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ORIGINAL ARTICLE

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The sagittal anatomy of the sacrum among young adults, infants, and spondylolisthesis patients

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Abstract The anatomic pelvic parameter “incidence” – the angle between the line perpendicular to the middle of the sacral plate and the line joining the middle of the sacral plate to the center of the bicoxofemoral axis – has been shown to be strongly correlated with the sacral slope and lumbar lordosis, and ensures the individual an economical standing position. It is important for determining the sagittal curve of the spine. The angle of incidence has also been shown to depend partly on the sagittal anatomy of sacrum, which is established in childhood while learning to stand and walk. The purpose of this study was (1) to define the relationship between the sacrum and the angle of incidence, and (2) to compare these parameters in three populations: young adults, infants before walking, and patients with spondylolisthesis. Forty-four normal young adults, 32 infants not yet walking and 39 patients with spondylolisthesis due to isthmic spondylolysis underwent a sagittal full-spine radiography. A graphic table and the software for bidimensional study of the sacrum developed by J. Hecquet were used to determine various anatomic and positional parameters. Comparison tests of means, and multiple and partial correlation tests were used. A study of the reliability of the measurements using factorial plan methods was performed. The sagittal anatomic parameters of the sacrum were found to have a close relationship with the pelvic parameter of incidence angle, and therefore with the sagittal balance of the spine. The anatomy of the sacrum in spondylolisthesis patients is particular in that some features are much like those of young infants, but it is more curved and the incidence angle is significantly larger. There is a close relationship between angle of incidence and the slip of spondylolisthesis. All the parameters of young infants are significantly smaller than those of adults. It can be concluded that the sagittal anatomy of the sacrum plays a key role in spinal sagittal balance. The sacral bone is an integral a part of the pelvis and constitutes the undistorted part of the spinal curves. Organization of sagittal curves during growth can be followed up by looking at the sacrum. The sacrum in the spondylolisthesis group differs from the normal, and the greater angle of incidence and sacral slope in this group could predispose to vertebral slip.

Keywords Sacrum · Sagittal shape · Pelvis · Spinal balance · Spondylolisthesis

Introduction

G. Duval-Beaupère and co-workers have previously shown that an anatomical pelvic parameter termed “incidence”, the angle between the line perpendicular to the middle of the sacral plate and the line joining the middle of the sacral plate to the center of the bicoxo-femoral axis, is important for determining the sagittal curve of the spine [8, 10]. They have also shown that this parameter is partially correlated with the sagittal morphology of the sacrum [12]. Abitbol [1, 3] demonstrated connections between the anatomy of the sacrum, which he defined by the lumbar-sacral and sacro-coccygeal angles, and standing posture in children. Anthropologists who have studied the evolution of the anatomy of the sacrum among monkeys and humans [2, 9] have found a gradual increase in the posterior obliquity of the sacrum: the lumbar-sacral and sacro-coccygeal angles [1, 2, 3]. This evolution can be correlated with the ability of these species to stand upright. The authors have also studied the sagittal anatomy of the sacrum in young infants before they begin to walk [5, 6], and the sacrum of a population of patients with isthmic spondylolisthesis [4]. (The evolution of the anatomy of the sacrum during the growth of the child is the subject of another study [5], which compares a population of infants before and after learning to walk and teenagers.) The present study compares the sagittal anatomy of the sacrum and the parameter “incidence” in young adults, young infants and patients suffering from spondylolisthesis, and examines the relationship between the anatomy of the sacrum, the incidence and the sagittal spinal balance in each of these populations.

Materials and methods

Subjects

Three groups were selected for the study. Population A comprised 44 healthy volunteers without spinal disorder. There were 23 male and 21 female health care professional and student volunteers, ranging in age from 19 to 28 years (mean 24 years).

Population B comprised 32 young infants, aged 4–15 months (mean 8 months). They were patients who had been admitted to the Pediatric and Rehabilitation Center of Bullion for various medical conditions excepting spinal and pelvic disorders.

Population C comprised 39 patients suffering from isthmic spondylolisthesis of L5-S1. There were 17 female and 22 male patients, with a mean age of 30 years, ranging in age from 12.7 to 67 years. These spondylolisthesis cases were graded 0–2, according to Meyerding’s classification [3 cases were isthmic spondylolysis (Meyerding grade 0), 34 cases were grade 1 and two cases were grade 2]. Twenty-nine patients complained of low back pain, while ten were symptom free and had been identified during a routine examination by gymnastics teachers.

After informed consent had been given, radiographs were obtained for the adults and children.

Methods

Data on age and sex were recorded, and each subject was subjected to a full-spine lateral X-ray (roentgenogram) in a standardized position (with the arms lying horizontally on a support) or lying down, for the infants. Care was taken to visualise both femoral heads. The X-ray data were computerized by means of a graphic table. The contours of the femoral heads, and four points for each of the five sacral vertebrae, the five lumbar vertebrae and the 12th thoracic vertebra were recorded for every radiograph. The software for the two-dimensional study of the sacrum was developed by J. Hecquet and was used to determine the following anatomic and positional parameters and the slip of the spondylolisthesis.

Anatomic parameters

The following anatomic parameters were measured (Fig. 1, Fig. 2):

1. *Incidence* β (Fig. 1): the angle between the line perpendicular to the middle of the sacral plate and the line joining the middle of the sacral plate to the center of the bicoxo-femoral axis. This parameter [7, 8, 10], describes the position of the femoral heads with respect to the superior plate of the sacrum. It is constant when there is no sacro-iliac joint motion.
2. S*acral angle, SA* (Fig. 2): the angle between the line joining the middle of the anterior edges of the first and second sacral vertebrae and the line perpendicular to the sacral plate. We used only the sacral angle defined by Abitbol [1]. (The lumbosacral angle defined by Abitbol is not anatomical, nor is it position related. It combines an anatomical sacral parameter – the sacral angle – and a positional lumbar parameter – the lumbar angle, formed by the sacral plate and the perpendicular to the anterior edge of L3. This provides less information than the lordosis, with which it is significantly correlated.)
3. *Sacro-coccygeal angle, SCA* (Fig. 2): the angle between a line joining the middle of the plates of the first sacral vertebra

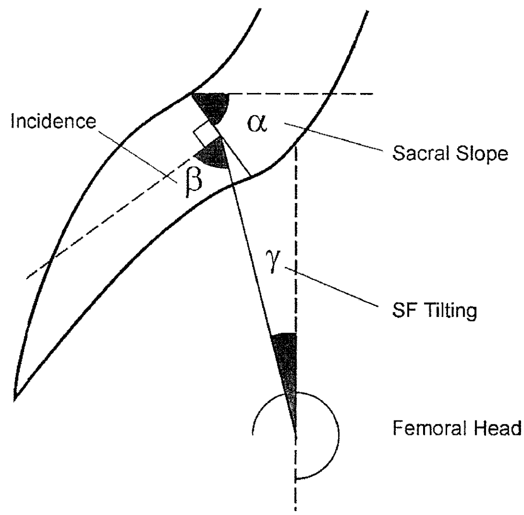

Fig. 1 Pelvic parameters on a sagittal view of the sacrum. The angle of incidence, β, is the angle between the line perpendicular to the middle of the sacral plate and the line joining the middle of sacral plate to the center of the bicoxo-femoral axis – an anatomic parameter. The sacral slope, α, is the angle between the superior plate of S1 and a horizontal line – a positional parameter. The pelvic tilt, γ, is the angle between vertical line and the line joining the middle of the sacral plate to the center of the bicoxo-femoral axis – a positional parameter

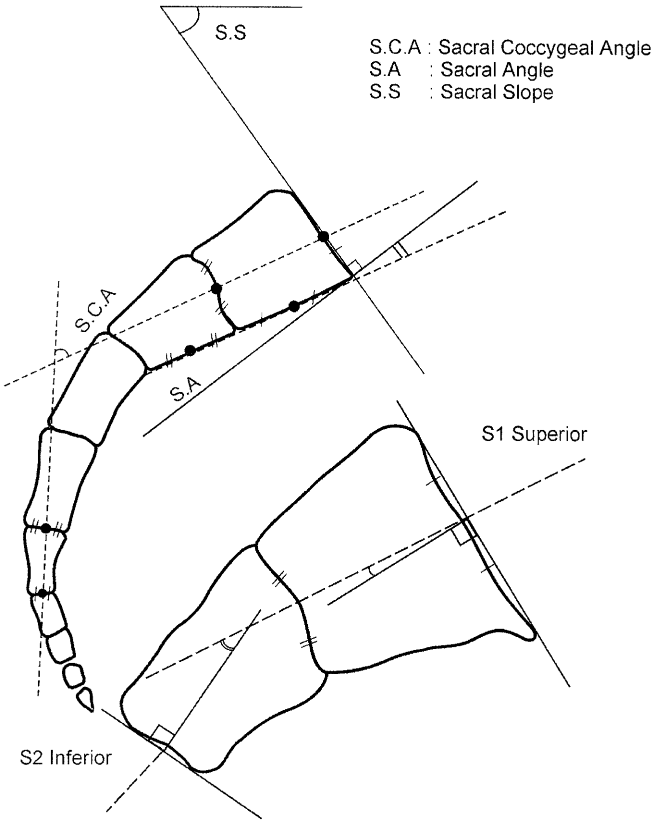

Fig. 2 Sagittal view of the sacrum and first two sacral vertebrae S1 and S2. The sacral coccygeal angle, SCA, is the angle between the line joining the middle of the plates of the first sacral vertebra (median of S1) and the line joining the middle of the plates of the last sacral vertebra (median of S5) – an anatomic parameter. The sacral angle, SA, is the angle between the line joining the middle of the anterior edges of the first and second sacral vertebrae and the line perpendicular to the sacral plate – an anatomic parameter. The sacral slope, SS, is the angle between the superior plate of S1 and a horizontal line – a positional parameter. The S1 superior angle is the angle between the median of S1 and a line perpendicular to the middle of the superior plate of the first sacral vertebra. It represents the slope of the sacral plate on the median – an anatomic parameter. The S2 inferior angle is the angle between a line perpendicular to the middle of the inferior plate of the second sacral vertebra and the median of S1 – an anatomic parameter

(median of S1) and the line joining the middle of the plates of the last sacral vertebra (median of S5).

4. *S1 superior* (Fig. 2): the angle between the median of S1 and the line perpendicular to the middle of the upper plate of the first sacral vertebra. It represents the slope of the sacral plate on the median.
5. *S2 inferior* (Fig. 2): the angle between the perpendicular of the middle of the lower plate of the second sacral vertebra and the median of S1.

Positional parameters

Positional parameters vary according to the position of the pelvis in space. Measurements were obtained for (Fig. 1):

1. *Sacral slope*, α: the angle formed between the sacral plate and the horizontal plane

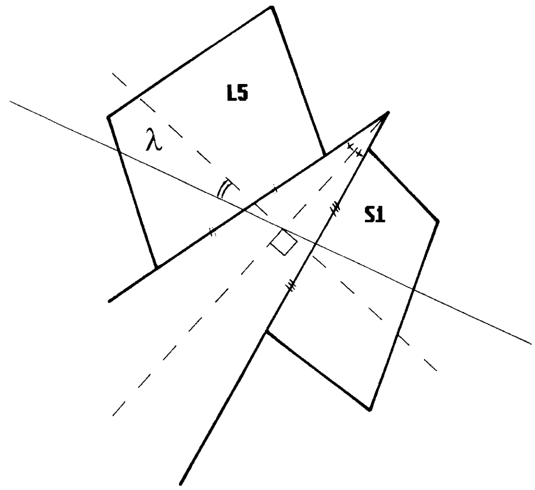

Fig. 3 Method of measurement of the slip of spondylolisthesis. The slip is defined by an angle, and is therefore adimensional. It is the angle between the line joining the middle of the adjacent vertebral plates and a line perpendicular to the bissector of the dihedral formed by the two plates. A positive value is seen with an antelisthesis, a negative value with a retrolisthesis

2. *Lordosis*: the angle formed between the sacral plate and the most tilted vertebra in the horizontal plane
3. *Pelvic tilt*, γ: the angle between vertical line and the line joining the middle of sacral plate to the center of the bicoxo-femoral axis

The incidence, which is an anatomic parameter, is the algebraic sum of the positional parameters, pelvic tilt and sacral slope (geometric demonstration).

The slip of the spondylolisthesis

The slip of the spondylolisthesis was measured by an angle, in order to avoid all linear measurement, and so it is adimensional. This angle is formed between the line joining the middle of the adjacent vertebral plates and the line perpendicular to the bisector of the dihedral formed by the two plates (J. Hecquet, Fig. 3). It has a positive value with a forward slipping and a negative value with a backward slipping.

Reliability of the measurements and statistical analysis

We tested the method by inter- and intra-observer comparisons of the measurements: three observers measured two radiographs of an adult sacrum with spondylolisthesis, one easy and the other more complex, five times each. The statistical analysis revealed no significant difference between the measurements. Some parameters – incidence, S1 superior, sacral angle – were very precise (within 2°–3°). Others – the sacro-coccygeal angle and S2 inferior angle (within 5°–6°) – were less precise, because the spacing between the sacral vertebrae is not always easy to visualise on radiographs.

The multiple regression and partial regression analyses of each population (performed successively for 3×3 parameters) were used to define the connections between the various parameters. Partial regression gave the link between the parameters. Each parameter was compared in the three populations by comparing the means (*t* Student-Fisher). Data were distributed normally.

Table 1 Anatomic and positional parameters of the normal sacrum (in degrees)

	Min.	Max.	Mean	SD
Anatomic parameters				
Sacral angle	6.9	33.8	22.72	6.25
Sacral-coccygeal angle	19.80	87.70	59.70	14.18
S1 superior	6.90	31.60	18.97	6.38
S2 inferior	–12.50	33.80	12.68	9.74
Incidence	33.40	77.70	51.44	10.85
Positional parameters				
Lordosis	34.40	78.70	59.60	10.24
Sacral slope	27.20	59.30	40.59	8.93
Pelvic tilt	–0.70	26.70	10.84	6.11

Table 2 Anatomic and positional parameters of the sacrum in children before walking (in degrees)

	Min.	Max.	Mean	SD
Anatomic parameters				
Sacral angle	6.1	25.4	16.45	4.2
Sacral-coccygeal angle	22.4	74.9	36	16
S1 superior	1.8	18.4	10.67	4.53
S2 inferior	–15.3	14	–0.91	7.5
Incidence	27.4	56.2	43.51	8.3
Positional parameters				
Lordosis	31.7	77.2	47.10	10.02
Sacral slope	13.3	51	30.27	8.53
Pelvic tilt	–2.3	34.4	13.19	8.06

Table 3 Anatomic and positional parameters of the sacrum in spondylolisthesis patients (in degrees)

	Min.	Max.	Mean	SD
Anatomic parameters				
Sacral angle	1.4	25.4	15.53	6.9
Sacral-coccygeal angle	28.5	88.1	63.84	13.19
S1 superior	–3.6	22.7	13.85	6.2
S2 inferior	–5.1	47.6	17.66	11.27
Slip of spondylolisthesis	–15.7	76.23	23.10	18.73
Incidence	36.2	118.1	64.49	16.1
Positional parameters				
Lordosis	44.4	96.7	64.94	12.88
Sacral slope	30.2	82.8	49.09	11.6
Pelvic tilt	–0.2	40.7	15.4	7.98

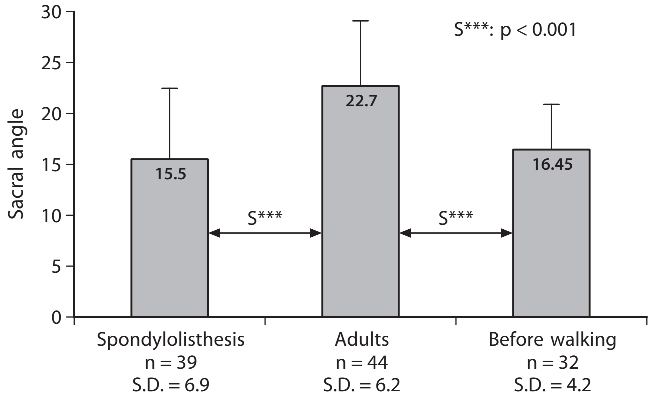

Fig. 4 Differences between the mean value of the sacral angle in the three groups: spondylolisthesis, normal adults, children before walking

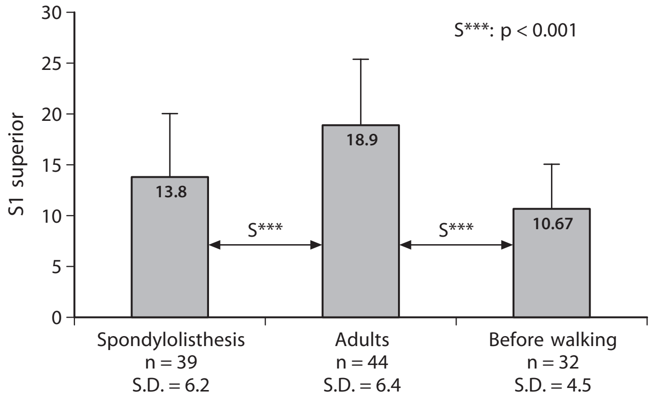

Fig. 5 Differences between the mean value of S1 superior in the three groups

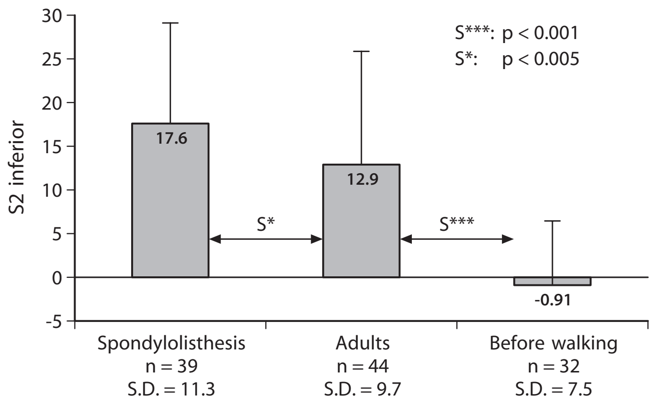

Fig. 6 Differences between the mean value of S2 inferior in the three groups

Results

The means and standard deviations of the parameters studied in each population are shown in Table 1, Table 2 and Table 3, and the means of each parameter for the three populations are shown in Fig. 4, Fig. 5, Fig. 6, Fig. 7, and Fig. 8. The sacral angle (Fig. 4) of the normal adult (22.7°) was significantly greater than the one of infants (16.45°). The sacral angle of the spondylolisthesis patients was small (15.5°) and significantly different from the one of the adults, but similar to the one in infants. The S1 superior angle (Fig. 5) of the normal adult (18.9°) was significantly greater than that of both the infants (10.6°) and the

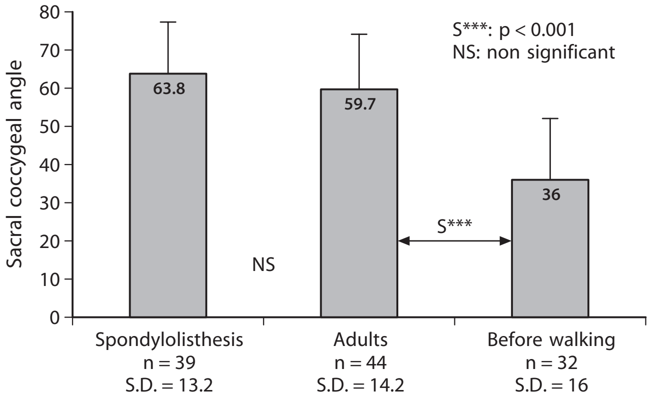

Fig. 7 There are significant differences between the mean values of the sacro-coccygeal angle among normal adults and young infants, but not between those of spondylolisthesis patients and normal adults

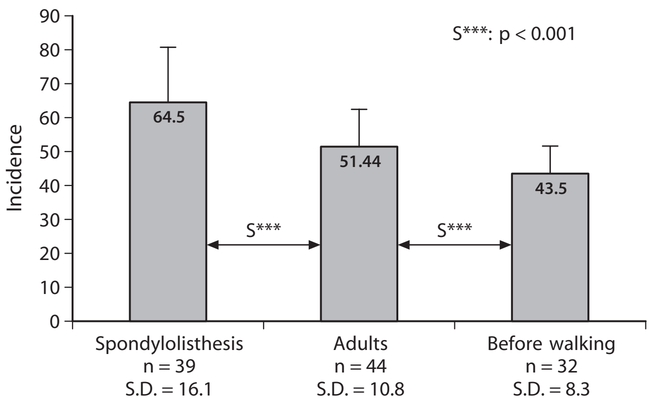

Fig. 8 Differences between the mean values of incidence in the three groups

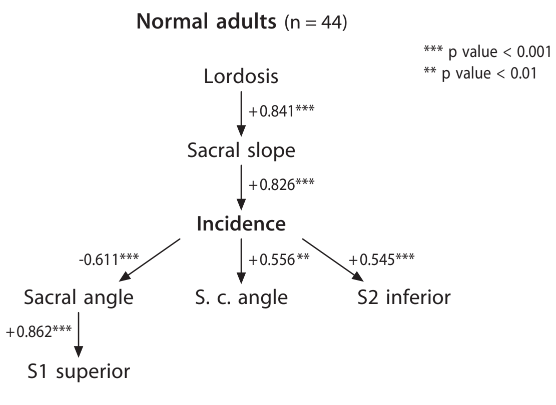

Fig. 9 Correlations between the anatomic sacral parameters, positional parameters, and incidence angle in the group of normal adults

spondylolisthesis patients (13.8°). The S1 superior angle of the spondylolisthesis patients was slightly but significantly greater than the one of infants. The S2 inferior angle (Fig. 6) of normal adults (12.9°) was significantly

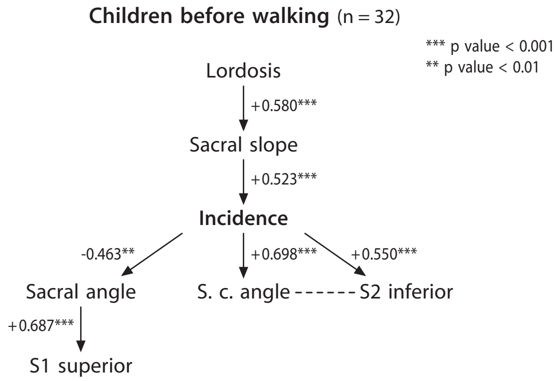

Fig. 10 Correlations between anatomic sacral parameters, positional parameters, and incidence angle among young infants

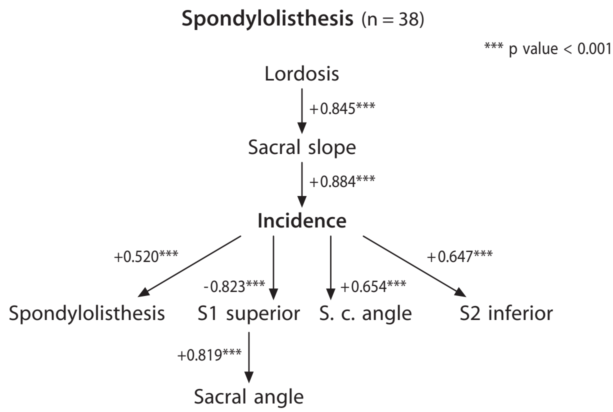

Fig. 11 Correlations between anatomic sacral parameters, positional parameters and incidence angle among spondylolisthesis patients

greater than the S2 inferior angle of infants (–0.91°) and significantly smaller than the one of spondylolisthesis patients (17.6°). The sacro-coccygeal angle (Fig. 7) of a normal adult (59.7°) was significantly greater than the one of infants (36°) and smaller than the one of spondylolisthesis patients (63.8°), but the difference was not statistically significant. The mean value of the incidence angle (Fig. 8) of normal adults (51.4°) was significantly greater than the one of infants (43.5°), and significantly smaller than the one of spondylolisthesis patients (64.5°). We found no difference between the sexes.

Figure 9, Fig. 10 and Fig. 11 show the significant correlations between the parameters for each population. The flow charts for normal adults, infants, and spondylolisthesis patients were very similar. The sacral angle and S1 superior angle were inverted among the spondylolisthesis patients and there was a positive significant correlation (P=0.001) between the incidence and the angle of slip.

Discussion

The incidence and sagittal anatomy of the sacrum among the three populations

All the parameters studied are significantly smaller among young infants than among young adults. The sacrum of a young infant is less curved, the first two sacral vertebrae are more oblong and the incidence of a young infant before walking age is significantly smaller than an adult's. The anatomy of the sacrum of the spondylolisthesis patients is significantly different from normal. The portion defined by the sacral angle and S1 superior remains infantile, while the parameters S2 inferior and the sacro-coccygeal angle are greater than among normal adults. Similarly, the incidence is significantly greater than among normal adults. Thus, the sagittal morphology of the first two sacral vertebrae is clearly abnormal, with the sacral plate and the inferior plate of S2 tending to be less backward convergent than among adults. This correlates with the finding of Vidal and Marnay [14] of an increase in the angle between the superior plates of S1 and S2.

Correlations between the parameters

Relation between incidence and anatomy of the sacrum and the sagittal anatomy of the spine (Fig. 9, Fig. 10, Fig. 11)

The incidence depends in part on all the anatomical parameters of the sacrum. Some anatomical parameters (sacral angle, S1 superior, S2 inferior) describe the sagittal shape of the first two sacral vertebrae and the degree of superior bending. The sacral angle and S2 inferior are directly correlated to the incidence: the sacral angle is correlated negatively and the S2 inferior positively. S1 superior is correlated with the incidence via the sacral angle. Thus, there can be two extreme shapes of the first sacral vertebra among the normal adult population, depending on whether the incidence is small or large. When the incidence is large, the sacral angle is small and the anterior-superior angle of the sacrum is great, S1 superior is small and S2 inferior is great. Thus the sacral plate and the inferior plate of S2 tend to converge anteriorly. The sacro-coccygeal angle defines the inferior curve of the sacrum and is positively correlated with the incidence. The greater the incidence is, the greater the kyphosis of the sacrum is, and vice versa.

We also measured kyphosis in the group of normal adults and in 30 of the 39 spondylolisthesis patients. We have demonstrated in previous publications that there is a chain of significative correlations between incidence and sacral slope, sacral slope and lumbar lordosis, and lumbar lordosis and kyphosis [4, 10, 12].

The sacral slope, lumbar lordosis, and thoracic kyphosis all depend on the value of the incidence. This interdependence guarantees an economical standing balance [8, 10]. The sacral slope and the lumbar lordosis increase as the incidence increases. Hence, the morphology of the sacrum contributes, through the incidence, to the shape of the sagittal spinal curve of an individual. And the configuration of the first two sacral vertebrae conditions the shape of the sacro-iliac joints.

All three populations show the same flow charts deduced from the partial correlations between parameters. The only variant is the inversion of the relationship between the sacral angle and S1 superior angle among spondylolisthesis patients. This difference in morphology may be due to a dysplasia of the first sacral vertebra among this population.

Incidence and angle of slip in spondylolisthesis

A large incidence predisposes to slip. There is a significant, positive correlation between incidence and the degree of slip. A greater incidence leads to a greater sacral slope, and therefore probably increases the local shearing forces that could be one of the predisposing factors of slipping. Sward et al. [13] found the same significant relationship between a large sacral slope, a spondylolysis, and the degree of slip in an identical population of spondylolisthesis patients. During et al. [7] found a smaller pelvic-sacral angle among 33 patients with spondylolysis and spondylolisthesis grade 1. This parameter is, in fact, the complementary angle of the incidence. The spondylolisthesis patients showed a greater lordosis than the normal subjects, but there was no statistically significant difference.

Incidence and age

There was a correlation between the incidence and age in the spondylolisthesis patients, but not among the normal adults. The normal adults were of similar ages, while the spondylolisthesis patients varied more, and included 16 subjects less than 20 years old. These subjects may not have acquired their definitive incidence. It seems less probable that the incidence changes during adult life.

Mangione et al. [11] found no correlation between incidence and age among adults. They found a significant linear correlation between age and incidence among the children.

Comparison of our findings with those of the anthropologists

Our findings partially corroborate those of the anthropologists and those of Abitbol [1, 2, 3, 9] concerning the relationships between the morphology of the sacrum and the standing position. Abitbol showed that there may be a significant correlation between the sacral angle and the stage of acquisition of the standing position and the gait for a child. Our work shows a significant correlation between the anatomical parameters of the sacrum and the incidence, and therefore, with the sagittal spinal curvatures, in all three populations. The incidence, the sagittal anatomy of the sacrum and the sagittal spinal curves all develop gradually with the acquisition of the erect position, walking, and further growth.

Limitations of the study

This study is two-dimensional, because of the difficulty of finding precise points on the anterior-posterior radiograph of the sacrum. However, the value of the incidence for the normal adult population studied in three dimensions is comparable to the one obtained here in two dimensions. The radiographs of the infants were taken with them lying prone to minimize errors. Less perfect lateral radiographs diminish the measured value of the incidence and slip among spondylolisthesis patients. Hence, the large values obtained for these subjects are not the result of poor X-ray technique.

Conclusion

In the pelvis, the sacral bone plays a role in determining the acquisition of the spinal curves to achieve the most economic position. We have demonstrated that there are strong correlations between the parameters defining the sagittal anatomy of the sacrum and incidence angle.

The authors have showed in previous publications that the incidence angle is an anatomic indicator of the spinal sagittal balance of an individual.

Organization of spinal sagittal curves during growth can be followed up by looking at the sacrum. We corroborate the findings of Abitbol, who has also shown the extent to which the sacrum plays a critical role in acquisition of standing posture in children.

The data for the spondylolisthesis patients compared to normal adults and to young infants show a sacrum altogether more infantile at the level of the first sacral vertebra, but also with a greater kyphosis. The incidence angle is greater than among normal adults, as is the sacral slope, and these could predispose the patients to spondylolisthesis and slip.

References

1. Abitbol MM (1987) Evolution of the lumbosacral angle. Am J Phys Anthropol 72:361–372
2. Abitbol MM (1987) Evolution of the sacrum in hominoïds. Am J Phys Anthropol 74:65–81
3. Abitbol MM (1989) Sacral curvature and supine posture. Am J Phys Anthropol 80:379–389
4. Boisaubert B, Montigny JP, Duval-Beaupère G, Hecquet J, Marty C (1997) Incidence, sacrum et spondylolisthésis. Rachis 9:187–192
5. Descamps H (1998) Sacrum et incidence dans 2 populations d'enfants avant et après la marche. Proceedings of the 29th GES, Toulouse, March
6. Descamps H, Commare MC, Marty C, Duval-Beaupère G (1996) Le paramètre incidence chez le petit enfant. Rachis 8:177–180
7. During J, Goudfrooij H, Keessen W, Beeker ThW, Crowe A (1985) Toward standards for posture. Spine 10:83–87
8. Duval-Beaupère G, Schmidt C, Cosso Ph (1992) A barycentremetric study of the sagittal shape of spine and pelvis. Ann Biomed Eng 20:451–462
9. Le Damany P (1905) L'adaptation de l'homme à la position debout. J Anat Physiol 41:133–170
10. Legaye J, Duval-Beaupère G, Hecquet J, Marty C (1998) Pelvic incidence: a fundamental pelvic parameter for three dimensional regulation of spinal sagittal curves. Eur Spine J 7:99–103
11. Mangione P, Gomez D, Sénégas J (1997) Study of the course of the incidence angle during growth 6:163–167
12. Marty C, Commare MC, Descamps H, Legaye J, Hecquet J, Duval-Beaupère G (1997) Sacrum et incidence: quelles relations. Rachis 9:109–114
13. Sward L, Hellstrom M, Jacobson B, Peterson L (1989) Spondylolysis and the sacrum horizontal angle in athletes. Acta Radiol 30:359–364
14. Vidal J, Marnay T (1983) La morphologie et l'équilibre corporel antéropostérieur dans le spondylolisthésis L5 S1. Rev Chir Orthop 69:17–28