)、PT(31.8°)、SS(15.5°)、PI-LL(16.7°)和 SVA(8.6cm)均较术前明显改善($P < 0.05$), ODI(23.45%)和 SRS-22(3.91 分)评分显著性优于术前($P < 0.05$)。术后 PI-LL 与末次随访时的 SVA 和 PT 呈显著性正相关($r = 0.525$ 和 0.659 , $P < 0.01$)。以末次随访时 SVA 为状态变量,通过 ROC 曲线分析获得术后 PI-LL 的阈值为 12.8° ;以末次随访时的 PT 为状态变量,计算得到术后 PI-LL 的阈值为 10.5° 。当术后 PI-LL $\leq 10.5^\circ$ 时,可同时满足预防脊柱和骨盆矢状面失衡的要求。与术后 PI-LL $> 10.5^\circ$ 组比较,术后 PI-LL $\leq 10.5^\circ$ 组患者末次随访时 PT (25.4° vs 36.6°)、LL (-40.8° vs -24.1°)、PI-LL (4.0° vs 26.2°) 和 SVA (5.6cm vs 10.9cm) 更小($P < 0.05$), 脊柱(36.1% vs 75.5%)和骨盆(38.9% vs 85.7%)矢状面失衡率更低($P < 0.05$)。腰椎 OVA 与 PI-LL 矫正值呈较高强度线性正相关($r = 0.707$, $P < 0.01$), 腰椎 $OVA = 17.12 + 0.62 \times (\text{PI-LL 矫正值})$, $R^2 = 50.1\%$ 。**结论:**AS 后凸畸形患者截骨矫形术后的 PI-LL 与末次随访 SVA 和 PT 紧密相关,术后重建 PI-LL $\leq 10.5^\circ$ 可维持良好的脊柱骨盆矢状面平衡,降低中远期随访脊柱和骨盆矢状面失衡的风险。

【关键词】强直性脊柱炎;后凸畸形;骨盆入射角与腰椎前凸角匹配度;矢状面失衡;截骨矫形术

doi: 10.3969/j.issn.1004-406X.2022.07.01

中图分类号:R682.3, R687.3 文献标识码:A 文章编号:1004-406X(2022)-07-0577-09

Effect of mismatch between pelvic incidence and lumbar lordosis on sagittal imbalance of ankylosing spondylitis following kyphosis correction/LUO Jianzhou, WU Tailin, YANG Zili, et al/Chinese Journal of Spine and Spinal Cord, 2022, 32(7): 577-585

【Abstract】Objectives: The current study aimed to investigate the effect of pelvic incidence and lumbar lordosis mismatch (PI-LL) on sagittal imbalance of ankylosing spondylitis (AS) following corrective osteotomy.

基金项目: 广东省基础与应用基础研究基金项目 (2020A1515010726); 深圳市科技计划项目基础研究(自由探索)项目(JCYJ20180305124242438); 深圳市基础研究专项(自然科学基金)基础研究重点项目(JCYJ20200109114233670); 广东省重点领域研发计划项目(2020B0909020002); 深圳市医疗卫生三名工程项目(SZSM201911011)

第一作者简介: 男(1995-), 硕士研究生, 研究方向: 脊柱畸形

电话: (0755)21839087 E-mail: jzhou1390003033@163.com

通讯作者: 段春光 E-mail: 19897550@qq.com; 陶惠人 E-mail: huiren_tao@163.com

Methods: 85 AS patients(75 men, 10 women) who underwent modified pedicle subtraction osteotomy(PSO) between January 2010 and October 2019 were enrolled in this study, with an average age of 37.1 ± 8.8 years (20–67 years). 63 underwent one-level osteotomy, and 22 underwent two-level osteotomy. The preoperative, postoperative(3–4 weeks after surgery) and final follow-up radiographic parameters were measured, including pelvic incidence(PI), pelvic tilt(PT), sacral slope(SS), lumbar lordosis(LL), PI-LL, osteotomized vertebral angle(OVA), and sagittal vertical axis(SVA). The function of limbs and health-related quality of life before operation and at the final follow-up were evaluated using Scoliosis Research Society-22(SRS-22) patient questionnaire and Oswestry disability index(ODI). At the final follow-up, $SVA>5\text{cm}$ was regarded as spinal imbalance, and $PT>25^\circ$ was considered pelvic imbalance. Correlations between postoperative PI-LL and final follow-up SVA and PT were analyzed using Pearson correlation coefficient. Threshold of PI-LL was figured out using receiver operating characteristic (ROC) curve and maximum Youden index to obtain the optimal postoperative PI-LL. Patients were divided into two groups by whether meeting the optimal postoperative PI-LL, and effects of different postoperative PI-LL on spino-pelvis sagittal alignment at the final follow-up were compared and evaluated. Subsequently, linear regression was used to evaluate the relationship between lumbar OVA and PI-LL correction to figure out the regression equation. **Results:** 85 AS patients were followed up for 30.8 ± 6.3 months(24–84 months). The final follow-up LL(-31.6°), PT(31.8°), SS(15.5°), PI-LL(16.7°) and SVA(8.6cm) were improved significantly($P<0.05$); and the final follow-up ODI(23.45%) and SRS-22 score(3.91) were better than those before surgery($P<0.05$). Postoperative PI-LL positively correlated with the final follow-up SVA and PT ($r=0.525$ and 0.659 respectively, $P<0.01$). Calculated with SVA using ROC and maximum Youden index, the optimal threshold of postoperative PI-LL was 12.8° ; while, calculated with PT, it was 10.5° . Postoperative PI-LL of $\leq 10.5^\circ$ met the needs for preventing both spinal and pelvic imbalance. Patients with postoperative PI-LL $\leq 10.5^\circ$ had better PT(25.4° vs 36.6°), LL(-40.8° vs -24.1°), PI-LL(4.0° vs 26.2°) and SVA(5.6cm vs 10.9cm) than those with postoperative PI-LL $>10.5^\circ$, and significantly decreased the rate of spinal (36.1% vs 75.5%) and pelvic(38.9% vs 85.7%) imbalance at the final follow-up($P<0.05$). Lumbar OVA highly correlated with PI-LL correction($r=0.707$, $P<0.001$), and the equation was Lumbar OVA= $17.12+0.62\times(\text{PI-LL correction})$, adjusted $R^2=50.1\%$. **Conclusions:** Postoperative PI-LL strongly correlated with final follow-up SVA and PT in AS patients after kyphosis correction. Reconstructing postoperative PI-LL $\leq 10.5^\circ$ could achieve better spino-pelvis sagittal alignment for AS kyphosis, and decrease the risk of spinal and pelvic imbalance in mid- to long-term follow-up.

【Key words】 Ankylosing spondylitis; Kyphosis; Pelvic incidence and lumbar lordosis mismatch; Sagittal imbalance; Osteotomy

【Author's address】 Department of Spine Surgery, Shenzhen University General Hospital, Shenzhen, 518000, China

强直性脊柱炎(ankylosing spondylitis, AS)后期常导致患者全脊柱僵硬和胸腰椎后凸畸形,代偿性发生骨盆后倾后旋和伸髋屈膝畸形,患者直立行走、平视和平卧等功能严重受限,极大影响生活质量^[1,2]。脊柱截骨矫形手术是矫正 AS 患者后凸畸形、改善脊柱骨盆矢状面平衡唯一有效的方法^[3]。然而部分截骨矫形术后的 AS 患者中远期随访仍会出现严重的矫形效果丢失,并导致脊柱后凸畸形和矢状面失衡再发出现,严重者甚至需要行翻修手术^[4,5]。而目前对于预防 AS 患者术后矫形效果丢失和矢状面失衡的方法仍非常有限。研究报道^[6-8], 术后重建良好的骨盆入射角(pelvic

incidence, PI)与腰椎前凸角(lumbar lordosis, LL)匹配度(PI-LL)可能是预防脊柱畸形患者矫形术后矢状面失衡的一种潜在方法。但是目前围绕 AS 后凸畸形患者术后重建 PI-LL 的相关研究较少,适合 AS 后凸畸形患者矫形重建的最佳 PI-LL 尚无定论^[8,9]。因此,本研究回顾性分析本团队行脊柱截骨矫形手术治疗的 AS 后凸畸形患者,分析 AS 后凸畸形患者术后重建的 PI-LL 与末次随访矢状面躯干偏移(sagittal vertical axis, SVA)和骨盆倾斜角(pelvic tilt, PT)的相关性,探讨维持 AS 后凸畸形患者术后脊柱骨盆矢状面平衡的最佳 PI-LL,阐明不同术后 PI-LL 对 AS 患者中远期随

访脊柱骨盆矢状面序列及临床疗效的影响。

1 资料和方法

1.1 一般资料

收集 2010 年 1 月~2019 年 10 月本团队行脊柱截骨矫形手术治疗的 AS 后凸畸形患者的临床及影像资料。纳入标准^[2,4]:(1)诊断为 AS 后凸畸形;(2)行脊柱截骨矫形手术;(3)随访 2 年以上。排除标准:(1)合并髋、膝关节骨性强直;(2)既往有其他脊柱相关病史及手术史;(3)随访资料不完整。

共 85 例患者符合上述标准纳入本研究,其中男 75 例,女 10 例,年龄 37.1 ± 8.8 岁(20~67 岁)。后凸畸形顶椎位于 T10~L1,其中 63 例行单节段截骨矫形,截骨椎体 L1 16 例、L2 34 例、L3 11 例、L5 2 例;22 例行双节段截骨矫形,截骨椎体 L1 和 L3 2 例,L1 和 L4 4 例,L1 和 L5 1 例,L2 和 L5 3 例,T10 和 L1 1 例,T11 和 L3 1 例,T12 和 L2 2 例,T12 和 L3 8 例。

1.2 手术步骤

本研究采用改良经椎弓根椎体截骨术行脊柱截骨矫形,术中均予体感诱发电位和运动诱发电位系统进行神经监测。全身麻醉后,根据患者后凸畸形特点摆放手术体位,取背部正中切口暴露手术区域,于各融合节段置入椎弓根螺钉。拟行椎体一侧截骨,从后往前咬除截骨椎的棘突、上半部分椎板和上关节突,向上咬除头侧相邻椎体的下半部分椎板和下关节突。暴露截骨椎双侧横突并切除,沿着椎弓根向前切除上半部分椎弓根以及上 $1/3 \sim 1/2$ 的椎体,连同头侧邻近椎间盘一并切除。保留截骨椎下半部分椎弓根、下半部分椎板以及完整的下关节突。完成一侧截骨后安装临时棒,同样方式行对侧椎体截骨。截骨完成后,巡回护士协助缓慢抬举患者双肩,从躯干整体向脊柱施加向后上的矫形力量。此时,术者借助该抬举的矫形力量,顺势加压折弯脊柱上的临时固定棒,逐步矫正患者脊柱后凸畸形并维持脊柱良好的对位对线。C 型臂 X 线机透视矫形效果满意后,依次以矫形棒替换双侧临时固定棒,并于截骨间隙置入椎间融合器和自体骨颗粒。检查无神经根卡压及硬膜囊膨出后,予充分冲洗和止血,留置引流管,逐层缝合切口。

1.3 资料收集与参数测量

收集所有患者术前、术后(3~4 周)和末次随访时的脊柱全长正侧位 X 线片和临床基本资料。两位经验丰富的脊柱外科医师使用 Surgimap 软件(Spine software,2.3.1.3 版,美国)于脊柱全长侧位 X 线片上测量影像参数,计算两者测量结果的平均值。

脊柱矢状面参数:(1)SVA,C7 铅垂线至 S1 终板上上角之间的水平距离;(2)LL,L1 上终板和 S1 上终板的夹角;(3)截骨角(osteotomized vertebral angle,OVA),手术前后截骨椎下终板及头侧相邻椎体上终板夹角的变化值(如为双节段截骨,则为两个节段截骨角度之和);(4)腰椎 OVA,腰椎截骨角度数总和(若为双节段腰椎截骨则为两 OVA 之和,若为胸椎和腰椎截骨,则只计算腰椎 OVA)。

骨盆矢状面参数:(1)PI,S1 上终板中点与两股骨头连线中点的连线与垂直 S1 上终板直线的夹角;(2)PT,S1 上终板中点与两股骨头中心连线中点的连线与重力铅垂线的夹角;(3)骶骨倾斜角(sacral slope,SS),S1 上终板与水平线的夹角。PI-LL,PI 与 LL 的差值。

患者的肢体功能和生活质量通过脊柱侧凸研究学会-22(Scoliosis Research Society-22,SRS-22)问卷和 Oswestry 功能障碍指数(Oswestry disability index,ODI)评估。脊柱骨盆矢状面失衡包括脊柱矢状面失衡和骨盆矢状面失衡,患者末次随访时 SVA>5cm 时为脊柱矢状面失衡,PT>25° 时为骨盆矢状面失衡^[6,10]。

1.4 统计学分析

采用 SPSS 22.0 软件进行数据分析,计量资料采用均数±标准差的形式表示。术前、术后及末次随访的脊柱骨盆参数、ODI 和 SRS-22 评分均采用配对 *t* 检验分析。采用 Pearson 相关系数分析术后 PI-LL 与末次随访 SVA 和 PT 的相关性,采用受试者操作特征(receiver operating characteristic,ROC)曲线分析和最大约登指数法计算术后 PI-LL 的阈值,获得最佳 PI-LL。

根据上述获得的术后最佳 PI-LL 分组,分析不同术后 PI-LL 对患者末次随访脊柱骨盆矢状面序列及临床疗效的影响。其中组间计量资料(脊柱骨盆参数、ODI 和 SRS-22 评分)的比较采用两个独立样本 *t* 检验,组间计数资料(性别和脊柱骨盆矢状面失衡率)的比较采用 χ^2 检验。最后以线

性回归分析腰椎 OVA 与 PI-LL 矫正值的线性关系,并计算线性回归方程。 $P<0.05$ 为差异有统计学意义。

2 结果

2.1 影像参数及临床疗效

85 例 AS 后凸畸形患者术后平均随访 30.8 ± 6.3 个月 (24~84 个月)。术后及末次随访的参数 LL、PT、SS、PI-LL 和 SVA 均较术前明显改善 ($P<0.05$),末次随访 ODI 和 SRS-22 评分均优于术前 ($P<0.05$)。手术前后 PI 无明显改变 ($P>0.05$) (表 1)。

2.2 术后 PI-LL 与末次随访 SVA 和 PT 的相关性

术后 PI-LL 与末次随访 SVA 呈中等强度正相关 ($r=0.525, P<0.001$),与末次随访 PT 呈较高等强度正相关 ($r=0.659, P<0.001$, 表 2)。

2.3 术后最佳 PI-LL

基于上述术后 PI-LL 与末次随访 SVA 和 PT 的显著相关性,运用 ROC 曲线分析方法确定术后 PI-LL 的阈值。以随访 SVA 为状态变量,PI-LL 为检验变量,ROC 曲线下面积为 0.764。根据最大约登指数法,计算获得 PI-LL 的阈值为 12.8° ,即术后 PI-LL $>12.8^\circ$ 时,患者末次随访可能发生脊柱矢状面失衡 (SVA $>5\text{cm}$),其灵敏度为 72.7%,假阳性率为 21.7% (表 3,图 1a)。以随访 PT 为状态变量,PI-LL 为检验变量,ROC 曲线下面积为 0.794。根据最大约登指数法,计算获得 PI-LL 阈值为 10.5° ,即术后 PI-LL $>10.5^\circ$ 时,患者末次随访可能发生骨盆矢状面失衡 (PT $>25^\circ$),其灵敏度为 76.0%,假阳性率为 23.1% (表 3,图 1b)。综合分析,即当 AS 患者术后 PI-LL $\leq 10.5^\circ$ 时,可同时满足预防末次随访脊柱和骨盆矢状面失衡的要求,为最佳 PI-LL。

2.4 术后 PI-LL 对脊柱骨盆矢状面序列及临床疗效的影响

根据患者术后最佳 PI-LL 匹配度 (10.5°) 分组 (PI-LL $\leq 10.5^\circ$ 为 A 组,PI-LL $>10.5^\circ$ 为 B 组),比较两组患者的脊柱骨盆矢状面参数及临床疗效的差异。A 组 36 例,B 组 49 例,术前 A 组 PT、PI、LL、PI-LL 和 SVA 较 B 组小,即 A 组脊柱骨盆矢状面失衡和骨盆后倾后旋程度较 B 组轻 ($P<0.05$)。两组的 OVA 相似,但术后 A 组 PT、PI、SS、

LL、PI-LL 和 SVA 较 B 组小,即术后 A 组脊柱骨盆矢状面序列重建效果更好 ($P<0.05$)。末次随访, A 组 PT、PI、LL、PI-LL 和 SVA 均小于 B 组 ($P<$

表 1 术后影像参数、ODI 和 SRS-22 评分的改变

Table 1 Changes of radiographic parameters, ODI and SRS-22 score after surgery

	术前 Preoperative	术后 Postoperative	末次随访 Final follow-up
腰椎前凸角($^\circ$) Lumbar lordosis	5.3 ± 21.9	-33.6 ± 17.7^{①}	-31.6 ± 17.7^{①}
骨盆倾斜角($^\circ$) Pelvic tilt	38.3 ± 11.3	28.3 ± 9.4^{①}	31.8 ± 10.1^{①}
骨盆入射角($^\circ$) Pelvic incidence	48.5 ± 13.2	48.3 ± 11.9	48.2 ± 12.0
骶骨倾斜角($^\circ$) Sacral slope	10.5 ± 12.5	20.1 ± 11.6^{①}	15.5 ± 12.6^{①}
PI-LL($^\circ$)	52.9 ± 21.9	14.2 ± 15.5^{①}	16.7 ± 16.4^{①}
SVA(cm)	22.5 ± 9.1	9.0 ± 5.7^{①}	8.6 ± 5.7^{①}
OVA($^\circ$)	—	45.7 ± 19.7	44.9 ± 20.7
SRS-22(分)	2.72 ± 0.62	—	3.91 ± 0.49^{①}
ODI(%)	39.88 ± 20.20	—	23.45 ± 13.95^{①}

注:①与术前比较 $P<0.05$;SVA,矢状面躯干偏移;OVA,截骨角;SRS-22,脊柱侧凸研究学会-22 问卷;ODI,Oswestry 功能障碍指数

Note: Comparing with preoperation, $P<0.05$; SVA, sagittal vertical axis; OVA, osteotomized vertebral angle; SRS-22, Scoliosis Research Society-22; ODI, Oswestry disability index

表 2 术后 PI-LL 与末次随访脊柱骨盆参数的相关性分析

Table 2 Correlation between postoperative PI-LL and final follow-up spinopelvic parameters

	相关系数(r) Coefficient	P 值 P value
LL	0.649	<0.001
PT	0.659	<0.001
PI	0.262	0.051
SS	-0.221	0.095
SVA	0.525	<0.001

表 3 术后 PI-LL 的 ROC 分析结果

Table 3 Results of ROC analysis for postoperative PI-LL

	基于 SVA Based on SVA	基于 PT Based on PT
线下面积 The area under the curve	0.764	0.794
标准错误 Standard error	0.064	0.054
显著性 Significance	0.001	<0.001
95%可行区间 95% confidence interval	0.638~0.890	0.689~0.899

0.05), 并且 A 组脊柱 (36.1% vs 75.5%) 和骨盆 (38.9% vs 85.7%) 矢状面失衡发生率较 B 组更低 ($P<0.05$)。两组 PT、SS、LL、PI-LL 和 SVA 的矫形效果丢失以及末次随访 ODI 和 SRS-22 评分均无统计学差异 ($P>0.05$) (表 4、图 2 和图 3)。

2.5 腰椎 OVA 与 PI-LL 矫正值的线性关系

腰椎 OVA 与 PI-LL 矫正值呈较高强度正相关 ($r=0.707, P<0.01$), 线性回归方程: 腰椎 OVA = $17.12+0.62\times(\text{PI-LL 矫正值})$, 调整后 $R^2=0.501, P<0.001$ (图 4)。

3 讨论

健康人直立行走时, 躯干重心经过髋轴, 骨盆呈前倾中立位, 脊柱与骨盆相互协调, 共同维持脊柱骨盆矢状面的平衡^[2]。而 AS 后凸畸形患者 LL 减小, 躯干重心前移, 打破了脊柱骨盆矢状面的平衡^[11]。机体代偿性调节骨盆后倾后旋、伸髋屈膝, 以适应躯干重心的前移, 但却影响患者直立行走、平视和平卧等基本功能^[2, 11, 12]。脊柱截骨矫形手术是解决这些问题唯一有效的方法。手术治疗的主要目的是矫正 AS 后凸畸形, 重建 LL, 改善骨盆代偿性后倾后旋姿势, 恢复 PI-LL。研究报道^[6, 7], 成人脊柱畸形 (adult spinal deformity, ASD) 患者术后重建 PI-LL = $\pm 9^\circ$ 可维持良好脊柱骨盆矢状面平衡效果, 而针对 AS 患者术后的最佳 PI-LL 至今尚无定论^[13]。

本研究基于 SVA 计算得到的术后 PI-LL 最

佳阈值为 12.8° , 而基于 PT 计算得到的术后 PI-LL 最佳阈值为 10.5° 。两者 PI-LL 最佳阈值存在差异的原因分析: (1) 对于髋膝关节功能正常的 AS 患者, 后倾后旋骨盆的矫正主要依赖于 LL 的重建, 对 LL 的矫形要求较高; 当 LL 重建良好, 术后 PI-LL 匹配时, PT 可由脊柱骨盆代偿机制间接地矫正, 恢复骨盆前倾中立位; 而如果 LL 重建不理想, PI-LL 不匹配, 术后矢状面畸形残留时, 骨盆仍需要后倾后旋代偿, 导致术后 PT 的代偿性矫正非常有限; 故欲恢复骨盆矢状面平衡, 要求术后重建的 PI-LL 值更小, 更加接近正常水平^[14]; (2) 脊柱 SVA 的矫正可通过脊柱截骨矫形手术直接恢复, 无需通过机体代偿机制间接矫正, 对 LL 的重建要求不高, 即便术后残留部分腰椎畸形亦对 SVA 的矫正影响不大, 故基于 SVA 计算获得的 PI-LL 阈值 (12.8°) 大于基于 PT 计算获得的阈值 (10.5°)。综合考虑维持 AS 患者术后脊柱和骨盆矢状面平衡的要求, 建议术后矫形重建 PI-LL $\leq 10.5^\circ$ 。本研究患者的 PI 平均为 49° , 基于 Inami 等^[15]报道的预测公式, 以 PI 计算获得的最佳 PI-LL 为 9° , 与本研究得出的 10.5° 相似。Schwab 等^[16, 16]报道, ASD 患者术后重建 PI-LL $\geq 11^\circ$ 时, 中远期随访时患者发生脊柱骨盆矢状面失衡风险较高, 术后临床疗效较差, 建议术后重建 PI-LL $\leq 9^\circ$, 该结论与本研究结果相互印证。虽然 AS 患者的发病机理及演化过程与 ASD 不尽相同, 但是对矢状面平衡的矫正和恢复脊柱骨盆匹

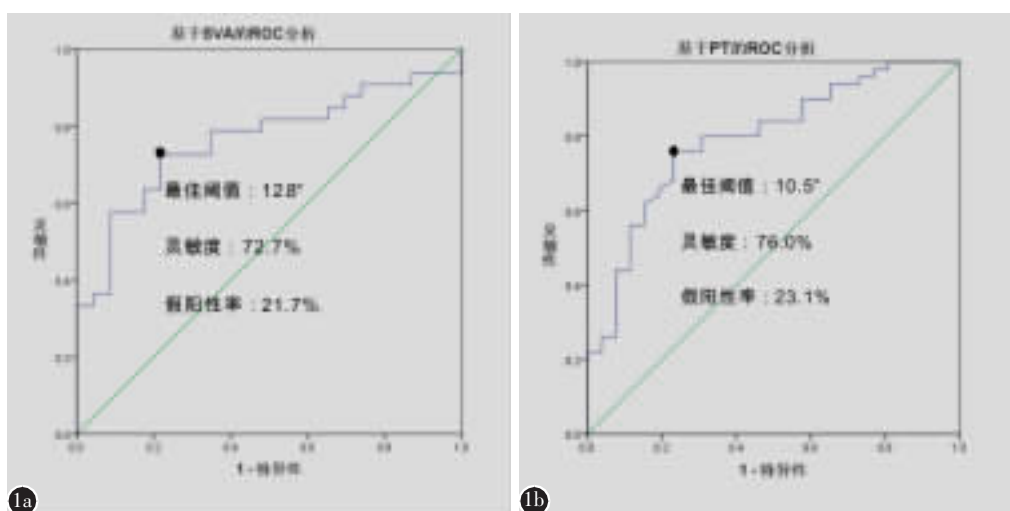


图 1 基于随访 SVA 和 PT, 术后 PI-LL 的 ROC 曲线分析结果 a 以随访 SVA 为状态变量 b 以随访 PT 为状态变量

Figure 1 The ROC curve analysis results of postoperative PI-LL based on SVA and PT at follow-up a With the follow-up SVA as state variable b With the follow-up PT as state variable

配度的要求是相似的,原因可能是该状态下的脊柱骨盆应力分布更为合适^[7,11]。

表 4 不同术后 PI-LL 患者影像参数和临床疗效的差异

Table 4 Differences of radiographic and clinical outcomes with different postoperative PI-LLs

	A组(n=36) Group A	B组(n=49) Group B	P值 P value
PT(°)			
术前/Preoperative	34.4±9.3	41.3±11.8	0.005
术后/Postoperative	21.9±7.1	33.0±8.0	<0.001
末次随访/Final follow-up	25.4±6.6	36.6±9.7	<0.001
矫形丢失/Correction loss	3.5±4.5	3.1±5.8	0.803
PI(°)			
术前/Preoperative	44.9±14.0	51.3±12.0	0.028
术后/Postoperative	45.2±12.6	50.7±10.9	0.038
末次随访/Final follow-up	45.4±11.9	50.3±11.8	0.045
矫形丢失/Correction loss	0.5±7.1	0.6±4.0	0.951
SS(°)			
术前/Preoperative	10.7±12.2	10.0±12.7	0.816
术后/Postoperative	23.3±11.9	17.5±10.8	0.023
末次随访/Final follow-up	17.7±13.7	13.7±11.5	0.243
矫形丢失/Correction loss	5.4±9.1	3.48±5.8	0.343
LL(°)			
术前/Preoperative	-2.2±20.2	10.5±21.8	0.008
术后/Postoperative	-44.6±16.2	-26.05±13.8	<0.001
末次随访/Follow-up	-40.8±15.8	-24.1±15.6	<0.001
矫形丢失/Correction loss	3.7±8.2	1.6±7.7	0.316
PI-LL(°)			
术前/Preoperative	42.9±20.6	60.4±19.9	<0.001
术后/Postoperative	0.6±7.4	24.4±11.7	<0.001
末次随访/Final follow-up	4.0±7.9	26.2±14.6	<0.001
矫形丢失/Correction loss	2.3±5.4	1.2±8.1	0.582
SVA (cm)			
术前/Preoperative	19.8±9.2	24.4±8.5	0.023
术后/Postoperative	5.8±4.6	11.3±5.2	<0.001
末次随访/Final follow-up	5.6±3.6	10.9±5.9	<0.001
矫形丢失/Correction loss	0.8±4.3	0.7±4.5	0.958
OVA(°)	42.7±19.4	47.0±19.6	0.316
末次随访 ODI(%)	24.98±12.19	22.92±14.85	0.607
SRS-22 总分/Total score	3.89±0.46	3.92±0.51	0.821
疼痛/Pain	3.90±0.68	3.89±0.75	0.946
功能/Function	3.51±0.55	3.35±0.67	0.394
形象/Appearance	3.81±0.70	3.90±0.62	0.649
心理/Mental health	3.88±0.69	4.03±0.81	0.506
满意度/Satisfaction	4.36±0.59	4.46±0.60	0.580
骨盆失平衡率(%) Incidence of pelvic imbalance	38.89	85.71	<0.001
脊柱失平衡率(%) Incidence of spinal imbalance	36.11	75.51	<0.001

比较 A、B 两组患者发现, A 组脊柱骨盆矢状面畸形矫正更充分, 术后参数恢复更好, 明显降低末次随访时脊柱和骨盆矢状面失衡的发生率, 证实 PI-LL $\leq$ 10.5°可有效减少中远期随访时脊柱和骨盆矢状面失衡的发生。两组 OVA 相似, 但是这对于脊柱骨盆矢状面失衡和畸形较重的 B 组患者而言, 脊柱的截骨矫形显然是不足够, B 组术后平均 PI-LL 为 24.4°, 大于推荐的 10.5°, 残留部分畸形和矢状面失衡。随着时间的推移, B 组患者矫形效果的丢失将会加重矢状面失衡, 进一步影响患者术后肢体功能和生活质量的改善。这类患者术后仍需骨盆后倾后旋和伸髋屈膝代偿, 腰背部及大腿伸肌群因持续收缩所致的肌肉酸痛会长期存在^[2,17]。严重者还可能导致脊柱后凸畸形进展、脊柱内固定松动或失败, 甚至需行翻修手术^[18-20]。因此充分矫正脊柱骨盆矢状面畸形, 重建匹配的 PI-LL, 是预防 AS 患者中远期矢状面失衡的重要条件^[18,21]。两组 ODI 及 SRS-22 评分均较术前明显改善, 但是两组之间无显著性差异, 这与 Liu^[8]和 Eskilsson 等^[9]观察的结果相似。原因可能是 AS 患者术前的生活质量较低, 肢体功能严重受限, 行截骨矫形手术治疗后, 肢体功能和生活质量得到极大改善, 即便残留部分 PI-LL 不匹配, 亦不足以影响他们的主观感受, 故随访时两组 ODI 及 SRS-22 评分无显著性差异。其次, 因 SRS-22 及 ODI 量表并非针对 AS 患者设计, 可能无法甄别 AS 患者截骨矫形术后 PI-LL 匹配与否的细微差别, 所以仍需深入探究适合 AS 患者术后肢体功能和生活质量的评分量表^[8,9]。

PI-LL 的矫正主要依靠 LL 的重建, 而 LL 的重建与腰椎 OVA 密切相关。本研究腰椎 OVA 与 PI-LL 矫正值呈线性正相关, 回归方程为: 腰椎 OVA=17.12+0.62×(PI-LL 矫正值)。根据该公式, 只需确定目标 PI-LL 即可计算出腰椎 OVA 以及需要重建的 LL, 继而指导手术截骨节段和手术方案的选择。但是目前对何时选择单节段或双节段截骨矫形尚无定论。如患者的 GK 较大, 预计 OVA 大于 60°者, 建议选择双节段截骨矫形^[22]。单节段截骨矫形过大(超过 60°)易引起局部脊髓过度短缩, 导致脊髓堆积、褶皱或神经根卡压, 继而引起神经损伤; 同时单节段截骨矫形过大易致使脊柱节段过度反折, 钉棒内固定系统受力过于集中, 增加中远期随访脊柱内固定失败的风险^[22,23]。

此外,对于矢状面失衡较严重或者脊柱后凸畸形呈“C 型”的 AS 患者,同样建议采取双节段截骨矫形,实现充分矫正矢状面畸形的同时,重建良好的腰椎前凸,恢复脊柱骨盆匹配度^[22-24]。但 Huang 等^[23]的研究指出,对 $GK<94^\circ$, $SVA<18.0\text{cm}$ 和 $LL<$

18° 的 AS 患者仍可采用单节段截骨矫形,术后亦可获得较满意的临床及影像效果。

本研究的局限之处:以目标 PI-LL 进行手术规划时,主要针对的是腰椎截骨矫形且髋膝关节功能正常的 AS 患者。对于后凸顶椎位于胸椎的

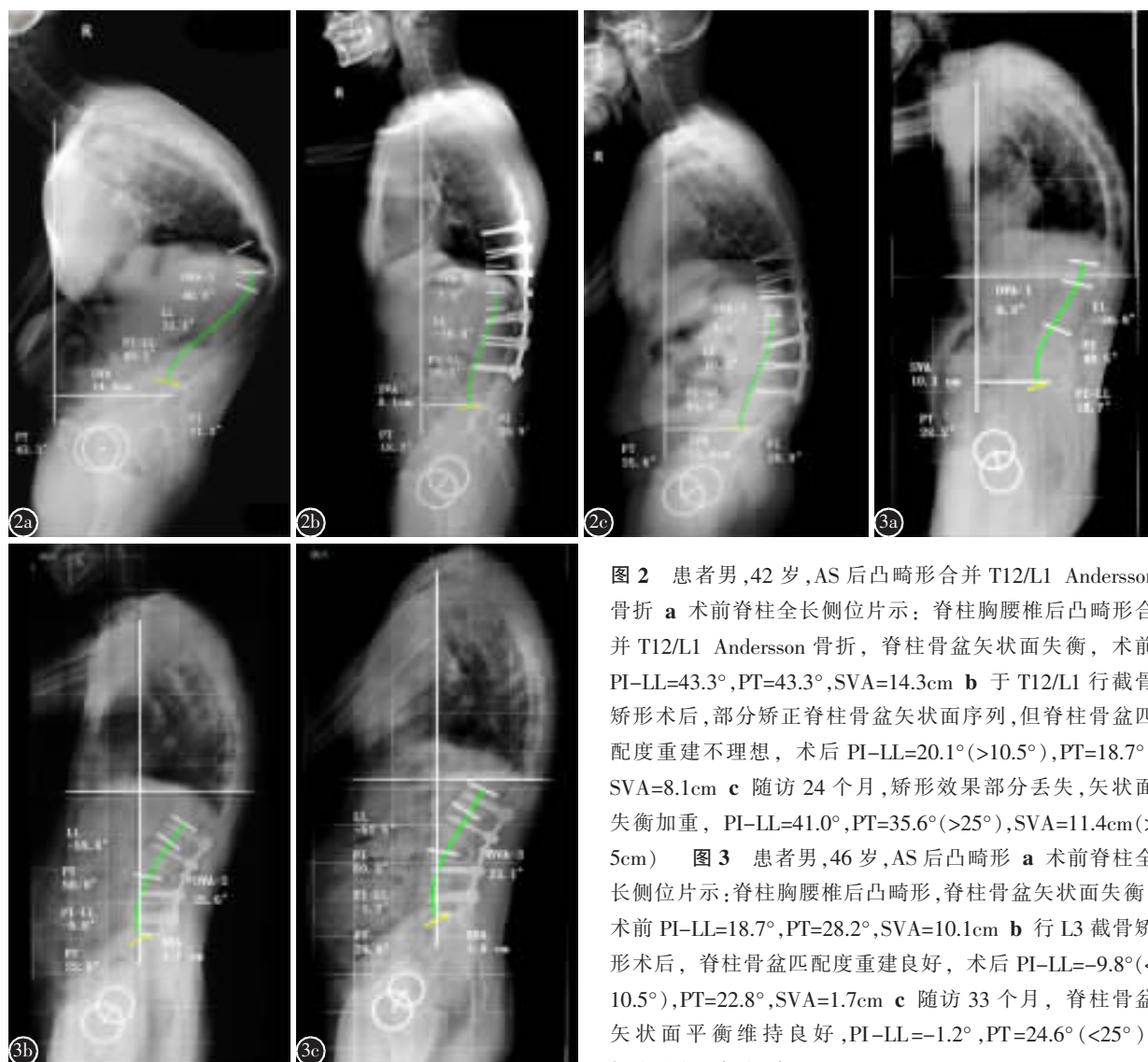


图 2 患者男,42 岁,AS 后凸畸形合并 T12/L1 Andersson 骨折 **a** 术前脊柱全长侧位片示:脊柱胸腰椎后凸畸形合并 T12/L1 Andersson 骨折,脊柱骨盆矢状面失衡,术前 $PI-LL=43.3^\circ$, $PT=43.3^\circ$, $SVA=14.3\text{cm}$ **b** 于 T12/L1 行截骨矫形术后,部分矫正脊柱骨盆矢状面序列,但脊柱骨盆匹配度重建不理想,术后 $PI-LL=20.1^\circ(>10.5^\circ)$, $PT=18.7^\circ$, $SVA=8.1\text{cm}$ **c** 随访 24 个月,矫形效果部分丢失,矢状面失衡加重, $PI-LL=41.0^\circ$, $PT=35.6^\circ(>25^\circ)$, $SVA=11.4\text{cm}(>5\text{cm})$ **图 3** 患者男,46 岁,AS 后凸畸形 **a** 术前脊柱全长侧位片示:脊柱胸腰椎后凸畸形,脊柱骨盆矢状面失衡,术前 $PI-LL=18.7^\circ$, $PT=28.2^\circ$, $SVA=10.1\text{cm}$ **b** 行 L3 截骨矫形术后,脊柱骨盆匹配度重建良好,术后 $PI-LL=-9.8^\circ(<10.5^\circ)$, $PT=22.8^\circ$, $SVA=1.7\text{cm}$ **c** 随访 33 个月,脊柱骨盆矢状面平衡维持良好, $PI-LL=-1.2^\circ$, $PT=24.6^\circ(<25^\circ)$, $SVA=1.8\text{cm}(<5\text{cm})$

Figure 2 A 42-year-old man suffered from ankylosing spondylitis with Andersson lesion at T12/L1 **a** Preoperative radiograph showed a severe thoracolumbar kyphosis with Andersson lesion at T12/L1, spinopelvic sagittal imbalance, and $PI-LL=43.3^\circ$, $PT=43.3^\circ$, and $SVA=14.3\text{cm}$ **b** The osteotomy was performed at T12/L1, the kyphosis was corrected partially and the sagittal alignment was restored to some extent, while it still didn't meet the standard; the postoperative $PI-LL=20.1^\circ(>10.5^\circ)$, $PT=18.7^\circ$, $SVA=8.1\text{cm}$ **c** At the follow-up of 24 months, the correction loss occurred and sagittal imbalance aggravated; $PI-LL=41.0^\circ$, $PT=35.6^\circ(>25^\circ)$, $SVA=11.4\text{cm}(>5\text{cm})$ **Figure 3** A 46-year-old man suffered from ankylosing spondylitis **a** Preoperative radiograph showed a severe thoracolumbar kyphosis with sagittal imbalance, and the preoperative parameters were $PI-LL=18.7^\circ$, $PT=28.2^\circ$, $SVA=10.1\text{cm}$ **b** The osteotomy was performed at L3, the sagittal alignment was restored properly; the postoperative parameters were $PI-LL=-9.8^\circ(<10.5^\circ)$, $PT=22.8^\circ$, $SVA=1.7\text{cm}$ **c** At the follow-up of 33 months, the correction and sagittal balance were maintained well, and the follow-up parameters were $PI-LL=-1.2^\circ$, $PT=24.6^\circ(<25^\circ)$, $SVA=1.8\text{cm}(<5\text{cm})$

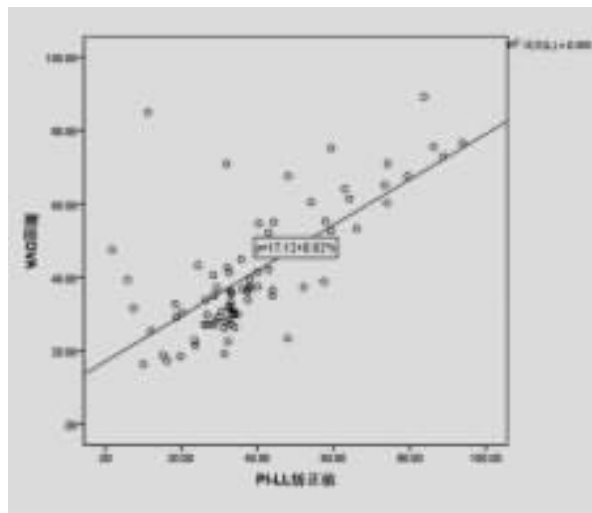


图 4 腰椎 OVA 与 PI-LL 矫正值的线性关系, 回归方程: 腰椎 OVA=17.12+0.62×(PI-LL 矫正值), $R^2=0.501$

Figure 4 Relationship between lumbar OVA and PI-LL correction. The linear regression equation: lumbar OVA=17.12+0.62× (PI-LL correction), with adjusted $R^2=0.501$

AS 患者, 可先行胸椎截骨矫形, 最大限度矫正局部后凸畸形, 恢复较为正常的胸椎后凸角 (thoracic kyphosis, TK), 而后根据预测公式 ($LL \leq 45^\circ - PI - TK^{[25]}$ 且 $PI-LL \leq 10.5^\circ$) 与本研究公式 [腰椎 OVA=17.12+0.62×(PI-LL 矫正值)] 计算出所需要的 LL 和 OVA, 继而指导第二处腰椎截骨矫形。对于合并颈椎强直的 AS 患者, 术后要求维持水平视野, 截骨矫形时常常受限, 无法充分纠正脊柱骨盆匹配度, 故不适用于本研究结果^[22, 26]。对于髋膝关节强直的 AS 患者, 因骨盆旋转受限, 影响脊柱骨盆矢状面序列的重建, 故亦不适用本研究结果。

综上所述, AS 后凸畸形患者术后 PI-LL 与末次随访 SVA 和 PT 的维持密切相关。术后重建 $PI-LL \leq 10.5^\circ$ 可降低中远期随访脊柱和骨盆矢状面失衡的发生。腰椎 OVA 与 PI-LL 矫正值的线性回归方程可为 AS 后凸畸形患者手术方案的制定提供参考。

4 参考文献

1. Sato T, Yonezawa I, Inoue H, et al. Relationship between characteristics of spinopelvic alignment and quality of life in Japanese patients with ankylosing spondylitis: a cross-sectional study[J]. BMC Musculoskelet Disord, 2020, 21(1): 41.
2. Qian BP, Jiang J, Qiu Y, et al. The presence of a negative

sacral slope in patients with ankylosing spondylitis with severe thoracolumbar kyphosis[J]. J Bone Joint Surg Am, 2014, 96(22): e188.

3. Enercan M, Ozturk C, Kahraman S, et al. Osteotomies/spinal column resections in adult deformity[J]. Eur Spine J, 2013, 22(Suppl 2): S254-264.
4. Qian BP, Jiang J, Qiu Y, et al. Radiographical predictors for postoperative sagittal imbalance in patients with thoracolumbar kyphosis secondary to ankylosing spondylitis after lumbar pedicle subtraction osteotomy[J]. Spine(Phila Pa 1976), 2013, 38(26): E1669-1675.
5. Kim YJ, Bridwell KH, Lenke LG, et al. Results of lumbar pedicle subtraction osteotomies for fixed sagittal imbalance: a minimum 5-year follow-up study [J]. Spine (Phila Pa 1976), 2007, 32(20): 2189-2197.
6. Schwab F, Patel A, Ungar B, et al. Adult spinal deformity—postoperative standing imbalance: how much can you tolerate: an overview of key parameters in assessing alignment and planning corrective surgery[J]. Spine(Phila Pa 1976), 2010, 35(25): 2224-2231.
7. Sun XY, Zhang XN, Hai Y. Optimum pelvic incidence minus lumbar lordosis value after operation for patients with adult degenerative scoliosis[J]. Spine J, 2017, 17(7): 983-989.
8. Liu ZJ, Qian BP, Qiu Y, et al. Does postoperative PI-LL mismatching affect surgical outcomes in thoracolumbar kyphosis associated with ankylosing spondylitis patients [J]. Clin Neurol Neurosurg, 2018, 169: 71-76.
9. Eskilsson K, Sharma D, Johansson C, et al. The impact of spinopelvic morphology on the short-term outcome of pedicle subtraction osteotomy in 104 patients [J]. J Neurosurg Spine, 2017, 27(1): 74-80.
10. Lee CS, Park JS, Nam Y, et al. Long-term benefits of appropriately corrected sagittal alignment in reconstructive surgery for adult spinal deformity: evaluation of clinical outcomes and mechanical failures[J]. J Neurosurg Spine, 2020: 1-9.
11. Shah AA, Lemans JV, Zavatsky J, et al. Spinal balance/alignment—clinical relevance and biomechanics [J]. J Biomech Eng, 2019.
12. Celestine PC, Dimar JR, Glassman SD. Spinopelvic parameters: lumbar lordosis, pelvic incidence, pelvic tilt, and sacral slope: what does a spine surgeon need to know to plan a lumbar deformity correction[J]. Neurosurg Clin N Am, 2018, 29(3): 323-329.
13. Koller H, Koller J, Mayer M, et al. Osteotomies in ankylosing spondylitis: where, how many, and how much[J]. Eur Spine J, 2018, 27(Suppl 1): 70-100.
14. Hyun SJ, Han S, Kim YB, et al. Predictive formula of ideal lumbar lordosis and lower lumbar lordosis determined by individual pelvic incidence in asymptomatic elderly population [J]. Eur Spine J, 2019, 28(9): 1906-1913.

15. Inami S, Moridaira H, Takeuchi D, et al. Optimum pelvic incidence minus lumbar lordosis value can be determined by individual pelvic incidence[J]. *Eur Spine J*, 2016, 25(11): 3638–3643.
 16. Schwab FJ, Blondel B, Bess S, et al. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis[J]. *Spine (Phila Pa 1976)*, 2013, 38(13): E803–812.
 17. Sahin N, Ozcan E, Baskent A, et al. Muscular kinetics and fatigue evaluation of knee using by isokinetic dynamometer in patients with ankylosing spondylitis [J]. *Acta Reumatol Port*, 2011, 36(3): 252–259.
 18. Yilgor C, Sogunmez N, Boissiere L, et al. Global alignment and proportion (GAP) score: development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery [J]. *J Bone Joint Surg Am*, 2017, 99(19): 1661–1672.
 19. Cho KJ, Suk SI, Park SR, et al. Risk factors of sagittal decompensation after long posterior instrumentation and fusion for degenerative lumbar scoliosis [J]. *Spine (Phila Pa 1976)*, 2010, 35(17): 1595–1601.
 20. Gilad R, Gandhi CD, Arginteanu MS, et al. Uncorrected sagittal plane imbalance predisposes to symptomatic instrumentation failure[J]. *Spine J*, 2008, 8(6): 911–917.
 21. Zhao SZ, Qian BP, Huang JC, et al. Failure patterns and related risk factors of sagittal reconstruction following pedicle subtraction osteotomy in patients with ankylosing spondylitis and thoracolumbar kyphosis[J]. *Neurosurg Focus*, 2021, 51(4): E7.
 22. Xu H, Zhang Y, Zhao Y, et al. Radiologic and clinical outcomes comparison between single- and two-level pedicle subtraction osteotomies in correcting ankylosing spondylitis kyphosis[J]. *Spine J*, 2015, 15(2): 290–297.
 23. Huang JC, Qian BP, Qiu Y, et al. When can one-level pedicle subtraction osteotomy obtain satisfied outcomes for severe thoracolumbar kyphosis with global kyphosis $\geq 80^\circ$ in ankylosing spondylitis: a comparison with two-level pedicle subtraction osteotomy[J]. *Spine(Phila Pa 1976)*, 2021, 46(6): E374–E383.
 24. Zheng G, Song K, Yao Z, et al. How to calculate the exact angle for two-level osteotomy in ankylosing spondylitis [J]. *Spine(Phila Pa 1976)*, 2016, 41(17): E1046–E1052.
 25. Rose PS, Bridwell KH, Lenke LG, et al. Role of pelvic incidence, thoracic kyphosis, and patient factors on sagittal plane correction following pedicle subtraction osteotomy [J]. *Spine(Phila Pa 1976)*, 2009, 34(8): 785–791.
 26. Song K, Su X, Zhang Y, et al. Optimal chin-brow vertical angle for sagittal visual fields in ankylosing spondylitis kyphosis[J]. *Eur Spine J*, 2016, 25(8): 2596–2604.
- (收稿日期:2021-12-08 末次修回日期:2022-03-24)
(英文编审 谭 啸)
(本文编辑 姜雅浩)