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Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves

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Abstract This paper proposes an anatomical parameter, the pelvic incidence, as the key factor for managing the spinal balance. Pelvic and spinal sagittal parameters were investigated for normal and scoliotic adult subjects. The relation between pelvic orientation, and spinal sagittal balance was examined by statistical analysis. A close relationship was observed, for both normal and scoliotic subjects, between the anatomical parameter of pelvic incidence and the sacral slope, which strongly determines lumbar lordosis. Taking

into account the Cobb angle and the apical vertebral rotation confers a three-dimensional aspect to this chain of relations between pelvis and spine. A predictive equation of lordosis is postulated. The pelvic incidence appears to be the main axis of the sagittal balance of the spine. It controls spinal curves in accordance with the adaptability of the other parameters.

Key words Sagittal shape · Pelvis · Lordosis · Spinal balance · Scoliosis · Posture

Introduction

Sagittal spinal morphology varies from one individual to the another and is specific to each person. Classifications proposed in the literature are based on the measurements of curvatures, angulations or other parameters, chiefly for a normal population [1–3, 7, 11, 13, 15–17]. They are purely descriptive rather than in any way analytic.

Modifications of sagittal spinal curvatures have been connected with changes in pelvic orientation [7, 11, 12, 16, 17]. Nevertheless, the role of pelvic anatomy in this positioning has never been investigated. A pelvic anatomic parameter named pelvic incidence is proposed in this study as the key factor for this sagittal balance regulation. Spinal balance is conceived as the result of an optimal lordotic positioning of the vertebrae above a correctly oriented pelvis. “Optimal lordotic positioning” and “correctly oriented pelvis” values are defined in this study, performed on a normal and a scoliotic population.

Materials and methods

Materials

The data of two population groups were analysed. The first group comprised a normal population of 49 adults free of vertebral disease. There were 21 women and 28 men, with a mean age of 24 years (SD 5.8 years; range 19–50 years). Mean height was 173 cm (SD 8 cm): 177 cm (SD 7 cm) for the men and 161 cm (SD 8 cm) for the women. Mean weight was 65.8 kg (SD 10 kg): 71 kg (SD 8.6 kg) for the men and 59.2 kg (SD 7.7 kg) for the women. These 49 adults constituted the control group for assessing the relationship between spine and pelvis for a normal population. They consisted of volunteer medical and physical therapy students.

The second group comprised 66 adult scoliotic women, with a mean age of 33 years (SD 19.8 years; range 10–84 years), and a mean height of 161 cm (SD 8 cm) and a mean weight of 55 kg (SD 8 kg). The frontal curves were lumbar in 24 cases and thoracolumbar in 42 cases.

Methods

The anatomical parameters (vertebral curvatures and pelvic parameters) were measured on orthogonal plain radiographs in stand-

Fig. 1 The pelvic parameters. *Pelvic incidence*: the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads. *Sacral slope*: the angle between the superior plate of S1 and a horizontal line. *Pelvic tilting*: the angle between the line connecting the midpoint of the sacral plate to the axis of the femoral heads, and the vertical. *Overhang of S1* (with regard to the femoral heads): the distance between the bicoxofemoral axis and the projection to this level of the midpoint of the sacral plate

ing position, with the arms lying on a support, and corrected for radiological distortion. "Rachis 91", the software of J. Hecquet [8, 9], for three-dimensional computerized reconstruction of the spine, was used for the capture of data from the radiographs, for analysis of the different parameters and for the statistical analysis.

The angular measurements were expressed in degrees.

The spinal parameters, in standing position, are:

1. The angle of lumbar lordosis (between L5 and T12)
2. The angle of thoracic kyphosis (between T12 and T1)

3. The Cobb angle (measured between the most tilted endplates)
4. The axial rotation of the top vertebra of the curve of scoliotic patients (the apical rotation), measured according to the technique of Perdriolle (for normal subjects it is zero.)

The pelvic parameters are: (Fig. 1)

1. The pelvic incidence, defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads. It is an anatomical parameter, unique to each individual, independent of the spatial orientation of the pelvis. The anatomical components involved in the make-up of this parameter are the first three sacral vertebrae, the sacro-iliac joints and the posterior segment of the iliac bone. This parameter could be considered as a constant because it is an anatomical one, independent of the position of the pelvis, the mobility of sacro-iliac joint being considered negligible, and independent of the age once growth is completed.
2. The sacral slope, defined as the angle between the superior plate of S1 and a horizontal line. A vertical sacrum is described by a low value, a horizontal sacrum by a high value.
3. Pelvic tilting, defined as the angle between the line connecting the midpoint of the sacral plate to the femoral heads axis and the vertical.
4. The overhang of S1 with regard to the femoral heads, defined as the distance between the bicoxofemoral axis and the projection to this level of the midpoint of the sacral plate. It is expressed in millimetres. A point posterior to the bicoxofemoral axis is considered positive, a point anterior to this axis is considered negative.

These last three parameters reflect the sagittal orientation of the pelvis.

Results

The mean values and the standard deviations for the studied parameters are reported in Table 1. Previous studies have demonstrated that age alone does not alter the values of the parameters [4–6, 10]. The regression coefficients between these parameters, for control patients and for scoliotic patients, are shown in Table 2.

Normal subjects

The anatomical parameter "pelvic incidence" is a constant for each individual. It determines the variable parameters

Table 1 Values of the spinal and pelvic parameters in 49 normal and 66 scoliotic subjects

	Normal subjects				Scoliotic subjects	
	Men (<i>n</i> = 28)		Women (<i>n</i> = 21)		Mean	SD
	Mean	SD	Mean	SD		
Lordosis (°)	61.4	10.2	58.1	10.8	58.2	12.3
Kyphosis (°)	45.0	8.3	42.2	13.4	45.6	17.5
Cobb angle (°)	–	–	–	–	42.4	25.3
Apical rotation (°)	–	–	–	–	19.3	12.4
Sacral slope (°)	41.9	8.7	38.2	7.8	38.6	11.0
Incidence (°)	53.2	10.3	48.2	7.0	51.0	9.7
Pelvic tilting (°)	11.9	6.6	10.3	4.8	12.3	8.6
Overhang S1 (mm)	22.6	12.5	19.2	7.9	22.4	15.9

Table 2 Regression coefficients between the parameters (significant coefficients are in *bold*)

	Normal subjects (n = 49)	P-value	Scoliotic subjects (n = 66)	P-value
Incidence – overhang S1	0.52335	***	0.46928	***
Incidence – pelvic tilting	0.54144	***	0.46448	***
Incidence – sacral slope	0.83752	***	0.65645	***
Incidence – lordosis	0.60032	***	0.45667	***
Sacral slope – lordosis	0.85943	***	0.80409	***
Pelvic tilting – lordosis	–0.10167	NS	–0.24080	NS
Kyphosis – lordosis	0.33667	*	0.29511	*
Cobb – lordosis			–0.04585	NS
Apical rotation – lordosis			0.15117	NS
Apical rotation – Cobb			0.79266	***

* $P < 0.05$; *** $P < 0.001$

Table 3 Predictive equation of the lordosis for **A** the normal subjects, **B** the scoliotics, using only the sagittal parameters, **C** the scoliotics, using both the frontal and sagittal parameters and **D** the whole population and all the parameters (r correlation between the predicted values of lordosis with the measured lordosis)

A. Lordosis = 0.3172 kyphosis – 0.05543 incidence + 0.3247 overhang S1 + 1.118 sacral slope – 0.791 pelvic tilting + 5.511 $r = 0.94948$ for the 49 normal subjects
B. Lordosis = 0.3187 kyphosis – 0.3502 incidence – 0.1667 overhang S1 + 1.274 sacral slope + 0.5821 pelvic tilting + 9.063 $r = 0.92426$ for the 66 scoliotic subjects
C. Lordosis = 0.2223 apical rotation – 0.06387 Cobb angle + 0.3361 kyphosis – 0.3542 incidence – 0.1357 overhang S1 + 1.312 sacral slope + 0.5108 pelvic tilting + 6.741 $r = 0.94118$ for the 66 scoliotic subjects
D. Lordosis = 0.06375 apical rotation + 0.005727 cobb angle + 0.3207 kyphosis – 0.1663 incidence + 0.03905 overhang S1 + 1.118 sacral slope + 0.01443 pelvic tilting + 6.592 $r = 0.91713$ for the 115 subjects

of “pelvic tilting”, “overhang of S1” and the “sacral slope”. A geometric construction by complementary angles reveals that the anatomical parameter “incidence” is the algebraic sum of the “sacral slope” and the “pelvic tilting”:

$$\text{Incidence} = \text{sacral slope} + \text{pelvic tilting}$$

The orientation of the pelvis determines the sagittal position of the sacral plate in relation to the femoral heads, adapted for each individual by the anatomical parameter “incidence”: the higher the value of the “pelvic incidence”, the higher the value of the adapted “overhang of S1”.

The close relationship between the pelvic and the spinal parameters is obvious from the values of the regression coefficients. Lordosis is closely related to the orientation of the pelvis, expressed by the “sacral slope” ($r = 0.85943$), which is strongly influenced by the “pelvic incidence” ($r = 0.83752$).

A significant chain of interdependence exists between the pelvic and spinal parameters. Pelvic incidence, which is the only independent and anatomical parameter, determines pelvic orientation and the size of the lordosis, which is closely correlated with it. A low value of pelvic incidence implies low values of pelvic parameters and a flattened lordosis; a high value implies well-tilted pelvic orientation and pronounced lordosis.

Scoliotic subjects

The mean values of the parameters (except those characterizing the scoliosis: the “Cobb angle” and “apical rotation”) are not significantly different for normal women and the scoliotic patients.

In the scoliotic group, the extreme values were more spaced than in the normal group, but the correlations between the parameters are the same.

Table 2 shows that the regression coefficients between the parameters of the scoliotic patients are significant, but lower than for the normal subjects. The Cobb angle and the apical rotation of scoliosis are related, though indirectly, to the pelvic parameters and the lordosis. Taking into account the Cobb angle and the apical rotation in a predictive equation of the lordosis thus increases the significance of the coefficient of correlation between the predicted values and the measured lordosis (Table 3). These three-dimensional aspects interfere with the significant chain of correlation between pelvic and sagittal spinal parameters. If this three-dimensional aspect is taken into account then the interrelation between pelvis and spine remains strongly significant. Only the adaptability of pelvic orientation to the overlying spinal conditions, which are affected by the frontal deviation of the scoliotic curve, allows maintenance of a harmonious sagittal balance.

Discussion

The values of the regression coefficients underline the close relationship between pelvic parameters and spinal curves. Any change in one of these parameters induces a change in the others, except for the pelvic incidence, which is the only anatomical and constant parameter, the others being positional parameters. Pelvic incidence is a reliable value for inter-individual variations of sacral slope and lumbar lordotic curves. This is true for the normal and the scoliotic population. The influence of pelvic anatomy on sagittal curve magnitude becomes obvious: a large pelvic incidence indicates a steep sacral slope and large sagittal curves.

A predictive equation for lordosis based on pelvic parameters is postulated (Table 3). For normal subjects, the correlation between predicted and measured values of lordosis is quite significant: $r = 0.94948$. For scoliotic patients, the correlation coefficient between measured and predicted lordosis is 0.92426 when using only the sagittal parameters. It increases to 0.94118 when both Cobb angle and apical rotation are taken into account.

Thus, Cobb angle and apical rotation, despite their lack of direct correlation with lordosis, affect the relationship between pelvic parameters and lordosis. A common predictive equation for lordosis curve can be proposed for all subjects (normal and scoliotic).

The ability of the functional unit spine-pelvis to seek and maintain a sagittal balance as well as possible, in spite of frontal distortion, depends both on the anatomical parameter "incidence" and on the adaptability of the other parameters.

The parameter "pelvic incidence" has the same regulating power in scoliotic subjects as in normal subjects. This relationship is three-dimensional, taking into account sagittal spinal and pelvic parameters as well as frontal and

axial parameters. The presence of a lateral deformity of the spine, a vertebral rotation of a certain magnitude, disturbs the regulating relationship in terms of energy economy. A relatively forwards position of the trunk increases the gravity load on the lumbar vertebral levels and on the bicoxofemoral axis [3–6, 10, 13, 14]. This study presents the first statistical demonstration of the role of vertebral axial rotation in the reduction of lordosis in scoliotics. The higher the scoliotic parameters, the more restricted the capacity to modulate the lordotic curve when the pelvic postural parameters change. This increases the risk of uneconomical conditions of balance.

Conclusion

This study demonstrates the key importance of the anatomical parameter of pelvic incidence in the regulation of the sagittal curves of the spine and in the individual variability of the sacral slope and the lordosis curve. The aim of this system of regulation is to ensure an economical sagittal balance by maintaining the weight forces sufficiently behind the lumbar spine and the coxofemoral heads, as has been shown by barycentrometric studies [4–6].

This regulation is maintained when a spine deformity occurs: it is a three-dimensional relationship between pelvis and spine. The greater the apical rotation and the Cobb angle of the scoliotic curve, the lower is the pelvic incidence, and the more restricted the possibilities of getting an economical sagittal balance. These results explain why the lordotic curve is very frequently reduced in scoliotic patients.

Taking into account the well-fitted individual values of sacral slope and lumbar lordosis curve in relation to the incidence value ought to ensure an economical balance after surgery.

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