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ORIGINAL ARTICLE

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Study of the course of the incidence angle during growth

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Abstract Standing posture is made possible by hip extension and lumbar lordosis. Lumbar lordosis is correlated with pelvic parameters, such as the declivity angle of the upper surface of the sacrum and the incidence angle, which determine the sagittal morphotype. Incidence angle, which is different for each individual, is known to be very important for upright posture, but its course during life has not yet been established. Incidence angle was measured on radiographs of 30 fetuses, 30 children and 30 adults, and results were analysed using the correlation coefficient r and Student's t test. A statistically significant correlation between age and incidence angle was observed. Incidence angle considerably increases during the first months, continues to increase during early years, and stabilizes around the age of 10 years. Incidence is a mark of bipedism, and its role in sagittal balance is essential.

Key words Sagittal balance · Sacral inclination or slope · Pelvis · Gravity · Sagittal plane compensatory mechanisms · Posture

Introduction

The acquisition of the upright position entails considerable modifications in spinal posture. In particular, it causes lordosis of the lumbar spine, and verticalizes the pelvis by coxofemoral extension.

Lumbar lordosis has been shown to be correlated with the declivity angle of the upper surface of the sacrum [5, 6, 8]. This notion has been recently confirmed by Gelb et al. [7].

The declivity angle of the upper surface of the sacrum is determined by the incidence angle [6], which is different for each individual. This angle is very important, because it determines the sagittal morphotype, and its evolution during life may be related to the acquisition of standing posture. However, to our knowledge, this has never been demonstrated.

The purpose of the present study is to determine the course of this angle throughout life, especially during acquisition of ambulation.

Materials and methods

The incidence angle is formed by the line perpendicular to the upper sacral endplate, beginning at its centre, and the line joining this point and the centre of the line uniting the middle of the femoral heads, on lateral view radiographs (Fig. 1). It was measured on lateral radiographs of 90 subjects from three age groups.

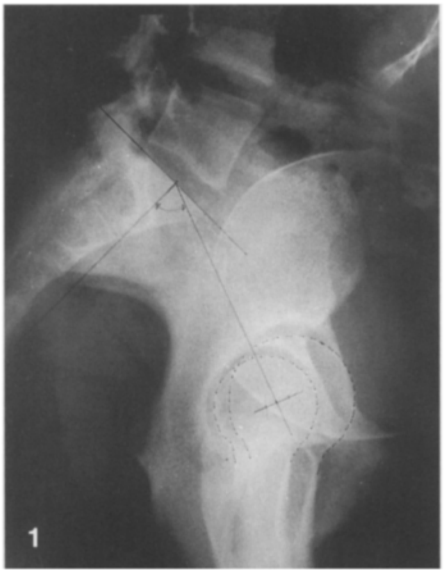
Group A: 30 fetuses

The radiographs were taken at autopsy. The first sacral vertebra is easily recognizable in the fetus, because it is the vertebra with the greatest interpedicular distance [2] (Fig. 2A). The centres of the femoral heads, not yet ossified in the fetus, were considered to be equidistant from the ischium, ilium and femur (Fig. 2B).

All records in which the femoral heads and the cephalad endplate of S1 were not localized with confidence were excluded, as were subjects suffering from a spinal or neuromuscular disorder.

Group B: 30 children

The radiographs came from hospital records and had most often been taken during routine evaluations of the extension of tumoral disease.



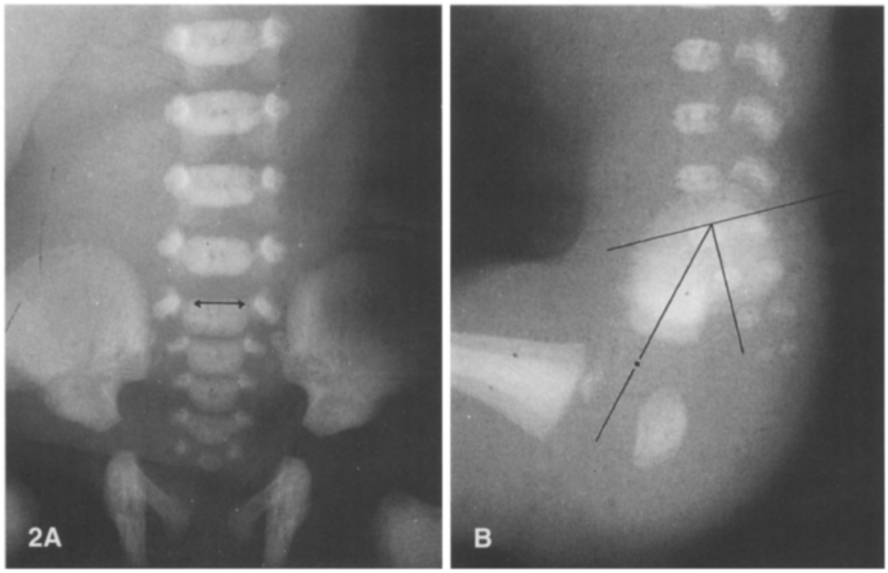


Fig. 1 The incidence angle is formed by a line perpendicular to the upper sacral endplate, beginning at its centre and the line joining this point and the centre of the line uniting the middle of the femoral heads, on lateral radiographs

Fig. 2 Radiograph of the fetal pelvis. **A** anteroposterior projection. The largest interpedicular distance (*arrow*) is in S1 permitting identification of this vertebra. **B** lateral view. The point equidistant from ilium, ischium and femur is used instead of the midpoint between the femoral heads, which are not yet ossified

Table 1 Sex, age and measured values of the incidence angles

Fetuses			Children			Adults		
Sex	Age	Incidence angle	Sex	Age	Incidence angle	Sex	Age	Incidence angle
F	35 weeks	21°	M	18 months	26°	F	25 years	42°
M	30 weeks	20°	M	12 months	38°	F	37 years	60°
F	33 weeks	28°	F	36 months	40°	F	28 years	47°
M	22 weeks	27°	–	24 months	45°	F	31 years	43°
M	35 weeks	30°	F	72 months	46°	F	30 years	52°
M	22 weeks	25°	M	15 months	42°	F	33 years	58°
F	34 weeks	23°	F	60 months	48°	F	27 years	47°
F	23 weeks	30°	F	30 months	28°	F	27 years	48°
M	35 weeks	30°	F	30 months	41°	F	28 years	41°
F	36 weeks	30°	M	72 months	45°	F	39 years	68°
M	23 weeks	30°	F	54 months	49°	F	26 years	52°
F	33 weeks	22°	F	60 months	22°	F	24 years	55°
F	38 weeks	22°	M	24 months	33°	F	23 years	53°
M	34 weeks	32°	M	24 months	22°	F	32 years	65°
F	23 weeks	36°	M	54 months	64°	F	19 years	57°
F	29 weeks	32°	F	17 months	37°	F	32 years	70°
M	30 weeks	32°	F	48 months	40°	F	36 years	68°
F	25 weeks	34°	M	30 months	50°	F	25 years	53°
F	25 weeks	37°	F	36 months	38°	F	34 years	42°
F	24 weeks	32°	M	36 months	40°	F	27 years	60°
M	20 weeks	30°	F	23 months	37°	F	23 years	41°
F	22 weeks	39°	F	72 months	48°	F	19 years	50°
F	26 weeks	26°	F	24 months	40°	F	17 years	68°
M	29 weeks	36°	F	14 months	42°	F	24 years	63°
F	36 weeks	36°	F	12 months	35°	F	26 years	74°
M	37 weeks	37°	M	108 months	51°	F	46 years	60°
M	40 weeks	38°	F	72 months	32°	F	24 years	43°
F	21 weeks	40°	F	36 months	28°	F	27 years	72°
M	22 weeks	36°	F	24 months	38°	F	34 years	63°
F	19 weeks	27°	F	24 months	42°	F	35 years	52°

Group C: 30 adults

Radiographs were taken during pelvic dimensional work-ups of pregnant women.

According to Legaye et al. [8], incidence angle is greater in males than females, which means that its value in the adult is underestimated in our series.

No particular position was employed in taking lateral films of the pelvis, since the incidence angle is independent of the position of the pelvis. Only substantial mobility of the sacroiliac joints could bring about significant modifications of this angle. However, the amplitude of this movement is considered to be very small, of the order of 2° or 3° [12], and it can therefore be ignored.

All measurements were made by the same observer (D.G.), and the intra-observer error was estimated to be 3°, on the basis of a study ot ten radiographs.

Statistical analysis was performed using the correlation coefficient r and Student's t test.

Results

The incidence angles for all of our subjects are shown in Table 1, and the average values, the extreme values and standard deviations are shown in Table 2.

In the fetuses and children, there was no observed variation in incidence angle according to sex. The existence of a sex-linked variation in incidence angle could not be verified in our adult group since it consisted entirely of women.

In the children, there is a significant linear correlation between age and incidence angle that clearly increases with age (Fig. 3), whereas in the fetuses (Fig. 4) and adults (Fig. 5), points are scattered and no relationship can be derived. Figure 6, in which all three groups are represented, shows the increase that the incidence angle undergoes during the initial weeks of life.

Because of the rise in this angle in children, a comparison of the mean incidence angles of the three populations shows significant differences (comparison fetus/child: standard error mean = 8,7049, $P < 0.01$; child/adult standard error mean = 9,7850, $P < 0.01$; fetus/adult: standard error mean = 24,2563, $P < 0.01$).

Table 2 Results of the series given as mean ± standard deviation. The extreme values are shown in parentheses. Age is given in weeks for group A (w) months for group B (m) and years for group C (y)

	Group A fetuses (n = 30)	Group B children (n = 30)	Group C adults (n = 30)
Age	28.7 ± 6.2 w	38.7 ± 23.1 m	28.6 ± 6.3 y
range	(19–40)	(12–108)	(17–46)
Incidence	30°6 ± 5°6	39°5 ± 8°9	55°4 ± 9°9
angle	(20°–40°)	(22°–64°)	(41°–74°)
Correlation age/incidence	NS	0.02	NS

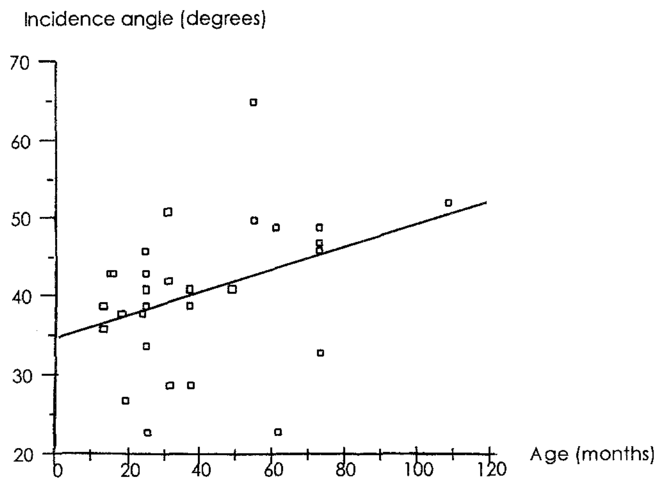


Fig. 3 Correlation between age and incidence angle in children ($y = 34{,}116 + 0.14085x$; R^2 = 0,132; $r = 0{,}3637$)

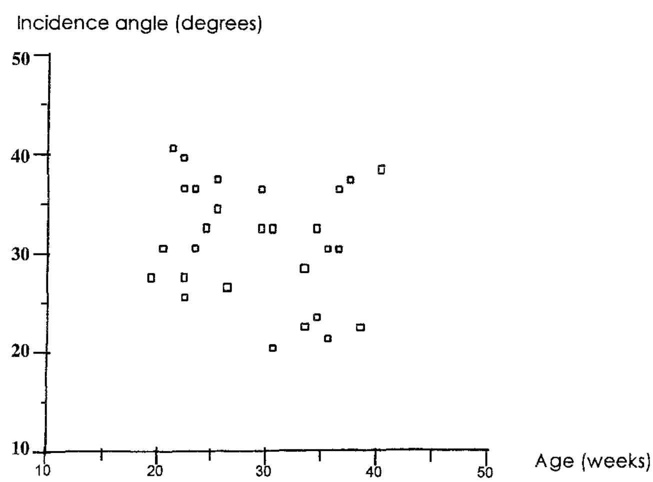


Fig. 4 Correlation between age and incidence angle in fetuses

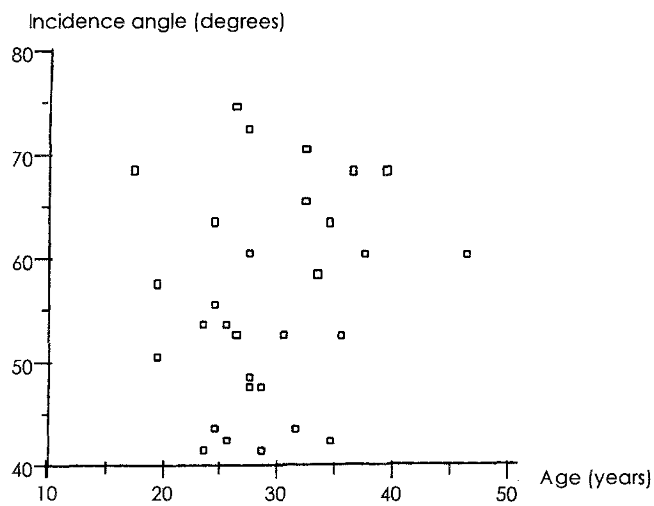


Fig. 5 Correlation between age and incidence angle in adults

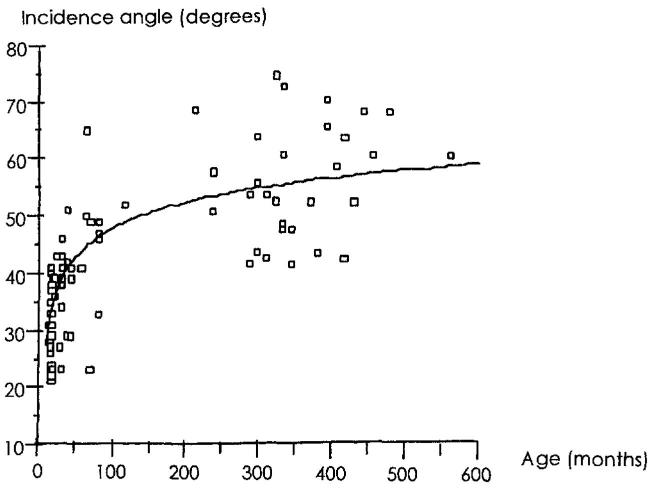


Fig. 6 Correlation between age and incidence angle in the overall population (y = 18,028 + 14,668 × LOG(x); R^2 = 0.615; r = 0,784)

Discussion

Though it is commonly accepted that the acquisition of ambulation leads to modifications in the lumbosacral junction in the individual, as it did in the human species [4, 9], the exact mechanisms of development of the upright position are poorly understood.

Two different phenomena are probably involved (Fig. 7).

1. Coxofemoral extension, effectuated by the gluteal muscles, permits a verticalization of the pelvis, which tilts backwards, bringing the upper sacral endplate into a more horizontal position, suitable for constituting the pedestal of the vertebral column.

2. Lumbar lordosis arises from the action of the erector spinae muscles. Whereas cervical lordosis is already apparent at the 4th month, with the progressive holding up of the head, and continues to develop with the acquisition of the sitting position, lumbar lordosis only appears as the child begins to acquire the upright position, and subsequently increases until 17 years of age [13].

Because of the insertion of the erector spinae by a thick fascia onto the sacral spinous processes [3], lordosis leads to horizontalization of the sacrum, i.e. to verticalization of its endplate.

The incidence angle reflects this horizontalization, explaining its augmentation after birth. The values that we observed show that a marked increase in the angle occurs during the first months of life, and that it continues to progress during the early years, stabilizing at around the age of 10.

Our adult population consisted only of females, so the incidence value in the adult is probably underestimated [8], which means that incidence probably rises even more with age than our results indicate.

The rise in this angle parallels that of the lumbosacral angle, studied by Abitbol [1], which is formed by the intersection of the lines tangent to the anterior aspects of L3 and S1, and is also an earmark of lumbar lordosis. This angle also widens (from 20° to 70°) until 10 years of age [11].

After growth ends, the incidence angle appears to remain constant. It can be considered to be a marker, that persists throughout life, of the process of gaining the upright position.

The declivity angle of the upper surface of the sacrum is proportional to the incidence angle, with a correlation coefficient $r = 0.795$ [6]. This relationship is not surprising, since a simple geometrical construct shows that (Fig. 8):

Incidence = Sacrofemoral tilt + declivity angle of the upper surface of the sacrum

Forward and backward tilts of the pelvis thus modify the slope of the sacral endplate by an amplitude that in-

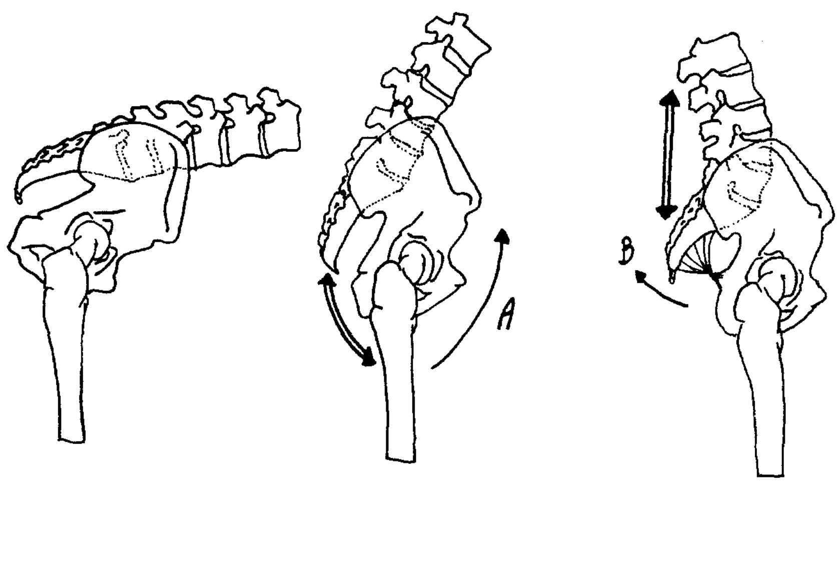


Fig. 7A, B Pelvic modifications during acquisition of the upright position. **A** Femoral extension by the gluteal muscles results in verticalization of the pelvis. **B** Horizontalization of the sacrum is brought about by the erector spinae muscles

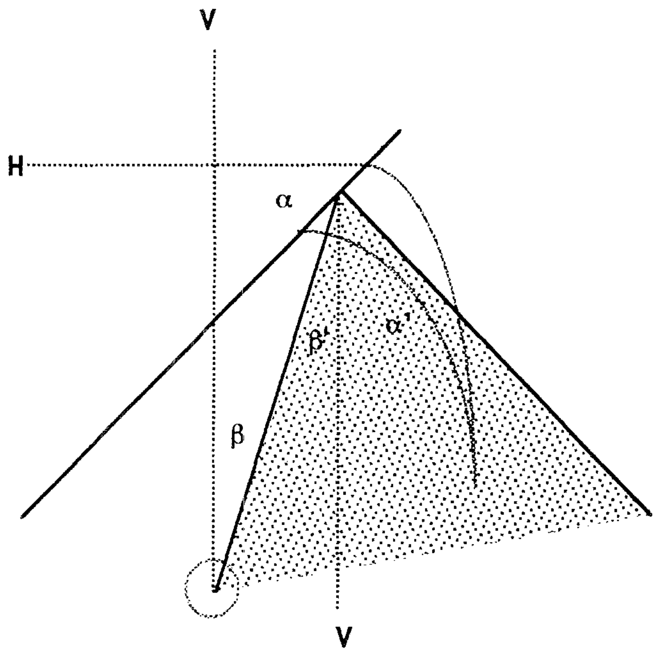


Fig. 8 Geometrical relation between pelvic parameters [6, 8]: α = α', because each side of each angle is perpendicular to one side of the other angle, and β = β', because they are formed by a diagonal crossing two parallel lines. Therefore, incidence angle = α + β. *H* horizontal, *V* vertical, α declivity angle of the upper surface of the sacrum, β Sacrofemoral tilt, *tinted area* incidence angle

creases as the incidence angle widens. This mechanism allows a compensation of the loss of physiological lordosis that occurs during aging [7, 10] or secondary to osteoporotic impaction fractures or posttraumatic deformity. The backward tilt of the pelvis reduces the declivity angle of the upper surface of the sacrum by an amount inversely proportional to incidence angle.

Conclusion

The incidence angle is an essential parameter of sagittal balance. It develops secondary to the horizontalization of the sacrum, under the influence of the erector spinae muscles, during the acquisition of lumbar lordosis. It increases during the first months of life, when the lumbosacral junction undergoes modifications. It subsequently remains stable and plays a role in the compensation of the reduction of lordosis through the diminution of the slope of the sacral plate, which prevents forward displacement of the axis of gravity.

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