AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 80:379-389 (1989)

Sacral Curvature and Supine Posture

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KEY WORDS Sacrum, Curvature, Supine, Child, Adult

ABSTRACT Sacral curvature (SC), represented by the angle between the first and the last sacral vertebrae, is a feature that differentiates the human pelvis from that of other animals. The sacral curvature was measured and studied in 14 cebids, 31 cercopithecids, 17 hylobatids, 85 pongids, 23 normal human children, 15 children with orthopedic handicaps, 49 normal adult human males, and 64 normal adult human females. Sacral curvature was minimal to nil in monkeys (mean 11.5 ± 6 SD degrees), and moderate in apes (hylobatids, mean 16 ± 10 SD degrees; pongids, mean 27.2 ± 16 SD degrees). In human newborns SC is minimal, increasing progressively until adolescence, reaching a mean of 64.7 ± 29 SD degrees in adult humans. This study investigates the different factors contributing to the formation of the sacral curvature. These factors include 1) the effect of erect posture, which tilts the upper part of the sacrum dorsally and the lower part of the sacrum ventrally, and 2) the influence of supine posture, which affects the development of the lower part of the sacrum. In addition to supine posture the levator ani, which is well developed in *Homo sapiens,* also affects the lower part of the sacrum and coccyx and influences its ventral orientation. Variation in SC can result from differences in onset and frequency of supine posture. This is the first time that supine posture has been shown to play a role in shaping the human pelvis, although it is as characteristic of *H. sapiens* as is erect posture.

Evolutionary changes in the pelvis of obstetrical significance have been discussed elsewhere (Abitbol, 1987a,b, 1988). These "obstetric" changes in the pelvis include formation and angulation of the sacrum, and development of prominent ischial spines. Sacral curvature is another distinctive feature of obstetrical significance that contributes to the unique shape of the human pelvis. The dorsal tilt of the sacrum in humans, extensively described in the anthropological literature (e.g., Robinson, 1972; Schultz, 1969), involves primarily the first two or three sacral vertebrae. It does not involve the last two sacral vertebrae which curve in the opposite direction, i.e. ventrally. Sacral curvature is minimal in tailed mammals and human newborns, but is pronounced in adult *Homo sapiens.* Weidenreich (1913) is one of the few workers who noted this curvature. He suggested that erect posture and intra-abdominal pressure contributed to sacral curvature in humans. Kapandji (1974) and DonTigny (1985) have described the dorsal tilting of the sacrum resulting from the weight of the trunk in erect posture and the ventral pull on the lower part of the sacrum by the sacrospinous and sacrotuberous ligaments.

In this article the angle of the sacral curvature (SC) was determined in young and adult human populations and in selected nonhuman primates. A relationship between the practice of supine posture and the formation of SC is observed in humans as they develop.

MATERIALS AND METHODS

SC was measured in 298 human and nonhuman primates (Table 1). Study subjects

Received March 28, 1988; accepted February 15, 1989.

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TABLE 1. *List of investigated subjects*

	Radiographs	Skeleton	Total
Nonhuman primates			
Cebidae (*Allouatta, Cebus, Ateles*)	1	13	14
Cercopithecidae (*Macaca, Cercopithecus*)	18	13	31
Hylobatidae	3	14	17
Pongo	0	17	17
Pan	2	27	29
Gorilla	0	39	39
Human subjects			
Normal adult human males	36	13	49
Normal adult human females	55	9	64
Normal human children	23	0	23
Children with orthopedic defects	15	0	15
Total	153	145	298

and specimens came from four different groups:

1. Nonhuman primates, housed in the Comparative Anatomy Collection in the Department of Anatomical Sciences, SUNY, Stonybrook, and in the American Museum of Natural History, New York. Also included were radiographs of Old World monkeys, previously taken by the author for a study of pelvic anatomy.
2. Adult human subjects, who were patients admitted to the Obstetrical and Medical Departments of the Jamaica Hospital (Queens, NY). A lateral radiograph of the pelvis was available. Patients with common pelvis abnormalities such as a sacrum with four or six sacral vertebrae were excluded. There were 91 patients varying in age from 18 to 53 years (Tables 2–4).
3. A sample of 23 children, all of them without any known orthopedic problem and admitted to the Pediatric Department at the same hospital for various acute medical conditions (Tables 5, 6). A lateral view of the pelvis was available. History and physical examination revealed details concerning their postural and locomotor status (see below).
4. Finally, a group of 15 young children and adolescents, all *with* orthopedic problems that were interfering with the normal human positional behaviors (erect and/or supine posture). These cases were collected from a file review of the Department of Orthopedics and Radiology at the same hospital and of Newington Children's Hospital in Newington, CT. Lateral radiographs of the pelvis and informations concerning interference of the handicap with different postures and locomotion were available (Table 7).

An attempt was made to determine a relationship between the degree of sacral curvature and other factors such as age, race, sex, parity in human female adults, progressive acquisition of erect posture in children, and the effect of supine posture.

Measurement of SC

SC can be evaluated by measuring the angle between the first and the last sacral

TABLE 2. *Sex differences in sacral curvature for all groups of human adults*

	Male			Female			Student-t
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	*P*-value
White	13	68	26	18	66	19	N.S.
Black	7	70	20	12	67	27	N.S.
Hispanic	3	69	22	5	66	28	N.S.
Total	23	69	22	35	66	22	N.S.

TABLE 3. *Effect of parity on sacral curvature*

	Nulliparous			Multiparous			Student-t
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	*P*-value
White	6	68	23	12	70	23	N.S.
Black	3	75	21	9	68	20	N.S.
Hispanic	1	83		4	64	29	
Total	10	72	20	25	68	23	N.S.

TABLE 4. *Effect of sleeping posture on sacral curvature*

	N	Range	$\bar{X}$	SD	*P**
Indifferent	34	35-87	65	11	<.001
Supine	16	80-107	93	8	<.001
Prone or lateral	8	29-44	32	5	<.001

*F = 105.25.

TABLE 5. *Data in normal children*[1]

Age	SC (degrees)	Sex	Race	Degree of bipedalism	Sleeping posture
3 weeks	18	Male	White	0	I
1 month	23	Male	White	0	P
1 month	25	Male	White	0	S
1 month	26	Female	Black	0	I
2 months	30	Male	White	0	I
2 months	30	Male	White	0	I
3 months	31	Male	White	0	I
4 months	22	Female	White	0	P
4 months	36	Female	White	0	I
4 months	38	Male	White	0	S
8 months	37	Male	White	1	I
1 year	40	Male	White	3	I
2 years	28	Male	Hispanic	5	P
2 years	40	Female	White	5	I
2 years	48	Male	Black	5	S
4 years	33	Female	White	6	P
4 years	39	Female	Black	6	I
4 years	56	Female	Hispanic	6	S
6 years	35	Male	Black	6	P
6 years	55	Female	White	6	I
8 years	49	Female	White	6	I
9 years	75	Male	Black	6	S
12 years	69	Female	White	6	I

[1]Sleeping postures: S = supine; I =indifferent; P = prone or lateral.

TABLE 6. *Linear regression of sacral angle on age in normal children*

Group	N	Intercept	Slope	Correlation coefficient
All ages	23	28.7	3.56	.83
Male	13	28.4	4.09	.78
Female	10	29.0	3.32	.86
White	16	28.8	3.23	.87
Black	5	27.2	4.13	.76
Bipedalism[1]	23	28.1	3.55	.69
Supine	5	33.2	4.91	.96
Prone	5	22.6	2.28	.98
Indifferent	13	30.0	3.17	.91

[1]Linear regression between stages of bipedalism and SC.

vertebrae when the pelvis is viewed laterally (Fig. 1). SC is measured either on lateral radiographs of the pelvis or on macerated skeletal material by placing the disarticulated sacrum laterally on a flat surface and tracing the borders of the first and last sacral vertebrae. Two straight lines are drawn: the first one joins the superior and the inferior borders of the first sacral vertebra, and the second one joins the same borders in the last sacral vertebra. The angle formed by the intersection of the two lines constitutes the

TABLE 7. *Handicapped children and sacral shape*

Age (yrs)	Sex	Race	SC (degrees)	Sleeping posture	Handicap
Curved sacrum					
7	F	W	58	Indifferent	Walks with difficulty
8	M	W	58	Indifferent	Walks with difficulty
9	M	W	61	Indifferent	Walks with difficulty
9	M	W	85	Mostly supine	Limps
13	F	W	72	Mostly supine	Limps
Straight-vertical sacrum					
6	M	W	Flat	Supine	Bedridden
7	F	W	Flat	Indifferent	Bedridden
8	F	W	Flat	Supine	Wheelchair
9	M	B	Flat	Supine	Wheelchair
10	F	W	Flat	Indifferent	Bedridden
10	M	W	Flat	Supine	Bedridden
Flat-horizontal sacrum					
7	M	B	Flat	Lateral only	Walks with crutches
9	F	W	Flat	Lateral only	Walks with crutches
10	M	B	Flat	Lateral only	Walks with crutches
13	M	W	Flat	Lateral only	Walks with crutches

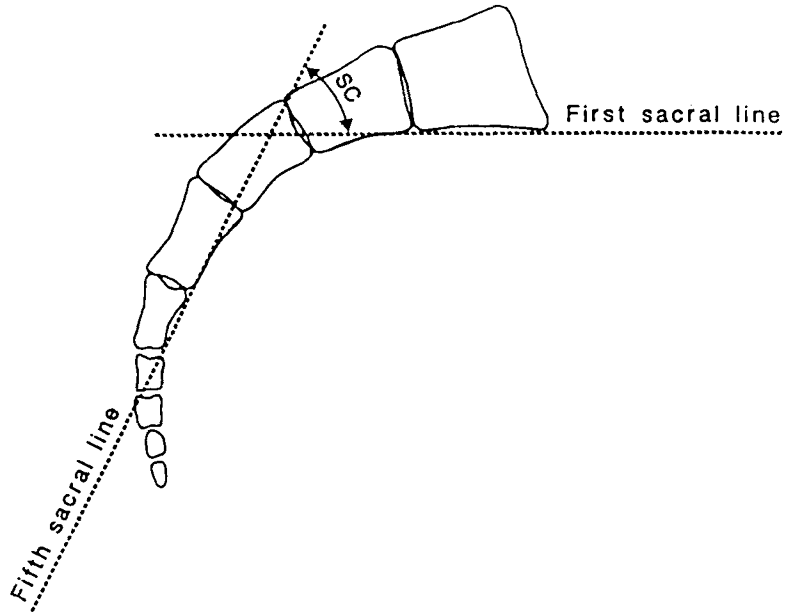


Fig. 1. Diagram showing SC formed by the inclination of S1 over S5 vertebra.

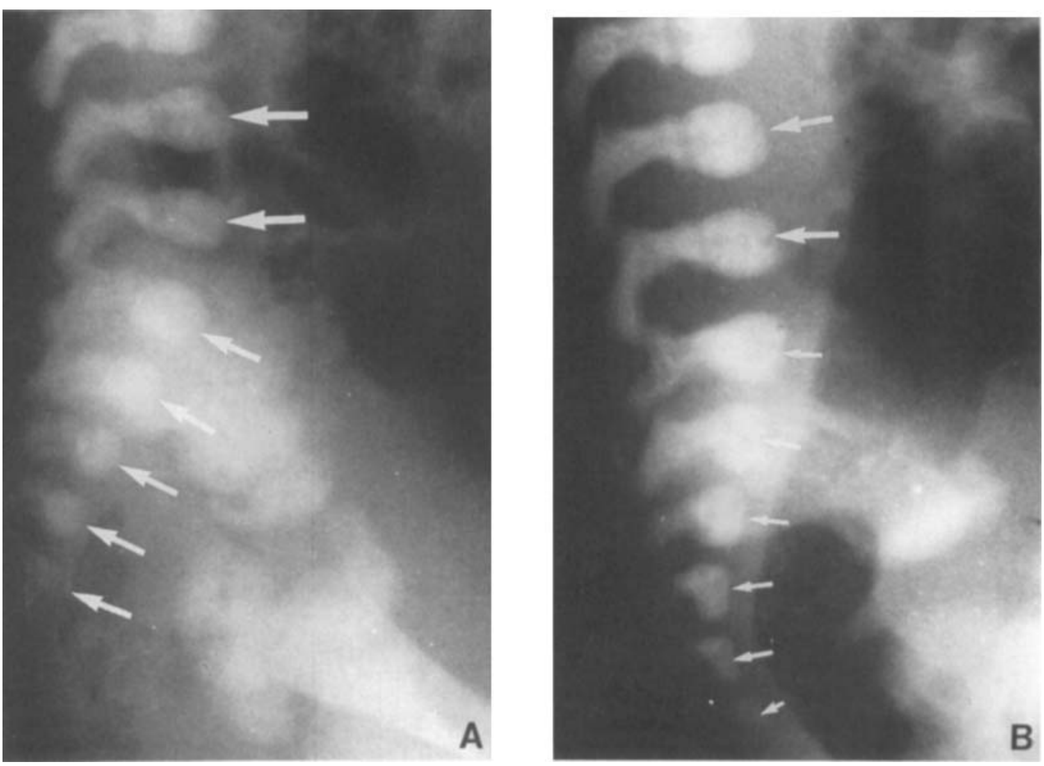


Fig. 2. Human infant at birth (A): there is no sacral curve on the anterior surface of the sacrum and SC is almost nil. At 1 month of age (B) with a supine sleeping posture, there is already a 26 degrees SC. Large, medium, and small arrows point to lumbar, sacral, and coccygeal vertebrae.

sacral curvature. This is measured with a two-piece protractor (C-Thru Ruler Co., Bloomfield, CT). When there are only ossification centers, as in very young children, the most anterior points of the first and last sacral vertebra serve as the sides of this angle (Fig. 2). Measurements on both radiographs and actual bones are repeated several times until three successive measurements give identical results. Only then is the SC value recorded.

Acquisition of bipedalism in normal children

Since children are "quadrupedal" (walking on hands and knees) before becoming "bipedal," an attempt was made to investigate the relationship between the formation of the sacral curvature and the acquisition of bipedalism. Seven developmental stages in the establishment of bipedal posture and locomotion are distinguished in humans (Abitbol, 1987a). The stages are classified as follows: stage 0, in which the child is unable to stand up even with help; stage 1, the child stands with help; stage 2, the child walks with help; stage 3, the child stands without help; stage 4, the child walks unaided; stage 5, progressive acquisition of elaborate bipedal locomotion (at this stage the child learns to run, hop, turn, walk backward, etc.); and stage 6, characterized by completely normal bipedal behavior.

Evaluation of supine posture

The human subjects (children and adults) investigated in this study were further categorized by the practice of supine posture. To simplify the study, the categorization was made in relation to the preferential posture taken by subjects when sleeping. It was relatively easy to record the sleeping posture of the 23 normal and the 15 handicapped children: the nursing night shift for hospitalized children was asked to monitor carefully their sleeping posture and/or the mothers, who were always familiar with the sleeping pattern of their children, volunteered to monitor their sleeping children. A careful record for a minimum of 10 days was required before the child was included in the study. It was more difficult to gather the data for the adults. Spouses were requested to observe each other as well as monitor themselves. After excluding ambiguous reports, 58 of the 113 adults investigated are included in the study of sleeping posture. Three groups are distinguished in terms of their sleeping posture: a) preferentially supine, b) ventral (prone) or lateral but never supine, c) indifferently supine, ventral, or lateral.

SC formation was also studied in relation to age, race, sex, and parity. Means, standard deviations, and t-test comparing age, sex, ethnic group, and affect of parity on SC, as well as ANOVA and ANCOVA comparing the influence of sleeping posture on SC were calculated. The relationship between age and SC was examined by correlation and regression analysis.

RESULTS

Nonhuman primates

In tailed primates SC is minimal (Fig. 3), varying from 10 to 22 degrees (mean 11.5 ± 6

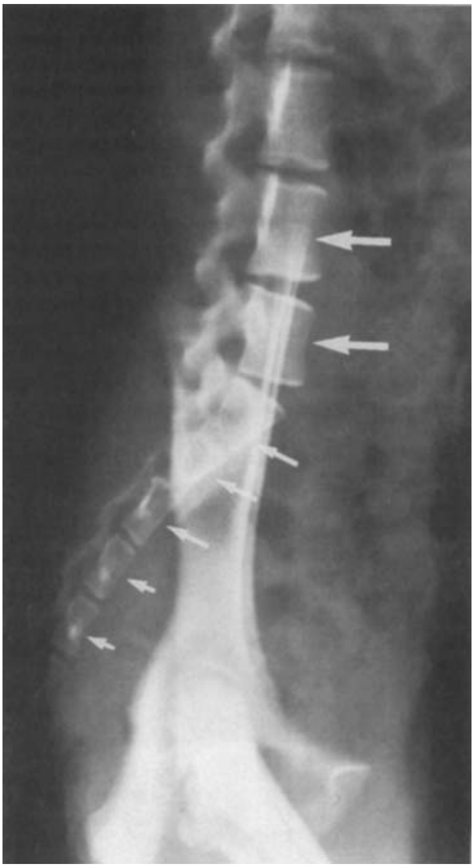


Fig. 3. Rhesus monkey. SC is formed by S1 and S3 and measures 13 degrees. In a caudad direction: large, medium, and small arrows point to 6th and 7th lumbar vertebrae, to 1st to third sacral vertebrae, and to 1st and 2nd caudal vertebrae.

SD). SC varies from 6 to 27 degrees (mean 16 ± 10 SD) in hylobatids and from 9 to 46 degrees mean (27.2 ± 16 SD) in pongids.

Human adults

Out of the 113 adult sacra investigated in the present study, 10 are angular with the first three sacral vertebrae forming a right angle with the last two sacral vertebrae (Fig. 4B), 11 are flat with only part of the fifth sacral vertebra making an abrupt ventral angle (Fig. 4A), and the 92 others display a sacral curvature (Fig. 5) varying from 29 to 107 degrees (mean 65 ± 29 SD). In order to explain these wide variations, an attempt was made to understand how SC varies with sex, race, parity (for females), age, and finally with presence or absence of supine sleeping posture. In only 58 cases were all of these data (characteristics) available. These 58 individuals were included in the statistical analysis (Tables 2–4). The following results were obtained: 1) SC is slightly greater in males than in females; 2) SC is slightly greater in the black and hispanic groups than in the white population (Table 2); 3) when parity is known, SC is slightly greater in nulliparous than in multiparous females (Table 3). T-tests comparing males and females, black and white, and primiparous and multiparous reveal no significant mean differences (Tables 2, 3). In addition, when age is plotted against sacral curvature in the adult sample, no age-related change is observed (the correlation coefficient of $r = .189$ is not significantly different from zero).

Adult subjects in which sleeping postures can be accurately investigated (Table 4), are divided into three groups according to their preferential sleeping posture. Statistically significant differences appear among the three groups:

a. Thirty-four (59%) show no preference. They slept either supine, or lateral, or prone. SC in this group varies from 35 to 80 degrees (mean 65 ± 11 SD). This group includes 20 females and 14 males.

b. Sixteen (28%) preferred to sleep supine. In this group, the angle varies from 82 to 107

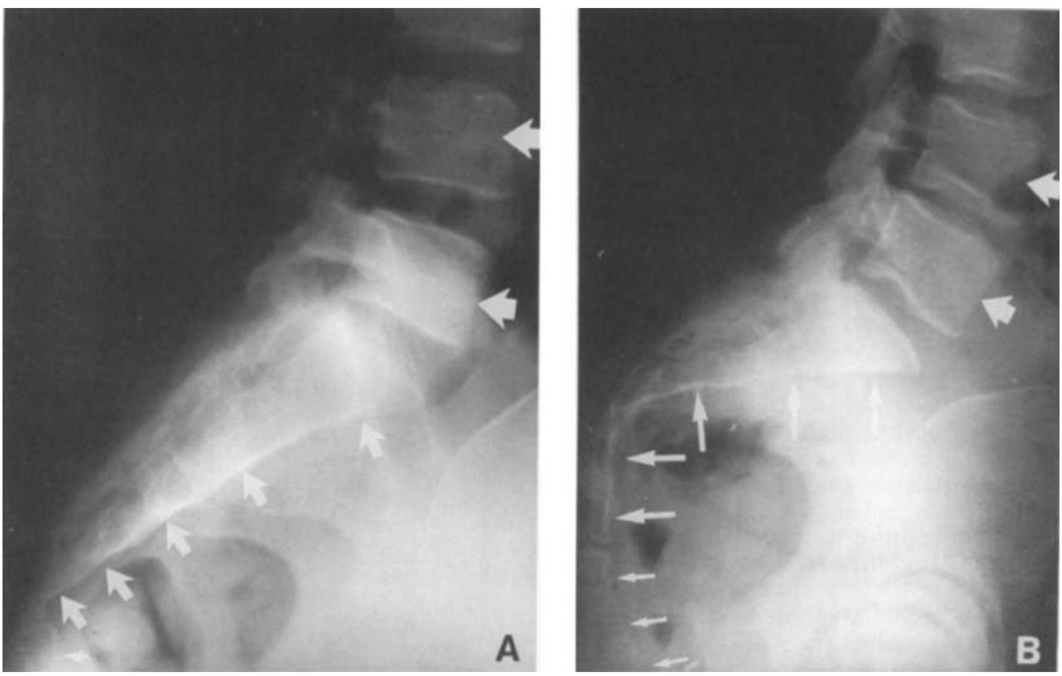


Fig. 4. Flat sacrum in A (note tip of last sacral vertebra and coccyx forming right angle with sacrum); supine posture is impossible. The sacrum on B forms a right angle with two straight sides, and the apex of this right angle is at S3–S4 junction. Legend for arrows, see Figure 2.

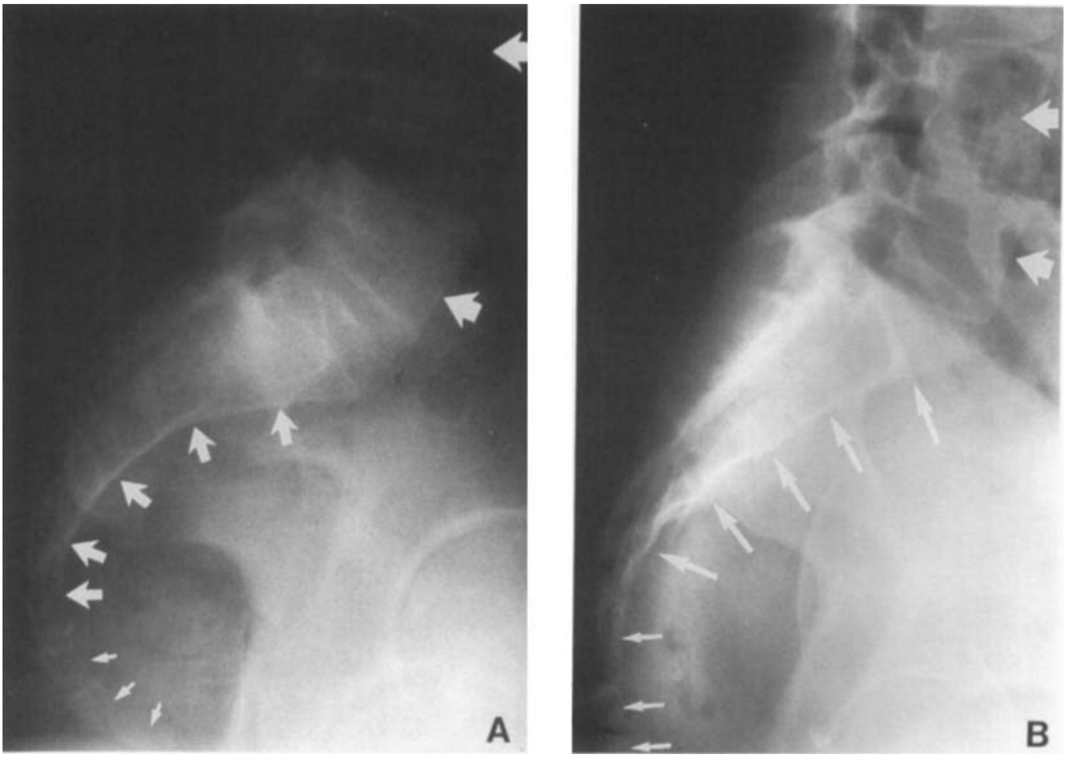


Fig. 5. SC is 97 degrees in A (preferential supine sleeping) and 36 degrees in B (preferential prone sleeping). Legend for arrows, see Figure 2.

degrees (mean 93 ± 8 SD). This group consists of 10 females and 6 males.

c. Eight individuals (13%) never slept supine in their life as determined by an indepth interview and subsequent monitoring. All the subjects in this latter group state that resting supine is not comfortable because of a low backache of varying intensity. SC in this group varies from 29 to 44 degrees (32 ± 6 SD). This group consists of five females and three males.

ANOVA reveals a significant difference in the sacral curvature among these last three groups ($P < .001$, see Table 4).

Normal human children

Tables 5 and 6 and Figure 6 summarize the sacral curvature data for these children. Although the numbers are rather small, statistical analysis is attempted in order to establish a relationship between SC formation and different factors.

a. In relation to age, the sacral curvature varies between 18 and 26 degrees in the 1st month of life (Fig. 2), and it progressively increases until it reaches adult status in adolescence (69 degrees at the age of 12 in one case). While the angle is minimal and presents minimal variations at birth, the variability increases with age (Fig. 6A). The correlation coefficient of SC and age is .83.

b. When the two sexes are separated (Fig. 6B), males have a correlation coefficient (SC and age) of .78 while females have a correlation coefficient of .86.

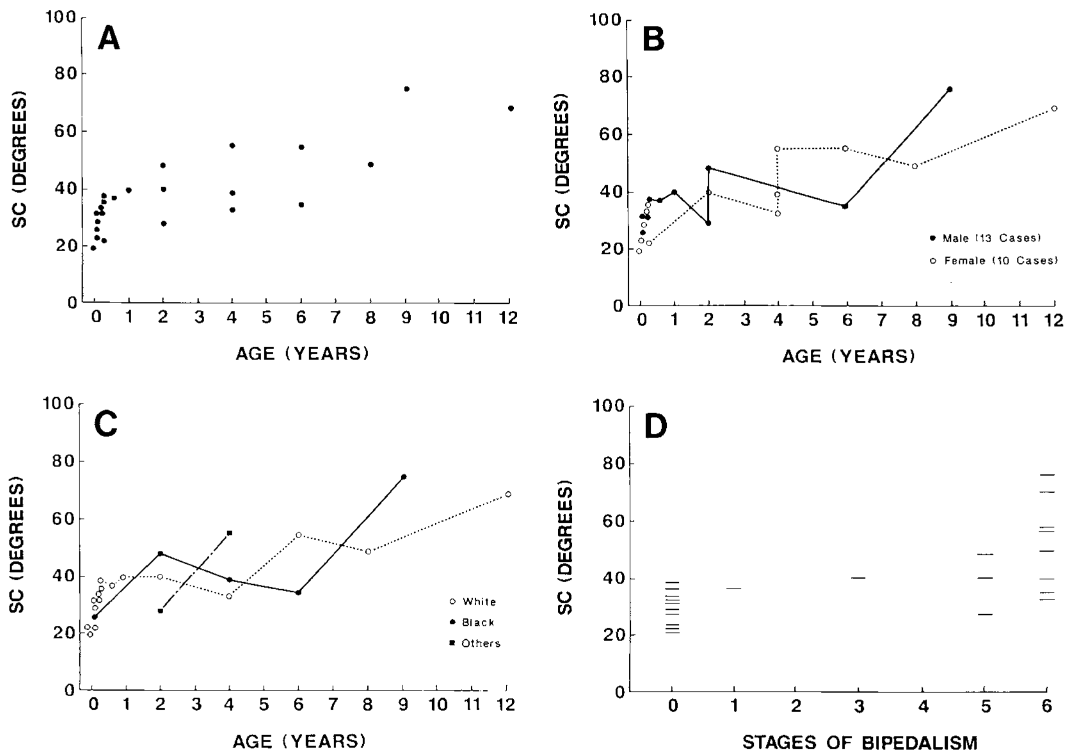
c. When children are grouped by race (Fig. 6C), the correlation coefficients (SC and age) is .87 for white and .76 for black.

d. When the different stages of bipedalism are related to sacral curvature, a correlation coefficient of .69 is obtained. Figure 6D shows that SC can be small or large before the onset of bipedalism (18 to 38 degrees) and also after bipedalism has been fully established (33 to 69 degrees).

e. Finally, in order to study the relationship with supine posture, the 23 normal children are divided into three groups according to their preference for sleeping, either supine (S), or lateral or prone (P), or indifferent (I) as to supine, lateral, or prone (Tables 5, 6).

For each of these categories, the children are grouped according to age. Figure 6E shows the relation between increasing age and SC: as age increases, SC is more accentuated in the five individuals who prefer supine sleeping posture; the correlation is .96. SC is less accentuated in the five individuals who exhibit preference for the prone or lateral sleeping posture; the correlation coefficient here is .98. SC for the 13 individuals with no preferential posture is intermediate in degree with a correlation coefficient of .91.

An analysis of covariance (ANCOVA) was performed to test for differences in regression parameters among sleeping postures. A



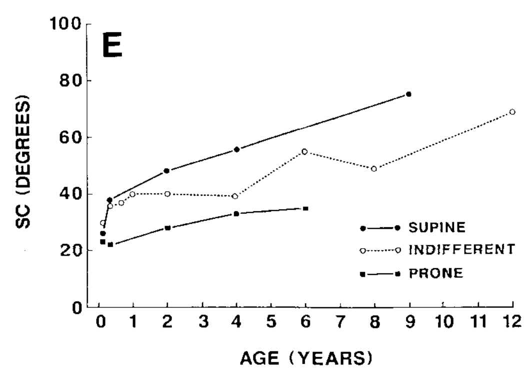


Fig. 6. SC formation in normal children. A: When plotted against age, the correlation coefficient is r = .83. B: When males are separated from females, the two correlation coefficients are r = .78 and r = .86. C: When separated by races, the coefficients are r = .87 and r = .76. D: Plotted against different stages of bipedalism, SC presents marked variations *before* and *after* bipedalism and r = .69. E: SC plotted against different sleeping postures, the coefficients become very significant (.96, .98, .91). For linear regression, see Table 6.

test for heterogeneity of slopes determined that the null hypothesis of equal slopes could not be rejected ($F = 2.281$; $df = 2, 17$; $P < .05$; common slope = 0.237). A test of adjusted means (intercepts) indicated significant overall heterogeneity ($F = 7.202$; $df = 2, 19$; $P < .02$). Further pair-wise testing, using Gabriel's approximation of the GT2-method (Sokal and Rohlf) indicated that there is no significant difference in adjusted means between the supine and indifferent groups, but the adjusted means of both of these groups (where supine posture is used) are significantly greater than that of the prone group. The adjusted mean of the supine group is significantly greater than that of the prone group. Therefore, while SC is related positively to age and onset of bipedalism, it is most strongly correlated with preference for supine or prone posture.

Children with orthopedic handicaps

The same sacral shapes (i.e., curved, flat-vertical, flat-horizontal) were observed in this sample of 15 children, but the variations were more extreme.

a. In five cases, in spite of severe orthopedic handicaps and severe malformations in other parts of the body, the shape of the sacrum and its relation to the lumbar spine were normal. These children were capable of erect posture without help and could sleep dorsally in spite of their orthopedic handicaps.

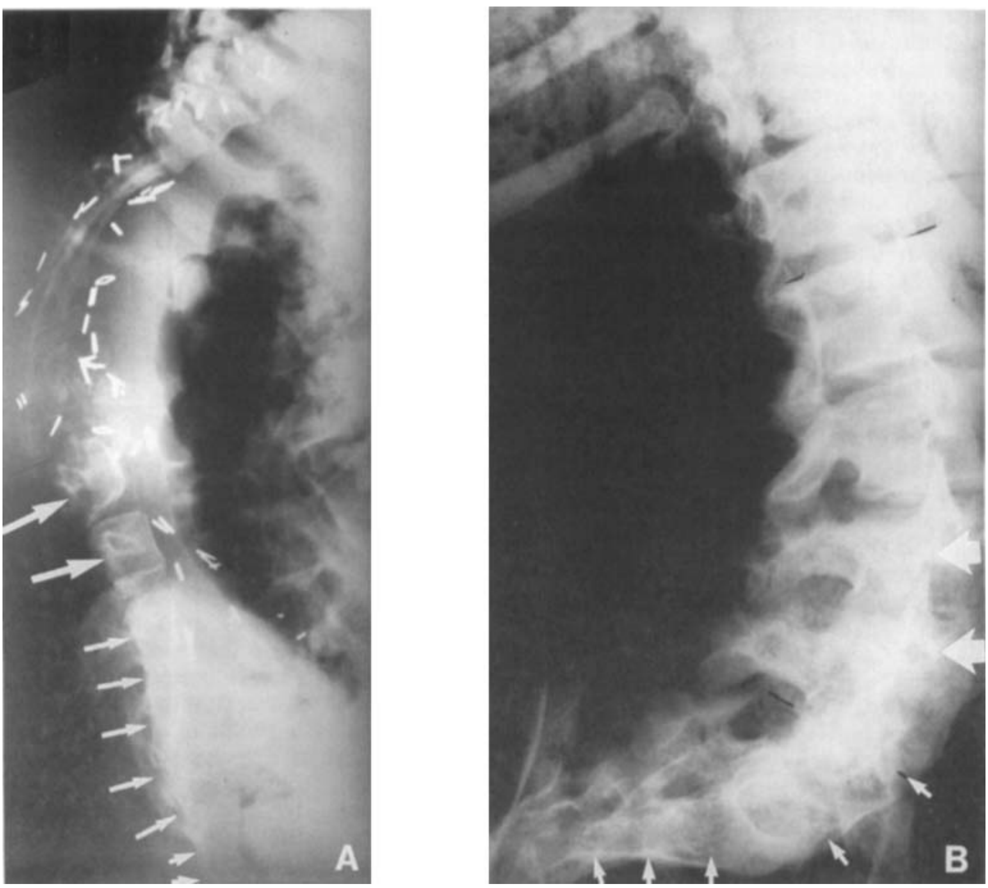


Fig. 7. **A:** Seven-year-old child orthopedic defect at the thoracolumbar junction. This child was unable to stand but could lie supine; the sacrum is flat-vertical, and the lumbosacrococcygeal complex mimics the condition in hylobatids and pongids. Legend for arrows, see Figure 2: here, the arrows are placed dorsally. Along the spine, numerous metallic clips were applied during surgical correction. **B:** Severe lordosis with flat-horizontal sacrum; this child can stand and walk but cannot assume supine posture.

b. In six cases the sacrum was straight (vertical), i.e., in continuity with the lumbar spine (Fig. 7, left), mimicking the bony condition of extant apes (Fig. 3) and human infants (Fig. 2). These children were incapable of erect posture without help but could sleep easily only in supine posture.

c. In four cases the sacrum was straight and horizontal, forming a right angle with the lumbar spine (Fig. 7, right). These 4 subjects were capable of erect posture without help but could not assume supine posture.

The above findings are summarized as follows. Tailed primates have minimal or no sacral curvature as defined here. This curvature is minimal-to-moderate in hylobatids and pongids. It is minimal in humans at birth and increases into adolescence. In human adults SC reaches an average of 67 degrees, but tremendous variation (29 to 107 degrees) is observed even in the absence of any orthopedic deficits. In addition, even without any orthopedic problem, the sacral configuration assumes any of a number of different curved, angular, or flat configurations. These variations are accentuated in children suffering from orthopedic handicaps: SC in these children can either be normal in appearance, be straight vertical (reminiscent of apes or human newborn), or flat horizontal. Supine posture, more than any other factor, appears to play the strongest role in the formation of the sacral curvature.

DISCUSSION

Supine posture, as described here, appears to contribute to the formation of human sacral curvature. Erect posture, obstetrical mechanics, and other factors, also appear to exert an influence.

Supine posture

This posture appears to play a role in the formation of SC. Data that support this hypothesis are as follows: 1) SC is minimal or nil in tailed mammals who almost never assume supine posture (when dogs, for example, lie on their back, they are forced to laterally flex their vertebral column due to the antero-posteriorly deep rather than medio-laterally wide thorax); 2) SC is minimal to moderate in pongids who only occasionally lie supine (e.g., see Fossey, 1983) in adult humans, SC is reduced when the practice of supine posture is limited, and increased when supine posture is practiced frequently; 4) in a population of 23 human infants, the appearance of sacral curvature seems more related to the practice of supine posture than to other factors such as the onset of bipedal locomotion; 5) in a population of 15 handicapped children, supine posture is nearly impossible for 4 of subjects who possessed a flat-horizontal sacrum (with such a sacral shape, supine posture is mechanically impossible) and is possible for 11 others who had normally curved or a flat-vertical sacrum (the only two sacral shapes for which supine posture is mechanically possible).

Human newborns can sleep in ventral, lateral, or supine positions (Behrman and Vaughn, 1983). Most newborn babies accept whatever initial position is imposed on them; some others, however, (about 15%, according to Hassall and Vandenberg, 1985), will refuse to sleep and will cry constantly until placed in a position different from the one imposed on them. The infant has the ability to turn over, from lateral to supine, on its own at birth, from prone to supine as of 2 months of age, and to any posture at the age of 4 months (Behrman and Vaughn, 1983). To a large extent the preferred sleeping posture adopted by a child depends on the one imposed initially on the infant at birth, on the individual response, and on the age of the child (Brackbill et al., 1973). These factors in turn will ultimately influence the sacral curvature.

The presented data suggest that supine posture exerts an important influence on the formation and shape of the lower part of the sacrum and coccyx. Unlike erect posture, which has tendency to "horizontalize," the sacrum and influence it posteriorly (Robinson, 1972), supine posture exerts a pressure on the lower part of the sacrum and coccyx which influence it in a ventral direction. This results in a forward angulation of the lower part of the sacrum and coccyx underneath the horizontal upper part of the sacrum. As a result of supine posture, the lower part of the sacrum and coccyx curve ventrally, where they would tend to be oriented dorsally. This is unlike other animals, wherein supine posture is essentially absent. One of the most prominent exceptions is found in the gorilla who occasionally rests in a supine position (Fossey, 1983).

Erect posture

During bipedal stance in humans, the entire sacrum rotates posteriorly, contributing to the formation of the lumbosacral angle. This movement is resisted strongly by the sacrotuberous and minimally by the sacrospinous ligament (Kapandji, 1974; DonTigny, 1985; Warwick and Williams, 1973), which attach to the lower part of the sacrum and to the coccyx. The combination of these two opposite influences on the sacrum results in the sacral curvature and are more accentuated during bipedal locomotion.

Obstetrical requirements

Sacral curvature is present in both males and females and is usually more accentuated in males than in females (Table 2) (Warwick and Williams, 1973). It is thus difficult to suggest that sacral curvature is the result of parturition, viz., the passing of the large fetal head during obstetrical delivery. From a clinical point of view it is also difficult to support the idea that parturition is primarily responsible for the shape of the human sacrum: in humans, the fetal head would have a far easier time passing through the lesser pelvis *if* the sacrum-coccyx tilted dorsally without the lower part of the sacrum and the coccyx tilting ventrally as it often does. In fact, in patients in whom the coccyx is "overtilted" ventrally, it can be fractured during delivery (Pritchard et al., 1985; Oxorn, 1986). The presence of the hormone relaxin may contribute to a minimal or inconstant relaxation of the pelvic joints in pregnancy and during labor (Birnberg and Abitbol, 1959). If obstetrical requirements play a role in the sacral curvature in humans, it must be minimal.

Action of the pubococcygeus muscle in Homo sapiens

A prominent levator ani (pubococcygeus and iliococcygeus) is found in the Hominoidea, and the acme of its development is found in humans. When this muscle contracts it pulls the coccyx ventrally. In tailed mammals this pull is countered by the sacrococcygeus dorsalis muscle (Sisson and Grossman, 1953). The latter has disappeared in humans and apes, and the contraction of the levator ani, not being countered, results in a progressive ventral displacement of the lower part of the sacrum and coccyx.

In summary, a marked sacral curvature is described in *Homo sapiens,* and different factors influence its formation. Some factors are more strongly correlated with sacral curvature than others, and their multiplicity contributes to the many and varied shapes of the human sacrum. This study suggests that supine posture is one of the factors affecting sacral curvature. Supine posture is as characteristic of *Homo sapiens* as is erect posture, and, as demonstrated here, also plays a role in shaping the human pelvis.

ACKNOWLEDGMENTS

Data on living primates were gathered in the laboratory of the Museum of Comparative Anatomy, Department of Anatomical Sciences, State University of New York at Stony Brook (supported by NSF Research grants BNS 8318013 and BNS 8311206); in the American Museum of Natural History, New York City; and in the Jamaica Hospital, Jamaica, New York.

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