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ORIGINAL ARTICLE

# Lumbopelvic parameters can be used to predict thoracic kyphosis in adolescents

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## Abstract

**Purpose** Distal thoracic kyphosis (DTK) equivalent to proximal lumbar lordosis (PLL) is the sum of pelvic tilt (PT) and the difference (Δ) between lumbar lordosis (LL) and pelvic incidence (PI): PLL = DTK = PT + Δ. With the assumption that proximal thoracic kyphosis (PTK) is similar to DTK, we propose the equation TK = 2(PT + LL − PI) to express the relationship between thoracic kyphosis (TK) and pelvic parameters. The objective of this work is to verify this relationship in a normal population.

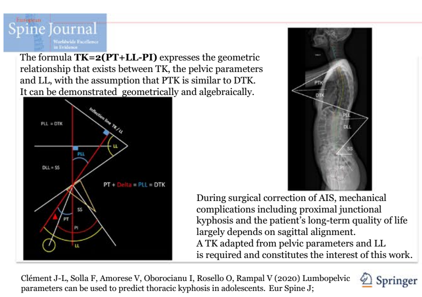
**Methods** Full spine radiographs of 100 adolescents and young adults (13 to 20 years old), free from vertebral pathology, were analyzed. Measurements included pelvic parameters, LL, PLL, DLL, TK, PTK, DTK and C7 global tilt. The measured global TK was compared with the theoretical TK calculated according to the formula TK = 2(PT + LL − PI).

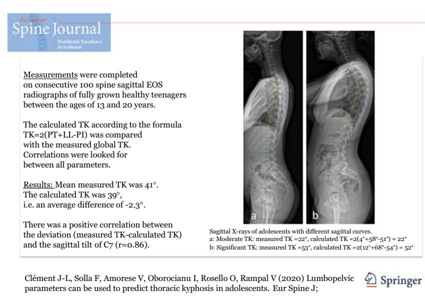
**Results** The difference between measured TK and calculated TK was + 2.3° and correlated with the C7 global tilt ($r = 0.86$). There was a significant linear regression between TK and PT + Δ ($p < 0.0001$). Given radiographs' inter-rater reliability of 5° for angled measurements, the $p$ value (0.047) between measured TK and calculated TK is statistically significant to support the hypothesis.

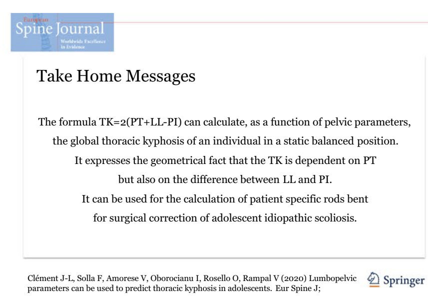
**Conclusion** This work validates the formula TK = 2(PT + LL − PI) which allows the calculation of global TK as a function of PT, LL and PI. This calculated TK can be used as a target for sagittal correction of adolescents with spine deformities.

### Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.




**Keywords** Thoracic kyphosis · Pelvic tilt · Lumbar lordosis · Pelvic incidence

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## Introduction

Many authors have shown correlations between the pelvic and spinal sagittal parameters [1–4]. Pelvic incidence is correlated to pelvic tilt, sacral slope (SS) and lumbar lordosis, while thoracic kyphosis is correlated with lumbar lordosis and proximal lumbar lordosis. They are the statistical expression of the geometric relationships that exist between adjacent angles. Therefore, a correlation between TK and the pelvic parameters via LL and PLL seems possible. To our knowledge, this relationship has not been described.

The wide range of normal TK values, which can vary from 10° to 55° according to the authors [5, 6], reflects the fact that everyone has their own TK, just as everyone has their own PI [7].

The effect of hypokyphosis correction on uninstrumented lumbar lordosis in the surgical treatment of adolescent idiopathic scoliosis (AIS) was evaluated in a recent study [8] and hypothesized that the formula TK = 2 (PT + LL − PI) expresses the relationship between TK and pelvic parameters. The goal of the present study is to verify this formula on normal sagittal radiographs.

During surgical correction of AIS, mechanical complications including proximal junctional kyphosis (PJK) and the patient's long-term quality of life largely depend on sagittal alignment [9–11]. A TK adapted from pelvic parameters and LL is required and constitutes the interest of this work.

## Methods

For the purpose of this article, we measured global TK and global LL [12]. They correspond to all the vertebrae which are in kyphosis or lordosis independently of a vertebral level defined theoretically (Fig. 1). TK and LL are separated by an inflection line, perpendicular to the spine, defined by the change of curvature between the thoracic and lumbar regions of the spine. When measuring, the positioning of this reversal point is like that of the coronal plane limit vertebrae.

Global LL was measured between sacral slope and the inflection line, and global TK between this inflection line and the inflection line between the thoracic and cervical regions. Global TK and LL are thus defined by their angular values and the number of vertebrae constructing them.

The global LL has been divided into two parts (Fig. 1): PLL above the horizontal and DLL below the same horizontal line [2]. Similarly, the global TK was divided into a proximal thoracic kyphosis (PTK) above the horizontal and a distal thoracic kyphosis (DTK) below: TK = PTK + DTK. On a balanced spine, it's assumed the horizontal divides TK into two equal parts [8] so that PTK = DTK and TK = 2DTK. DTK is geometrically equal to PLL as DLL is equal to SS.

As per Fig. 2, a line perpendicular to the inflection line passing through the middle of SS creates an angle Δ which added to PI is equal to LL (angles with perpendicular sides). This angle Δ represents the angular value which must be added to PI to obtain LL: Δ = LL − PI.

The angle Δ + PT is equal to PLL (angles with perpendicular sides) and therefore to DTK: PLL = DTK = PT + Δ.

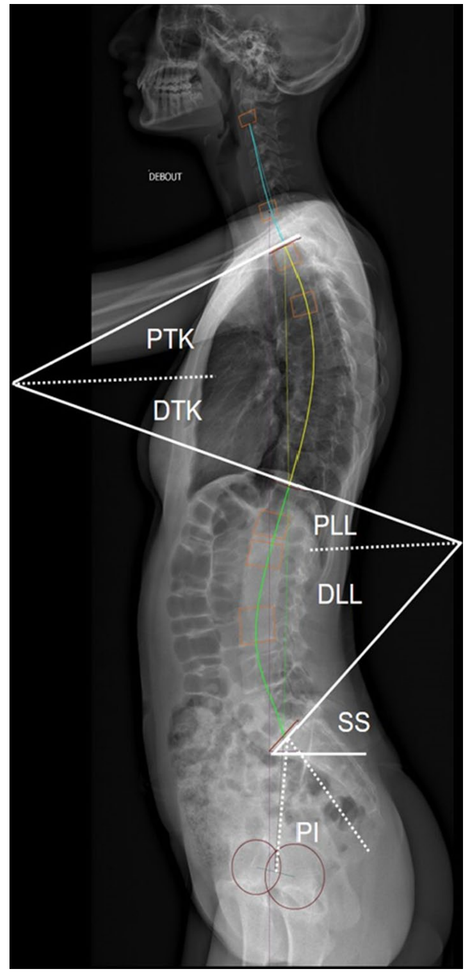


**Fig. 1** The global LL is divided into proximal lumbar lordosis (PLL) above the horizontal and distal lumbar lordosis (DLL) below the horizontal. Global TK is divided into a proximal thoracic kyphosis (PTK) above the horizontal and distal thoracic kyphosis (DTK) below. DTK = PLL and DLL = SS

In equation TK = 2DTK, replacing DTK (PT + Δ) and Δ (LL − PI), the formula TK = 2(PT + LL − PI) expresses the geometric relationship that exists between TK, the pelvic parameters and LL.

It also can be demonstrated algebraically: DTK = PLL = LL − SS; PI = PT + SS that to say SS = PI − PT therefore replacing SS, DTK = LL − (PI − PT), in progress DTK = PT + LL − PI.

Measurements were completed on consecutive spine sagittal EOS radiographs of fully grown (Risser 4 or 5) healthy teenagers (70 girls and 30 boys) between the ages of 13 and 20 years (average 16 years), chosen from the radiographs of a hospital imaging unit. Radiographs with vertebral pathology (scoliosis, hyperkyphosis > 60°, vertebral growth dystrophy, sequelae of fracture, spondylolysis, etc.) were excluded.

The spinopelvic parameters were measured using the graphical software "Keops Analyzer" [13]. The inflection

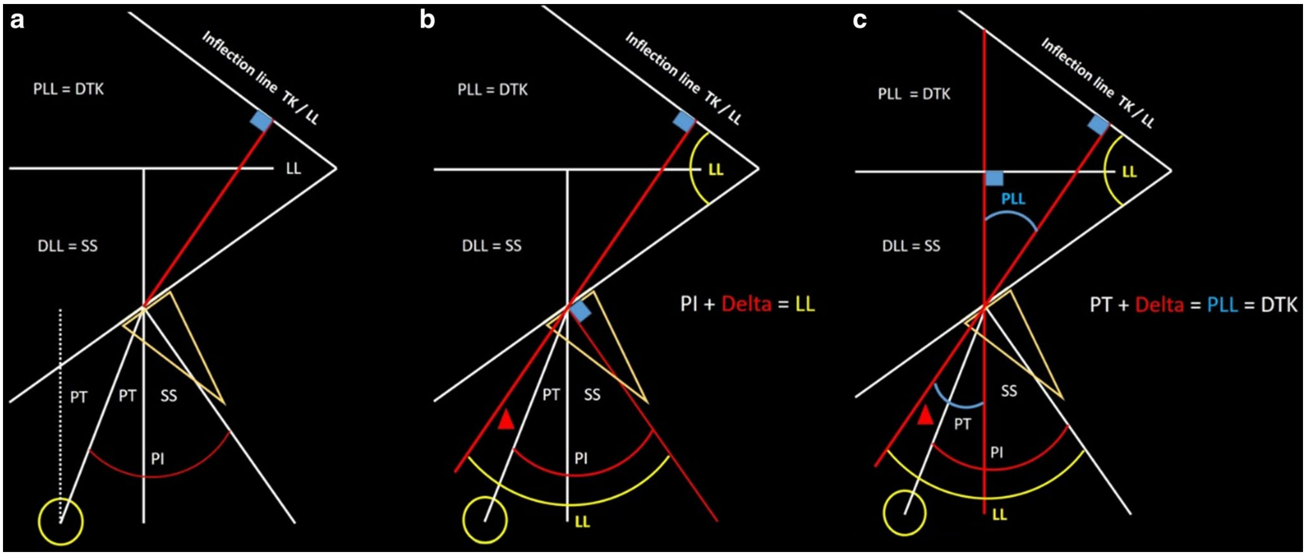


**Fig. 2** Geometric demonstration of DTK = PT + LL − PI. **a** We draw a line perpendicular to the inflection line and passing through the middle of SS. **b** It creates an angle Δ which added to PI is equal to LL (angles with perpendicular sides). Δ = LL − PI. **c** If we associate Δ and PT, we obtain an angle equal to PLL (perpendicular sides). PLL = PT + Δ or PLL = DTK = PT + LL − PI

points and limit vertebrae were automatically determined by the software.

The sagittal tilt of C7, the angle between the vertical and the line from the center of C7 vertebral body to the middle of the sacral plate, was chosen as the balance parameter. It was positive if the angle was opened forward and negative backward. The calculated TK according to the formula TK = 2(PT + LL − PI) was compared with the measured TK. Correlations were looked for between all parameters.

## Ethic

This study has been approved by the authors' Institutional Review Board: CCP (committee for the protection of persons) with Number FC/2019-91.

## Statistical analysis

It was performed using the XLSTAT Addinsoft software. The means were compared by Student's *t* test. Univariate correlations were explored by Pearson's formula. Multivariate analysis was performed through linear regressions [14].

## Results

The values of the parameters from the 100 radiographs are reported in Table 1. Mean measured TK was 41°. The inflection points were on average around T12 and T2 for the LL/TK and TK/CL regions, respectively. On average, the thoracic kyphosis was composed of 11 vertebrae and five vertebrae for the lumbar lordosis. The calculated TK was 39°, i.e., an average difference of −2.3° compared to the measured TK. Age, sex and Risser sign did not correlate with sagittal parameters ($p > 0.2$).

Assuming the radiographs' inter-rater reliability of 5° for angled measurements, the *p* value (0.047) between measured TK and calculated TK ± 5° is statistically significant to support the hypothesis.

Through well-known correlations (PI/SS, PI/PT, PI/LL, PI/Δ, SS/LL and PT/Δ), TK was correlated with PTK, PLL,

**Table 1** Average, minimum, maximum and standard deviation of pelvic and spinal parameters on 100 EOS sagittal radiographs of healthy adolescents

| | Average | Min | Max | Standard deviation |
|---|---|---|---|---|
| PI | 45.7 | 26.3 | 69.8 | 10.6 |
| PT | 7.7 | −9.8 | 22.9 | 6.7 |
| SS = DLL | 38.1 | 18.1 | 62.8 | 8.3 |
| LL | 57.6 | 35.1 | 87.7 | 10.0 |
| PLL = DTK | 19.5 | 8.2 | 30.4 | 4.5 |
| Δ = LL − PI | 11.9 | −9.1 | 31.9 | 8.5 |
| PTK | 21.8 | 10.2 | 31.5 | 4.8 |
| Measured TK | 41.3 | 19.7 | 59.6 | 7.9 |
| Calculated TK | 39.0 | 16.5 | 60.8 | 8.9 |
| Gap | −2.3 | −8.7 | 11.5 | 4.8 |

*PI* pelvic incidence, *PT* pelvic tilt, *SS*: sacral slope, *DLL* distal lumbar lordosis, *LL* lumbar lordosis, *PLL* proximal lumbar lordosis, *DTK* distal thoracic kyphosis, *PTK* proximal thoracic kyphosis, *TK* thoracic kyphosis; Gap = measured TK—calculated TK

Δ and LL. DTK correlated with Δ and LL (Table 2). There was a positive correlation between the deviation (measured TK–calculated TK) and the sagittal tilt of C7 ($r = 0.86$).

There was a significant linear regression between TK and PT + Δ ($p < 0.0001$). The regression equation was TK = 25° + PT + 1.01*Δ.

## Discussion

The gap between calculated and measured TK is clinically small (2.3°); therefore, we can validate the formula TK = 2(PT + LL − PI) and calculate TK of a healthy individual from their pelvic parameters and LL (Fig. 3). Because DTK is geometrically equal to PLL, PTK is 2.3° higher than DTK confirming the assumption that TK is divided into two similar parts, PTK and DTK.

The correlations confirm that TK and DTK are linked to LL and Δ. The formula TK = 25° + PT + Δ found from the linear regression confirms the geometric relationship. The algebraic form of the regression equation requiring a constant, the multiplicator 2* is replaced by adding 25°.

This geometric construction is only applicable with all the vertebrae which are in kyphosis or in lordosis, i.e., global TK and LL. Segmental measurements of TK (T4 or T5–T12) and LL (L1–L5 or S1) overlook the vertebrae located above or below the considered segment, which may be in kyphosis or lordosis.

The 2.3° difference is strongly correlated with the sagittal C7 global tilt. If the gap increases (measured TK > calculated TK and PTK > DTK), the global tilt increases, reflecting an anterior imbalance. Conversely, if the gap decreases or becomes negative (measured TK < calculated TK and PTK < DTK), the global tilt is negative, reflecting a posterior imbalance.

The search for an optimal TK after surgery for idiopathic scoliosis is at the origin of recent publications [8, 15–17] motivated by the frequency (26%) of proximal junctional kyphosis (PJK) [18]. PJK is a compensation phenomenon to help recover a spinal balance when the thoracic kyphosis is not restored [9].

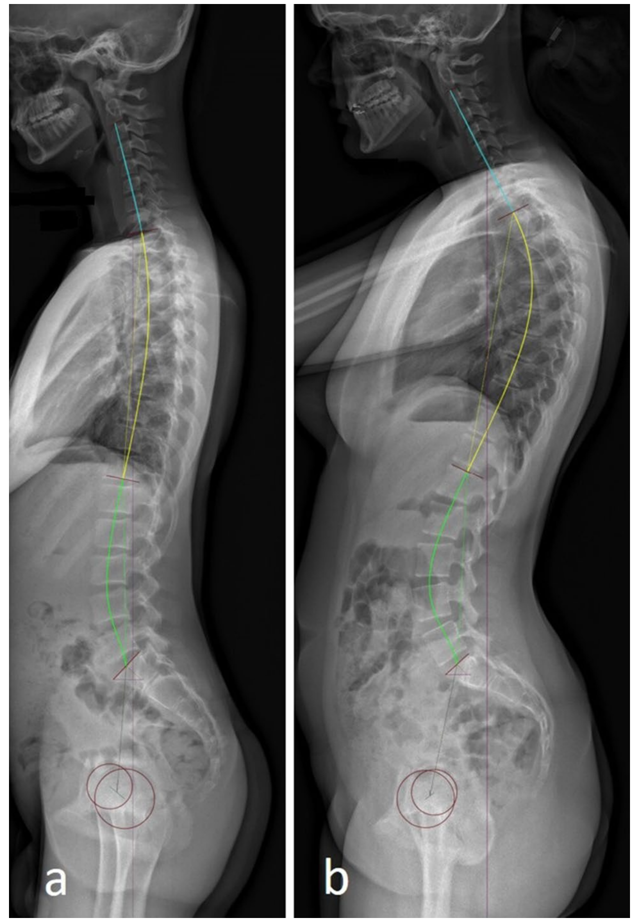


**Fig. 3** Sagittal X-rays of adolescents with different sagittal curves. **a** Moderate TK: measured TK = 22°, PT = 4°, PI = 51°, LL = 58°, Δ = +7°, calculated TK = 2(4° + 58° − 51°) = 22°. **b** Significant TK: measured TK = 53°, PT = 12°, PI = 54°, LL = 68°, Δ = +14°, calculated TK = 2(12° + 68° − 54°) = 52°

Pelvic parameters are not changed after surgical correction of scoliosis [8, 17]. The preoperative values of PI, PT and SS are found to remain consistent at follow-up allowing the calculation of TK based on the preoperative values of the pelvic parameters. The formula TK = 2(PT + LL − PI) can also be written TK = 2(PT + PLL + SS − PI), as LL is the

**Table 2** Correlations between the different pelvic and spinal parameters

| | PI | SS = DLL | PT | LL | Δ | PLL = DTK | TK | PTK |
|---|---|---|---|---|---|---|---|---|
| SS = DLL | **0.84** | | | | | | | |
| PT | **0.63** | 0.09 | | | | | | |
| LL | **0.71** | **0.87** | 0.2 | | | | | |
| Δ | **−0.49** | −0.03 | **0.84** | 0.26 | | | | |
| PLL = DTK | −0.02 | 0.07 | −0.14 | **0.50** | **0.66** | | | |
| TK measured | −0.07 | 0.01 | −0.14 | **0.43** | **0.63** | **0.96** | | |
| PTK | −0.1 | 0.04 | 0.12 | 0.34 | **0.56** | **0.85** | **0.97** | |

Bold values indicate the correlations of medium or strong intensity sum of SS and PLL. It shows that TK is dependent on three invariable pelvic parameters PT, SS and PI and a variable spinal parameter PLL.

In case of selective thoracic fusion, uninstrumented PLL can adapt to the variation in TK. LL increases after correction of hypokyphosis, 40% of the increase in TK being transmitted to LL via DTK geometrically equal to PLL [8]. More generally, any variation in TK and therefore DTK induces a variation in LL which should be considered in the calculation of TK.

In case of fusions below L2, instrumented upper lumbar spine loses its adaptability and PLL depends on instrumentation. Thus, rods' contouring becomes essential for achieving a good balance. PLL is the basis for sagittal balance adjustment.

Thus, the calculation of TK must be done in two steps. TK is first calculated with the preoperative values of PT, PI and LL. A second calculation is performed with the new expected postoperative value of LL. The post-op LL is linked to the variation of TK and equal to LL pre-op increased or decreased by 40% of the variation of TK. This gives the optimal global TK of the patient.

Therefore, the surgeon can calculate the global thoracic kyphosis required for his patient and adapt the bending of the rods. At best, using a method allowing precise bending according to the chosen angulation should lead to obtaining an optimal sagittal balance. The use of a kyphogenic reduction technique is then necessary to obtain this optimal TK [19–21].

It is then necessary to relate the value of the global TK to the length of the instrumentation. The global TK comprises on average 11 vertebrae (T2–T12); if the instrumentation includes 9 thoracic vertebrae (T4–T12), it will be necessary to bend the rods to 9/11th of the calculated global TK. This calculation can be adapted if you want to modify the inflection points according to the type of curvature you want to obtain [7].

## Conclusion

The formula $TK = 2(PT + LL - PI)$ can calculate, as a function of pelvic parameters, the global thoracic kyphosis of an individual in a static balanced position. It expresses the geometrical fact that the TK is dependent on PT but also on the difference between LL and PI. It can be used for the calculation of patient specific rods bent for surgical correction of adolescent idiopathic scoliosis.

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## Compliance with ethical standards

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

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