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ORIGINAL ARTICLE

# Global analysis of sagittal spinal alignment in major deformities: correlation between lack of lumbar lordosis and flexion of the knee

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**Abstract**
*Introduction* It has become well recognised that sagittal balance of the spine is the result of an interaction between the spine and the pelvis. Knee flexion is considered to be the last compensatory mechanism in case of sagittal imbalance, but only few studies have insisted on the relationship between spino-pelvic parameters and lower extremity parameters. Correlation between the lack of lumbar lordosis and knee flexion has not yet been established.
*Materials and methods* A retrospective study was carried out on 28 patients with major spinal deformities. The EOS system was used to measure spinal and pelvic parameters and the knee flexion angle; the lack of lumbar lordosis was calculated after prediction of lumbar lordosis with two different formulas. Correlation analysis between the different measured parameters was performed.
*Results* Lumbar lordosis correlated with sacral slope ($r = -0.71$) and moderately with knee flexion angle ($r = 0.42$). Pelvic tilt correlated moderately with knee flexion angle ($r = 0.55$). Lack of lumbar lordosis correlated best with knee flexion angle ($r = 0.72$ and $r = 0.63$ using the two formulas, respectively).
*Conclusion* Knee flexion as a compensatory mechanism to sagittal imbalance was well correlated to the lack of lordosis and, depending on the importance of the former parameter, the best procedure to correct sagittal imbalance could be chosen.

**Keywords** Sagittal imbalance · Knee flexion · Osteotomy · EOS · Lumbar lordosis

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## Introduction

Nowadays, it has become evident that analysis of the spine balance cannot be done without taking into account the pelvis or the *pelvic vertebra* as designated by Dubousset [1]. When a spinal deformity with sagittal imbalance occurs, compensatory mechanisms include not only the spinal column but also the pelvis; pelvic retroversion or posterior tilt of the pelvis is the main mechanism of compensation when the normal spinal segment compensation has reached its maximum. When the sagittal imbalance is major, pelvic retroversion can no more be efficient and another compensatory mechanism is recruited involving the lower extremities, first the hips reach their maximum of extension at the same time of pelvic tilting and then the knees start to flex. The knee flexion is the last compensatory mechanism to come into the picture and to enable a standing balance; it is also the best one seen clinically on a side view of a standing patient. We could easily deduce that the more the anterior inclination is, the more the knee flexion will be important, when the knee flexion become incompatible with normal walking, the use of a walking stick becomes mandatory. This series of compensatory mechanisms beginning at the spine and ending at the knees leads us to analyse the relationship between the spine, the pelvis and the lower extremities. To assess such relationship, radiographs including the full spine, the pelvis and the lower extremities are needed. This kind of imaging is now possible with the use of the EOS [2] low dose system (Biospace, Paris, France) that enables accurate analysis of spino-pelvic parameters and also knee flexion.

Few studies have analysed the relationship between spine, pelvis and lower extremities. The aim of this study is to determine the correlation between the lack of lumbar lordosis, defined as the difference between the theoretical lumbar lordosis and the measured lumbar lordosis, and the knee flexion.

## Materials and methods

Since the works of Duval-Beaupère and the first description of Pelvic incidence as the key factor for managing the spinal balance by Legaye et al. [7], several authors have proposed a formula for the prediction of lumbar lordosis based on the pelvic incidence which is a morphologic parameter that define the shape of the pelvis and remain constant over the time during adulthood [8, 9], it can be modified only by a pelvic osteotomy. We have used the formulas proposed by Legaye et al. [6] and Schwab et al. [14] to determine the ideal lumbar lordosis, therefore, having the measured lumbar lordosis and the theoretical lordosis, we could establish the lack of lordosis for each patient which seemed to us as a more interesting parameter to correlate with the knee flexion than the lumbar lordosis itself. As the lumbar lordosis depends on the pelvic incidence, to establish an accurate correlation between the former parameter and the knee flexion, the latter parameter should be taken into account; the best way was to calculate the difference between the theoretical lordosis based upon the pelvic incidence and the measured lordosis. In this manner, when two patients having the same lumbar lordosis with different pelvic incidences and different knee flexion angles, calculating the lack of lordosis would give us a better idea of the range of knee flexion needed to compensate explaining the two different knee angles and thus, a correlation between the lack of lordosis and the knee flexion should be higher than the correlation between the lumbar lordosis and the knee flexion.

The study included 27 patients (18 female, 9 male), all had a major spinal deformity with severe sagittal imbalance necessitating major correction surgery.

The EOS low dose system (Biospace, Paris, France) was used to measure spinal and pelvic parameters and the knee flexion angle. Posture in the EOS device was in an easy standing position (spontaneous knee position) with fists overlying ipsilateral clavicles.

The following radiographic parameters were measured:

| | |
|---|---|
| Lumbar lordosis | the angle between the superior endplate of L1 and the endplate of S1 |
| Thoracic kyphosis | the angle between the superior endplate of T4 and the inferior endplate of T12 |
| Pelvic incidence | the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral heads axis |
| Sacral slope | the angle between the horizontal and the sacral plate |
| Pelvic tilt | the angle between the vertical and the line through the midpoint of the sacral plate to femoral heads axis |
| C7-CSVL | the alignment of the C7 plumb line in relation to the center sacral vertical line (CSVL) |
| Sagittal vertical axis | distance between C7 plumb line and posterior superior corner on the top margin of S1 |
| Knee flexion angle | the angle between the femoral axis and the tibial axis |

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

Two parameters were derived from the pelvic incidence measured above:

The ideal lumbar lordosis based on the formula described by Legaye et al.: $LL = -((PI \times 0.5481 + 12.7) \times 1.087 + 21.61)$.

The ideal lumbar lordosis based on the formula described by Schwab et al.: $LL = PI + 9$.

Correlations between measurements were analysed by simple linear regression, and the significance of the correlation coefficient was tested with the *t*-test.

## Results

Radiographic measurements: Table 1

Lumbar lordosis was −23.1° (mean value), thoracic kyphosis was 29.5°, pelvic incidence was 57.3°, sacral slope was 27°, pelvic tilt was 30.39°, C7-CSVL was 0.93 cm, SVA was 13.11 cm, knee flexion was 14.31° ranging from 1.2° to 36.4°, lack of lordosis based on Legaye formula was −46.5°, lack of lumbar lordosis based on Schwab formula was −43.2°. We have noticed that from a 10° angle of knee flexion, all patients had at least 30° of lack of lumbar lordosis.

**Table 1**

| Lumbar lordosis | Exact value | | | | | | | Lumbar lordosis [6] | Lumbar lordosis [9] | Lack of lumbar lordosis [6] | Lack of lumbar lordosis [9] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thoracic kyphosis | Pelvic incidence | Sacral slope | Pelvic tilt | C7-CSVL (cm) | SVA (CM) | Knee flessum | | | | | |
| −25.8 | 60.9 | 68.7 | 39.7 | 29 | 3.7 | 27.7 | 26.6 | −76.3 | −77.7 | −50.5 | −51.9 | 1 |
| −31.7 | 46.3 | 45.6 | 23.5 | 22.1 | −2.4 | 4.1 | 7.8 | −62.6 | −54.6 | −30.9 | −22.9 | 2 |
| −5 | 48.1 | 58.7 | 2.6 | 56.1 | 1.9 | 12.3 | 27.7 | −70.4 | −67.7 | −65.4 | −62.7 | 3 |
| −39.2 | 37.1 | 64.2 | 34.5 | 29.7 | 1.9 | 7.9 | 10.2 | −73.7 | −73.2 | −34.5 | −34.0 | 4 |
| −12.9 | 21.2 | 60.4 | 9.2 | 51.2 | 2.7 | 7.8 | 16.4 | −71.4 | −69.4 | −58.5 | −56.5 | 5 |
| 2.2 | 4.3 | 47.8 | 21.8 | 26 | 10.1 | 19.4 | 8.2 | −63.9 | −56.8 | −66.1 | −59.0 | 6 |
| −40.2 | 42.7 | 67.9 | 35.9 | 32 | −0.7 | 14 | 14.9 | −75.9 | −76.9 | −35.7 | −36.7 | 7 |
| −49.3 | 72.5 | 50.1 | 35 | 15.1 | −3.5 | 8 | 4.5 | −65.3 | −59.1 | −16.0 | −9.8 | 8 |
| −13 | −2.7 | 44.2 | 15.1 | 29.1 | 1.6 | 4.2 | 1.2 | −61.7 | −53.2 | −48.7 | −40.2 | 9 |
| −24.2 | 11.2 | 55.7 | 42.3 | 13.4 | −2.2 | 17.5 | 11.1 | −68.6 | −64.7 | −44.4 | −40.5 | 10 |
| −54.9 | 62.3 | 61.4 | 31.2 | 30.4 | 11.4 | 5.5 | 8.8 | −72.0 | −70.4 | −17.1 | −15.5 | 11 |
| −38.5 | 22.3 | 53.9 | 26.2 | 27.7 | −1.7 | 7.3 | 7.1 | −67.5 | −62.9 | −29.0 | −24.4 | 12 |
| −6 | 3.6 | 84.3 | 26.9 | 57.4 | 4.7 | 17 | 36.4 | −85.6 | −93.3 | −79.6 | −87.3 | 13 |
| −30.6 | 2 | 50.7 | 27.8 | 22.9 | −0.3 | 5.3 | 6.4 | −65.6 | −59.7 | −35.0 | −29.1 | 14 |
| −19.9 | 23.8 | 28.7 | 17.6 | 11.1 | 2.9 | 10.9 | 9.4 | −52.5 | −37.7 | −32.6 | −17.8 | 15 |
| −24.5 | 63.4 | 63.9 | 29.4 | 34.5 | 6.4 | 24.8 | 28.4 | −73.5 | −72.9 | −49.0 | −48.4 | 16 |
| 29.7 | 3.8 | 31.5 | 7.4 | 24.1 | 1 | 24.7 | 20.7 | −54.2 | −40.5 | −83.9 | −70.2 | 17 |
| −15.9 | 28.5 | 54.2 | 20.9 | 33.3 | −1.1 | 8.2 | 12.8 | −67.7 | −63.2 | −51.8 | −47.3 | 18 |
| −4.4 | 19.9 | 50 | 11.6 | 39.3 | −0.7 | 13.6 | 11.8 | −65.2 | −59.0 | −60.8 | −54.6 | 19 |
| −25.9 | 26.8 | 55.2 | 31.3 | 23.9 | −6.1 | 12.3 | 19.3 | −68.3 | −64.2 | −42.4 | −38.3 | 20 |
| −18.4 | 2.3 | 48.2 | 26.1 | 22.1 | 3.6 | 8.9 | 10.9 | −64.1 | −57.2 | −45.7 | −38.8 | 21 |
| 15.5 | 25.9 | 38.1 | 0.9 | 37.2 | 0 | 14.6 | 25.1 | −58.1 | −47.1 | −73.6 | −62.6 | 22 |
| −46.3 | 58.7 | 60.8 | 29 | 31.8 | −7.9 | 10.5 | 9.9 | −71.6 | −69.8 | −25.3 | −23.5 | 23 |
| −45.1 | 24.6 | 78.9 | 49.8 | 30 | 0.2 | 6.6 | 4.1 | −82.4 | −87.9 | −37.3 | −42.8 | 24 |
| −41 | 37.5 | 79.2 | 52.2 | 27 | 5.3 | 26.1 | 21.2 | −82.6 | −88.2 | −41.6 | −47.2 | 25 |
| −47.8 | 37.8 | 85.7 | 40.5 | 45.3 | −2.9 | 6.2 | 13.6 | −86.5 | −94.7 | −38.7 | −46.9 | 26 |
| −10.6 | 11.7 | 60 | 41.1 | 18.9 | −2.7 | 28.8 | 17.5 | −71.2 | −69.0 | −60.6 | −58.4 | 27 |
| −23.1 | 29.5 | 57.3 | 27.0 | 30.4 | 0.9 | 13.1 | 14.5 | −69.6 | −66.3 | −46.5 | −43.2 | |

Correlations in radiographic measurements

Lumbar lordosis correlated moderately with knee flexion angle ($r = 0.42$) (Fig. 2). Pelvic tilt correlated moderately with knee flexion angle ($r = 0.55$) (Fig. 3). Lumbar lordosis correlate best with sacral slope ($r = -0.71$) (Fig. 5) and lack of lumbar lordosis correlated best with knee flexion angle (Fig. 4); there was a better correlation when using Schwab formula ($r = 0.72$) (Fig. 1) compared to Legaye formula ($r = 0.63$) (Fig. 4).

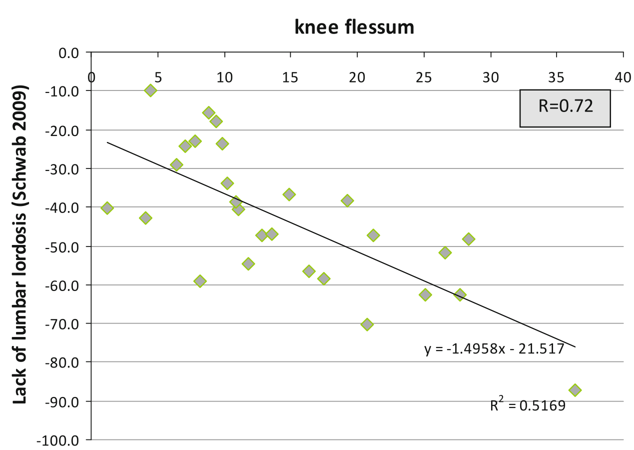


**Fig. 1** Correlation between knee flessum and lack of lumbar lordosis calculated by the method described by Schwab [14]

## Discussion

Comprehension of sagittal alignment in healthy people without previous history of spine pathology has led us to

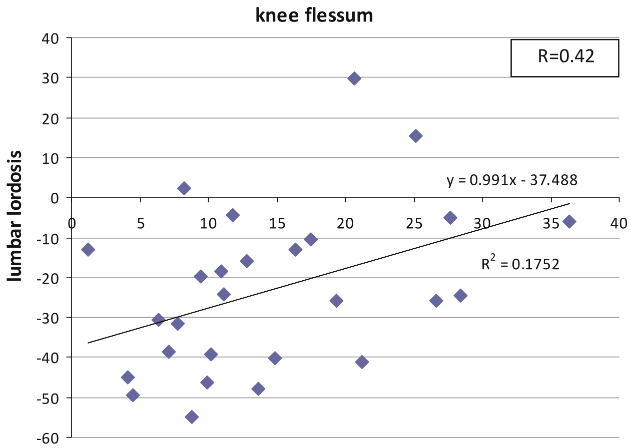


**Fig. 2** Correlation between knee flessum and lumbar lordosis

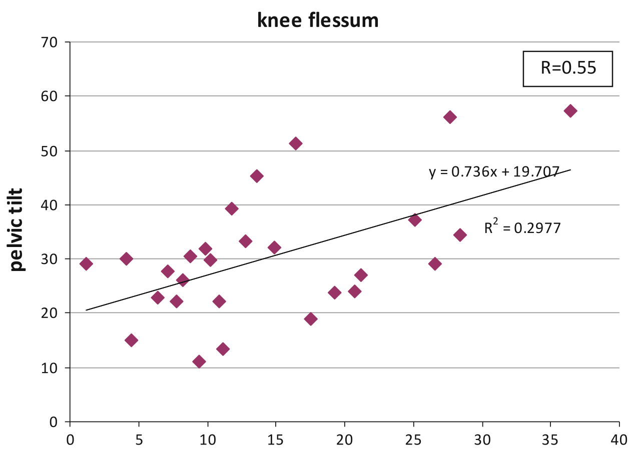


**Fig. 3** Correlation between knee flessum and pelvic tilt

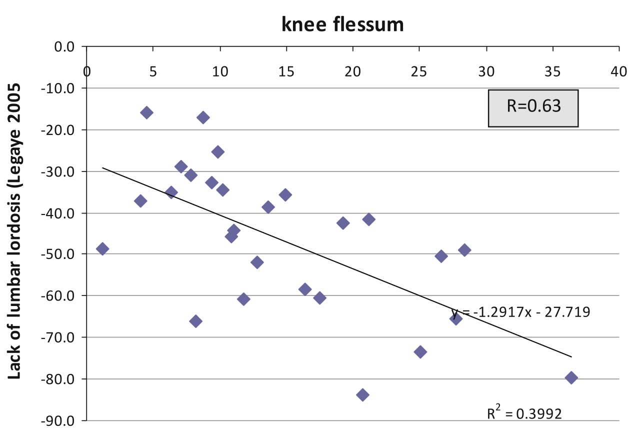


**Fig. 4** Correlation between knee flessum and lack of lumbar lordosis calculated by the method described by Legaye [6]

understand the sagittal balance in various kinds of deformities. One of the major points was the understanding of the interaction existing between the spine and the pelvis; when imbalance occurs, a compensatory mechanism is activated to

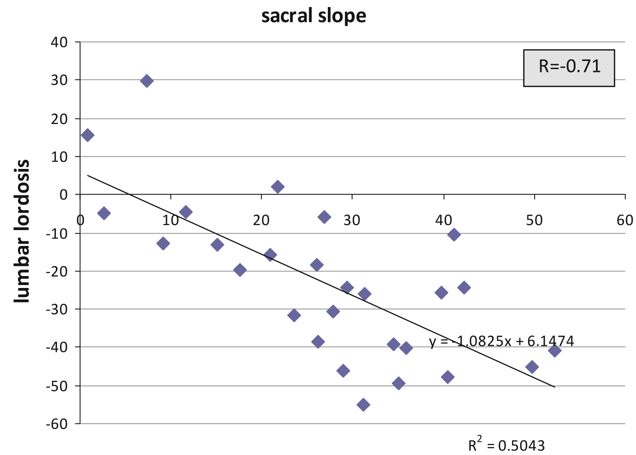


**Fig. 5** Correlation between sacral slope and lumbar lordosis

restore a correct balance, compensation begins at the spine level, and if is not sufficient the pelvis tilts, and at last when all compensatory mechanisms have been used, the lower extremities can help restoring a horizontal gaze by the mean of knees flexion. This last parameter is now studied accurately by the use of the EOS system (Biospace, Paris, France) that allow a full body radiograph with very low irradiation, enabling on one lateral view to calculate all sagittal parameters of the spine, pelvis and lower extremities. Many papers have studied the relationship between spine parameters and pelvic parameters [4, 12, 13, 15], but only few insisted on the relationship of these parameters with the lower extremities parameters. In this study, the interest was focused on the knee flexion angle and the spine or pelvic parameter that is best correlated to it.

Two recent studies [6, 14] have used statistical calculations to predict the ideal lumbar lordosis using formulas based on the pelvic incidence; we used these formulas to calculate the theoretical lumbar lordosis, we could than deduce the lack of lordosis as the difference between the theoretical lordosis and the measured lordosis.

This is the first series of major deformities analysing the knee flexion angle as a compensatory mechanism for sagittal imbalance and correlating it to the lack of lumbar lordosis.

The theoretical lumbar lordosis given by the two formulas were close but not identical (the difference was not significant, $p = 0.28$), nevertheless the correlation between the lack of lordosis and the knee flexion angle was significant with use of both formulas.

In a recent paper, Rose et al. [11] showed that thoracic kyphosis and pelvic incidence can predict with high sensitivity the lumbar lordosis necessary to achieve good sagittal balance following Pedicle substraction osteotomy. The formula for prediction was $LL \leq 45 - TK - PI$. This formula included a position-dependant parameter i.e. the thoracic kyphosis, thus, the prediction needed approximate adjustment after each calculation to take into account the thoracic kyphosis modification (increasing) after PSO. We could not use such formula for our study.

Our results are similar to those mentioned by Itoi [3] with moderate correlation between lumbar lordosis and sacral slope, between lumbar lordosis and knee flexion, and between pelvic tilt and knee flexion; lack of lordosis was not studied in his report, in fact the pelvic incidence was not yet described in the literature. In his study the knee flexion angle correlated best with the femoral shaft inclination angle.

Knee flexion angle was also studied by Lee et al. [5] in a paper analysing surgical treatment of degenerative flat back. The paper classified two types of population based on their ability to tilt the pelvis to compensate sagittal imbalance, those that had pelvic extensor muscle weakened could not tilt enough and so compensated by knee flexion that was significantly higher than those that could tilt posteriorly the pelvis. In this report, the knee flexion angle as a compensatory mechanism was analysed but no correlation between spine parameters and lower extremities parameters was searched out.

A paper by Murata et al. [10] studied the relation between lumbar lordosis and the knee extension, in fact, the relationship between the spinal parameter and the lower extremity parameter was analysed in a reverse order showing that degenerative changes in the knee that diminish its extension (and thus, increasing the knee flexion) are compensated in the spine by decreasing the lumbar lordosis. This report confirm the close interaction between spine and lower extremities, however it is always difficult to determine which parameter is the primary factor and which one is the compensatory factor; besides, in this paper, patients were asked to extend the knee to its maximum while standing, with both hands gripping a supporting bar. We think that a spontaneous knee position is preferred to not underestimate the deformity and the use of supporting bars could help the patient to hold an upright position he usually can not hold without any support.

In this study, all patients having at least 10° of knee flexion had at least 30° of lack of lumbar lordosis, which suggest that in this category of patients the imbalance is important and a significant correction is needed. Thus, if a 10° knee flexion angle or more is noted, a PSO procedure would eventually be necessary to achieve a correct sagittal outcome.

Moreover there is always an important dynamic part in spine deformities with sagittal imbalance increasing during walking.

## Conclusion

Normal sagittal alignment of the spine is a combination of balance between pelvic parameters, spine parameters and the lower extremities parameters. Knee flexion as a compensatory mechanism to sagittal imbalance was well correlated to the lack of lordosis calculated after prediction of lumbar lordosis with two different formulas.

Depending on the importance of the knee flexion angle, the type of the surgical procedure could be chosen. We think that a PSO procedure is more likely to be used if knee flexion angle is of 10° or more.

**Conflict of interest** None.

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