临床论著

成人脊柱畸形矫形术后早期躯体重心线(W-line)与近端交界区失败的相关性分析

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【摘要】目的:探讨成人脊柱畸形(adult spinal deformity,ASD)矫形术后早期躯体重心线(W-line)与近端交界区失败(proximal junctional failure,PJF)的相关性。**方法**:回顾性分析 2014 年 6 月~2019 年 3 月在我院行手术治疗的 99 例 ASD 患者的临床资料,其中男 19 例,女 80 例。均行单纯后路长节段(固定椎体≥4 个)固定融合手术,术后随访至少满 2 年。测量并记录所有患者术前、术后 3 个月及末次随访时的脊柱-骨盆参数。在脊柱全长侧位 X 线片上,将经外耳道口垂线定义为 W-line,根据 W-line 不同位置分为 A 组、B 组及 C 组。测量术后 3 个月时 W-line 到 S1 后上角水平距离(WSD)及 W-line 到股骨头中心连线中点的水平距离(WHD),将 W-line 位置进行数值转化(the numeric value of W-line,N-W-line):N-W-line=WHD/WSD。W-line 位于参考点前方数值为正,反之为负。采用受试者工作特征(receiver operating characteristic,ROC)曲线分析得出 N-W-line 临界值。三组患者参数进行方差分析,应用 Kaplan-Meier 曲线分析非 PJF 生存时间。**结果**:ROC 曲线分析得出术后 3 个月 N-W-line 临界值为±0.78[敏感度=75%,特异度=75.9%,曲线下面积(the area under the curve,AUC)=0.736,*P*=0.003]。A 组 32 例,N-W-line>0.78;B 组 49 例,-0.78≤N-W-line≤0.78;C 组 18 例,N-W-line<-0.78。A 组患者骨盆入射角(pelvic incidence,PI)最小(*P*<0.05),术后 3 个月矢状面平衡距(*P*<0.001)、T1 骨盆角(*P*<0.001)及骨盆腰椎匹配度(*P*<0.001)均显著小于其他两组患者。但随访中,A、B 及 C 组分别有 12 例、3 例及 1 例患者出现 PJF,A 组患者 PJF 发生率显著高于其他两组(12/32 vs 3/49 vs 1/18,*P*<0.001)。此外,A 组患者非 PJF 生存时间显著低于其他两组患者(*P*=0.005,Log-rank 检验)。B、C 组患者 W-line 位置逐渐前移,脊柱-骨盆矢状位参数逐渐增大,但术后 PJF 发生率显著降低。**结论**:ASD 患者矫形术后早期 W-line 位置可有效预测 PJF 发生。矫形手术后 W-line 偏后或过度偏前,术后随访中 PJF 发生率显著增加,矫形术后躯干呈轻度前屈为最佳。

【关键词】成人脊柱畸形;W-line;近端交界区失败;ROC 曲线分析;长节段固定融合术
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【Abstract】 Objectives: To explore the correlation between the early postoperative center of gravity line of the human body, namely W-line in this study, and the proximal junctional failure(PJF) developing in adult spinal deformity (ASD). **Methods:** We retrospectively analyzed the data of 99 adult spinal deformity (ASD) patients (male: 19; female: 80) who received surgery operation in our single institution from June 2014 to March 2019. All of the patients underwent posterior long-segments(≥4 vertebras) fusion with instrumentation, and were followed up for a minimum of 24 months. The spinopelvic parameters before operation, at 3 months after operation and the final follow-up were measured and recorded. On the lateral full-spine X-ray radiographs, the vertical line through the external auditory canal was defined as the W-line, according to which, all the patients were divided into three groups: group A, group B, group C. The horizontal distance

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between W-line and S1 was defined as WSD, and the horizontal distance from W-line to the midpoint of the central line of the femoral head was defined as WHD. WSD and WHD were measured at 3 months after operation, and the position of W-line was converted into numeric value of W-line (N-W-line): N-W-line= WHD/WSD. The value of WSD/WHD was recorded as positive if W-line was in front of the reference point, and vice versa. The optimal location of W-line was deduced using receiver operating characteristic (ROC) curve analysis. A Kaplan-Meier curve and Log-rank were used to analyze the differences in PJF-free survival. **Results:** ROC curve analysis determined the optimal threshold of N-W-line at the 3rd month postoperatively was ±0.78 [sensitivity=75.0%, specificity=75.9%, the area under the curve (AUC)=0.736, *P*= 0.003]. Then, three groups were defined as group A: the N-W-line>0.78, group B: −0.78≤N-W-line≤0.78, and C: N-W-line<−0.78, respectively. The pelvic incidence of patients in group A was the smallest among the three groups(*P*<0.05), and the sagittal vertical axis (*P*<0.001), T1 pelvic angle (*P*<0.001) and mismatch of pelvic incidence minus lumbar lordosis(*P*<0.001) at the 3rd month postoperatively were smaller than the other two groups significantly. Yet, of groups A, B and C, the number of patients occurring PJF was 12, 3, and 1, respectively, and the patients in group A suffered the highest incidence of PJF comparing with groups B and C (12/32 vs 3/49 vs 1/18, *P*<0.001). Moreover, PJF-free survival was the lowest in the group A(*P*=0.005, Log-rank test). In groups C and B, the W-line position gradually moved forward, and the sagittal spinopelvic parameters increased gradually, while the incidence of PJF decreased significantly. **Conclusions:** The early postoperative W-line could be an effective predictor for PJF in ASD patients after deformity correction. ASD patients with W-line behind the sacrum or deviating away from the hip forwardly at the early post-operation would be vulnerable to PJF-developing. Those ASD patients with mildly inclination forwardly may have the optimal spinopelvic alignment after surgery.

【Key words】 Adult spinal deformity; W-line; Proximal junctional failure; Receiver operating characteristic curve analysis; Long-fusion surgery

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长节段(≥4 个椎体)固定融合手术是治疗成人脊柱畸形(adult spinal deformity,ASD)的有效手段[1,2]。但也带来一些手术相关并发症[3,4]。其中近端交界性后凸 (proximal junctional kyphosis, PJK)和近端交界区失败(proximal junctional failure,PJF)较为常见[5]。既往研究将 PJK 定义为近端交界角 (上端椎下终板与上端椎近端第二椎体上终板间 Cobb 角)>10°或术后较术前增加>10°[6,7]。近期临床研究结果显示,PJK 并非单纯影像学变化, 常导致患者生活质量低下, 且其发病率高达 60%[8]。PJF 是 PJK 的进展阶段,影像学表现有固定节段上端椎或后方韧带复合体骨折、半脱位。患者多伴有背痛,甚至神经功能障碍,常需行翻修手术治疗[5,7]。PJK/PJF 的危险因素包括患者个人因素(体重指数、年龄、性别及骨质疏松)、手术因素(固定椎体数,上、下端椎位置,内置物种类)及脊柱-骨盆影像学参数[9,10]。

人躯体平衡由脊柱、骨盆及下肢关节相互协调维持[11,12]。此外,头颅位置也为代偿因素之一[13]。躯体重心线 (本研究中称为 W-line)[14] 位置是脊柱-骨盆-下肢关节共同作用的结果。对于 ASD 患者, 恢复脊柱矢状位整体平衡是矫形手术的主要目的之一,而脊柱-骨盆序列矫正与 PJK/PJF 显著相关[15]。目前关于脊柱-骨盆-髋关节综合因素与 PJF 相关性仍缺乏系统的研究报道。因此,本研究旨在探讨 ASD 患者矫形术后早期 W-line 与 PJF 的相关性及 ASD 矫形术后最佳脊柱-骨盆序列。

1 资料与方法

1.1 一般资料

本研究经我院伦理委员会批准。回顾性分析 2014 年 6 月~2019 年 3 月在我院诊疗的 ASD 患者资料。所有患者均行单纯后路长节段(≥4 个椎体)固定融合手术,术中均采用钛合金材质的椎弓根螺钉及双棒固定。纳入标准:(1)ASD 诊断明确;(2)年龄≥45 岁;(3)研究资料完整;(4)随访至少满 24 个月。排除标准:(1)患者既往有脊柱、关节手术史;(2)既往有脊柱肿瘤、结核病史;(3)双下肢长度差≥2cm。

W-line 为基线。在患者术后 3 个月时的脊柱全长侧位 X 线片上, 将经外耳道口垂线定义为 W-line,将股骨头中心连线中点至 W-line 水平距

离定义为 WHD,若 W-line 位于股骨头中心后方,则 WHD 为负值(-),前方为正值(+);骶骨后上角至 W-line 水平距离定义为 WSD,若 W-line 位于骶骨后方 WHD 规定为负值(-),前方则为正值(+)。根据以下方程将 W-line 位置进行数值转化(the numeric value of W-Line,N-W-line)以便于统计学分析,N-W-line=WHD/WSD(图 1)。

统计所有患者的一般情况及手术参数。一般情况包括年龄、性别、体重指数(body mass index,BMI)及相关基础性疾病;手术参数包括手术时间、术中出血量、上端椎(upper instrumented vertebra,UIV)、下端椎(lower instrumented vertebra,LIV)、固定椎体数、术后随访时间及 PJF 发生时间。收集、测量并记录所有患者术前、术后 3 个月及末次随访时的影像学参数。

1.2 影像学参数与测量方法

所有患者均行站立位脊柱全长 X 线片检查,摄片时双上肢置于支架上、肩关节前屈 30°、双侧肘关节轻度屈曲[16]。所有影像学参数均使用 Surgimap 软件测量(版本:2.3.2.1,美国)。

1.2.1 脊柱矢状面参数(图 2) ①颈椎前凸角(cervical lordosis,CL):C2 下终板与 C7 下终板间的夹角;②胸椎后凸角(thoracic kyphosis,TK):T4 上终板与 T12 下终板间夹角;③胸腰段后凸角(thoracolumbar kyphosis,TLK):T10 上终板与 L2 下终板间夹角;④腰椎前凸角(lumbar lordosis,LL):L1 上终板与 S1 上终板间夹角。

1.2.2 骨盆参数(图 2) ①骶骨倾斜角(sacral slope,SS):S1 上终板切线与水平线间夹角;②骨盆倾斜角(pelvic tilt,PT):S1 上终板中点与双侧股骨头中点连线与铅垂线所成夹角;③骨盆入射角(pelvic incidence,PI):S1 上终板中点与双侧股骨头中点连线与经 S1 上终板中点垂线相交所成夹角。

1.2.3 脊柱整体平衡参数(图 2) ①矢状面平衡距(sagittal vertical axis,SVA):经 C7 椎体中心铅

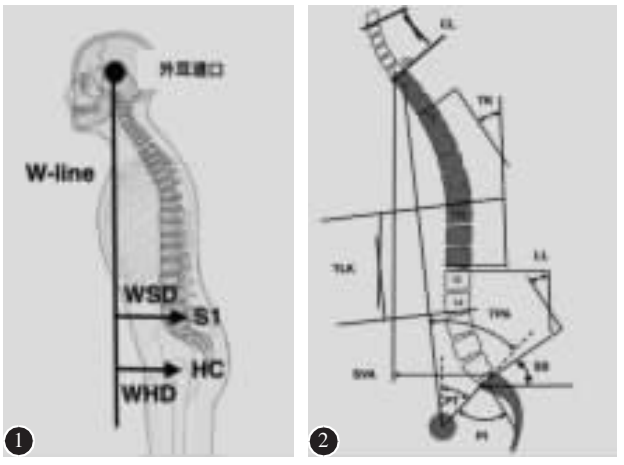


图 1 W-line 为经外耳道口垂线,WSD 为 W-line 至骶骨后上缘水平距离,WHD 为 W-line 至股骨头中心投影水平距离 **图 2** 脊柱骨盆影像学参数测量示意图:颈椎前凸角(CL),C2 下终板切线与 C7 下终板切线之间 Cobb 氏角;胸椎后凸角(TK),T4 上终板切线与胸 12 下终板切线之间 Cobb 氏角;胸腰段后凸角(TLK),T10 上终板切线与 L2 下终板切线之间 Cobb 氏角;腰椎前凸角(LL),L1 上终板切线与 S1 上终板切线之间 Cobb 氏角;骶骨倾斜角(SS),S1 上终板切线与水平线之间夹角;骨盆倾斜角(PT),股骨头中心连线中点与 S1 上终板中点连线与经股骨头中心连线中点垂线之间夹角;骨盆入射角(PI),股骨头中心连线中点与 S1 上终板中点连线与经 S1 上终板垂线之间夹角;矢状位平衡距(SVA),C7 垂线至 S1 后上角水平距离;胸 1 骨盆角(TPA),T1 椎体中心与股骨头中心连线中点连线与股骨头中心连线中点与 S1 上终板中点连线夹角

Figure 1 W-line represents the vertical line through external auditory canal. WSD indicates the horizontal distance from the posterosuperior corner of S1 to the W-line. WHD is the horizontal distance from the center of femoral heads (HC) to the W-line **Figure 2** The schematic diagram of radiographic sagittal spinopelvic parameters measurement: cervical lordosis(CL), the Cobb angle between the lower endplates of C2 and C7; thoracic kyphosis(TK), the Cobb angle between the upper endplate of T4 and the lower endplate of T12; thoracolumbar kyphosis(TLK), the Cobb angle between the upper endplate of T10 and the lower endplate of L2; lumbar lordosis(LL), the Cobb angle between the upper endplates of L1 and S1; sacral slope(SS), the angle between the sacral endplate and the horizontal line; pelvic tilt(PT), the angle between the line from the middle of the sacral plate to the middle of the hip axis and the vertical line; pelvic incidence (PI), the angle between the line perpendicular to the midpoint of the sacral plate and the line connecting the midpoint of the central line of the femoral head and the midpoint of S1 superior endplate; sagittal vertical axis(SVA), the horizontal distance between the C7 plumb line and the posterosuperior corner of S1; T1 pelvic angle(TPA), the angle between the line from the midpoint of femoral head axis to T1 center and the midpoint of femoral head axis to the midpoint of S1 upper endplate

垂线到 S1 后上角水平距;②T1 骨盆角(T1 pelvic angle,TPA):T1 椎体中心与双侧股骨头中点连线及 S1 上终板中点与双侧股骨头中点连线间夹角。

上述参数后凸角定义为正值(+),前凸角定义为负值(-)。PI 与 LL 匹配程度(PI-LL)由以上参数绝对值计算得出。

1.3 统计学方法

正态分布的连续变量采用均数±标准差记录,非正态分布采用中位数记录;分类参数采用百分数记录。在术后 3 个月时的脊柱全长侧位 X 线片上,根据 W-Line 不同位置分为 A 组、B 组及 C 组。受试者工作特征(receiver operating characteristic,ROC)曲线分析得出术后 3 个月的 N-W-line 临界值。采用 Kaplan-Meier 曲线及 Log-rank 检验分析非 PJF 生存时间。分类资料选用卡方检验;计数资料选用方差分析;术前、术后 3 个月及末次随访时相关影像学参数采用重复测量方差分析。所有检验分析选用 SPSS 软件完成(Mac 版 26.0,IBM 公司),可信区间为 95%,P<0.05 为有统计学差异。

2 结果

2.1 一般资料

本研究共纳入 99 例 ASD 患者,其中男 19 例,女 80 例,年龄 64.48±8.88 岁(45~79 岁),术后随访 51.68±15.6 个月(24~87 个月)。随访过程中,16 例(16.16%)患者发生 PJF(其中 3 例螺钉拔出或切割,13 例出现上端椎或上端椎第一邻椎骨折),其中 14 例患者在术后 2 年内出现 PJF,其余 2 例分别发生于术后第 36 个月和第 43 个月。

2.2 三组患者一般资料对照分析

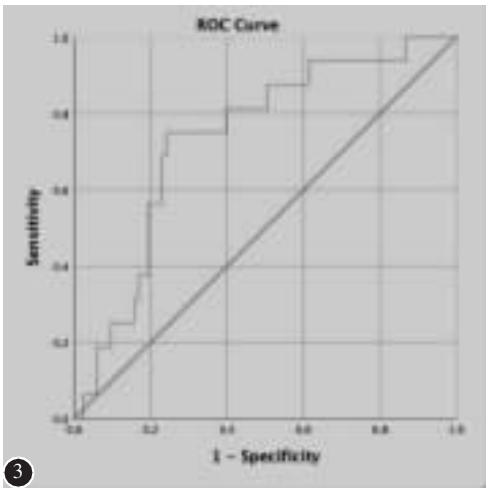
ROC 曲线检验得出术后 3 个月时 N-W-line 临界值为 0.78[敏感度 75%,特异度 75.9%,曲线下面积(the area under the curve,AUC)=0.736,P=0.003](图 3)。由于 N-W-line 数值有正负之分,因此临界值为±0.78。A 组,N-W-line>0.78,共 32 例;B 组,-0.78≤N-W-line≤0.78,49 例;C 组,N-W-line<-0.78,18 例(图 4)。三组患者术前一般情况,如年龄、性别、BMI 及相关基础性疾病均无统计学差异(P>0.05,表 1)。三组患者术后随访时间相似,随访过程中分别有 12 例(A 组)、3 例(B 组)及 1 例(C 组)发生 PJF,PJF 发生率有显著性差异(12/32:3/49:1/18,P<0.001)。

2.3 三组患者脊柱矢状面影像学参数比较

A 组患者术前 TLK(P=0.037)、术后 3 个月 TLK(P=0.015)及末次随访 TLK(P<0.001)均为最大;末次随访时,TK(P=0.014)及 LL(P=0.023)三组患者也有显著性差异(表 2)。

2.4 三组患者骨盆影像学参数比较

A 组患者手术前后 PI 最小(P<0.05);尽管术前 SS 和 PT 三组患者无统计学差异,但 A 组患者术后 3 个月(P=0.004)及末次随访时(P<0.001)PT



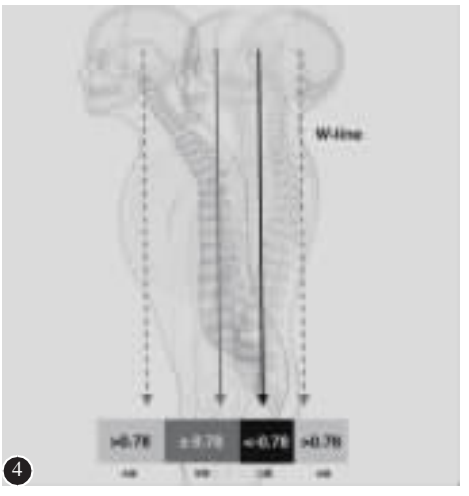


图 3 ROC 曲线分析显示 N-W-line 临界值为 0.78,敏感度=75%,特异度=75.9%,AUC=0.736,P=0.003 **图 4** 三组患者 W-line 分布示意图:A 组,N-W-line>0.78;B 组,-0.78≤N-W-line≤0.78;C 组,N-W-line<-0.78

Figure 3 The ROC curve showed that the critical value of N-W-line was 0.78, sensitivity=75%, specificity=75.9%, AUC=0.736, P=0.003 **Figure 4** W-line distribution diagram in patients belonging to the group A(N-W-line>0.78), B(-0.78≤N-W-line≤0.78), and C(N-W-line<-0.78)

均显著小于其他两组(表 3)。

2.5 三组患者整体脊柱影像学参数比较

A 组患者术前 SVA(*P*<0.001)最小;术后 3 个月时,三组患者 SVA(*P*<0.001)、TPA(*P*<0.001)及 PI-LL(*P*<0.001)均有统计学差异;末次随访时,A 组 SVA(*P*<0.001)及 PI-LL(*P*<0.001)显著小于其他两组(表 4)。

2.6 三组患者手术参数及脊柱影像学参数变化值比较

A、B 及 C 组患者手术时间、术中出血量、固定椎体数、UIV 及 LIV 均无统计学差异(*P*>0.05);此外,三组患者脊柱矢状位参数矫正度如 TK、TLK、LL、SVA 及 TPA 等均无统计学差异(*P*>0.05,表 5)。

Kaplan-Meier 曲线及 Log-rank 检验显示 A 组患者非 PJF 生存时间显著小于其他两组(图 5)。

表 1 A、B 及 C 组患者一般情况对照

Table 1 Demographic data of patients in groups A, B, and C

	A组(*n*=32) Group A	B组(*n*=49) Group B	C组(*n*=18) Group C	*P*值 *P* value
女性占比 No. of females	25(78.1%)	42(85.7%)	13(72.2%)	0.414
年龄(岁) Age	63.84±9.47	64.14±8.20	66.89±6.60	0.422
体重指数(kg/m^2) BMI	24.58±10.30	24.17±10.59	25.13±7.27	0.618
基础疾病占比 No. of comorbidities	23(71.9%)	38(77.6%)	10(55.6%)	0.208
随访时间(月) Follow-up(month)	51.90±17.05	51.39±14.86	50.17±16.19	0.932

3 讨论

人体脊柱、骨盆及下肢关节相互协调,保持头颅位于骨盆上方以维持良好视觉,且确保躯体重心线维持在正常范围[17,18]。Schwab 等[19]认为 ASD 患者术后脊柱矢状位序列与生物力学相关并发症如 PJK/PJF 等密切相关。ASD 患者矫形术后 W-line 偏后时,手术节段近端交界区应力可能显著增加,随之发生 PJK/PJF。

根据既往研究结果[14],我们将经外耳道口铅垂线定义为 W-line,并根据 W-line 与骶骨及髋关节中心的相对位置将所有患者分为三组。三组患者术中 LL 矫正度相似,术后 A 组患者 W-line 均位于骶骨后方。A 组患者 SVA(-12.01±39.67mm)及 TPA(9.15°±6.06°)显著小于其他两组,且按早期研究结果[19-21]均为正常范围。但随访过程中,A 组患者 PJF 发生率显著高于其他两组

表 2 A、B 及 C 组脊柱矢状面影像学参数对照

Table 2 Sagittal imaging parameters of spine in groups A, B, and C

参数 Variable	A组(*n*=32) Group A	B组(*n*=49) Group B	C组(*n*=18) Group C	*P*值 *P* value
颈前凸 CL(°)				
术前 Pre-operation	-13.25±17.78	-19.88±19.33	-17.85±16.21	0.482
术后 3 个月 The 3rd month post-operatively	-7.52±16.68	-10.45±13.94	-7.97±17.65	0.829
末次随访 Final follow-up	-10.56±13.88	-16.80±11.20	-13.77±15.77	0.109
胸后凸 TK(°)				
术前 Pre-operation	19.85±13.84	15.26±13.19	15.58±9.51	0.258
术后 3 个月 The 3rd month post-operatively	23.18±10.07	20.92±11.40	23.54±7.67	0.601
末次随访 Final follow-up	29.87±10.30	24.41±11.33	31.89±9.04	0.014
胸腰段后凸 TLK(°)				
术前 Pre-operation	28.40±16.85	19.77±16.01	17.50±17.78	0.037
术后 3 个月 The 3rd month post-operatively	13.25±10.05	9.96±10.33	5.70±9.27	0.015
末次随访 Final follow-up	33.58±12.05	11.90±8.37	10.70±8.70	<0.001
腰前凸 LL(°)				
术前 Pre-operation	-27.37±20.69	-17.63±21.16	-25.71±16.62	0.09
术后 3 个月 The 3rd month post-operatively	-41.83±11.59	-35.63±12.51	-38.08±10.88	0.084
末次随访 Final follow-up	-44.60±12.87	-32.08±13.42	-42.80±11.82	0.023

(12/32:3/49:1/18,P<0.001)。由此可见 ASD 患者矫形术后重心线偏后,即 W-line 位于骶骨后方将显著增加 PJF 发生率。我们推断 W-line 偏后患者体位变化时,胸腰段力矩将显著增加,固定近端交界区应力骤增,随之发生 PJF,这与近期的研究结论[22]相似。此外,Kaplan-Meier 曲线(图 5)显示 A 组患者非 PJF 生存时间显著低于其他两组患者(P=0.005,Log-rank 检验)。由此可见,ASD 患者矫形术后 W-line 越偏后,患者躯干前倾时,固定近端交界区产生的应力越大, 术后 PJF 发生时间越早,相应非 PJF 生存时间越短。

随着年龄增加,健康人群躯干逐渐前倾,即相应参数如 TPA、SVA 及 PI-LL 等逐渐增大[23,24]。中老年健康人群体位变化过程中 (站立-坐位),躯干亦处于前倾状态[25]。ASD 患者大多为中老年人群[1],且此类人群行走过程中脊柱也有明显前倾趋势[26]。因此,此类患者矫形手术维持其脊柱整体前倾状态应为其最佳功能位。本研究中 B、C 组患者矫形术后,随着 W-line 位置前移,脊柱-骨盆影像学参数如 SVA、PI-LL 及 TPA 等逐渐增大,但是 PJF 的发生率显著降低。由此可见,ASD 患者矫形术后 W-line 位于骶骨前方、股骨头中心附近

表 3 A、B 及 C 组骨盆影像学参数对照

Table 3 Imaging parameters of pelvic in groups A, B, and C

参数 Variable	A组(n=32) Group A	B组(n=49) Group B	C组(n=18) Group C	P值 P value
骶骨倾斜角 SS(°)				
术前 Pre-operation	20.66±13.44	20.14±13.74	27.03±10.00	0.108
术后 3 个月 The 3rd month post-operatively	29.20±10.78	29.55±10.82	29.39±9.60	0.99
末次随访 Final follow-up	31.32±9.44	28.43±10.39	30.36±8.19	0.419
骨盆倾斜角 PT(°)				
术前 Pre-operation	21.80±11.75	26.53±12.25	23.15±9.70	0.197
术后 3 个月 The 3rd month post-operatively	12.46±8.35	18.24±9.60	19.98±8.67	0.004
末次随访 Final follow-up	12.84±9.84	23.14±10.74	22.98±10.67	<0.001
骨盆入射角 PI(°)				
术前 Pre-operation	42.46±9.61	46.68±11.54	50.64±12.66	0.029
术后 3 个月 The 3rd month post-operatively	41.93±9.00	47.79±11.88	49.36±12.22	0.026
末次随访 Final follow-up	41.88±9.87	48.79±10.90	49.92±11.87	0.017

表 4 A、B 及 C 组脊柱整体矢状面影像学参数对照

Table 4 Global sagittal imaging parameters of spine in groups A, B, and C

参数 Variable	A组(n=32) Group A	B组(n=49) Group B	C组(n=18) Group C	P值 P value
骨盆腰椎适配 PI-LL(°)				
术前 Pre-operation	14.45±21.62	28.15±19.72	27.92±15.38	0.017
术后 3 个月 The 3rd month post-operatively	0.09±10.39	12.16±12.30	11.27±9.84	<0.001
末次随访 Final follow-up	0.10±9.96	11.92±11.22	13.06±9.77	<0.001
T1 骨盆角 TPA(°)				
术前 Pre-operation	18.24±11.40	27.42±13.99	22.41±10.49	0.008
术后 3 个月 The 3rd month post-operatively	8.99±5.99	17.81±9.56	15.82±7.47	<0.001
末次随访 Final follow-up	16.78±10.21	21.86±10.88	22.83±11.73	0.106
矢状面平衡距 SVA(mm)				
术前 Pre-operation	23.08±36.40	76.49±60.57	47.34±43.22	<0.001
术后 3 个月 The 3rd month post-operatively	−7.72±42.45	32.24±24.50	14.76±14.16	<0.001
末次随访 Final follow-up	17.97±30.21	43.67±23.45	35.6±19.65	<0.001

时,脊柱–骨盆序列为最佳,更符合患者生物力学需求。

既往研究提出 PI 与术后 PJK/PJF 发生显著相关,作用机制均与 LL 矫正度相关[27,28]。但相关研究均未能在脊柱整体生物力学方面进行论述,且关于 PI 大小方面结论相悖。本研究中 A 组患者 PJF 发生率最高,其 PI 值显著小于其他两组,但三组患者 LL 矫正度及术后早期 LL 相似。PI 决定脊柱整体序列特点[29]。因此,A 组患者存在严重脊柱–骨盆失匹配。PI 较小的患者,相似的 LL 矫正度将导致其整体重心线后移,胸腰段力臂增加,固定近端交界区应力增加,从而导致 PJF。因此,相似的 LL 矫正度对于 PI 较小患者则为过度矫正,而脊柱的过度矫正一直被国内外学者证实为 PJK/PJF 的独立危险因素[28,30]。此外,Zhang 等[31,32]最新研究结果显示,PI 较小的 ASD 患者矫形术后髋关节参数改变显著。本研究结果也显示 A 组患者 PT 值显著小于其他两组患者。对于僵直性脊柱患者,PT 较小将导致其正常坐位时髋关节曲屈度受限[33],患者需坐高凳、前倾躯干以维持其坐位

表 5 A、B 及 C 组患者影像学参数纠正度及手术参数对照

Table 5 The correction of imaging parameters and surgical data in groups A, B, and C

参数 Variable	A组(*n*=32) Group A	B组(*n*=49) Group B	C组(*n*=18) Group C	*P*值 *P* value
手术时间(min) Operative time	276.41±57.39	287.91±51.14	263.56±60.20	0.285
术中出血量(ml)Intraoperative blood loss	497.58±173.48	518.93±173.50	489.37±134.43	0.777
手术节段 Surgical segments	8.03±1.89	8.55±2.46	8.26±2.27	0.451
上端椎,T10/以上 UIV(T10 or above)	24(75%)	31(63.3%)	12(63.2%)	0.506
下端椎,S1/S2/骨盆 LIV(S1/S2/pelvis)	13(40.6%)	30(61.2%)	10(55.6%)	0.188
胸后凸矫正度(°) d–TK	3.20±9.90	6.10±9.83	6.20±12.14	0.429
胸腰段后凸矫正度(°) d–TLK	–15.48±12.95	–9.88±15.10	–11.89±17.62	0.272
腰前凸矫正度(°) d–LL	15.30±14.99	16.83±16.88	12.27±16.17	0.606
矢状面平衡距矫正度(mm) d–SVA	–37.70±48.53	–35.30±55.61	–40.28±44.49	0.939
T1 骨盆角矫正度(°) d–TPA	–9.72±8.99	–8.71±8.93	–7.08±6.66	0.602

注:d–,表示手术矫正度

Note: d–, indicates the correction of imaging parameters

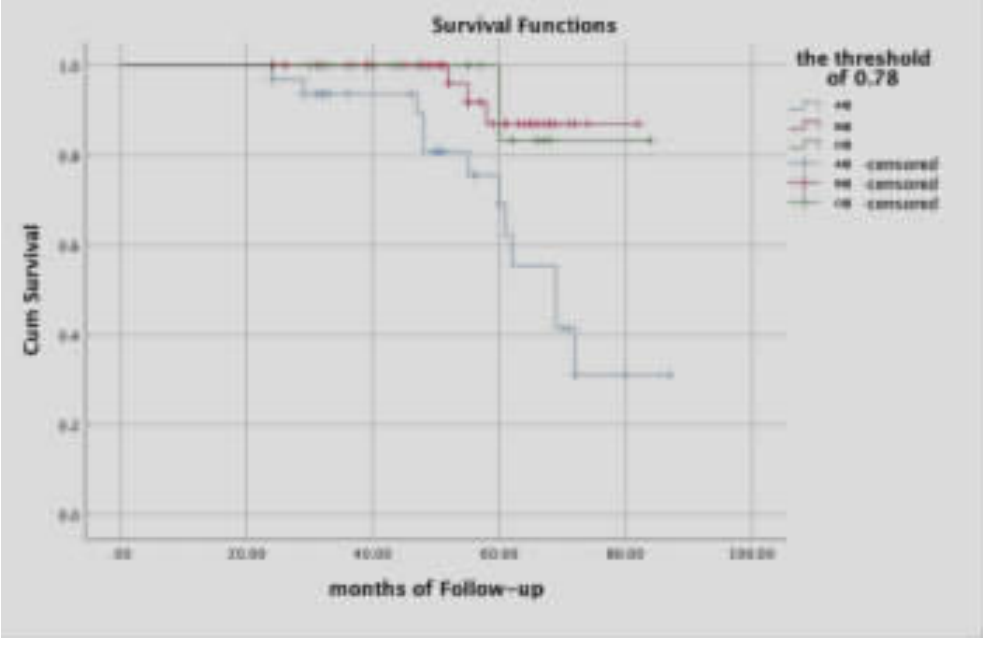


图 5 生存分析曲线分析 A、B 及 C 组患者非 PJF 生存时间对照结果

Figure 5 Kaplan–Meier curves of survival time of PJF–free patients in groups A, B, and C

平衡。此体位变化过程中固定近端交界区应力显著增加，随着术后随访时间延长，将发生 PJK/PJF。我们推断小 PI 为 PJK/PJF 危险因素之一，可能与此类人群矫形术后 W-line 位置偏后密切相关。

既往研究[9,34,35]证实，患者自身因素（如年龄、性别、BMI 及骨密度）及手术因素（如固定椎体数、内固定物材质、上下端椎位置等）与 PJK/PJF 显著相关。本研究中，术前三组患者一般情况对照分析，年龄、性别及 BMI 均无统计学差异。此外，三组患者固定椎体数、上端椎及下端椎位置比例数均无统计学差异。因此，可排除上述因素对本研究结果的干扰。由于本研究为回顾性研究，骨密度检测结果不全，因此未能进行相关分析，存在一定缺陷。但是，患者骨密度与其年龄、性别、基础疾病及 BMI 有一定相关性，而上述结果统计学上均未见统计学差异，因此，骨密度造成的偏倚有限。

综上，W-line 综合参考了脊柱、骨盆及髋关节三组因素。该线在脊柱全长侧位片上易于发现，且经本研究证实可有效预测 PJF 的发生，对临床有一定指导价值，但有待前瞻性研究进一步论证。

4 结论

ASD 矫形术后早期 W-line 位置可有效预测 PJF 发生。PI 较小的 ASD 患者，腰前凸过度矫正将导致 W-line 显著后移，胸腰段力臂增加，固定近端交界区应力显著增加，随之发生 PJK/PJF。因此，对于小 PI 患者，临床医师应尽量减小其腰椎矫正度，以保证术后其 W-line 维持在骶骨前方，从而避免 PJF 发生。此外，矫形术后 ASD 患者躯干轻度前屈可能为最佳。

5 参考文献

1. Diebo BG, Shah NV, Boachie-Adjei O, et al. Adult spinal deformity[J]. The Lancet, 2019, 394(10193): 160-172.
2. Silva FE, Lenke LG. Adult degenerative scoliosis: evaluation and management[J]. Neurosurg Focus, 2010, 28(3): E1.
3. Sugawara R, Takeshita K, Takahashi J, et al. The complication trends of adult spinal deformity surgery in Japan: the Japanese Scoliosis Society Morbidity and Mortality survey from 2012 to 2017[J]. J Orthop Sci, 2021, 26(4): 533-537.
4. Charosky S, Guigui P, Blamoutier A, et al. Complications and risk factors of primary adult scoliosis surgery: a multicenter study of 306 patients[J]. Spine (Phila Pa 1976), 2012, 37(8): 693-700.
5. Hyun SJ, Lee BH, Park JH, et al. Proximal junctional kyphosis and proximal junctional failure following adult spinal deformity surgery[J]. Korean J Spine, 2017, 14(4): 126-132.
6. Glattes RC, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis[J]. Spine (Phila Pa 1976), 2005, 30(14): 1643-1649.
7. Kim HJ, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis results in inferior SRS pain subscores in adult deformity patients[J]. Spine (Phila Pa 1976), 2013, 38(11): 896-901.
8. Lee JH, Kim JU, Jang JS, et al. Analysis of the incidence and risk factors for the progression of proximal junctional kyphosis following surgical treatment for lumbar degenerative kyphosis: minimum 2-year follow-up [J]. Br J Neurosurg, 2014, 28(2): 252-258.
9. Zhao J, Chen K, Zhai X, et al. Incidence and risk factors of proximal junctional kyphosis after internal fixation for adult spinal deformity: a systematic evaluation and meta-analysis[J]. Neurosurg Rev, 2021, 44(2): 855-866.
10. Mika AP, Mesfin A, Rubery PT, et al. Proximal junctional kyphosis: a pediatric and adult spinal deformity surgery dilemma[J]. JBJS Rev, 2019, 7(4): e4.
11. Savarese LG, Menezes-Reis R, Bonugli GP, et al. Spinopelvic sagittal balance: what does the radiologist need to know[J]. Radiol Bras, 2020, 53(3): 175-184.
12. Nishida N, Izumiyama T, Asahi R, et al. Changes in the global spine alignment in the sitting position in an automobile[J]. Spine J, 2020, 20(4): 614-620.
13. Yagi M, Kaneko S, Yato Y, et al. Standing balance and compensatory mechanisms in patients with adult spinal deformity[J]. Spine(Phila Pa 1976), 2017, 42(10): E584-E591.
14. Le Huec JC, Saddiki R, Franke J, et al. Equilibrium of the human body and the gravity line: the basics[J]. Eur Spine J, 2011, 20(Suppl 5): 558-563.
15. Yagi M, Akilah KB, Boachie-Adjei O. Incidence, risk factors and classification of proximal junctional kyphosis: surgical outcomes review of adult idiopathic scoliosis [J]. Spine (Phila Pa 1976). 2011, 36(1): E60-68.
16. Marks M, Stanford C, Newton P. Which lateral radiographic positioning technique provides the most reliable and functional representation of a patient′s sagittal balance[J]. Spine (Phila Pa 1976), 2009, 34(9): 949-954.
17. Duval-Beaupere G, Schmidt C, Cosson P. A Barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position [J]. Ann Biomed Eng, 1992, 20(4): 451-462.
18. Roussouly P, Gollogly S, Berthonnaud E, et al. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position [J].

Spine(Phila Pa 1976), 2005, 30(3): 346-353.
19. Schwab F, Ungar B, Blondel B, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study[J]. Spine(Phila Pa 1976), 2012, 37(12): 1077-1082.
20. Banno T, Hasegawa T, Yamato Y, et al. T1 pelvic angle is a useful parameter for postoperative evaluation in adult spinal deformity patients[J]. Spine(Phila Pa 1976), 2016, 41(21): 1641-1648.
21. Mendoza-Lattes S, Ries Z, Gao Y, et al. Proximal junctional kyphosis in adult reconstructive spine surgery results from incomplete restoration of the lumbar lordosis relative to the magnitude of the thoracic kyphosis[J]. Iowa Orthop J, 2011, 31: 199-206.
22. Faundez AA, Richards J, Maxy P, et al. The mechanism in junctional failure of thoraco-lumbar fusions. Part II: Analysis of a series of PJK after thoraco-lumbar fusion to determine parameters allowing to predict the risk of junctional breakdown[J]. Eur Spine J, 2018, 27(Suppl 1): 139-148.
23. Roussouly P, Gollogly S, Noseda O, et al. The vertical projection of the sum of the ground reactive forces of a standing patient is not the same as the C7 plumb line: a radiographic study of the sagittal alignment of 153 asymptomatic volunteers[J]. Spine(Phila Pa 1976), 2006, 31(11): E320-325.
24. Iyer S, Lenke LG, Nemani VM, et al. Variations in sagittal alignment parameters based on age: a prospective study of asymptomatic volunteers using full-body radiographs[J]. Spine (Phila Pa 1976), 2016, 41(23): 1826-1836.
25. Zhou S, Li W, Wang W, et al. Sagittal spinal and pelvic alignment in middle-aged and older men and women in the natural and erect sitting positions: a prospective study in a Chinese population[J]. Med Sci Monit, 2020, 26: e919441.
26. Miura K, Kadone H, Koda M, et al. Thoracic kyphosis and pelvic anteversion in patients with adult spinal deformity increase while walking: analyses of dynamic alignment change using a three-dimensional gait motion analysis system[J]. Eur Spine J, 2020, 29(4): 840-848.
27. Carender CN, Morris WZ, Poe-Kochert C, et al. Low pelvic incidence is associated with proximal junctional kyphosis in patients treated with growing rods[J]. Spine(Phila Pa 1976), 2016, 41(9): 792-797.
28. Maruo K, Ha Y, Inoue S, et al. Predictive factors for proximal junctional kyphosis in long fusions to the sacrum in adult spinal deformity[J]. Spine(Phila Pa 1976), 2013, 38(23): E1469-1476.
29. Laouissat F, Sebaaly A, Gehrchen M, et al. Classification of normal sagittal spine alignment: refounding the Roussouly classification[J]. Eur Spine J, 2018, 27(8): 2002-2011.
30. 刘盾, 史本龙, 朱泽章, 等. 脊柱侧后凸:后凸畸形 SRS-Schwab 四级截骨术后近端交界性后凸的危险因素分析 [J]. 中国脊柱脊髓杂志, 2021, 31(7): 579-585.
31. Zhang ZF, Qi DB, Wang TH, et al. Spine-pelvis-hip alignments in degenerative spinal deformity patients and associated procedure of one-stage long-fusion with multiple-level PLIF or apical-vertebra three column osteotomy: a clinical and radiographic analysis study[J]. Orthop Surg, 2021, 13(7): 2008-2017.
32. Zhang ZF, Qi DB, Wang TH, et al. Correlation of acetabular anteversion and thoracic kyphosis postoperatively with proximal junctional failure in adult spinal deformity fused to pelvis[J]. Orthop Surg, 2021, 13(8): 2289-2300.
33. 陈康明, 黄钢勇, 赵广雷, 等. 脊柱矢状面平衡对髋臼假体朝向的影响及其临床意义[J]. 中华骨科杂志, 2020, 40(2): 103-109.
34. Kim JS, Phan K, Cheung ZB, et al. Surgical, radiographic, and patient-related rsk factors for proximal junctional Kkyphosis: a Meta-analysis[J]. Global Spine J, 2019, 9(1): 32-40.
35. Sebaaly A, Sylvestre C, El Quehtani Y, et al. Incidence and risk factors for proximal junctional kyphosis: results of a multicentric study of adult scoliosis [J]. Clin Spine Surg, 2018, 31(3): E178-E183.

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