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ORIGINAL ARTICLE

C7 sacral tilt (C7ST): a novel spinopelvic parameter reveals the relationship between pelvic parameters and global spinal sagittal balance and converts pelvic parameters into spinal parameters

Wen Zhang[1] · Tao Li[1] · Mengmeng Xu[2] · Xiaoyang Liu[1] · Guodong Wang[1] · Bingxiang Wang[1] · Jianmin Sun[1] · Xingang Cui[1] · Zhensong Jiang[1]

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Abstract

Purpose The aim is to propose a novel spinopelvic parameter C7 sacral tilt (C7ST), of which its sum with global tilt (GT) is equal to pelvic incidence (PI), from a geometrical point of view.

Methods A cohort of 198 patients was recruited and the whole lateral spine and pelvic radiographs were performed. The following sagittal parameters were measured: sagittal vertical axis (SVA), C7 vertical tilt (C7VT), sacral slope (SS), pelvic tilt (PT), PI, GT and C7ST. The correlations between them were analyzed using the Pearson or Spearman correlation coefficient, and simple linear regressions were simultaneously conducted. $P < 0.05$ was set as the level of significance.

Results Geometric construction by complementary angles revealed that PI = C7ST + GT, GT = PT + C7VT, and C7ST = SS − C7VT. Both C7ST and GT were moderately correlated with PI ($R = 0.52$ and 0.596, respectively), strongly correlated with SS and PT, respectively (SS = 0.9 * C7ST + 1.15, $R = 0.955$; PT = 0.87 * GT + 3.86, $R = 0.96$). The correlation coefficients of the SVA and C7VT, SVA and SS − C7ST, and SVA and GT − PT were 0.935, 0.925 and 0.863, respectively.

Conclusion The novel proposed spinopelvic parameter C7ST has the advantages of convenient measurement, reduced error, and extrapolation of other parameters. The greatest significance of proposing C7ST is that pelvic parameters (PI, PT and SS) are converted into spinal parameters (C7ST and GT), which is very helpful for a more intuitive understanding of the progression of spinal sagittal imbalance.

Keywords C7 sacral tilt · Global tilt · Pelvic incidence · Pelvic tilt · Sacral slope

Introduction

The importance of spinal sagittal balance for maintaining normal spinal function has been increasingly recognized over the past 2 decades [1]. Numerous studies have been conducted to understand the relationship between sagittal spinal alignment and pelvic parameters, which is fundamental for the restoration of sagittal plane balance. Royen et al. proposed the sagittal vertical axis (SVA) to reflect spine behavior [2]. Legaye et al. used 3 pelvic parameters to describe the orientation and size of the pelvis: pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS) [3]. Geometric construction by complementary angles revealed that PI is the algebraic sum of PT and SS: PI = PT + SS.

Based on these spine sagittal plane parameters, to obtain good surgical outcomes, Schwab et al. advanced an adult spinal deformity classification system and proposed ideal spinopelvic parameters, which are widely used by many spinal surgeons for correcting spinal deformities [4, 5]. However, the SVA may be influenced by the subject's posture and height; compensated by posture, such as pelvic retroversion and knee flexion; and requires radiographic calibration [2, 6].

More recently, the T1-pelvic angle (TPA) [7, 8] and global tilt (GT) [9] were proposed as novel spinopelvic

Wen Zhang and Tao Li contributed equally to this work.

✉ Zhensong Jiang
jiangzhensongsph@163.com

[1] Department of Spine Surgery, Shandong Provincial Hospital Affiliated to Shandong First Medical University, Shandong Provincial Hospital Affiliated to Shandong University, No. 9677 in Jingshi Road, Jinan City, China

[2] Department of Pediatrics, Qilu Hospital of Shandong University, Jinan, China

parameters, which account for both pelvic retroversion and trunk inclination simultaneously in order to assess global spinal deformity. Although they are less affected by patient posture and do not require calibration, there is a need to identify the femoral head, which may increase the error margin during the measurement if the femoral heads are not clearly identifiable on X-ray [10].

In the current study, we introduced C7 sacral tilt (C7ST), a novel angular measure of global sagittal spinal deformity. C7ST is the angle between the line perpendicular to the midpoint of the sacral plate and the line connecting this point to the center of the C7 vertebral body. C7ST seems interesting, as the sum of C7ST and GT is equal to PI, which are opposite angles, and the main advantage of C7ST over GT is its easy and quick calculation. The purpose of this study was to investigate the utility of C7ST, investigate its correlation with other radiographic spinopelvic sagittal parameters and distinguish the role of C7ST and GT in evaluating spinal sagittal balance.

Materials and methods

Patient population

A cohort of 198 patients older than 18 years was recruited from our institution between Oct 2018 and Sep 2019 and enrolled in this retrospective study. Written informed consent was obtained from all subjects who participated in this study, and the study was approved by our institutional ethics committee. The exclusion criteria were (1) lumbar or thoracic disease; (2) history of hip or knee arthroplasty; (3) history of prior spinal surgery; (4) pregnancy; and (5) who had L6 or sacralization of L5, in which spinopelvic parameters could not be assessed accurately.

Radiographic measurement and data collection

Whole lateral spine and pelvic radiographs were performed to assess spinopelvic alignment in the standardized, naturally standing posture: patients were asked to stand with the knees fully extended and the feet no more than shoulder width apart, to relax their heads while looking straight ahead, to flex their shoulders approximately 30° and to place their fists in the supraclavicular fossa [11]. The following spinopelvic radiographic parameters were measured:

- Sagittal vertical axis (SVA): distance, in mm; the horizontal offset from the posterior superior corner of S1 to the C7 plumb line. The C7 plumb line is within 5 cm of the posterior superior corner of the sacrum, and the spinal sagittal plane is considered balanced [12–14].
- Pelvic incidence (PI): Angle between the line perpendicular to the midpoint of the sacral plate and the line connecting this point to the axis of the femoral head.
- Sacral slope (SS): angle between a horizontal line and the S1 superior plate.
- Pelvic tilt (PT): angle between the line connecting the midpoint of the sacral plate to the axis of the femoral head and the vertical axis.
- Global tilt (GT): angle between a line from the midpoint of the superior sacral end plate to the center of the C7 vertebral body and a line from the femoral head to the midpoint of the superior sacral end plate. If the line connecting the midpoint of the superior sacral plate to the center of the C7 vertebral body is in front of the line from the femoral head to the midpoint of the superior sacral end plate, GT is positive; otherwise, it is negative.
- C7 sacral tilt (C7ST): angle between the line perpendicular to the midpoint of the superior sacral plate and the line connecting this point to the center of the C7 vertebral body. If the line connecting the midpoint of the superior sacral plate to the center of the C7 vertebral body is in front of the line perpendicular to the midpoint of the superior sacral plate, C7ST is negative; otherwise, it is positive.
- C7 vertical tilt (C7VT): angle between a line drawn from the center of C7 to the midpoint of the superior sacral endplate and the vertical axis. A value greater than 0° indicates that the center of the C7 vertebral body is in front of the midpoint of the superior sacral endplate, whereas for values inferior to 0°, the center of the C7 vertebral body is behind the midpoint of the superior sacral endplate [9].

All radiographic analyses were performed using Surgimap, version 2.3.1.5 (Nemaris, Inc., New York, USA) [15], by two experienced spine surgeons, and the results were averaged for the following analysis.

Statistical analysis

All parameters were expressed as the mean ± SD (standard deviation). The data that met a normal distribution was assessed with the Shapiro–Wilk test. The correlations between pelvic sagittal parameters, C7ST, C7VT and GT were analyzed using the Pearson or Spearman correlation coefficient, and simple linear regressions were simultaneously conducted. All statistical analyses were performed using SPSS software (version 25; IBM Corp., Armonk, NY, USA). A two-tailed P value < 0.05 was set as the level of significance.

Table 1 Description of spinopelvic sagittal radiographic parameters

Parameter	Mean	SD	Min.	Max.	Coefficient of Variation*
PI (°)	48.79	12.44	16.60	85.10	0.25
PT (°)	14.73	10.30	−8.50	45.20	0.69
SS (°)	34.06	10.40	−3.10	60.00	0.31
C7ST (°)	36.64	11.06	−5.30	64.90	0.30
C7VT (°)	−2.46	3.13	−9.60	4.80	−1.27
GT (°)	12.54	11.41	−14.50	46.90	0.91
SVA (mm)	−0.71	2.53	−4.76	4.74	−3.58

PI pelvic incidence, *PT* pelvic tilt, *SS* sacral slope, *C7ST* cervical 7 sacral tilt, *C7VT* cervical 7 vertical tilt, *GT* global tilt, *SVA* sagittal vertical axis

*Coefficient of variation is the standard deviation divided by the mean

Results

A total of 198 subjects (98 females and 100 males) participated in the present study. Twelve adults withdrew from the study because C7 was not visible due to shoulder obstruction or because the femoral head could not be recognized on spinal sagittal radiographs. The mean age (and standard deviation) of the remaining 186 adults was 42.9 ± 13.7 years (range 18 to 66 years), and the body mass index was 24.7 kg/m^2.

The descriptive statistics, the range of the normal variations and the coefficient of variation for the spinopelvic sagittal parameters are detailed in Table 1.

It can be seen from the schematic diagram that the angle formed by the reverse extension line of PI includes two angles: GT and the newly proposed angle C7ST: PI = C7ST + GT (Fig. 1). Moreover, geometric construction by complementary angles revealed that GT was the algebraic sum of PT and C7VT, GT = PT + C7VT, while C7ST was the SS minus C7VT, C7ST = SS − C7VT (Fig. 1). The C7ST + GT and PI, SS − C7VT and C7ST, PT +C7VT and GT correlation analyses showed that there were strong correlations between them, and the correlation coefficients were 0.993, 0.998 and 0.882, respectively (Table 2). The results of the linear regression analysis are displayed in Fig. 2.

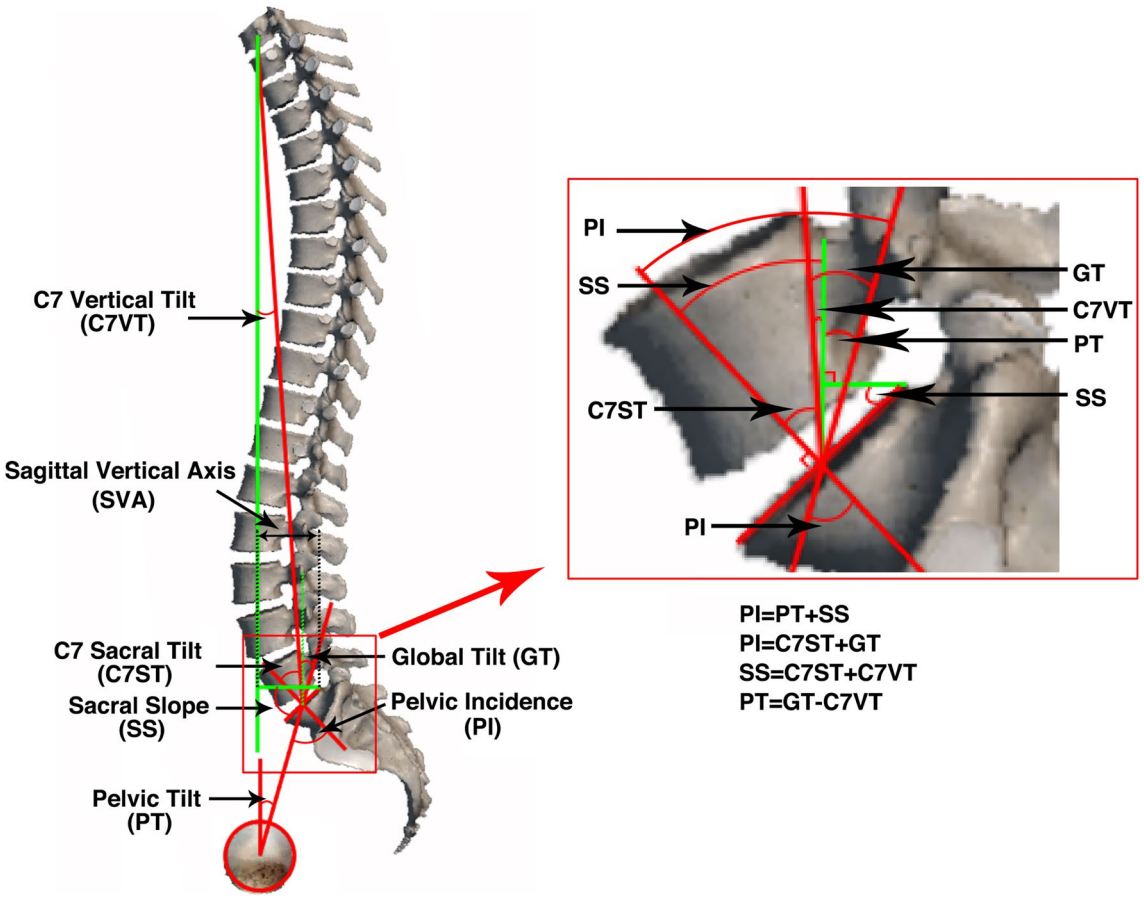

Fig. 1 Descriptions of spinopelvic sagittal parameters. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; C7ST, cervical 7 sacral tilt; C7VT, cervical 7 vertical tilt; GT, global tilt; SVA, sagittal vertical axis

The results of correlation analyses between the sagittal parameters and C7ST as well as the sagittal parameters and GT are shown in Tables 3 and 4, respectively. Both C7ST and GT were moderately correlated with PI (PI = 0.59 * C7ST + 27.35, $R = 0.52$; PI = 0.65 * GT + 40.63, $R = 0.596$), G7ST was strongly correlated with SS (SS = 0.9*C7ST + 1.15, $R = 0.955$), and GT was strongly correlated with PT (PT = 0.87 * GT + 3.86, $R = 0.96$); the linear regression analysis results are shown in Fig. 3.

It can be seen from the equations "GT = PT + C7VT" and "C7ST = SS − C7VT" that C7VT is an important adjustment parameter that is considered the angular version of the SVA [9]. To verify this standpoint and the accuracy of our measurement data, we conducted correlation analyses between SVA and C7VT, SVA and SS − C7ST, and SVA and GT − PT, and the correlation coefficients were 0.935, 0.925 and 0.863, respectively (Table 5). The linear regression analysis results were as follows: SVA = 0.76*GT + 1.15, SVA = 0.71*(SS − C7ST) + 1.13, and SVA = 0.67*(GT − PT), which are shown in Fig. 4.

Table 2 Correlations between C7ST + GT and PI, SS − C7VT and C7ST, PT + C7VT and GT

Parameter	Correlation coefficient	*P* value
PI vs. C7ST + GT	0.993	< 0.001
C7ST vs. SS − C7VT	0.998	< 0.001
GT vs. PT + C7VT	0.992	< 0.001

PI pelvic incidence, *PT* pelvic tilt, *SS* sacral slope, *C7VT* cervical 7 vertical tilt, *GT* global tilt, *C7ST* cervical 7 sacral tilt

Discussion

Spinopelvic sagittal balance has been confirmed to have a greater impact on patients' clinical symptoms than the coronal plane, the importance of which has been increasingly recognized by the majority of spine surgeons [16, 17]. Over the past 2 decades, on the basis of these three important pelvic parameters, pelvic incidence (PI), pelvic tilt (PT) and sacral slope (SS) [3, 18–20], the study of spinal sagittal imbalance has rapidly increased [21–24]. However, there is

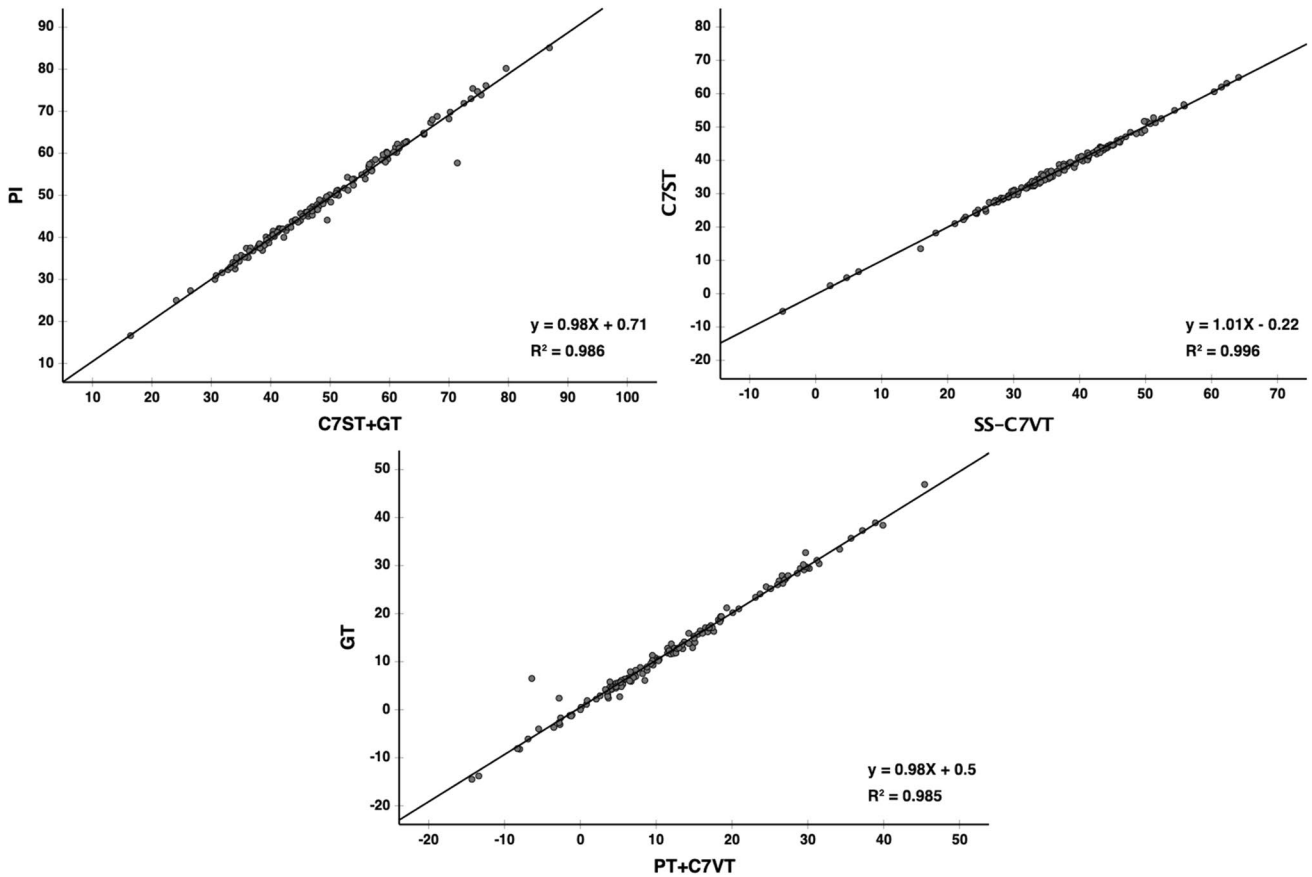

Fig. 2 Linear regression between C7ST + GT and PI, SS − C7VT and C7ST, PT + C7VT and GT. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; C7ST, cervical 7 sacral tilt; C7VT, cervical 7 vertical tilt; GT, global tilt

Table 3 Correlations between Spinal Sagittal Parameters and C7ST

Parameter	Correlation coefficient	*P* value
PI (°)	0.520	< 0.001
PT (°)	− 0.336	< 0.001
SS (°)	0.955	< 0.001
C7VT (°)	− 0.313	< 0.001
GT (°)	− 0.367	< 0.001
SVA (mm)	− 0.361	< 0.001

PI pelvic incidence, *PT* pelvic tilt, *SS* sacral slope, *C7ST* cervical 7 sacral tilt, *C7VT* cervical 7 vertical tilt, *GT* global tilt, *SVA* sagittal vertical axis

Table 4 Correlations between spinal sagittal parameters and GT

Parameter	Correlation coefficient	*P* value
PI (°)	0.596	< 0.001
PT (°)	0.960	< 0.001
SS (°)	− 0.237	< 0.01
C7VT (°)	0.496	< 0.001
SVA (mm)	0.492	< 0.001

PI pelvic incidence, *PT* pelvic tilt, *SS* sacral slope, *C7ST* cervical 7 sacral tilt, *C7VT* cervical 7 vertical tilt, *GT* global tilt, *SVA* sagittal vertical axis

no parameter that considers the spine and pelvis simultaneously to evaluate global sagittal spinopelvic alignment.

Recently, Obeid et al. proposed global tilt (GT) as a single spinopelvic parameter incorporating pelvic behavior (reflected by PT) and spinal behavior (reflected by the SVA) and found that it was least affected by patient positioning [9, 10]. In the current study, we introduced another spinopelvic parameter and named it cervical 7 sacral tilt (C7ST). The schematic diagram shows that the angle formed by the reverse extension line of PI includes two parts: GT and the newly proposed angle C7ST: PI = C7ST + GT. To better understand the difference between C7ST and GT and to assess which parameter has the advantage in evaluating spinal sagittal balance, we performed a correlation analysis between sagittal parameters and C7ST as well as sagittal parameters and GT. The correlation analysis results showed that there was no significant difference between C7ST and GT in terms of their correlation with PI; both of them were moderately related to PI, but their sum was strongly related to PI. From the correlation analysis results, we also found that C7ST and GT were strongly related to SS and PT, respectively. Moreover, geometric construction by complementary angles revealed that GT was the algebraic sum of PT and C7VT, GT = PT + C7VT, while C7ST was the SS minus C7VT, C7ST = SS − C7VT.

Understanding the nature of sagittal spinal balance and the associated compensatory mechanisms is important for spinopelvic realignment. Considering the spine and pelvis as a whole, since C7ST and GT are strongly related to SS and PT, respectively, we can infer the generation process of C7ST and GT from the generation process of SS and PT. During the action of the pelvis, the sacrum rotates forward around the femoral heads so that the pelvis rotates anteriorly, which results in an increase in SS. Due to the body balance mechanism of maintaining a level visual gaze and the center of mass over feet in the sagittal plane, the spine as a whole extends backwards to achieve a good balance between the spine and pelvis, which results in an increase in C7ST. This is the reason why C7ST is closely related to SS. If the spine is regarded as an inactive whole, then C7ST should be equal to SS, but in fact, there is relative movement between spinal segments, so the actually measured C7ST and SS are not completely equal, and the difference between them is C7VT. Similarly, during the development of the pelvis, the sacrum translates backwards relative to the femoral head to a certain extent, which produces PT. To ensure the balance of the sagittal plane, the spine flexes forward, which produces GT. Due to the relative movement of spinal segments, the actually measured GT and PT are also not completely equal, and the difference between them is also C7VT. Therefore, we speculate that the newly proposed parameter C7ST is complementary to GT, and the combination of the two can be used to evaluate the global balance of the spinopelvic sagittal plane. C7VT is the link between C7ST and SS as well as GT and PT. Through C7VT, the pelvic parameters (PI, PT and SS) proposed by Legaye et al. in 1998 are converted into spinal parameters, which is very helpful for understanding the progression of spinal sagittal imbalance.

The SVA is a widely used parameter for evaluating global sagittal balance, and global spinal realignment should attempt to obtain a postoperative SVA < 50 mm, which facilitates a level gaze and achieves a physiologic standing posture and a better health-related quality of life (HRQL) score [25]. The current study results showed that the correlation coefficients of C7ST and SVA and of GT and SVA were -0.361 and 0.492, respectively, but the correlation coefficients of SS − C7ST and SVA and of GT − PT and SVA increased to 0.925 and 0.863, respectively, which confirms the previous point that C7VT is somewhat the angular version of the SVA [9] and validates the accuracy of our measurement data.

A previous study conducted by I. Obeid et al. proposed GT and concluded that it was less affected by the patient's position than the SVA or PT because it contained both pelvic compensation and spinal alignment [9]. Although we did not measure C7ST in different standing positions in the current study, PI is an anatomic parameter that is unique to each individual after skeletal maturity and is the sum of C7ST

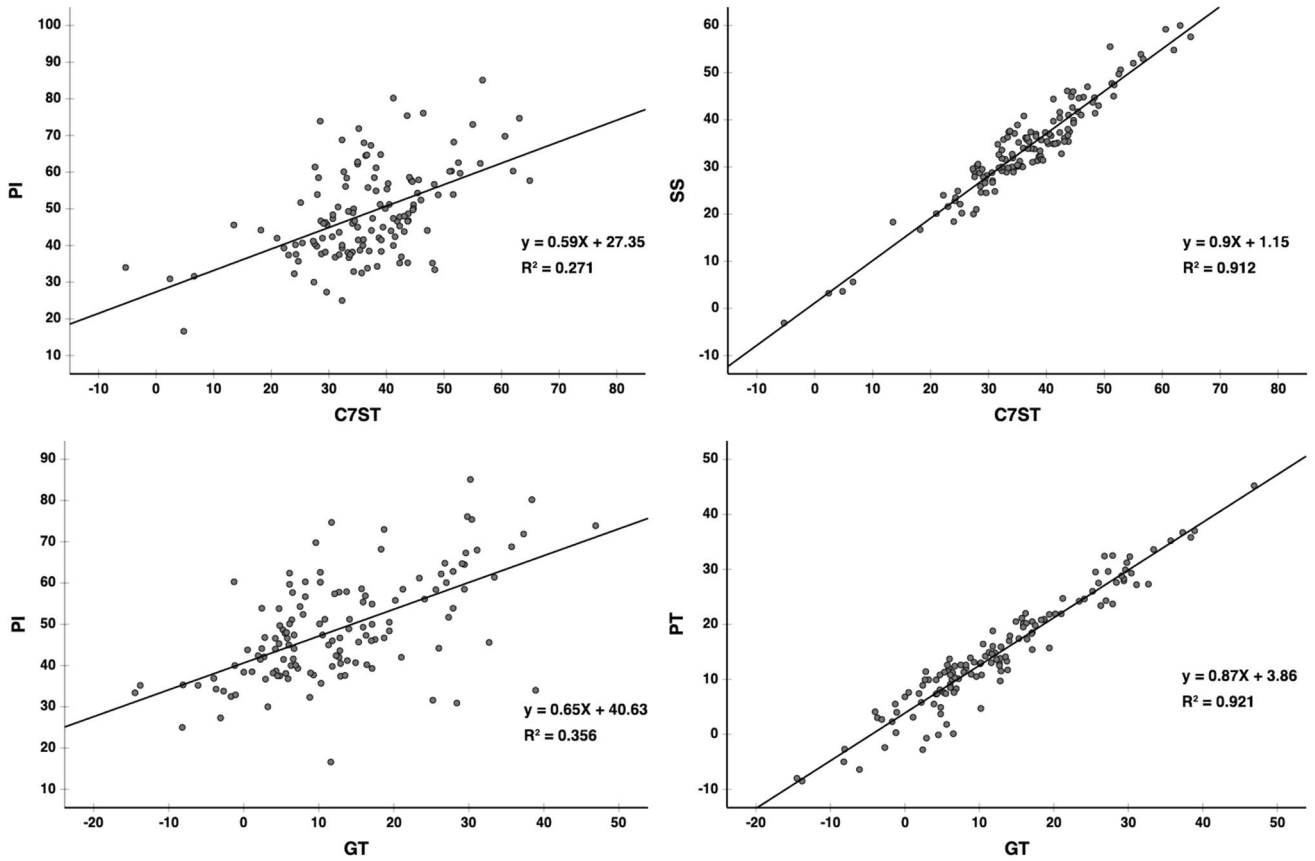

Fig. 3 Linear regression between the sagittal parameters (PI and SS) and C7ST, the sagittal parameters (PI and PT) and GT. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; C7ST, cervical 7 sacral tilt; GT, global tilt

Table 5 Correlations between C7VT, SS-C7ST, GT-PT and SVA

Parameter	Correlation coefficient	*P* value
SVA vs. C7VT	0.935	< 0.001
SVA vs. SS − C7ST	0.925	< 0.001
SVA vs. GT − PT	0.863	< 0.001

PT pelvic tilt, *SS* sacral slope, *C7ST* cervical 7 sacral tilt, *C7VT* cervical 7 vertical tilt, *GT* global tilt, *SVA* sagittal vertical axis

and GT. Therefore, we speculate that C7ST may also be less affected by the patient's position, and we will confirm this in future studies.

By reviewing the literature, we found that the previously proposed parameters have some shortcomings. For example, the SVA requires calibration and can be influenced by the patient's height or can be compensated by posture [2, 6]. Recently proposed novel spinopelvic parameters, such as the T1-pelvic angle (TPA) [7, 8] and GT [9, 10], need to identify the T1 vertebral body and femoral head, which may increase measurement error given that the T1 vertebral body and femoral head are sometimes unclear on lateral radiographs. Compared to these previously proposed parameters, the newly proposed parameter C7ST has many advantages for assessing spinopelvic sagittal global alignment. First, it does not need to identify the T1 vertebral body or femoral head and does not require radiographic calibration, which may reduce measurement error. Second, even without standardized whole lateral spine and pelvic standing radiographs with a clear femoral head, we can obtain PI from other lateral pelvic radiographs, can obtain C7ST and C7VT from the current whole lateral spine radiograph, and can use those parameters to extrapolate all the other spinopelvic parameters, such as GT, PT and SS. In addition to the advantages of convenient measurement, reduced measurement error, and extrapolation of other parameters, we think that the greatest significance of proposing C7ST is that pelvic parameters (PI, PT and SS) are converted into spinal parameters (C7ST and GT), which is very helpful for a more intuitive understanding of the progression of spinal sagittal imbalance.

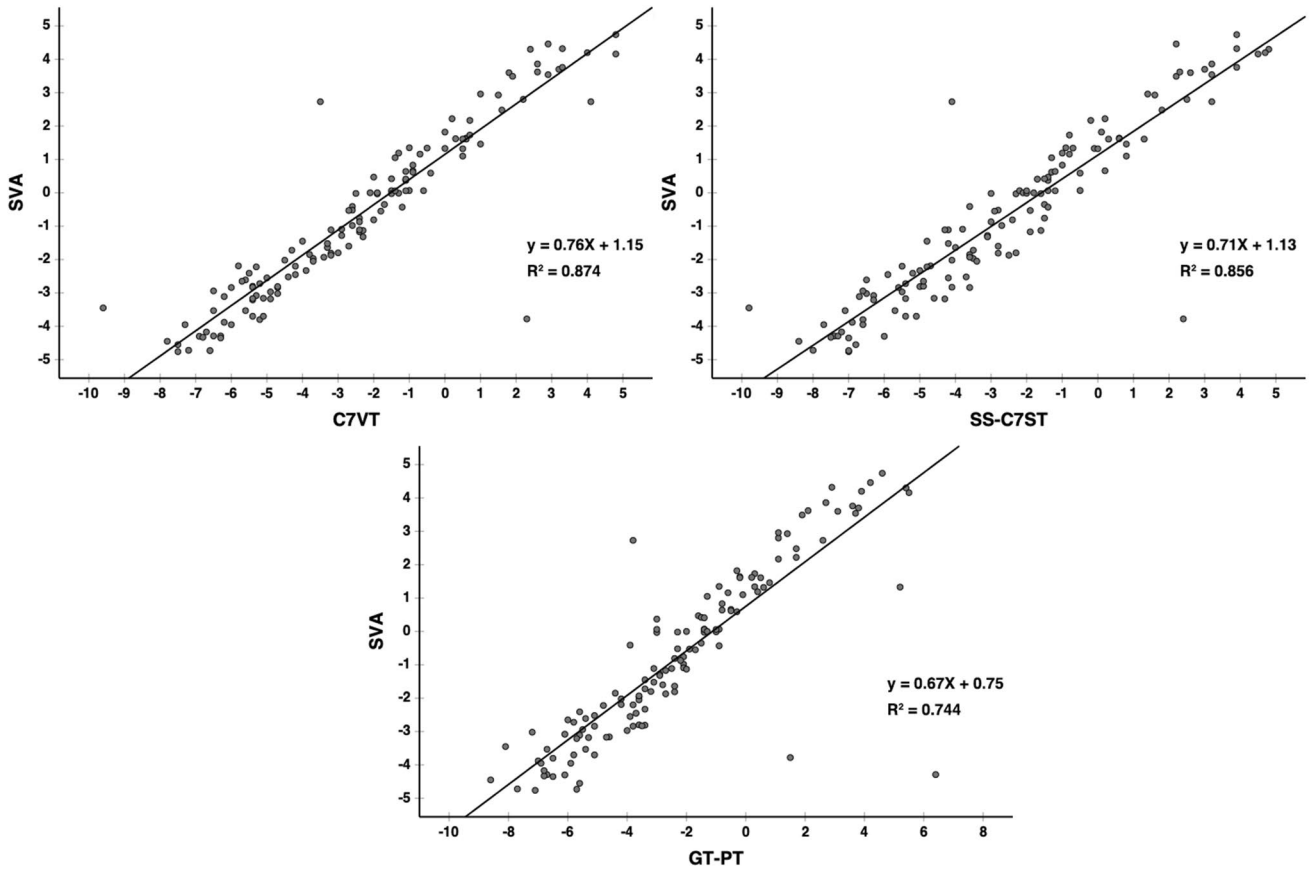

Fig. 4 Linear regression between SVA and C7VT, SVA and SS – C7ST, and SVA and GT – PT. PT, pelvic tilt; SS, sacral slope; C7ST, cervical 7 sacral tilt; C7VT, cervical 7 vertical tilt; GT, global tilt; SVA, sagittal vertical axis

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Authors' contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Wen Zhang], [Tao Li] and [Zhensong Jiang]. The first draft of the manuscript was written by [Wen Zhang] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

Data transparency All authors make sure that all data and materials support our published claims and comply with field standards.

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