Lumbo-pelvic lordosis and the pelvic radius technique in the assessment of spinal sagittal balance: strengths and caveats

I. G. Sergides · Peter F. McCombe · G. White ·
Sabarul Mokhtar · William R. Sears

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Abstract

Introduction The two main methodologies described for the assessment of spinal sagittal alignment are the pelvic radius (PR) technique and that based on measures of the Pelvic Incidence (PI) and Spino-Sacral Angle (SSA). Both methods stress the fundamental relationship between the anatomical position and orientation of the sacrum within the pelvis and the spinal curves above. The aim of the current study was to assess the strengths and potential weaknesses of the PR technique. The PR technique uses measures based on a line (the PR), drawn between the hip axis and the posterior corner of the S1 endplate. The angle formed between the PR line and the sacral endplate, PRS1, is a developmental measure of sacropelvic morphology. Geometrically, PI and PRS1 are approximately complementary angles and both reflect reciprocal alterations in pelvic tilt (for PI) or angulation (for PRS1) and the slope of the S1 endplate. The angle formed between PR and T12,

the PR-T12, reflects a combined measure of pelvic morphology and lumbar lordosis. It appears to be a useful measure, which provides a simple and rapid assessment of lumbopelvic sagittal balance, but only in the presence of a congruent thoracic curvature.

Materials and methods After reviewing the literature, published measures made using the PR technique were compared to measures taken from a substantial patient population (479 adult patients).

Conclusions Errors can occur using the PR technique if the PRT12 is viewed in isolation from the thoracic kyphosis. We found the ratio of the thoracic kyphosis to lumbar lordosis (T4-T12/T12-S1) to be a useful predictor of congruent sagittal alignment, which may alert the clinician to situations where use of the PR-T12 in isolation may be misleading.

Keywords Spine · Sagittal balance · Pelvic radius

I. G. Sergides · W. R. Sears
Royal North Shore Hospital, Sydney, Australia

I. G. Sergides (✉) · W. R. Sears
Dalcross Private Hospital, Sydney, Australia
e-mail: ysergides@hotmail.com

I. G. Sergides · G. White · W. R. Sears
Sydney NeuroSpine Clinic, Sydney, Australia

P. F. McCombe
Royal Brisbane Hospital, Brisbane, Australia

P. F. McCombe
St Andrews War Memorial Hospital, Brisbane, Australia

S. Mokhtar
Australian School of Advanced Medicine, Macquarie University,
Sydney, Australia

Introduction

Understanding the diversity of human spinal shape and orientation is pivotal in appreciating how optimal alignment is achieved and how it may be restored in cases of sagittal imbalance.

Despite ongoing interest in understanding and describing the nature of the ‘normal’ curvature of the spine, there are no universally accepted parameters for its form [2–6, 9, 12–18, 20–24, 26–29]. Two principal methodologies which have been described for assessing the spine in the sagittal plane are the pelvic radius (PR) technique (Fig. 1a) [14, 17, 19] and that based on the pelvic incidence (PI) and the Spino-Sacral Angle (SSA) (Fig. 1b) [25, 27, 28]. Both methods stress that the anatomical position and orientation

Fig. 1 **a** Pelvic radius technique as described by Jackson. *HA* bisector of line joining the centres of both femoral heads, pelvic radius line from *HA* extended through posterior *S1* end plate, *PRnn* (where *nn* vertebral name) angle between the pelvic radius and the superior end plate of the named vertebrae, i.e. *PRT12* angle between pelvic radius and the *T12* vertebrae. **b** Pelvic incidence technique described initially by Legaye and Duval-Beaupère. *HA* bisector of line joining the centres

of both femoral heads, *PI* pelvic incidence (angle between a perpendicular to the sacral end plate and a line extending to the Hip Axis), *PT* pelvic tilt, *SS* sacral slope, *SSA* spino-sacral angle. Lumbar lordosis is split between upper and lower lordosis. The lordosis ends at the point of inflection (where the curve changes from concave to convex). The lordosis and Kyphosis tilt angles are measured with reference to a vertical line (removed for clarity)

of top of the sacrum in relation to the hip axis is relatively fixed throughout adult life and a fundamental determinant of the shape of the spinal curves above.

The concept that the sacrum and pelvis act as a sixth lumbar or pelvic vertebra was described by Dubousset [8]. Jackson [17] was one of those who took an early interest in the morphology of the sacrum and the variability of its spatial position and orientation with respect to the ilia. He described strong correlations between pelvic parameters and spinal shape using the fixed angle (*PRS1*), which is formed between a line (the pelvic radius or *PR*) drawn from the hip axis (*HA*) to the posterior point of the sacral end plate, and a line drawn along the sacral (*S1*) end plate [19]. This angle or parameter was conceptually referred to as the 'pelvic lordosis'. As the position and orientation of the sacrum within the pelvis (reflected in the *PRS1* angle) varies considerably between individuals, he postulated that it would be conceptually useful to define the orientation of

each vertebra (including the sacral end plate orientation) with respect to a reference frame that already included this variability. Spinal angular measures that include this pelvic measurement were defined as 'spinopelvic' measures. He referred to 'sagittal spinal balance' measures as those defining horizontal distance relationships between the *C7* and *T4* plumb lines with both the posterior *S1* endplate and the *HA*. With co-authors, he reported normative values for spinal sagittal alignment based on spinopelvic measures, spinal angular measures and the horizontal measures of various plumb lines, in 75 healthy volunteers [14]. Jackson et al. claimed that measurements involving the pelvis and sacrum, made with the *PR* technique (spinopelvic balance), were more reliable and, in cross-sectional studies, demonstrated less inter- and intra-observer variability than the plumb line measurements (sagittal spinal balance) taken from *C7* and *T4* [18]. Further, in a longitudinal study of 20 patients and 20 volunteers they found measures of

spinopelvic morphology using the PR technique were more reliable than spinal balance techniques involving plumb lines (which demonstrated lower correlation coefficients and greater variation between X-rays) [15]. Strong correlations between spinopelvic and sagittal balance measurements have been found by other authors using the PR technique [11].

This methodology of Jackson will, for the purposes of this paper, be defined as the ‘pelvic radius’ or PR technique. Based on this technique, Jackson defined four parameters for ‘congruent’ alignment: the total lumbopelvic lordosis (PR-T12); the pelvic angle (PA); the T4 sagittal plumbline and the thoracic kyphosis/lumbar lordosis ratio (T4-T12/PR-T12) [14].

The aim of this paper was to assess the strengths and potential weaknesses of the PR technique after reviewing the published measures made using the PR technique and comparing these to measures taken from a substantial patient population with mixed lumbar degenerative pathology (479 adult patients). Based on this review, potential errors in the assessment of sagittal balance, which can be made if the pelvic radius technique is not used correctly, are presented. Selected case studies are used to illustrate these.

Methods

Literature review

A review was conducted searching for articles reporting measures of spinal sagittal alignment using the PR technique, both in patients with spinal pathology and in normal healthy volunteers. The spinopelvic parameters studied included (Fig. 1a, b)

1. PR—the distance in millimetres between the HA and the posterior-superior corner of the S1 endplate
2. PRS1—the angle between the PR line and the endplate of S1
3. Pelvic angulation [PA]—the angle between the PR line and the vertical [a similar measure to Pelvic Tilt (PT) used in the PI technique]
4. Total lumbar lordosis [T12-S1] and thoracic kyphosis, both T1-T12 and T4-T12, measured using the Cobb technique
5. PR-T12—the angle between the an extension of the PR line and a line drawn along the T12 inferior endplate, a measure of total lumbo-pelvic lordosis
6. T4-T12/PR-T12 ratio
7. T4-T12/T12-S1 ratio
8. Measures of focal lordosis from superior endplates [L4-S1 and L5-S1]

9. Spinal balance measures [HA-T4, S1-T4 and the L1 plumb line (relative to S1 posterior-superior end plate)]

Spinal pathology cohort analysis

A study of sagittal spinal alignment was undertaken of 479 adult patients (age range 16–93 years, mean 66.8 years, 196 male, 343 female) from one unit operated on by one surgeon [WS] over a period of 10 years, using the PR technique. Inclusion criteria were

1. over 16 years of age
2. undergoing posterior lumbar interbody fusion for symptoms relating to degenerative or developmental lumbar spinal pathology, including:
 - (a) degenerative spondylolisthesis [DSPL]
 - (b) isthmic (lytic) spondylolisthesis [ISPL]
 - (c) flat back deformity [FBD]
 - (d) adult degenerative scoliosis [ADSC]

Radiographic data were derived from standing sagittal and coronal radiographs taken on a single 3-foot cassette with a Shimadzu R-20J erect X-Ray unit at a distance of 72 inches between the source and the cassette. Sagittal radiographs were obtained with the patients in a comfortable position with their hands on their heads and elbows forward. Measurements were acquired manually using the techniques described by Jackson et al. [8]. Inter- and intra-observer measurement reliability was determined for all parameters using data from subsets of patients (30 and 16 patients, respectively). Thereafter, based on satisfactory inter- and intra-observer reliability studies, one experienced observer made measurements.

Statistical analysis

1. Inter- and Intra-observer measurement reliability was assessed on 30 and 16 patients, respectively, by performing Spearman rank order correlations.
2. The data were analysed as a whole (ALL) and then subset analyses were carried out for the DSPL, ISPL and ADSC groups.
3. Comparisons were made to the available normative and patient data in the literature [14, 15, 17, 18].
4. Means and 95% confidence intervals (95% CI) were determined for the study population and derived from the published results of the PR technique. Non-parametric [Mann–Whitney test] methods were used for statistical comparison of the study population results. Lack of overlap of 95% CIs was taken to represent a significant difference between the study population and published mean values.

Table 1 Inter- and intra-observer correlation coefficients for measurements using the PR technique

Parameter	Correlation co-efficients	
	Inter-observer (<i>n</i> = 30)	Intra-observer (<i>n</i> = 16)
L1 plumb	0.99	0.95
Sacral inclination	0.87	0.81
L1-S1	0.97	0.96
T12-S1	0.96	0.98
T4-T12	0.80	0.96
PR	0.95	0.80
PRT12	0.98	0.92
PRL1	0.98	0.97
PRL2	0.99	0.98
PRL3	0.97	0.99
PRL4	0.99	0.98
PRL5	0.97	0.89
PRS1	0.96	0.98
L5-S1	0.91	0.84
PA	0.95	0.96
HA-S1	0.97	0.95
HA-SP	0.89	0.93
HA-T4	0.98	0.98
S1-T4	0.98	0.97
L4-T4	0.99	0.98

Results

The inter-observer and intra-observer correlation coefficients for PR measures in the sub-sample of the authors' series, evaluated for measurement reliability, are shown in Table 1. Aside from the L1 plumbline, Sacral Slope (SS) and thoracic kyphosis (T4-T12) measures, all correlation coefficients for intra- and inter-observer reliability were very strong [7]. Of note, correlation coefficients for observer agreement about PR-T12 and PRS1 were above 0.96.

Spinal pathology cohort analysis (*n* = 479)

The means, standard deviations and 95% CI's for all patients in the current study are shown in Table 2 (alongside results from the published literature). Significant differences (lack of overlap of 95% CIs) were found between published data for healthy volunteers and several of the measured parameters in the current study.

When all of the current study patients were analysed as a group, significant correlations were found between a number of spinopelvic parameters and also with a number of plumbline measures. These data and their related *p* values are displayed in Table 3. Of note, there was a strong

correlation between PRS1 and lumbar lordosis in all patients [$R = 0.57$], DSPL [$R = 0.53$] and ISPL [$R = 0.51$]. There was also a strong correlation between the L1 plumb line and PRS1 in all groups.

Thoracic kyphosis (T4-T12) had moderate correlation with lumbar lordosis and plumbline measurements but not with pelvic parameters, in the ALL group. This correlation was present but weaker in the subset analysis.

Degenerative (*n* = 194) and Isthmic (*n* = 50) spondylolisthesis sub-groups

Correlations between spinopelvic parameters for the DSPL and ISPL sub-groups are shown as in Tables 4 and 5, respectively. Pelvic angulation was observed to be strongly associated with PR-T12 and less strongly correlated with PRS1. The ISPL segmental kyphosis measures at L4-S1 and L5-S1 were very similar for the authors' and Jackson et al's groups. The authors' DSPL group showed a non-significant trend towards greater segmental kyphosis at these levels than either ISPL or Jacksons et al's volunteers.

The patients in the ISPL sub-group had significantly different values for several measures when compared with previously published data of ISPL patients [18]. In particular, PRS1 was significantly larger in the current study group than the previously studied ISPL patients, but still significantly smaller than PRS1 in healthy volunteers [14].

Discussion

In 1985, During et al. [10] described an angle formed between a line drawn along the S1 end plate and a line drawn from the centre of the S1 end plate to the central axis of the hip joints. Jackson [17] subsequently called this the pelvisacral angle. He modified it by moving the apex of the angle from the centre of the S1 end plate to the posterior margin: the PRS1 (Fig. 1a). Legaye and Duval-Beaupère went on to describe the complementary angle to During et al's pelvisacral angle: the pelvic incidence (i.e. $PI = 90^\circ - \text{pelvisacral angle}$; Fig. 1b) [25]. All of these angles are inherited and represent developmental morphological signatures of an individual [14, 15]. Geometrically, the PI is equal to the sum of the SS and PT—i.e. $PI = SS + PT$. For any individual, as the sacral slope changes, a reciprocal change occurs in the PT. Similarly, the PRS1 is the complementary angle to the sum of the SS and PA—i.e. $PRS1 = 90^\circ - (SS + PA)$. As $PT \approx PA$, it follows that PRS1 is approximately equal to the complement of the PI—i.e. $PRS1 \approx 90^\circ - PI$ (Fig. 2).

Jackson has reported intra- and inter-observer reliabilities to be similar for measurements of PR-T12, PI and PRS1 (the latter two requiring good visualisation of the S1

Table 2 Published and authors' results of pelvic radius and plumbline measures

	Jackson's volunteers (n = 75) [14]	Jackson's low back pain (n = 20) [15]	Jackson's ISPL (n = 75) [18]	WS mixed pathology (n = 479)	WS ISPL (n = 50)	WS DSPL (n = 194)	WS ADSC (n = 60)
PRSI	-32 ± 10 -[29.8 to 34.2]	-34 ± 12 -[28.8 to 29.2]	-14 ± 8 -[12.1 to 15.9]	-26 ± 12* -[24.9 to 27.1]	-24 ± 13*† -[20.5 to 27.5]	-24 ± 12* -[22.3 to 25.7]	-30 ± 10 -[27.5 to 32.5]
PR (mm)	137 ± 9 -[135 to 139]	-	137 ± 9	-	-	135 ± 11	138 ± 11 [135.2 to 140.8]
PA	-18 ± 6 -[16.7 to 19.3]	-17 ± 7 -[13.8 to 20.2]	-21 ± 6 -[19.6 to 22.4]	-27 ± 10* -[26.1 to 27.9]	-28 ± 8*† -[25.7 to 30.3]	-29 ± 7* -[27.9 to 30.1]	-30 ± 10* -[27.6 to 32.4]
PRT12	-92 ± 10 -[89.8 to 94.2]	-87 ± 8 -[83.3 to 90.7]	-89 ± 10 -[86.8 to 91.2]	-79 ± 15* -[77.6 to 80.4]	-77 ± 13*† -[73.7 to 80.3]	-81 ± 13* -[79.1 to 82.9]	-70 ± 15* -[66.1 to 73.9]
T12-S1	-62 ± 12 -[59.3 to 62.7]	-53 ± 14 -[46.6 to 59.4]	-75 ± 10 -[72.6 to 77.9]	-52 ± 19* -[50.2 to 53.8]	-53 ± 15*† -[48.7 to 57.3]	-57 ± 17* -[54.4 to 59.6]	-40 ± 15* -[36.1 to 43.9]
T4-T12	-38 ± 12 -[35.3 to 40.7]	-	-36 ± 11 -[33.6 to 38.4]	-39 ± 15 -[37.3 to 40.7]	-37 ± 14 -[32.9 to 41.1]	-42 ± 15 -[39.5 to 44.5]	-39 ± 15 -[34 to 44]
L4-S1	-39 ± n/a	-36 ± 12 -[30.5 to 41.5]	-45 ± n/a	-	-40 ± 12	-28 ± 10	-25 ± 23
L5-S1	-23 ± 10 -[20.6 to 25.4]	-23 ± 5 -[20.5 to 25.5]	-23 ± n/a	-	-23 ± 11	-17 ± 8	-22 ± 10
HA-T4 (mm)	-71 ± 22 -[66.1 to 75.9]	-	-70 ± 29 -[63.6 to 76.6]	-67 ± 41 -[62.5 to 71.5]	-65 ± 37 -[54.9 to 66.1]	-71 ± 36 -[64.9 to 77.1]	-69 ± 41 -[55.3 to 82.7]
S1-T4 (mm)	-31 ± 23 -[25.8 to 36.2]	-	-	-7 ± 44 -[2.1 to 11.9]	-2 ± 43 [-15 to +11]	-8 ± 39 -[1.4 to 14.6]	-1 ± 47 [-16.7 to +14.7]
L1-S1 Plumb (mm)	-	-	-	-18 ± 30 -[15.3 to 20.7]	-21 ± 29 -[13 to 29]	28 ± 28 -[24 to 32]	1 ± 25 [-4.7 to +6.7]
Ratios							
T1-T12/ T12-S1	-0.75 ± 0.15 [±0.03]	-0.84 ± n/a	-0.59 ± 0.14 [±0.03]	-	-	-	-
T1-T12/ PRT12	-0.49 ± 0.09 [±0.02]	-0.50 ± n/a	-0.50 ± 0.12 [±0.03]	-	-	-	-
T4-T12/ T12-S1	-	-	-	-0.78 ± 0.4 [±0.04]	-0.71 ± 0.27 [±0.08]	-0.75 ± 0.34 [±0.06]	-1.1 ± 0.7 [±0.2]
T4-T12/ PRT12	-0.41 ± 0.11 [±0.02]	-	-0.40 ± 0.11 [±0.02]	-0.50 ± 0.2 [±0.02]	-0.47 ± 0.19 [±0.06]	-0.51 ± 0.18 [±0.03]	-0.6 ± 0.3 [±0.1]

The means and standard deviations (°) are displayed for each value. 95% Confidence Intervals for the means are shown in square brackets [95% CI]. The kyphosis/lordosis ratios are displayed below the measurements

* Denotes a significant difference in values when compared with Jackson et al's 75 volunteers (lack of overlap of 95% CIs)

† Denotes a significant difference in values between Jackson et al's patients with ISPL and the patients in the current study

Table 3 A correlation coefficient matrix of values obtained using the PR technique (Spearman *R* values and their related *p* values) for all patients in the current study

Variables	L1-S1	L1 plumb	T12/S1	T4/T12	PRT12	PRS1	Pelvic angle	HAT4	S1T4
<i>R</i> values									
L1-S1 lordosis	1	−0.16	0.92	−0.40	−0.65	0.52	0.26	0.21	0.30
L1 plumb	−0.17	1	−0.23	−0.16	−0.21	−0.56	0.23	0.41	0.49
T12/S1	0.92	−0.23	1	−0.39	−0.68	0.57	0.26	0.23	0.33
T4/T12	−0.40	−0.16	−0.39	1	0.40	−0.08	0.04	−0.15	−0.12
PRT12	−0.65	−0.21	−0.68	0.40	1	0.13	−0.69	−0.43	−0.66
PRS1	0.52	−0.56	0.57	−0.08	0.13	1	−0.38	−0.15	−0.28
Pelvic angle	0.26	0.23	0.26	0.04	−0.69	−0.38	1	0.00	0.36
HAT4	0.21	0.41	0.23	−0.15	−0.43	−0.15	0.00	1	0.91
S1T4	0.30	0.49	0.33	−0.12	−0.66	−0.28	0.36	0.91	1
<i>p</i> values									
L1-S1 lordosis	0	−0.16	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.000	<0.0001
L1 plumb	0.000	0	<0.0001	0.003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T12/S1	<0.0001	<0.0001	0	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T4/T12	<0.0001	0.003	<0.0001	0	<0.0001	0.13	0.49	0.009	0.030
PRT12	<0.0001	<0.0001	<0.0001	<0.0001	0	0.007	<0.0001	<0.0001	<0.0001
PRS1	<0.0001	<0.0001	<0.0001	0.13	0.007	0	<0.0001	0.010	<0.0001
Pelvic angle	<0.0001	<0.0001	<0.0001	0.49	<0.0001	<0.0001	0	0.94	<0.0001
HAT4	0.000	<0.0001	<0.0001	0.009	<0.0001	0.010	0.94	0	<0.0001
S1T4	<0.0001	<0.0001	<0.0001	0.030	<0.0001	<0.0001	<0.0001	<0.0001	0

Table 4 A correlation coefficient matrix of values obtained using the PR technique (Spearman *R* values and their related *p* values) for patients in the current study with DSPL

Variables	L1 plumb	T12/S1	T4/T12	Pelvic radius	PRT12	PRS1	Pelvic angle	HAT4	S1T4
<i>R</i> values									
L1 plumb	1	−0.12	−0.22	−0.07	−0.37	−0.56	0.31	0.39	0.46
T12/S1	−0.12	1	−0.36	0.26	−0.58	0.53	0.22	0.29	0.43
T4/T12	−0.22	−0.37	1	0.06	0.43	−0.03	−0.04	−0.15	−0.15
Pelvic radius	−0.07	0.26	0.06	1	−0.03	0.30	−0.10	0.01	0.08
PRT12	−0.37	−0.58	0.43	−0.03	1	0.26	−0.72	−0.44	−0.68
PRS1	−0.56	0.53	−0.03	0.30	0.26	1	−0.43	−0.10	−0.19
Pelvic angle	0.31	0.22	−0.04	−0.10	−0.72	−0.43	1	−0.07	0.28
HAT4	0.39	0.29	−0.15	0.01	−0.44	−0.10	−0.07	1	0.90
S1T4	0.46	0.43	−0.15	0.08	−0.68	−0.19	0.28	0.90	1
<i>p</i> values									
L1 plumb	0	0.101	0.011	0.350	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T12/S1	0.101	0	<0.0001	0.000	<0.0001	<0.0001	0.004	0.001	<0.0001
T4/T12	0.011	<0.0001	0	0.521	<0.0001	0.735	0.615	0.084	0.080
Pelvic radius	0.350	0.000	0.521	0	0.713	<0.0001	0.167	0.943	0.332
PRT12	<0.0001	<0.0001	<0.0001	0.713	0	0.000	<0.0001	<0.0001	<0.0001
PRS1	<0.0001	<0.0001	0.735	<0.0001	0.000	0	<0.0001	0.274	0.028
Pelvic angle	<0.0001	0.004	0.615	0.167	<0.0001	<0.0001	0	0.421	0.001
HAT4	<0.0001	0.001	0.084	0.943	<0.0001	0.274	0.421	0	<0.0001
S1T4	<0.0001	<0.0001	0.080	0.332	<0.0001	0.028	0.001	<0.0001	0

Table 5 A correlation coefficient matrix of values obtained using the PR technique (Spearman *R* values and their related *p* values) for patients in the current study with ISPL

Variables	L1 plumb	T12/S1	T4/T12	PR	PRT12	PRS1	Pelvic angle	HAT4	S1T4
<i>R</i> values									
L1 plumb	1	−0.13	−0.09	−0.08	−0.43	−0.60	0.49	0.37	0.47
T12/S1	−0.13	1	−0.43	0.23	−0.60	0.51	0.17	0.34	0.32
T4/T12	−0.09	−0.43	1	−0.06	0.36	−0.22	0.20	−0.32	−0.17
Pelvic radius	−0.08	0.23	−0.06	1	−0.03	0.22	−0.15	−0.17	−0.18
PRT12	−0.43	−0.60	0.36	−0.03	1	0.33	−0.74	−0.62	−0.76
PRS1	−0.60	0.51	−0.22	0.22	0.33	1	−0.59	−0.22	−0.39
Pelvic angle	0.49	0.17	0.20	−0.15	−0.73	−0.59	1	0.30	0.59
HAT4	0.37	0.34	−0.32	−0.17	−0.62	−0.22	0.30	1	0.93
S1T4	0.47	0.32	−0.17	−0.18	−0.76	−0.39	0.59	0.93	1
<i>p</i> values									
L1 plumb	0	0.376	0.552	0.594	0.002	<0.0001	0.001	0.016	0.002
T12/S1	0.376	0	0.005	0.120	<0.0001	0.000	0.241	0.026	0.037
T4/T12	0.552	0.005	0	0.704	0.017	0.164	0.203	0.041	0.287
Pelvic radius	0.594	0.120	0.704	0	0.856	0.124	0.300	0.274	0.260
PRT12	0.002	<0.0001	0.017	0.856	0	0.022	<0.0001	<0.0001	<0.0001
PRS1	<0.0001	0.000	0.164	0.124	0.022	0	<0.0001	0.154	0.011
Pelvic angle	0.001	0.241	0.203	0.300	<0.0001	<0.0001	0	0.053	<0.0001
HAT4	0.016	0.026	0.041	0.274	<0.0001	0.154	0.053	0	<0.0001
S1T4	0.002	0.037	0.287	0.260	<0.0001	0.011	<0.0001	<0.0001	0

end plate) [18]. With the exception of PRS1, measurements can be made using the PR method without the need to identify the entire S1 end plate. Factors such as sacral doming seen in high-grade spondylolisthesis [23], or previous surgery may inhibit clear delineation of the S1 end plate. With the PI method, clear visualisation of the S1 end plate and cervico-thoracic junction is important.

On dedicated whole spine standing lateral images, the C7 end plates are reported to be visible in 50–52% of cases [12, 14, 15]. The current authors' experience supports the reported difficulty in visualising this landmark and T4 has consequently been chosen as the primary point of reference for plumbline measurements. In an effort to overcome this some authors use digitalised images, which are analysed with specialised software. They have found this to be superior to manual evaluation [1, 4, 27, 29]; however, this software is not universally available.

Some spinopelvic measurements show a considerable range in cross-sectional studies of volunteers and patients [14]. In a study of 20 patients and 20 volunteers, Jackson et al. [15] stated pelvic radius techniques were more reliable than plumbline measurements which demonstrated lower inter-observer correlation coefficients. The results from our studies would support this observation. The weakest correlation coefficients in our inter-observer studies were for plumbline measurements. In longitudinal

studies, considerable variabilities in plumblines have been shown within the same subject [12, 30].

Jackson et al. devised several PR parameters which, if fulfilled, constituted 'congruent' spinal alignment so long as the C7 plumb line was no more than 3 cm in front of the HA. For 'congruent' alignment they proposed [14]

1. the PR-T12 must be between −70 and −110
2. the PA must be between −3 and −33
3. the T4-T12/PR-T12 ratio must be between 0.15 and 0.75

PR-T12 represents the sum of PRS1 and the T12-S1 lordosis. Consequently, as PRS1 increases or decreases, a reciprocal change is evident in the lumbar lordosis. The net result of this is a relatively constant value for lumbopelvic lordosis [PR-T12] of $90^\circ \pm 10^\circ$ (Fig. 3). In accordance with this observation, the correlation coefficient between measures of PR-T12 and PRS1 in the current study is weak.

Independently, PR-T12 appears to be a useful parameter for rapidly assessing the lumbar sagittal balance, but it is very important to note that it should not be viewed in isolation from the spine above. Normally, the lordosis of the lumbar spine is balanced by the kyphosis of the thoracic spine, i.e. their alignment is congruent (Fig. 3). Jackson et al. [15] attempted to define congruent alignment between the thoracic and lumbar spine using the T4-T12/PRT12 ratio.

Fig. 2 A schematic diagram of the lumbo-pelvic spine illustrating the two measures of spino-pelvic morphology, the PRS1 and the Pelvic Incidence (PI), their relationship to sacral slope (SS) and pelvic angulation or tilt (PA or PT) and between each other ($PRS1 \approx 90^\circ - PI$)

Fig. 3 Drawings of theoretical spinal shapes based on variability of the pelvic parameter PRS1 for 5° (a), 25° (b) and 40° (c). The drawings have been constructed such that PRT12 remains constant at 90° , two-thirds of the lumbar lordosis occur at L4/5 and L5/1 and the total thoracic kyphosis is spread evenly between all thoracic segments. The thoracic kyphosis was adjusted to approximate a reasonable value for the spinosacral angle (SSA). The Pelvic angulation was adjusted to make the plumblines appear reasonable

In their publication which contrasted PR measures in normal volunteers and patients with spondylolisthesis, they reported that a T4-T12/PR-T12 ratio of less than 0.75 is necessary for congruent sagittal plane alignment [15]. However, only a negligible difference was evident in the ratio between the 75 normal adult volunteers and 75 patients with spondylolisthesis (0.41 vs. 0.40, respectively) [18]. This was probably due to the lack of difference in the PR-T12 values seen between these two groups (-93.7 and

-88.8° , respectively). The relatively constant PR-T12 was evident, despite the large difference in the mean measured PR-S1 angles of 30.9 and 14.1° , respectively. The compensation was provided by the mean 12.4° increase in lumbar lordosis.

Unlike the relatively similar T4-T12/PR-T12 ratios of these two patient groups of Jackson et al. [18], a significant decrease was evident if one instead examines the T1-T12/T12-S1 ratio: 0.75 and 0.59, respectively. Accordingly, the

Fig. 4 A standing lateral radiograph of a 54-year-old man with Scheuermann's kyphosis and lumbar and thoracic back pain. The T4T12/PRT12 ratio = 0.71 but the T4T12/T12S1 ratio is 0.87

current authors suggest that the T1-T12/T12-S1 ratio may provide a better reflection of changes, which occur in sagittal curvatures to maintain congruent alignment, as the denominator used in this ratio (T12-S1 or total lumbar lordosis) is not the relatively constant PR-T12 (Fig. 3). In the case of Jackson et al's 75 ISPL patients [18], the value of this ratio falls because as the lumbar lordosis increases (to compensate for the focal spondylolisthesis deformity), the thoracic kyphosis remains unchanged (45 and 43° for the two groups—ISPL and healthy volunteers). When considering the spine as a whole, we believe use of the T1-T12/T12-S1 ratio to assess the extent of surgical correction of lumbar lordosis is less likely to result in under-correction than the T1-T12/PR-T12 ratio. Further, to avoid difficulties with clear visualisation of the cervico-thoracic junction the T4-T12/T12-S1 ratio may be preferable. Figure 4 illustrates a case in which this ratio may be of value. The T4-T12/PRT12 ratio is 0.71 suggesting congruent alignment, but the T4-T12/T12-S1 ratio is 0.87 which suggests that a larger lumbar lordosis is required.

Fig. 5 Standing lateral radiographs of a 76-year-old male who presented with increasing back pain on standing and walking. He had previously undergone a L3-L5 laminectomy for spinal canal stenosis and had developed thoraco-lumbar osteoporotic wedge compression fractures. The PR-T11 is 50°, the PR-T12 65° is and the PR-L1 81° illustrating the marked effect of wedge fractures in the vicinity of the thoracolumbar junction on the PR measurements

It has been noted that T12 may not actually be the junction between the thoracic kyphosis and the lumbar lordosis. Roussouly [5, 27] observed that the end points of the spinal curvatures are in fact points of inflection: where the 'curvature' changes direction. He identified that these points were not necessarily at the thoracolumbar junction. This has obvious ramifications for interpretation of the PR-T12 measure, depending upon the location of the inflection point. Similarly, consideration must be given to the presence of wedge fractures or other kyphotic deformities in the vicinity of the thoracolumbar junction. In such circumstances, interpretation of spinal balance, based on PR-T12 will vary profoundly depending on the exact location of these fractures, above or below T12. Figure 5 illustrates the profound effect on global sagittal balance of an angular deformity above the inferior endplate of T12 (to where the PR-T12 measure is taken). In this figure the PRL1 is 81° but the PRT12 reduces dramatically to 65° due to the presence of wedge fractures at the thoracolumbar junction. Therefore, it is important if and when using the PR-T12 measure for a 'rapid' assessment of lumbar sagittal balance that the thoracic kyphosis is taken into account, noting the presence of any focal kyphotic deformity above T12 or more overall thoracic kyphosis, which may be seen in cases

such as Schuermann's disease. It may be that in cases of focal kyphosis that the angle measured between the pelvic radius and the inflection point (the PR-Inflection Point) will be more constant and useful. This requires further investigation in healthy volunteers.

Conclusion

Over the past decade, there has been increasing recognition of the importance of maintaining or restoring spinal sagittal balance. It is important therefore that clinicians have a way of assessing and describing sagittal alignment and balance to aid diagnosis and plan surgical management. It should be reliable and preferably, simple.

The Jackson et al. PR technique, described in 1998/2000, is a simple way of rapidly, and visually assessing lumbopelvic sagittal balance on a standard lateral lumbar radiograph and assessing the degree of correction required but consideration must be given to anomalies of sagittal balance, elsewhere in the spine.

The PR-T12 is a useful and overall measure of lumbopelvic lordosis. It normally approximates a right angle. It is relatively constant in healthy individuals and has a narrow standard deviation. A PR-T12 under 70° suggests the presence of flat back deformity but the PR-T12 must not be considered in isolation from the thoracic spine. An apparently normal PRT12 value may not be sufficient in the presence of an excessive thoracic kyphosis.

Pelvic radius (PR) technique key points

1. In any individual, a low PRS1 predisposes to the development of a large lumbar lordosis. Conversely, a large PRS1 is normally associated with a shallow lumbar lordosis.
2. The PR-T12 relatively constant in healthy individuals and has a narrow standard deviation. A PR-T12 under 70° suggests the presence of flat back deformity.
3. The PR-T12 must not be considered in isolation from the thoracic spine.
4. In cases where the inflection point between the thoracic and lumbar curves is above the T12/L1 level, the PR-Inflection point angle may prove to be a more reliable measure of lumbar sagittal balance.
5. In cases of focal thoracic kyphotic deformity and especially, those immediately above the T12/L1 junction, the PR-T12 is likely to underestimate the required lumbar lordosis to achieve congruent spinal balance (Fig. 5).
6. In a balanced spine, the thoracic kyphosis should reflect the lumbar lordosis (Fig. 3). Therefore, in the presence of a pathologically large thoracic kyphosis

while the pelvic radius measures for the lumbar spine may appear to be appropriate, the lumbar lordosis may need to be substantially larger.

7. The T4-T12/T12-S1 ratio should be between 0.15 and 0.75 for congruent alignment [15, 18].

Conflict of interest None.

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