

## ORTHOPAEDICS

# THE GLOBAL TILT: EVALUATION OF A PARAMETER CONSIDERING THE GLOBAL SPINOPELVIC ALIGNMENT

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**ABSTRACT • Purpose:** Regarding the close interaction between the spinal balance and the pelvis orientation no parameter is routinely used to describe and to evaluate the global spinopelvic balance, taking into account simultaneously the spinal part and the pelvic part of the global alignment. The global tilt was described to analyze malalignment, considering spinal and pelvic imbalance together. From a geometrical point of view, the global tilt is the sum of the C7 vertical tilt and the pelvic tilt. The aim of this study is to evaluate the global tilt by analyzing its correlation with spinal malalignment. **Methods:** A cohort of patients who underwent a lumbar pedicle subtraction osteotomy (PSO) for major sagittal malalignment was realized. All patients had preoperative and postoperative full spine EOS radiographies to measure spinopelvic parameters. The lack of lordosis was calculated after prediction of theoretical lumbar lordosis. Correlation analysis between different spinopelvic parameters, including the global tilt, was performed for preoperative and postoperative values. **Results:** Thirty-one consecutive patients were included. All parameters were correlated with spinal malalignment but the global tilt was the most correlated parameter in preoperative ( $r = 0.71$ ) and in postoperative ( $r = 0.78$ ). When spinal and pelvic parameters were analyzed separately, 19% of patients presented mismatches between spine and pelvis. **Conclusion:** This study highlights the interest of a global parameter evaluating the spinal balance and the pelvic balance together. The global tilt appeared to be the most correlated parameter in this study with spinal malalignment and could be used for the interpretation of clinical series in spine surgery.

Keywords : global tilt; spinal-pelvic balance; spinal malalignment; pedicle subtraction osteotomy; adult spinal deformity

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**RÉSUMÉ • Objectif :** Le rapport entre l'équilibre sagittal du rachis et l'orientation pelvienne est bien démontré actuellement, mais aucun paramètre n'est utilisé en routine pour décrire et évaluer l'équilibre spinopelvien global, prenant en compte simultanément les deux composants rachidien et pelvien de l'équilibre global. La version globale est un nouveau paramètre qui permet de prendre en compte simultanément les deux versants de l'équilibre sagittal global. D'un point de vue géométrique, la version globale est la somme de la version verticale de C7 et de la version pelvienne. L'objectif de cette étude est d'évaluer la version globale en analysant sa corrélation avec le déséquilibre rachidien. **Méthode :** Un groupe homogène de patients traité chirurgicalement par ostéotomie transpédiculaire lombaire pour déséquilibre sagittal majeur a été sélectionné. Tous les patients ont bénéficié de radiographies EOS du rachis entier en préopératoire et postopératoire avec mesure des paramètres rachidiens et pelviens. Le manque de lordose lombaire a été mesuré après le calcul de la lordose lombaire théorique. Des analyses de corrélation ont été réalisées entre les différents paramètres rachidiens et pelviens incluant la version globale, en préopératoire et postopératoire. **Résultats :** Trente et un patients ont été inclus. Tous les paramètres mesurés étaient corrélés avec le déséquilibre rachidien, mais la version globale était le paramètre qui présentait la corrélation la plus forte en préopératoire ( $r = 0,71$ ) et en postopératoire ( $r = 0,78$ ). Lorsque les paramètres rachidiens et pelviens étaient mesurés séparément, il existait une non concordance des résultats dans 19% des cas entre la compensation rachidienne et la compensation pelvienne. **Conclusion :** Cette étude démontre l'intérêt d'un paramètre global évaluant simultanément les composants rachidiens et pelviens de l'équilibre global. La version globale est, dans cette étude, le paramètre le plus fortement corrélé au déséquilibre rachidien et pourrait être utilisée dans l'évaluation et l'interprétation de séries cliniques de chirurgie de déformations rachidiennes.

## INTRODUCTION

Spinal balance analysis can't be done without taking into account the pelvis or the pelvic vertebra as designated by Dubousset [1]. When sagittal imbalance occurs, with the loss of lumbar lordosis, compensatory mechanisms such as modifications of the spinal curvatures and retrover-

sion of the pelvis are put into play to offset the balance. When these mechanisms are overwhelmed, the sagittal vertical axis (SVA) increases leading to decompensated balance. Different parameters are widely used to analyze the *spinal balance* such as the SVA, the spinal tilt (also named C7 tilt), and the T1 tilt and the *pelvic balance* such as sacral slope (SS) and pelvic tilt (PT). All these parameters need to be considered to evaluate sagittal balance. Despite the close interaction between the spinal balance and the compensatory mechanisms, no parameter

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is commonly used to evaluate the global spino-pelvic balance taking into account simultaneously the spinal part and the pelvic part of the alignment. This issue is of most importance as in some cases spinal and pelvic parameters are modified in opposite ways making the sagittal balance difficult to read. A postoperative improper sagittal balance is the main cause of disability and pain [2, 3] and a thoughtful preoperative analysis should prevent it. What is the real global alignment of a negative SVA associated to an increased PT or a positive SVA associated to a normal PT (Figure 1)?

To answer these questions we reported a spinopelvic parameter taking into account the spinal balance (C7 vertical tilt) and the pelvic rotation around the femoral heads (PT) and named it the global tilt. The global tilt (GT) is the angle between the line drawn from the center of C7 to the center of the sacral endplate and the line drawn from the center of the sacral endplate to the center of the femoral head. From a geometrical point of view, GT equals the sum of PT and C7 vertical tilt angle (C7VT) (Figure 2). This parameter seems interesting as it overcomes the alternate changes of the C7VT and the PT making sagittal balance easier to consider. To assess these considerations we will try to answer a question: Which parameter between C7VT, SVA, PT and GT is the most correlated with lumbar malalignment?

#### MATERIALS AND METHODS

As it has already been done in the literature [4, 5], the correlation between the spinopelvic parameters described above and the lack of lumbar lordosis (LL) was used to estimate spinal malalignment. This association offers the possibility to correlate sagittal malalignment parameters (C7VT, SVA, PT and GT) to an independent parameter, the lack of LL. This association between spinal malalignment and lack of lordosis is possible if all hyperkyphosis sources of malalignment are excluded. If in the inclusion criteria the main deformity is lumbar, we can suppose that the gap of LL would be the best way to evaluate sagittal malalignment.

This study prospectively included patients who underwent pedicle subtraction osteotomy (PSO) for major spinal deformity. Inclusion criteria were age over 40 and a PSO needed for the correction of the spinal deformity. Exclusion criteria were thoracic kyphosis higher than 60° and subjects with neuromuscular disorders such as Parkinson's disease.

The EOS [6] radiographs (EOS Imaging) were used to measure preoperative and postoperative spinal, pelvic and spinopelvic parameters. The following *radiographic parameters* were measured with Spineview (Surgiview) validated software:

- *Pelvic incidence* (PI): the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral heads axis.
- *Lumbar lordosis* (LL): the angle between the superior endplate of L1 and the endplate of S1.



FIGURE 1. Panel a: Patient presenting negative SVA (-6.7 mm) and increased PT (37°).  
Panel b: Patient presenting increased SVA (990 mm) and normal PT (17°)

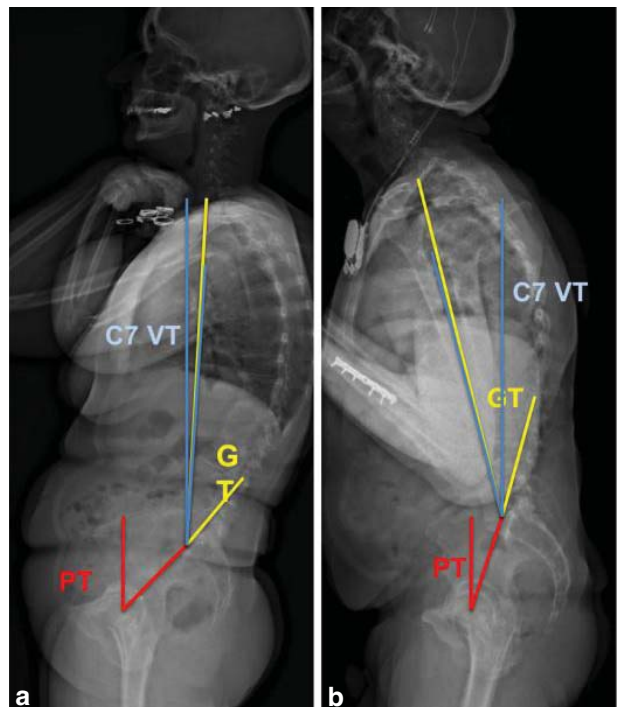


FIGURE 2. Same patients with global tilt measurement. GT equals the sum of C7 vertical tilt and PT. Its values are 39° for patient A & 30° for patient B. If both patients present sagittal malalignment, patient A's malalignment is more important.

- *Thoracic kyphosis (TK)*: the angle between the superior endplate of T4 and the inferior endplate of T12.
- *Sagittal vertical axis (SVA)*: distance between C7 plumb line and posterior superior corner on the top margin of S1.
- *C7 vertical tilt (C7VT)*: the angle between the vertical axis and a line drawn from the center of C7 to the center of the sacral endplate. This angle corresponds to the C7 tilt (also named spinal tilt) minus 90°. A value inferior to 0° indicates that the center of C7 vertebral body is behind the center of the upper sacral endplate, whereas for values greater than 0°, the center of C7 vertebral body is in front of the center of the upper sacral endplate. C7VT is somewhat an angular version of SVA.
- *Pelvic tilt (PT)*: the angle between the vertical and the line through the midpoint of the sacral plate to the femoral heads axis.
- *Global tilt (GT)*: the angle between the line drawn from the center of C7 to the center of the sacral endplate and a line drawn from the center of the sacral endplate to the center of the femoral head.

For all sagittal measurements, the angle was considered to be negative if the curve was lordotic and positive if the curve was kyphotic.

Since the works of Duval-Beaupère and the first description of PI, the relationship between LL and PI has been admitted. Several authors proposed formulas for the prediction of the theoretical LL based on the PI. PI is indeed a morphologic parameter, which defines the shape of the pelvis, and remains constant over the time during adulthood [7, 8]. The theoretical LL was derived from the PI measured above, and its value was based on the formula described by Schwab *et al.* [9]:  $LL = PI + 9$ . Therefore, having the measured lumbar lordosis and the theoretical lordosis, we could establish the LL gap for each patient:  $LL\ gap = PI + 9 - LL$ . As described above, this LL gap represents sagittal malalignment in this study.

Relationships between parameters were evaluated by Pearson correlation coefficient, and the significance was tested with the t test. A  $p < 0.05$  was considered statistically significant. A correlation coefficient greater than 0.71 was considered as a high correlation, between 0.51 and 0.70 a moderate correlation and less than 0.51 a poor correlation.

## RESULTS

This single center study included prospectively 31 consecutive patients from April 2010 to June 2012. There were 23 females and 8 males with an average age of 63 years (range 42-79).

### Radiographic measurements

Preoperative and postoperative measurements are recorded in Table I.

### Population description (Table II)

Pelvic incidence was 58.4° (mean value) in preoperative and 56.7° in postoperative. There were no differences between these two values. LL was 19.9° in preoperative and 57.6° in postoperative. SVA was 11.1 cm in preoperative and 2.6 cm in postoperative. C7VT was 13.9° in preoperative and 1.7° in postoperative. PT was 32.4° in preoperative and 17.4° in postoperative. GT was 46.4° in preoperative and 19.1° in postoperative. LL gap was 47.5° in preoperative and 8.1° in postoperative.

Except for PI all other values were statistically different between pre- and postoperative.

**TABLE II**  
PATIENTS' RADIOGRAPHIC PARAMETERS (mean values)

| Measurement                 | Preoperative  | Postoperative | p       |
|-----------------------------|---------------|---------------|---------|
| Pelvic incidence (°)        | 58.4 (± 16.4) | 56.7 (± 14.3) | n.s.    |
| Lumbar lordosis (°)         | 19.9 (± 19.5) | 57.6 (± 12.8) | < 0.001 |
| Thoracic kyphosis (°)       | 26.2 (± 17.2) | 44.0 (± 10.5) | < 0.001 |
| Sagittal vertical axis (cm) | 11.1 (± 15.5) | 2.6 (± 4.0)   | < 0.001 |
| C7 vertical tilt (°)        | 13.9 (± 7.6)  | 1.7 (± 4.9)   | < 0.001 |
| Pelvic tilt (°)             | 32.4 (± 11.8) | 17.4 (± 10.2) | < 0.001 |
| Global tilt (°)             | 46.4 (± 13.7) | 19.1 (± 12.5) | < 0.001 |

### Preoperative mismatches between PT, ST and GT

Six patients out of 31 (19%) presented a mismatch between spinal and pelvic parameters: 3 patients had PT value less than 20° as 3 other patients had C7VT less than 5° (and SVA less than 5 cm). All GT values were more than 25° in preoperative for the 31 patients.

### Correlation between spinopelvic parameters and LL gap (Table III)

#### Preoperative correlation

All measures correlated with the preoperative LL gap. The correlation was high for GT ( $r = 0.71$ ), moderate for PT ( $r = 0.53$ ) and poor for SVA ( $r = 0.46$ ) and C7VT ( $r = 0.45$ ).

#### Postoperative correlation

All measures correlated with the postoperative LL gap. The correlation was high for GT ( $r = 0.78$ ) and PT ( $r = 0.74$ ), moderate for SVA ( $r = 0.56$ ) and poor for C7VT ( $r = 0.45$ ).

**TABLE III**  
PEARSON CORRELATION COEFFICIENT TESTS BETWEEN LL GAP and SPINOPELVIC PARAMETERS for PRE- & POSTOPERATIVE MEASUREMENTS

|                      | SVA  | C7VT | PT   | GT   |
|----------------------|------|------|------|------|
| Preoperative LL gap  | 0.46 | 0.45 | 0.53 | 0.71 |
| Postoperative LL gap | 0.56 | 0.45 | 0.74 | 0.78 |

SVA: sagittal vertical axis C7VT: C7 vertical tilt PT: pelvic tilt GT: global tilt

| RADIOGRAPHIC MEASUREMENTS |       |       |         |         |       |       |                      |       |       |         |         |       |       |
|---------------------------|-------|-------|---------|---------|-------|-------|----------------------|-------|-------|---------|---------|-------|-------|
| Preoperative Values       |       |       |         |         |       |       | Postoperative Values |       |       |         |         |       |       |
| PI(°)                     | LL(°) | TK(°) | SVA(cm) | C7VT(°) | PT(°) | GT(°) | PI(°)                | LL(°) | TK(°) | SVA(cm) | C7VT(°) | PT(°) | GT(°) |
| 45.6                      | -31.7 | 46.3  | 4.1     | 4.5     | 22.1  | 26.6  | 40.4                 | -56.3 | 51.3  | -3      | -5.9    | 2.6   | -3.3  |
| 58.7                      | -5    | 48.1  | 12.3    | 13.2    | 56.1  | 69.3  | 55.9                 | -45.7 | 51.8  | 6.6     | 5.7     | 20.2  | 25.9  |
| 64.2                      | -39.2 | 37.1  | 7.9     | 10.4    | 29.7  | 40.1  | 66.3                 | -62.6 | 54.6  | 1       | 0       | 26    | 26    |
| 60.4                      | -12.9 | 21.2  | 7.8     | 9.9     | 51.2  | 61.1  | 56.5                 | -55.2 | 46    | -0.5    | 3.1     | 29.2  | 32.3  |
| 47.8                      | 2.2   | 4.3   | 19.4    | 24.6    | 26    | 50.6  | 59                   | -62.8 | 25.1  | -0.4    | -2      | 9     | 7     |
| 67.9                      | -40.2 | 42.7  | 14      | 16.6    | 32    | 48.6  | 36.7                 | -67.5 | 63.5  | 2.3     | 1.8     | 20    | 21.8  |
| 55.7                      | -24.2 | 11.2  | 17.5    | 21.4    | 13.4  | 34.8  | 40.5                 | -48.2 | 28.8  | 3.3     | 2.8     | 8.9   | 11.7  |
| 53.9                      | -38.5 | 22.3  | 7.3     | 8       | 27.7  | 35.7  | 24.4                 | -73.3 | 42.4  | -1.6    | 3.7     | 2.7   | 6.4   |
| 88.7                      | -6    | 3.6   | 17      | 23.5    | 56    | 79.5  | 91.7                 | -67.5 | 42.4  | 6.4     | 7.2     | 23.3  | 30.5  |
| 50.7                      | -30.6 | 2     | 5.3     | 7.4     | 22.9  | 30.3  | 29.1                 | -70   | 37.9  | 3.1     | 3.4     | 4.8   | 8.2   |
| 28.7                      | -19.9 | 23.8  | 10.9    | 13.1    | 12.1  | 25.2  | 17.8                 | -47.1 | 43.4  | 0.7     | -1.1    | 3.6   | 2.5   |
| 31.5                      | 29.7  | 3.8   | 24.7    | 38.6    | 24.1  | 62.7  | 70.2                 | -69.2 | 37.4  | -4.7    | -9.1    | 3     | -6.1  |
| 54.2                      | -15.9 | 28.5  | 8.2     | 9.4     | 33.3  | 42.7  | 47.3                 | -56.4 | 53.5  | 2.3     | 1.1     | 16.6  | 17.7  |
| 50.9                      | -4.4  | 19.9  | 13.6    | 13.5    | 39.3  | 52.8  | 55.5                 | -55   | 45.8  | 1.5     | 0       | 15.3  | 15.3  |
| 55.2                      | -25.9 | 26.8  | 12.3    | 14.4    | 23.9  | 38.3  | 38.3                 | -81.5 | 43    | 2.6     | 2.4     | 3.3   | 5.7   |
| 48.2                      | -18.4 | 2.3   | 8.9     | 10.2    | 22.1  | 32.3  | 38.8                 | -59.2 | 30.1  | 0       | -1.5    | 13.9  | 12.4  |
| 30.7                      | 15.5  | 25.9  | 14.6    | 17.8    | 34.7  | 52.5  | 55.2                 | -37.4 | 48.9  | -4.2    | -8.2    | 15.9  | 7.7   |
| 55                        | -46.3 | 58.7  | 10.5    | 15.6    | 32    | 47.6  | 17.7                 | -43.3 | 53.4  | 7.9     | 11.9    | 23    | 34.9  |
| 79.8                      | -45.1 | 24.6  | 6.6     | 8.5     | 30    | 38.5  | 43.7                 | -58.6 | 41.5  | -0.2    | -1.8    | 29.1  | 27.3  |
| 44.2                      | -13   | -2.7  | 4.2     | 3.3     | 29.1  | 32.4  | 40.2                 | -38.7 | 44.8  | 2.4     | 0       | 21.5  | 21.5  |
| 87.1                      | -47.8 | 37.8  | 6.2     | 6.4     | 44    | 50.4  | 48.3                 | -84.6 | 55.9  | 1.8     | 1       | 22.2  | 23.2  |
| 77                        | -24   | 20.2  | 14.9    | 18.4    | 44    | 62.4  | 62                   | -59.1 | 37.4  | 14.4    | -1.9    | 33.9  | 32    |
| 38.5                      | 4     | 18.7  | 10.4    | 12.4    | 22.3  | 34.7  | 51.5                 | -36.2 | 42.8  | 4.5     | 5.4     | 10.2  | 15.6  |
| 82                        | -35.4 | 37.5  | 14.5    | 20.2    | 45.9  | 66.1  | 55.6                 | -61.6 | 58.7  | 5.9     | 8.2     | 42    | 50.2  |
| 54.8                      | 4.7   | 37.6  | 6.9     | 10      | 48.6  | 58.6  | 68.5                 | -49.8 | 48.7  | 4.4     | 3       | 26.1  | 29.1  |
| 53                        | -30.1 | 43.4  | -1.3    | 3.5     | 38    | 41.5  | 31.9                 | -54.8 | 46.5  | 1.2     | -1.3    | 13.5  | 12.2  |
| 53                        | -21.5 | 48    | 14      | 15.9    | 26.1  | 42    | 40.5                 | -56.3 | 50.2  | 2.4     | 0.7     | 18.6  | 19.3  |
| 63.7                      | -2.3  | 23.9  | 8.1     | 9.2     | 17.6  | 26.8  | 70.4                 | -32.4 | 27.9  | 5.9     | 7.4     | 13.6  | 21    |
| 88.9                      | -49.5 | 36    | 8.5     | 7.8     | 42    | 49.8  | 48.4                 | -73.2 | 31.9  | 1       | 0.1     | 33.4  | 33.5  |
| 70                        | -30.1 | 55.8  | 20.4    | 26.8    | 24    | 50.8  | 48.9                 | -66.7 | 58.2  | 10.1    | 12.5    | 20    | 32.5  |
| 71.2                      | -14.7 | 3.2   | 14.3    | 17.2    | 36.4  | 53.6  | 65.5                 | -54.4 | 20.3  | 4.2     | 3.6     | 14    | 17.6  |

TABLE I

## DISCUSSION

Sagittal balance understanding and analysis became, in the last decade, of most importance as it is directly correlated with disability and pain. Sagittal malalignment can be appreciated by the measures of LL, TK, PT, SVA and knee flexion [10]. These parameters are daily used in clinical routine but individually take in consideration part of the sagittal balance. Recently a “second generation” of parameters considering globally sagittal malalignment and its compensatory mechanism appeared.

In this study we reviewed the global tilt, which is a modified version of the spinopelvic angle (SPA) described by Roussouly [11]. SPA corresponds to the angle drawn between two lines, the first line joins the center of C7 to the center of S1 endplate, and the second line joins the center of the femoral head to the center of the sacral endplate. From a geometrical point of view, this angle corresponds to the following formula:  $SPA = 180 - GT$ . GT and SPA are indeed supplementary angles. On the other hand GT seems easier to read than the SPA as it corresponds to the sum of PT and C7VT angles. For normal balanced subjects, the GT approaches the value of the PT as the C7VT approaches 0°. If sagittal imbalance occurs the GT will raise due to retroversion of the pelvis (raise of PT) and/or spinal malalignment (raise of C7VT). In other words, a GT value over 20° signs spinopelvic malalignment and should be considered by the surgeon in his management.

To describe the GT we introduced the notion of C7VT. The C7 tilt is the angle between the horizontal axis and the line drawn between the C7 body and the middle of the sacral endplate [11]. In the asymptomatic population its values approaches 90°. To make the GT more understandable we described the C7VT. It is the angle between the vertical axis and the line drawn between the C7 body and the middle of the sacral endplate. This construction can be resumed by the following formula:  $CT\ Tilt = C7VT + 90^\circ$ . C7VT approaches 0° in the asymptomatic population and can be assimilated to an angular version of SVA. An interesting point between C7VT compared to SVA is that it is an angle and does not need to be calibrated like SVA which is a distance.

To describe the GT we presented in this study a cohort of major deformities surgically managed by PSO. The choice of this population was to illustrate the differential adaptation of the pelvis and the spine in some cases and to highlight the need of a global spinopelvic parameter. In further studies GT could be measured with other populations to evaluate a potential therapeutic impact in spinal malalignment management or to integrate a new spinal deformity classification.

Mismatches appeared for 6 out of 31 patients. These mismatches between spine and pelvis reveal the interest of the GT. The choice of a PT over 20° or a SVA over 5 cm was based on values commonly seen in the literature and associated with spinal malalignment [12]. All patients in

this study presented a major spinal malalignment and a GT over 25°. In this study we can't deduce that all patients with a GT over 25° should have a PSO, as it wasn't the aim of the study to underline a therapeutic impact of GT. But we can observe that some patients with a PT less than 20° or a SVA less than 5 cm (or C7VT less than 5°) can require a spinal osteotomy to correct the malalignment. The interaction existing between the spine and the pelvis is a major keypoint in the understanding of sagittal balance and the analysis of spinal deformities. When imbalance occurs, the compensatory mechanisms are activated to restore a correct balance. Compensation begins at the spine level (modifications of spinal curves), and if this compensation is not sufficient the pelvis tilts, increasing the PT value. Many parameters have been described for the evaluation of the spinal balance or the pelvic compensatory mechanisms on the other side [13-16]. But no parameter is commonly used for the assessment of the global spinopelvic alignment, taking into account simultaneously the two parts (spinal and pelvic) of this issue.

In this study GT appeared to be a more correlated parameter than PT, SVA or C7VT with spinal malalignment. An explanation we can bring forward is that the GT takes into consideration the spinal and the pelvic balance. This is of most importance as in some situations the spinal and the pelvic balance aren't modified the same way. This first study introducing GT should be completed in the future by the evaluation of the GT in other series of patients and its clinical impact should be demonstrated.

## CONCLUSION

Normal sagittal alignment is a combination of multiple parameters including the spine, the pelvis and the lower extremities parameters. Global tilt is a parameter for the evaluation of the global spinopelvic alignment. It appears in this study more correlated with spinal malalignment than the spinal or pelvic parameters taken individually.

CONFLICT OF INTEREST: None

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