Spine

SPINE Volume 39, Number 25, pp 2103-2107
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DEFORMITY

T1 Pelvic Angle

A New Predictor for Postoperative Sagittal Balance and Clinical Outcomes in Adult Scoliosis

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Study Design. A retrospective radiographical study.

Objective. To compare the prediction abilities of T1 pelvic angle (TPA) and other parameters for postoperative sagittal balance, and investigate the relationships between these parameters and health-related quality of life.

Summary of Background Data. Using sagittal vertical axis (SVA) to assess sagittal alignment fails to take account of the pelvic compensation. A new parameter, TPA, has been recommended to represent the global sagittal balance of adult scoliosis.

Methods. A retrospective review was performed on patients with adult scoliosis undergoing correction surgery from May 2009 to March 2013. The Spearman ρ was used to determine the correlations between the radiographical parameters (preoperative, postoperative, and changes) and the overall Oswestry Disability Index (ODI), visual analogue scale (VAS), and Scoliosis Research Society-22 (SRS-22) questionnaire scores.

Results. Significant correlations were found between the changes of TPA and the changes of lumbar lordosis, pelvic tilt, sacral slope, pelvic incidence, SVA, spinosacral angle, ODI, VAS, SRS-22, and pedicle subtraction osteotomy (PSO) degrees ($P < 0.05$). The changes of SVA were significantly related to the changes of lumbar lordosis, TPA, C7–sacrofemoral distance, ODI, VAS, SRS-22 ($P < 0.05$) but not PSO degrees ($P > 0.05$). Significant correlations were found between the changes of spinosacral angle and the changes of thoracolumbar kyphosis, TPA, ODI, VAS, SRS-22, and PSO degrees ($P < 0.05$). The changes of C7 plumb line to sacrofemoral distance ratio were significantly related to the changes of SVA ($P < 0.05$), but not the changes of ODI, VAS, SRS-22, or PSO degrees ($P > 0.05$).

Conclusion. TPA could better reflect the postoperative changes of sagittal alignment and health-related quality of life for patients with adult scoliosis. Moreover, the changes of TPA are strongly correlated to the osteotomy degrees for PSO and, TPA could be used as a reference parameter in surgical planning.

Key words: T1 pelvic angle (TPA), adult scoliosis, sagittal alignment, pedicle subtraction osteotomy.

Level of Evidence: 4

Spine 2014;39:2103–2107

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Acknowledgment date: May 27, 2014. Revision date: August 2, 2014. Acceptance date: September 13, 2014.

The manuscript submitted does not contain information about medical device(s)/drug(s).

The National Public Health Benefit Research Foundation, China (grant no. 201002018) funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000000635

Adult scoliosis, including *de novo* scoliosis and adult idiopathic scoliosis, features a combination of coronal and sagittal imbalance.[1] Unlike adolescent idiopathic scoliosis, where the treatment is guided by radiographical risk of progression, the treatment of adult scoliosis should be focused on the patients' self-perception of pain/disability, which was assessed by health-related quality of life (HRQOL) instruments.[2,3] Numerous studies have demonstrated sagittal balance parameters, rather than those of coronal balance determine the HRQOL of patients with adult scoliosis; thus, many efforts should be made to achieve an optimal sagittal alignment.[4,5] Several parameters have been proposed to describe the global sagittal alignment, including sagittal vertical axis (SVA), spinosacral angle (SSA), the C7 plumb line to sacrofemoral distance ratio (C7–SFD), and so on, among which SVA is the most commonly used that is measured by calculating the offset between the posterior corner of the sacrum and the vertical line passing through the vertebral body of C7.[6] Although a strong correlation has been confirmed between SVA and the HRQOL of patients with adult scoliosis,[1–5] the disadvantages of using SVA as a reference parameter should not be neglected. First, SVA is a distance parameter, and requires a calibrated image, which could be a source of measurement error.[7] Second, using SVA to assess sagittal alignment fails to take account of the pelvic compensation, which is deemed as an important factor guiding the treatment algorithm.[8] Third, SVA could only be assessed on upright standing radiographs, and is greatly influenced by patients' postures. Recently, a new parameter—T1 pelvic angle (TPA) has been recommended to represent the global sagittal balance of adult scoliosis. TPA, immune to patients' postures, is the angle from T1 to femoral heads and a line from femoral heads to the center of S1 endplate, which combines the information of SVA and pelvic tilt (PT). A preliminary study has demonstrated that the TPA is strongly related to the HRQOL of patients with adult scoliosis.[9] The aim of this study is to compare the prediction abilities of TPA and other parameters including SVA, SSA, and C7–SFD for postoperative sagittal balance. Moreover, the relationships between these parameters and HRQOL were also investigated.

MATERIALS AND METHODS

A retrospective review was performed on patients with adult scoliosis (*de novo* scoliosis and adult idiopathic scoliosis) undergoing correction surgery from May 2009 to March 2013. To reflect degenerative changes of the spine, only those who were older than 41 years with preoperative and at least 1-year postoperative full-length 36-in. posteroanterior and sagittal radiographs were included. Patients with underlying neurological or neuromuscular conditions were excluded. Patients were also excluded if the femoral heads or T1 superior endplates were not visible on any of the sagittal radiographs.

Radiographical Analysis

Patients were instructed to assume a freestanding posture, with elbows flexed at approximately 45° and fingertips on the clavicles. The following parameters were measured on both pre- and postoperative radiographs[3]:

1. *Thoracic kyphosis*: Cobb angle of superior endplate of T5 to inferior endplate of T12.
2. *Thoracolumbar kyphosis*: Cobb angle of superior endplate of T10 to inferior endplate of L2.
3. *Lumbar lordosis (LL)*: Cobb angle of superior endplate of T12 to superior endplate of S1.
4. *PT*: Angle between the vertical line and the line through the midpoint of the sacral plate to axis of femoral heads.
5. *Sacral slope (SS)*: Angle between the horizontal and the superior S1 endplate.
6. *Pelvic incidence (PI)*: Angle between the perpendicular to the superior S1 endplate at its midpoint and the line connecting this point to the center of the femoral heads.
7. *SVA*: The offset between the posterior corner of the sacrum and the vertical line passing through the vertebral body of C7.
8. *SSA*: The angle between the sacral plate and the line connecting the centroid of C7 vertebral body and the midpoint of the sacral plate.
9. *C7–SFD*: This ratio is equal to zero, when C7 plumb line projects exactly on the posterior corner of the sacrum, and equal to 1, when C7 plumb line projects exactly on the bicoxofemoral axis. It is negative when C7 plumb line projects posteriorly to the sacrum, and more than 1 when C7 plumb line projects from anterior to the femoral heads.
10. *TPA*: The angle from T1 to femoral heads and a line from femoral heads to the center of S1 endplate (Figure 1).
11. *Pedicle subtraction osteotomy (PSO)*: Its degree of resection was defined as the change of the angle formed by the lower vertebral endplate of the cephalic adjacent vertebra and the upper vertebral endplate of the caudal adjacent vertebra.

The Oswestry Disability Index (ODI), visual analogue scale (VAS), and Scoliosis Research Society-22 (SRS-22) questionnaire were completed by the patients before surgery and at the 1-year follow-up.

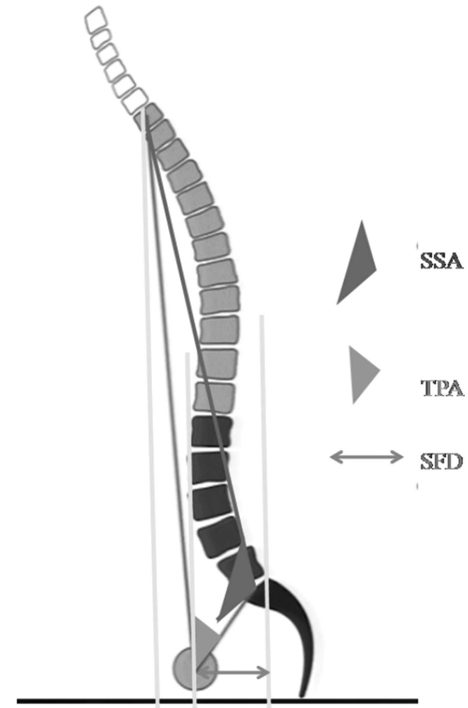

Figure 1. TPA is the angle from T1 to femoral heads and a line from femoral heads to the center of S1 endplate. SSA is the angle between the sacral plate and the line connecting the centroid of C7 vertebral body and the midpoint of the sacral plate. SFD is the horizontal distance between the vertical bicoxofemoral axis and the vertical line passing through the posterior corner of the sacrum. TPA indicates T1 pelvic angle; SFD, sacrofemoral distance; SSA, spinosacral angle.

Statistical Analysis

Data were analyzed using SPSS (SPSS, Chicago, IL). The Spearman ρ was used to determine correlations between radiographical parameters (preoperative, postoperative, and changes) and the overall ODI, VAS, and SRS-22 scores.

RESULTS

A total of 92 patients (14 males, 78 females) were included in the study. Mean age at the time of surgery was 56.3 years (range: 48–76 yr). Among these patients, 24 underwent posterior instrumentation, 35 posterior instrumentation plus Smith-Petersen osteotomy, and 33 posterior instrumentation plus PSO.

All the sagittal parameters were improved after surgery (Table 1). Preoperative TPA was significantly related to preoperative LL, PT, SS, PI, SVA, SSA, and C7–SFD ($r = -0.485$–0.832). Preoperative SVA was significantly related to preoperative LL, PI, TPA, SSA, and C7–SFD ($r = -0.438$ to 0.883). Preoperative SSA was significantly related to preoperative LL, PT, SS, SVA, TPA, and C7–SFD ($r = -0.544$ to 0.756).

Preoperative C7–SFD was significantly related to preoperative TPA, SVA, and SSA ($r = 0.651$–0.883) (Table 2).

Postoperative TPA was significantly related to postoperative LL, PT, SS, PI, SVA, and SSA ($r = -0.527$ to 0.835).

TABLE 1. Comparison of Pre- and Postoperative Radiographical Parameters

	Preoperative	Postoperative
TK	17.0	22.2
TLK†	31.4	9.4
LL†	15.6	40.2
SS*	17.6	29.0
PT*	28.8	16.8
PI	45.9	45.9
TPA†	29.3	13.6
SVA†	60.5	14.7
SSA*	102.6	117.7
SFD*	1.02	0.43

*$P < 0.05$. †$P < 0.01$.

TPA indicates T1 pelvic angle; SSA, spinosacral angle; SVA, sagittal vertical axis; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; SFD, sacrofemoral distance.

Postoperative SVA was significantly related to postoperative TPA and C7–SFD (r = −0.652–0.764). Postoperative SSA was significantly related to preoperative LL, PT, SS, and TPA (r = −0.625–0.478). Postoperative C7–SFD was significantly related to postoperative TPA (r = 0.764) (Table 3).

The changes of TPA were significantly related to the changes of LL, PT, SS, PI, SVA, and SSA (r = −0.749–0.759). The changes of SVA were significantly related to the changes of LL, TPA, and C7–SFD (r = −0.424–0.759). The changes of SSA were significantly related to the changes of thoracolumbar kyphosis and TPA (r = 0.406–0.442). The changes of C7–SFD were significantly related to the changes of SVA (r = 0.689) (Table 4).

TABLE 2. Correlations Between Preoperative Radiographical Parameters

	SVA	SSA	TPA	C7–SFD
TL	0.158	−0.201	0.172	0.056
TLK	0.149	0.164	−0.092	−0.033
LL	−0.438*	−0.600†	−0.512†	−0.341
SS	−0.386	−0.544†	−0.485†	−0.294
PT	0.386	0.544†	0.485†	0.294
PI	0.311	0.289	0.748†	0.353
TPA	0.832†	0.649†	1	0.798†
SVA	1	0.756†	0.832†	0.883†
SSA	0.756†	1	0.649†	0.651†
SFD	0.883†	0.651†	0.798†	1

*$P < 0.05$.

†$P < 0.01$.

TPA indicates T1 pelvic angle; SSA, spinosacral angle; SVA, sagittal vertical axis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; C7–SFD, C7 plumb line to sacrofemoral distance ratio; TLK, thoracolumbar kyphosis; LL, lumbar lordosis.

TABLE 3. Correlations Between Postoperative Radiographical Parameters

	SVA	SSA	TPA	C7–SFD
TL	−0.012	−0.289	−0.144	−0.027
TLK	−0.091	0.108	−0.073	−0.100
LL	−0.364	−0.625*	−0.542*	−0.299
SS	−0.190	−0.613*	−0.427*	0.007
PT	0.190	0.613*	0.427*	−0.007
PI	−0.212	0.356	0.835*	−0.004
TPA	0.652*	0.408†	1	0.351
SVA	1	0.361	0.652*	0.764*
SSA	0.361	1	0.478†	0.167
SFD	0.764*	0.167	0.351	1

*$P < 0.01$.

†$P < 0.05$.

TPA indicates T1 pelvic angle; SSA, spinosacral angle; SVA, sagittal vertical axis; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; TLK, thoracolumbar kyphosis; SFD, sacrofemoral distance.

TABLE 4. Correlations Between the Changes of Radiographical Parameters and ODI

	Δ SVA	Δ SSA	Δ TPA	Δ C7–SFD
TL	−0.026	−0.124	−0.020	−0.267
TLK	0.113	0.442*	0.137	−0.183
LL	−0.424*	−0.378	−0.668†	−0.236
SS	−0.164	−0.249	−0.749†	0.141
PT	0.164	0.249	0.749†	−0.141
TPA	0.759†	0.406*	1	0.359
SVA	1	0.384	0.759†	0.689†
SSA	0.348	1	0.406*	0.211
SFD	0.689†	0.211	0.359	1
ODI	0.431*	0.416*	0.629†	0.102
VAS	0.452*	0.442*	0.635†	0.202
SRS-22	−0.393*	−0.374*	−0.461*	−0.197
PSO degrees	0.226	0.495	0.787	0.206

*$P < 0.05$.

†$P < 0.01$.

TPA indicates T1 pelvic angle; SSA, spinosacral angle; PSO, pedicle subtraction osteotomy; SVA, sagittal vertical axis; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope; ODI, Oswestry Disability Index; VAS, visual analogue scale; SRS-22, Scoliosis Research Society-22; C7–SFD, C7 plumb line to sacrofemoral distance ratio; TLK, thoracolumbar kyphosis.

The changes of TPA were significantly related to the changes of ODI (r = 0.629), VAS (r = 0.635), SRS-22 (r = −0.461), and PSO degrees (r = 0.787). The changes of SVA were significantly related to ODI (r = 0.431), VAS (r = 0.452), SRS-22 (r = −0.393), and not related to PSO degrees (r = 0.226). The changes of SSA were significantly related to the changes of ODI (r = 0.416), VAS (r = 0.442), SRS-22 (r = −0.374), and PSO degrees (r = 0.495). The changes of C7–SFD were not significantly related to the changes of ODI (r = 0.102), VAS (r = 0.202), SRS-22 (r = −0.197), or PSO degrees (r = 0.206) (Table 4).

DISCUSSION

Because positive sagittal balance has been showed to strongly correlate with poor clinical outcomes, proper restoration of sagittal plane alignment is critical in improving clinical outcome and avoiding implant failure.[2,3,5,10] A number of parameters have been proposed to represent sagittal balance, including SVA, SSA, C7–SFD, and so on. SVA is the most widely used parameter to evaluate pre- and postoperative sagittal balance for patients with adult scoliosis, and a strong association between SVA and HRQOL of patients has been demonstrated.[5,10] However, the recognition of the role of pelvis in the sagittal balance of spine has revealed several disadvantages when using SVA as a reference parameter. Patients experiencing sagittal imbalance typically demonstrate a loss of LL and a positive SVA; meanwhile, compensatory mechanisms were initiated to maintain a global balance.[9,11,12] The most important compensatory mechanism is pelvic retroversion, defined by high PT. The previous studies have indicated that PT, in addition to SVA, was also strongly correlated to the HRQOL of patients. The notion has been renewed that the PT and SVA should be coconsidered in the treatment decision making for adult scoliosis. Lafage *et al* performed a prospective study on 125 adult patients experiencing spinal deformity to investigate the relationships between radiographical parameters and the HRQOL of patients with adult scoliosis, finding that PT, SVA, and truncal inclination, measured by T1 spinopelvic inclination (T1–SPI) (angle between T1–hip axis and vertical line) were correlated with the HRQOL of the patients; moreover, T1–SPI revealed greater correlation with HRQOL than SVA.[2] They concluded that T1–SPI outperforms SVA for the correlations with HRQOL and carries the advantage of being an angular measurement, which avoids the error inherent in measuring offsets in noncalibrated radiographs. TPA is the angle from T1 to femoral heads and a line from femoral heads to the center of S1 endplate, which integrates the information of T1–SPI and PT, showing superior correlations with radiographical parameters and HRQOL as compared with SVA, SSA, and C7–SFD. Moreover, as was stated for T1–SPI, TPA is an angular measurement, which does not bear the error inherent in measuring offsets in noncalibrated radiographs. With this consideration in mind, it is more reliable to compare data between centers where varying magnification factors may not be defined. In the emerging standard of digital images, an angular measure is also certainly easier to measure with on-screen tools that do not require calibration of distances.[2]

For severe adult scoliosis, corrective osteotomy is often performed to restore sagittal balance. Pedicle subtraction osteotomy is an increasingly used technique to correct sagittal imbalance and can obtain approximately 25° of increased lordosis when performed in the lumbar spine.[13,14] However, either undercorrection or overcorrection of PSO could generate unfavorable operative outcomes. To optimize the operative outcomes using PSO, several formulas have been developed to predict the required osteotomy degrees. Ondra *et al*[15] pioneered a method that uses a tangent function to calculate the size of the desired osteotomy. However, it fails to take pelvic parameters into account. Accordingly, even if the SVA is within the normal range, patients may still be compensating for a loss of lordosis through the pelvis, which can lead to decompensation and a poor clinical outcome (Figure 2). Lafage *et al*[16] developed a PI-based formula to predict postoperative sagittal alignment by predicting postoperative PT and SVA. Although it is valuable for calculating the required osteotomy angle for PSO, factors other than PT should also be considered. As the spine is not a rigid unit, the unfused segments are dynamic and allow for ongoing alignment changes to occur. Modification in unfused regions of the spine can generate a compensatory mechanism to obtain an optimal global alignment. The possibility and impact of modifications must be taken into account, particularly when short fusions have been increasingly applied in the treatment of adult scoliosis. Lafage *et al*[17] later designed a formula taking account

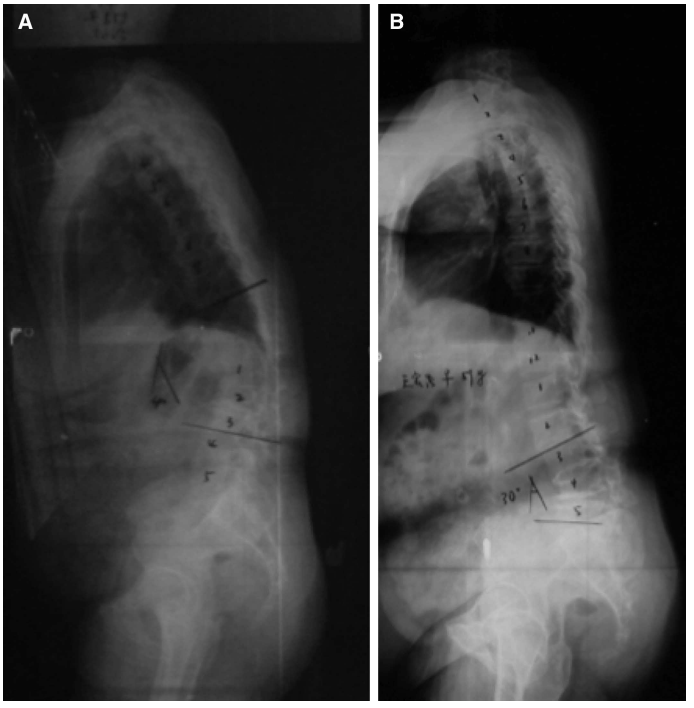

Figure 2. Patient A had a SVA of 98 mm, LL of 15°, and TPA of 29°, whereas patient B had a SVA of 102 mm, LL of −15°, and TPA of 40°. Two patients had similar global spinopelvic balance, but different regional balance. TPA could better represent global and regional sagittal balance. TPA indicates T1 pelvic angle; SVA, sagittal vertical axis; LL, lumbar lordosis.

all the mentioned factors, and got a satisfactory accuracy, but this formula entails too many calculation steps, each of which would add errors. Moreover, the formula proposed by Lafage *et al* did not take knee flexion into consideration, which is also an important compensatory mechanism.[18] TPA incorporates the information of spine and pelvis, reflecting the whole changes of the spine-pelvis unit without individually considering their changes. In addition, TPA only reflected the degenerative process of the spine itself, and is not influenced by postures or knee flexion. This study also demonstrated that the changes of TPA are significantly correlated to the changes of radiographical parameters and HRQOL. In a subgroup analysis for PSO, a strong correlation was also noted between the osteotomy degrees and the changes of TPA, which implied that TPA could be used to calculate the required osteotomy degrees for PSO. Further study is needed to establish a TPA-based formula to predict postoperative sagittal balance and calculate the required osteotomy degrees for PSO on a larger volume of patients.

CONCLUSION

TPA could better reflect the postoperative changes of sagittal alignment and the HRQOL for patients with adult scoliosis. Moreover, the changes of TPA are strongly correlated to the osteotomy degrees for PSO, and TPA could serve as a reference parameter in surgical planning.

➢ Key Points

- ❑ Using SVA to assess sagittal alignment fails to take account of the pelvic compensation.
- ❑ TPA integrates the information of SVA and PT.
- ❑ TPA could better reflect the postoperative changes of sagittal alignment and HRQOL for patients with adult scoliosis.
- ❑ The changes of TPA are strongly correlated to the osteotomy degrees for PSO and, TPA could be used as a reference parameter in surgical planning.

Acknowledgments

Authors Jun Qiao and Feng Zhu contributed equally to this study.

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