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ORIGINAL ARTICLE

Cervical sagittal deformity develops after PJK in adult thoracolumbar deformity correction: radiographic analysis utilizing a novel global sagittal angular parameter, the CTPA

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Abstract

Purpose To describe reciprocal changes in cervical alignment after adult spinal deformity (ASD) correction and subsequent development of proximal junctional kyphosis (PJK). This study also investigated these changes using two novel global sagittal angular parameters, cervical–thoracic pelvic angle (CTPA) and the T1 pelvic angle (TPA).

Methods Multicenter, retrospective consecutive case series of ASD patients undergoing thoracolumbar three-column osteotomy (3CO) with fusion to the pelvis. Radiographs were analyzed at baseline and 1 year post-operatively. Patients were substratified into upper thoracic (UT; UIV T6 and above) and lower thoracic (LT; UIV below T6). PJK was defined by >10° angle between UIV and UIV + 2 and >10° change in the angle from baseline to post-op.

Results PJK developed in 29 % (78 of 267) of patients. CTPA was linearly correlated with cervical plumbline (CPL) as a measure of cervical sagittal alignment ($R = 0.826$, $p < 0.001$). PJK patients had significantly greater post-operative CTPA and SVA than patients without PJK (NPJK) ($p = 0.042$; $p = 0.021$). For UT ($n = 141$) but not LT ($n = 136$), PJK patients at 1 year had larger CTPA (4.9° vs. 3.7°, $p = 0.015$) and CPL (5.1 vs. 3.8 cm, $p = 0.022$) than NPJK patients, despite similar corrections in PT and PI-LL.

Conclusions The prevalence of PJK was 29 % at 1 year follow-up. CTPA, which correlates with CPL as a global analog of cervical sagittal balance, and TPA describe relative proportions of cervical and thoracolumbar deformities. Patients who develop PJK in the upper thoracic spine after thoracolumbar 3CO also develop concomitant cervical sagittal deformity, with increases in CPL and CTPA.

Keywords Proximal junctional kyphosis · Cervical alignment · Sagittal alignment · Adult spinal deformity · Three-column osteotomy

Introduction

Proximal junctional kyphosis (PJK) is a common complication following surgery for adult spinal deformity (ASD), with rates in the literature ranging from 11 to 41 % [1–5]. PJK has been defined as greater than 10° change in kyphosis between the upper instrumented vertebra (UIV) and the vertebra 2 segments cranial to the UIV (UIV + 2) [2–4, 6–9]. Risk factors reported for the development of PJK include age, combined anterior/posterior fusion, fusions to the sacrum, and larger deformity corrections [2, 5, 10]. Studies have described recurrent deformity

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following PJK, but these descriptions have primarily focused on measurements of thoracolumbar or sacral nature [2, 3]. In a study on ASD surgery, O'Shaughnessy et al. found that fusions to the upper thoracic spine had higher prevalence of revision surgery and more complications, whereas fusions to the lower thoracic spine had a higher rate of PJK [11].

Reciprocal changes in adjacent regional spinal alignment have been described after ASD surgery [12, 13]. Reciprocal thoracic hyperkyphosis occurs across unfused segments following lumbar osteotomy, while thoracic osteotomies and limited fusions for the correction of thoracic kyphosis result in decreased lumbar lordosis [13, 14]. Smith et al. demonstrated that patients with thoracolumbar sagittal malalignment have reciprocal cervical hyperlordosis which resolves following correction of the underlying thoracolumbar deformity [15].

However, little is known regarding the extent to which PJK affects adjacent regional alignment, especially cervical sagittal deformity. This study introduces a novel radiographic measure, the cervico-thoracic pelvic angle (CTPA), an angular measure of cervical sagittal alignment used to describe the effect of PJK on adjacent sagittal spinal alignment. The recently described T1 pelvic angle (TPA) is a measure of global angular thoracolumbar deformity that correlates with disability [16]. The CTPA and TPA define the relative proportions of cervical and thoracolumbar deformity, respectively.

The purpose of this study was to investigate changes in cervical sagittal alignment after PJK following three-column osteotomy (3CO) using CTPA and TPA. This study seeks to further correlate CTPA and TPA with established linear measures of deformity, CPL and SVA.

Materials and methods

Patient selection

This study was a multicenter retrospective review of 567 patients who underwent 3CO and had baseline radiographic data. Data were collected at eight sites across the United States with institutional review board approval. Inclusion criteria for this database included age >18 years, full-standing scoliosis radiographs with visualization of C2 to the femoral heads and thoracic or lumbar 3CO (Schwab grade 3 or 4) [17]. For this analysis, patients were included only if they had 3CO in the lumbar or thoracic spine, extension of fusion to the pelvis, and minimum 1-year follow-up. Patients were substratified based on the upper instrumented vertebra (UIV) into upper thoracic (UT) with UIV T6 and above, and lower thoracic (LT) with UIV at T7 and below.

Data collection

Demographic data, perioperative characteristics, and preoperative and post-operative radiographs were collected at each site. Office charts were reviewed for demographic variables including, age, height, weight, sex and history of prior surgery.

Radiographic parameters

Radiographs before surgery and at 1 year after surgery were obtained. Sagittal cervical, thoracolumbar and spinopelvic parameters were measured using Spineview software (Laboratory of Biomechanics, ENSAM ParisTech, Paris, France), a validated and computer-based tool that enables quantitative measures of the spine and pelvis. Pre-operative thoracolumbar deformity severity was quantified using the SRS-Schwab classification of adult spinal deformity [17].

- The proximal junctional angle was measured by the angle between the UIV and the vertebra 2 segments cranial to UIV (UIV + 2) and considered to be PJK if angle was >10° and the change in the angle from baseline to post-op was >10°.
- Cervical radiographic parameters included C2 slope (C2S), C2–C7 plumbline (CPL), C2–C7 lordosis (CL), T1 slope (TS), and T1 slope minus cervical lordosis (TS-CL).
- Thoracolumbar and spinopelvic radiographic parameters included T2–T12 thoracic kyphosis (TK_T2), T4–T12 thoracic kyphosis (TK_T4), L1–S1 lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and pelvic incidence minus lumbar lordosis (PI–LL).
- Global radiographic parameters (Fig. 1) included sagittal vertical axis (SVA), cervico-thoracic pelvic angle (CTPA), C2 pelvic angle (CPA) and T1 pelvic angle (TPA).

Statistical analysis

Analysis of total population radiographic and demographic parameters was conducted. Correlation of existing and novel radiographic parameters was performed. The CTPA and TPA were further correlated with established linear plumbline measures of cervical and thoracolumbar sagittal deformity, such as the C2–C7 cervical plumbline (CPL) and the sagittal vertical axis (SVA). A linear regression

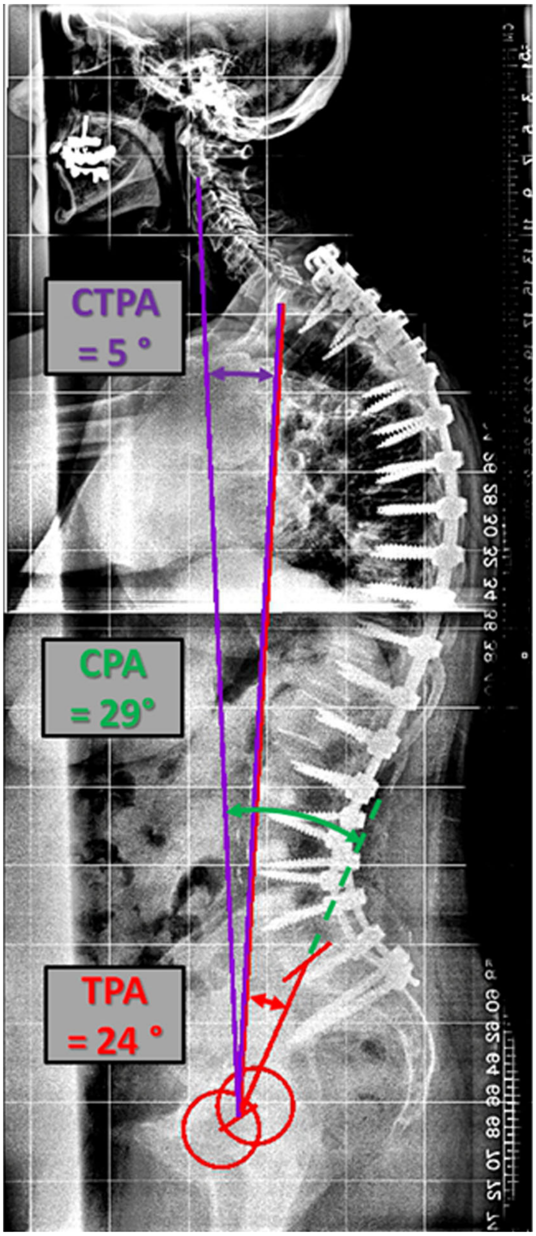

Fig. 1 Global radiographic parameters: CTPA, which is the angle of a line from center of C2 to femoral heads (FH) and a line from FH to center of T1, is a global angular measure of cervical sagittal balance and a correlate of the C2–C7 plumbline. TPA is a global sagittal alignment measure that correlates with C7 SVA and is measured by the angle of a line from the center of T1 to the FH and a line from the FH to the center of the S1 endplate. CPA (C2 pelvic angle) is the angle of a line from C2 centroid to the femoral heads (FH) and a line from the FH to the middle of the S1 endplate. CTPA is the result of subtracting the TPA from the CPA (CTPA = CPA − TPA)

analysis was performed to determine the threshold of CTPA that corresponds to a CPL of 4 cm.

Radiographic parameters between groups (UT-PJK vs. UT-NoPJK and LT-PJK vs. LT-NoPJK) were compared using unpaired *t* test analysis. Radiographic correlations were analyzed within the groups using Pearson's correlations. Level of significance was set to 0.05.

Results

Study sample

There were 550 eligible patients in the database based on general inclusion criteria, and 385 (70 %) had 1-year follow-up data. A total of 267 consecutive patients met additional criteria of thoracolumbar 3CO and fusion to pelvis. The mean age was 59.1 years (range 20–82 years) with 67 % female patients and average body mass index 28.0 kg/m^2 (SD 5.9 kg/m^2). The majority of patients ($n = 227$, 85 %) had a history of prior spine surgery. The majority of patients had lumbar osteotomy (94 %) and 5.6 % of patients had thoracic osteotomy. The most common osteotomy sites were L3 (36 %) and L4 (27 %). Of the 15 patients who had thoracic osteotomies, T12 was the most common site ($n = 6$).

Entire cohort: radiographic parameters

As shown in Table 1, analysis of the pre-operative radiographic parameters by SRS-Schwab classification revealed that 72 % of patients had marked global malalignment (SVA >9.5 mm), 81 % had marked PI-LL mismatch (PI-LL >20°) and 57 % had marked pelvic tilt (PT >30°). Post-operatively, 17 % had marked SVA, 20 % of patients had marked PI-LL, and 26 % had marked PT. As shown in Table 1, the comparison of pre-operative and post-operative radiographic parameters revealed significant changes, with the exception of C2C7 plumbline and T1 slope.

Cervico-thoracic pelvic angle (CTPA) correlated strongly with C2–C7 plumbline (CPL) as an angular analog to this linear measure of cervical alignment with pre-operative $R = 0.826$ and $R^2 = 0.682$ ($p < 0.001$), and post-operative $R = 0.912$ and $R^2 = 0.832$ ($p < 0.001$) (Fig. 2). Utilizing linear regression analysis, a CTPA value of 2.7° was found to correspond to CPL of 4.0 cm.

PJK vs. NPJK

PJK developed in 29.2 % (78 of 267) of the entire patient population. There were no significant differences between the PJK and NPJK groups in terms of, age, sex, BMI, magnitude of correction, pre-operative cervical alignment by CPL or CTPA and global alignment by SVA or TPA before or after surgery (Table 2). In the entire population, the proximal junctional angle was 10.1° ± 18.3° (range 125.8°) at baseline and 14.9° ± 14.4° at 1 year (range 81.7°).

Table 1 Comparison of the pre-operative and post-operative radiographic parameters following 3CO (paired *t* test)

	Pre-op		1 year		p
	Mean	SD	Mean	SD	
C2–C7 plumbline (CPL) (mm)	38.9	19.6	38.2	19.6	0.524
C2 slope (C2S)	15.2	14.2	18.4	13.6	0.002*
Cervical lordosis (CL)	17.2	16.8	10.5	16.8	<0.0001*
T1 slope (T1S)	34.4	16.1	28.3	13.6	<0.0001*
T1 slope minus CL (TS-CL)	16.1	14.3	18.7	13	0.0159*
T2_T12 kyphosis (TK_T2)	−30.9	21.7	−45.8	17.6	<0.0001*
T4_T12 kyphosis (TK_T4)	−28.9	20.5	−38.9	16.5	<0.0001*
Lumbar lordosis (LL)	23.5	20.6	52.7	14.8	<0.0001*
Pelvic tilt (PT)	33	11.3	24.4	11	<0.0001*
PI minus LL (PI-LL)	36.6	29.4	6.7	17.4	<0.0001*
Sagittal vertical axis (SVA) (mm)	150	77	42.7	62	<0.0001*
Cervico-thoracic pelvic angle (CTPA)	2.54	2	3.59	1.91	<0.0001*
C2 pelvic angle (CPA)	40.3	13.5	23.5	12.4	<0.0001*
T1 pelvic angle (TPA)	38.2	13.5	21.1	12.3	<0.0001*
PJK angle	9.9	18.2	15.6	13.9	0.006*

All values are in degrees (°) unless otherwise specified. Statistical significance ($p < 0.05$) is denoted by asterisk (*)

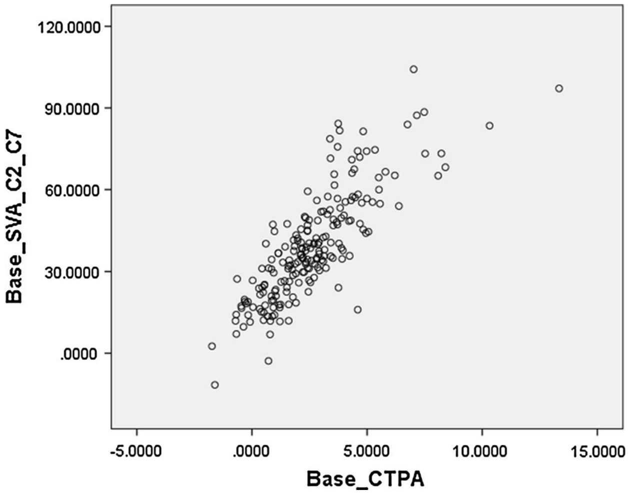

Fig. 2 *Scatter plot* depicting the relationship between cervico-thoracic pelvic angle (CTPA) and the C2–C7 plumbline (CPL). CTPA correlated with CPL at baseline with $R = 0.826$ and R2 $= 0.682$ ($p < 0.001$). This correlation was even stronger at 1 year post-operatively, with $R = 0.912$ and R2 $= 0.832$, ($p < 0.001$)

LT vs. UT

There were 141 patients (51 %) in the UT group and 136 patients in the LT group (49 %). The groups were similar in age (UT 60.6 ± 11.4 years; LT 59.2 ± 10.6 years; $p = 0.303$). PJK developed in 27 % of the UT group (38 of 141), and 29.4 % (40 of 136) in the LT group. There was no significant difference between the UT and LT PJK rates ($p = 0.514$). In patients with no PJK, the post-operative radiographic parameters were similar between the UT and LT groups; the only difference was the baseline proximal junctional angle, which was significantly greater in the UT-NPJK group (13.2°) than the LT-NPJK group (3.1°; $p = 0.014$). However, the post-operative proximal junctional angle was similar in the UT-NPJK and LT-NPJK groups (11.6° vs. 9.6°; $p = 0.456$).

In the patients who developed PJK, there were no significant differences in baseline radiographic parameters between UT and LT (Table 3). However, at 1 year post-operatively, the PJK patients who were fused to the UT had significantly greater CTPA than the PJK patients fused to the LT (4.9° vs. 2.9°; $p = 0.025$). In addition, these UT patients with PJK had significantly greater T1S (34.2° vs. 26.2°; $p = 0.010$). There were no differences between UT-PJK and LT-PJK patients in baseline proximal junctional angle ($p = 0.292$) or the change in this angle from baseline to 1 year ($p = 0.416$). However, the UT-PJK patients had a significantly smaller proximal junctional angle at 1 year (18.7°) than LT-PJK patients (25.1°; $p = 0.007$).

UT cohort: PJK vs. No PJK ($n = 141$)

Post-operatively, UT-PJK patients had larger cervical sagittal deformity in terms of CTPA (4.9° vs. 3.7°, $p = 0.015$), CPL (5.1 vs. 3.8 cm, $p = 0.022$) than UT-NPJK patients (Table 4). The UT patients had paradoxical increases in CTPA from pre-op to post-op but UT-PJK patients had greater paradoxical changes in CTPA (UT-PJK $\Delta + 2.32°$, standard error 0.45° vs. UT-NPJK

Table 2 Demographic and radiographic data [pre-operative (pre), 1-year post-operatively (post), and change from baseline to follow-up] for PJK and NoPJK groups

Parameters	No PJK ($n = 78$)	PJK ($n = 189$)	p
Age (years)	58.2	60.9	0.1
BMI (kg/m^2)	28.2	28.1	0.94
C2C7PL (pre)	37.2	39.3	0.55
C2C7PL (post)	34.7	39.8	0.11
CTPA (pre)	2.5°	2.5°	0.85
CTPA (post)	3.1°	3.9°	0.042*
Change CTPA	Δ + 0.7°	Δ + 1.5°	0.004*
SVA (pre)	142	153	0.32
SVA (post)	55.9	33.8	0.021*
Change SVA	Δ − 88	Δ − 123	0.002*
TPA (pre)	37.5°	38.9°	0.46
TPA (post)	23°	20°	0.112
Change TPA	Δ − 14.9°	Δ − 18.9°	0.016*
LL (pre)	26.8°	22°	0.1
LL (post)	51.2°	56°	0.027*
PT (pre)	33.1°	33.6°	0.74
PT (post)	24.9°	24.1°	0.63
PI-LL (pre)	36.0°	37.5°	0.61
PI-LL (post)	10.3°	3.3°	0.006*
PJK angle (pre)	7.4°	10.8°	0.327
PJK angle (post)	10.8°	22.1°	<0.001*
Change PJK angle	Δ + 9.0°	Δ + 20.2°	<0.001*

Statistical significance ($p < 0.05$) between No PJK and PJK is denoted by asterisk (*). All units in degrees except age, BMI, C2C7 plumbline, and SVA

Δ + 0.77°, standard error 0.31°; $p = 0.006$), TPA (Δ − 23° vs. Δ − 17°, $p = 0.015$), and SVA (Δ − 14.4 vs. Δ10 cm; $p = 0.004$).

LT cohort: PJK vs. no PJK ($n = 136$)

The LT patients who developed PJK were significantly older (61.9 years) than the patients who did not (57.2 years). LT-PJK patients had significantly greater correction in PI-LL, both early post-operative and 1-year time points (Table 5). At the first post-operative visit, the change in PI-LL was −36.1° for LT-PJK and −27.4° for LT-NPJK ($p = 0.001$); this difference was still significant at 1 year (−35.5° vs. −25.3°; $p = 0.001$). The amount of correction in SVA was modestly but not significantly different between LT-PJK and LT-NPJK groups (−100.8 vs. −78 mm; $p = 0.143$). One year post-operatively, LT-PJK patients had larger TK compared to LT-NoPJK (46.6° vs. 32.3°; $p < 0.001$). The mean PI-LL was significantly smaller for the LT-PJK cohort (1.4° vs. 13.6°, $p < 0.001$).

However, the mean PI of LT-PJK patients was significantly smaller (by approximately 8°) than that of the LT-NPJK patients at both baseline and 1 year (LT-PJK 55.9° vs. LT-NPJK 64.9°; $p = 0.008$). Though there was no significant difference in TPA between the two groups (20.5° vs. 24.5°; $p = 0.074$), LT-PJK patients had less severe global malalignment as assessed by SVA (42.9 vs. 68.8 cm; $p = 0.029$). There were no statistically significant differences in PT.

Discussion

Proximal junctional kyphosis is a common complication in long fusions and spinal deformity correction that can be a source of pain and need for revision surgery [18]. In a retrospective case series of 81 patients with minimum 2-year follow-up, Glattes et al. reported a PJK incidence of 26 %, though no significant impact on outcome measures was identified [1].

In a retrospective case series of 161 ASD patients with 5-year minimum follow-up, Kim et al. found a PJK prevalence of 39 % [19]. Early and late progression groups were identified with 59 % occurring within 8 weeks and 35 % after 2 years. Modes of proximal junctional failure (PJF) were further characterized by Watanabe et al. with UIV collapse and adjacent subluxation occurring at an average of 3 months and adjacent vertebral fracture occurring at an average of 33 months [20]. Hart and colleagues have highlighted the distinction between PJK and PJF, noting that PJF is associated with higher morbidity, spinal instability, neurologic injury and revision surgery [21, 22].

Reported risk factors for the development of PJK include age >55, osteopenia, fusions to the sacrum, combined anterior/posterior fusion, proximal junctional angle >5°, and larger deformity corrections [10, 18–20, 23]. Studies have noted loss of correction following PJK, but this malalignment has been characterized with a limited range of alignment measures [18].

This study demonstrates that patients undergoing 3CO with UIV in the upper thoracic spine develop cervical sagittal deformity, as evidenced by the larger CPL and CTPA in the UT-PJK group. In a study on 113 patients undergoing posterior cervical fusion, Tang et al. found that a CPL >4 cm was associated with greater disability by validated health-related quality of life (HRQOL) outcome measures [24]. This study introduces the CTPA, a novel global angular measure of cervical sagittal alignment which correlated strongly with CPL ($R = 0.826$; $p < 0.001$). Angular measures have the advantage over linear measures in that they do not require calibration of the radiograph, which can add error to the measurement.

Table 3 Pre-operative and post-operative values for radiographic parameters for each group

	Pre-Op				Post-Op (1 year)			
	UT		LT		UT		LT	
	NPJK	PJK	NPJK	PJK	NPJK	PJK	NPJK	PJK
Cervical alignment								
C2C7PL (mm)	38.9	42.7	35.8	35.2	_38.3_	_50.6_	31.5	30.1
CL (°)	_11.3_	_23.1_	18.0	11.2	10.3	15.1*	_13.7*_	_5.6*_
CTPA (°)	2.73	2.77	2.3	2.2	_3.7*_	**_4.9*_**	2.7*	2.9*
Thoracic alignment								
T1 slope (°)	32.7	39.0	31.2	30.9	29.0*	**34.5**	26.5*	26.2*
TK (°)	33.3	34.1	23.2	23.4	38.4	37.3	_34.3*_	_46.6*_
Thoracolumbar alignment								
TPA (°)	37.2	42.5	37.7	35.5	20.9*	19.6*	_24.5*_	_20.5*_
SVA (mm)	137	165	146	141	38.8*	24.3*	_68.8*_	_42.8*_
Pelvic and lumbar alignment								
PI-LL (°)	32.1	38.1	38.9	36.9	6.0*	5.3*	_13.6*_	_1.4*_
PT (°)	33.3	37.0	32.9	30.4	24.1*	24.8*	25.6*	23.5*
PJK								
PJK angle (°)	**13.2**	13.5	**3.1**	7.6	_9.5_	**_18.7_**	_11.6*_	**_25.1*_**
Δ PJK (°)	–	–	–	–	_8.5_	_19.1_	_9.3_	_21.1_

Statistical significance between NPJK and PJK ($p < 0.05$) denoted in italics. Within each subgroup, statistical significance from baseline to follow-up is denoted by asterisk (*). Statistical significance between UT and LT is denoted by bold

Table 4 One-year post-operative radiographic data for the UT cohort comparing those with PJK and NoPJK

Parameter	UT-No PJK ($n = 103$)	UT-PJK ($n = 38$)	p
Cervical alignment parameters			
Cervical lordosis	10.3	15.1	0.292
CTPA	3.7	4.9	0.015*
C2C7 plumbline (mm)	38.3	50.6	0.022*
Thoracic alignment parameters			
T1 slope	29.0	34.5	0.099
Thoracic kyphosis (T4–T12)	−38.4	−37.3	0.735
Thoracolumbar global alignment parameters			
TPA	20.9	19.6	0.658
SVA (mm)	38.8	24.3	0.338
Pelvic and lumbar alignment parameters			
PT	24.1	24.8	0.763
PI-LL	6.0	5.3	0.850
PJK parameters			
PJK angle	9.5	18.7	0.001*
PJK change from base	8.5	19.1	<0.001*

All values in degrees (°) unless otherwise specified. (*denotes significance with $p < 0.05$)

Moreover, spinopelvic measures such as the CTPA and TPA offer the ability to assess the magnitude of sagittal spinal deformity independent of pelvic and lower extremity compensation [16]. Linear measures such as CPL and SVA can be diminished by patient compensatory mechanisms such as pelvic retroversion (Fig. 3).

Thus, knee flexion or extensive pelvic retroversion can "hide" a larger spinal deformity when only the SVA or CPL is considered. Spinopelvic measures such as the CTPA and TPA may be more reliable and reproducible in patients regardless of the day-to-day variation in their standing compensation (Fig. 4).

Table 5 Demographics and post-operative radiographic data for the LT cohort comparing those with PJK and No PJK

Parameter	LT-No PJK ($n = 96$)	LT-PJK ($n = 40$)	p
Age (years)	57.2	61.9	0.030*
Cervical alignment parameters			
Cervical lordosis	13.7	5.6	0.027*
CTPA	2.7	2.9	0.589
C2C7 plumbline (mm)	31.5	30.1	0.756
Thoracic alignment parameters			
T1 slope	26.5	26.2	0.89
Thoracic kyphosis	34.3	46.6	0.0003
Thoracolumbar global alignment parameters			
TPA	24.5	20.5	0.074
SVA (mm)	68.8	42.8	0.029*
Pelvic and lumbar alignment parameters			
PT	25.6	23.5	0.324
PI-LL	63.0	55.3	0.013
PJK parameters			
PJK angle	11.6	25.1	<0.001*
PJK change from base	9.3	21.1	<0.001*

Statistical significance ($p < 0.05$) is denoted by (*). All units are degrees (°) unless otherwise specified

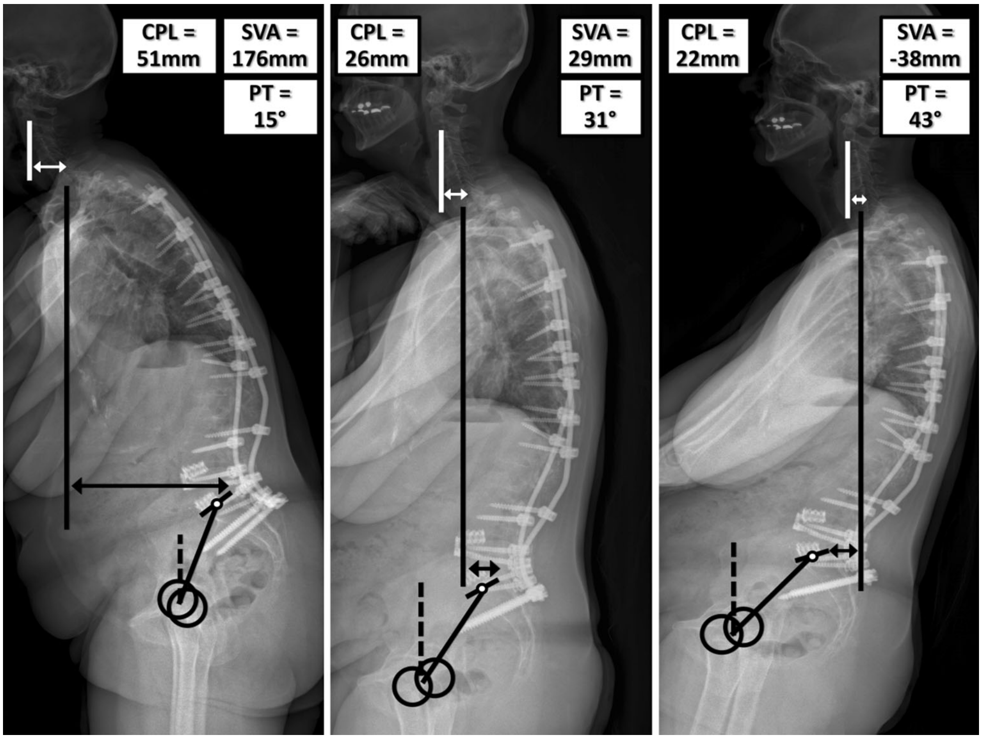

Fig. 3 The variability of SVA and CPL in a single patient with different degrees of pelvic retroversion. The image to the *left* shows the alignment with no pelvic compensation; the middle image is the patient's usual standing alignment with moderate pelvic compensation and the image to the *right* shows the patient flexing her knees to maximize her pelvic retroversion. *SV* sagittal vertical axis, *CPL* C2–C7 cervical plumbline, *PT* pelvic tilt

Rousouly et al. have described spinopelvic relationships using the spinopelvic and spinosacral angles, which are somewhat similar to the concept of TPA, but these angles have not been correlated with HRQOL [25]. Conversely, TPA has been correlated with many health status measures [16].

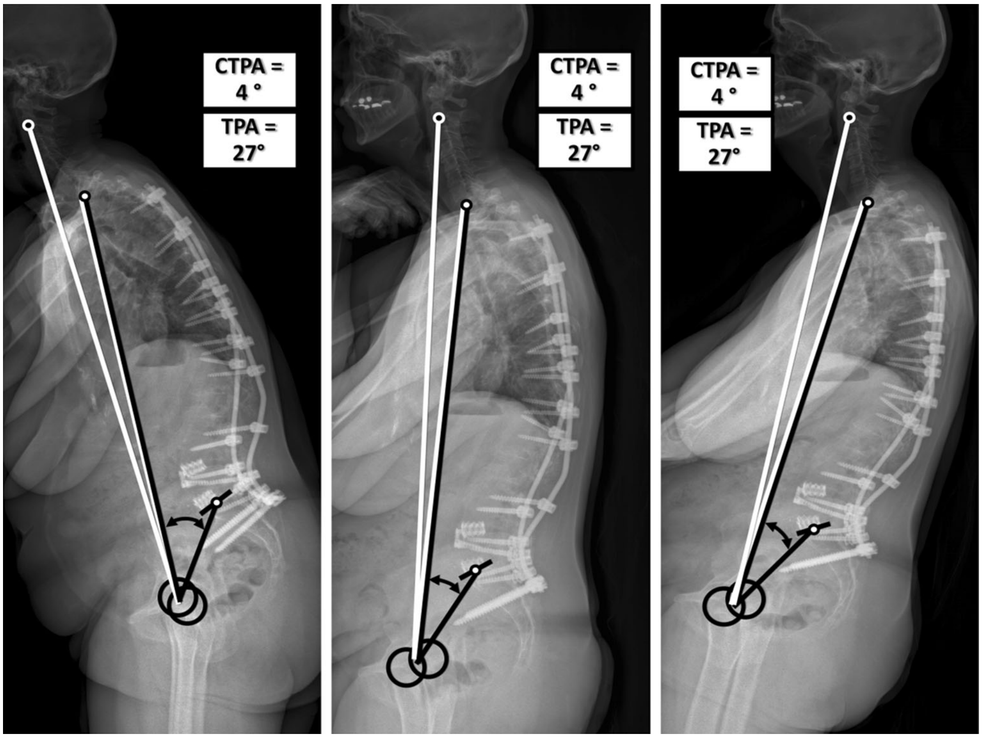

Fig. 4 The consistency of CTPA and TPA in the same patient despite varying degrees of pelvic retroversion and knee flexion. *CTPA* cervicothoracic pelvic angle, *TPA* T1 pelvic angle

This study identified no significant differences in the PJK rates between the UT and LT groups. Ha et al. and Kim et al. have also found that the incidence of PJK is similar between patients fused to the proximal thoracic spine and the distal thoracic spine [4, 26]. However, Ha et al. observed that patients with UIV in the upper thoracic spine were more likely to have PJK associated with subluxation, whereas patients with UIV in the distal thoracic spine had greater rates of compression fractures [4]. These results echoed those of Watanabe et al. who found that longer fusion constructs (10 segments) had higher rates of subluxation but lower rates of fracture than shorter constructs (7 segments) [20].

Smith et al. demonstrated that an underlying thoracolumbar sagittal malalignment results in increased CPL; in turn, correction of this thoracolumbar deformity leads to improved cervical offset with a decrease in the CPL [15]. This finding was corroborated by Ha et al. who demonstrated that patients with large thoracolumbar deformities (SVA >9 cm) have a decrease in cervical lordosis after correction of the underlying thoracolumbar deformity [27]. Obeid et al. similarly found that following lumbar PSO, the C7 tilt decreases with a concomitant decrease in the C2–C7 angle [28]. They further observed that this chain of correlations extends to the occipitocervical junction as the upper cervical angle (C0–C2) adjusts to maintain horizontal gaze and the head centered over C7 [28]. In the present study, proximal junctional kyphosis proved to be a disruptive factor in the balance of spinal alignment; the UT-PJK group had paradoxical increases in CTPA and CPL post-operatively, leading to more cervical deformity pre-operatively despite the underlying thoracolumbar correction. Conversely, the UT-NoPJK group experienced a decrease in the CPL post-operatively and improved cervical alignment. Patients with upper thoracic proximal junctional kyphosis have an increase in the slope of the upper thoracic and lower cervical vertebra which results in sagittal malalignment of the subaxial cervical spine, a finding that also was demonstrated by Pereira et al. who showed that increased C7 slope correlated with an increase in the cervical plumbline, particularly among patients with neck pain [29].

A primary limitation of the study is that this data set did not include HRQOL measures; thus, the threshold of cervical sagittal deformity (CPL >4 cm) was extrapolated from the literature [24]. However, it is important to note that a questionnaire specific for cervical sagittal alignment does not exist. Another limitation of this study is the retrospective design, although the analyses were based on prospectively collected data. The strengths of the study include the contribution of cases from multiple spinal deformity centers and the use of multiple standardized measures of regional and global sagittal spinal alignment.

This study demonstrates the utility of CTPA in identifying cervical sagittal deformity as an angular correlate to the CPL linear plumbline. CTPA should be investigated further in primary cervical sagittal deformity and correlated with disease-specific health measures.

Compliance with ethical standards

Conflict of interest The ISSG received unrestricted grants from DePuy Spine and individual donors in support of this research. None of the authors have conflicts of interest directly related to the research.

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