When this general pattern of the lamina area is compared with that of modern man it is evident that the difference between the two groups lies mainly in the lumbar region. The laminae of modern human lumbar vertebrae increase from L1 to L5, while a decrease occurs in the great ape columns. Fig. 9.22 shows graphically this seemingly important difference in lamina index values of modern man and the two *Pan* vertebral columns.

A comparison of Sts 14 lamina area with those of the previous two hominoid groups is presented in Fig. 9.23. The most important feature to emerge is the increase in the australopithecine lamina area between L2 and L5 as in the modern human series. The lamina index value of L6 in Sts 14 is however unknown. In the thoracic region the three groups correspond approximately. This graph also underlines the difference in absolute size between modern human and *A. africanus* laminae.

4.2 Lamina Index/Inferior Body Area Ratio

When the pattern of lamina area increase and decrease in relation to the inferior body area is compared between modern humans and pongids (Figs. 9.24, 9.25) three features are apparent. Firstly, the values for lamina size/ inferior body area increase at the last two lumbar vertebral levels in modern human male and female columns. In the great ape series an increase occurs at L4, the last lumbar vertebra of the *Gorilla* (Za 1312) column, a decrease occurs at L4 of the *Pan* (Za 94) column, while the ratios have the same value in the last three lumbar vertebrae of the *Pongo* (Za 93) column. No sudden sharp increase thus occurs in the last two lumbar vertebrae of the pongid vertebral columns.

Secondly, an increase of this ratio occurs at the lower thoracic vertebrae; slightly between T8 and T9 in the Zulu and the *Gorilla* male columns, gradually between T5 and T8 in the *Pan* (Za 94) and between T6 and T11 in the *Pongo* (Za 93) columns. Thirdly, in the male columns, the lamina size/inferior area ratio is greater in the African apes than in modern man. On the other hand, this ratio is smaller in the *Pongo* female than in modern human female columns.

A comparison of Sts 14 lamina index/inferior body area with that of modern human and *Pongo* females is presented in Fig. 9.25. The most important feature which comes forward is the increase of this ratio at the L3, L4 and L5 levels in Sts 14. In the light of the previous comparison this seems to be an essentially human-like characteristic. Again it must be emphasized that the lamina index value of the last lumbar vertebra of Sts 14 is however unknown.

C. The Pedicle Size

1. Modern Human Series

1.1 Zulu Series

1.1.1 Pedicle Index (gped x lped)

The product of the greatest sagittal (gped) and the least transverse (lped) diameters at the slenderest part of the pedicle is calculated for both left and right sides. This index indicates the cross-sectional size of the pedicles. The mean pedicle index of the two sides is calculated for each vertebra. The results are listed in Table 9.16 and presented graphically in Fig. 9.26.

In the male Zulu spinal columns the mean pe icle index values decrease from T1 to T5. The mean index values of the pedicles increase then from T6 to T11, followed by another decrease to L2 and another increase to L5. The mean pedicle index values of the female Zulu spinal columns correspond with those of the male columns, save that the first increase extends from T6 to T12 instead of to T11.

TABLE 9.16

The Mean Pedicle index of Zulu Thoracic and Lumbar Vertebrae (cm^2)

Vertebra	Zulu males			Zulu females		
	Mean	±SD	Observed Range	Mean	±SD	Observed Range
T1	0,78	0,11	0,56 - 1,05	0,60	0,12	0,42 - 0,90
T2	0,77	0,11	0,60 - 1,02	0,56	0,10	0,45 - 0,82
T3	0,62	0,11	0,47 - 0,98	0,48	0,09	0,36 - 0,72
T4	0,55	0,10	0,42 - 0,85	0,41	0,08	0,24 - 0,69
T5	0,52	0,10	0,32 - 0,63	0,40	0,11	0,25 - 0,68
T6	0,52	0,09	0,39 - 0,71	0,40	0,09	0,24 - 0,55
T7	0,58	0,12	0,32 - 0,85	0,43	0,08	0,25 - 0,58
T8	0,64	0,14	0,40 - 0,98	0,46	0,09	0,30 - 0,66
T9	0,74	0,15	0,47 - 1,05	0,58	0,13	0,33 - 0,88
T10	1,10	0,26	0,64 - 1,76	0,84	0,15	0,60 - 1,16
T11	1,43	0,24	0,98 - 1,98	1,13	0,22	0,58 - 1,48
T12	1,38	0,26	0,80 - 2,04	1,18	0,26	0,79 - 1,62
L1	1,30	0,26	0,77 - 1,76	1,02	0,27	0,65 - 1,84
L2	1,27	0,19	0,91 - 1,65	1,01	0,19	0,68 - 1,36
L3	1,45	0,21	1,04 - 1,82	1,23	0,22	0,80 - 1,68
L4	1,52	0,20	1,21 - 2,03	1,29	0,20	1,02 - 1,68
L5	2,07	0,33	1,43 - 2,87	1,83	0,37	0,34 - 2,79

n = 30

Sex differences: The mean pedicle index values of female vertebrae are smaller than those of corresponding male vertebrae. Student's t-Test (Table 9.17) shows highly significant differences (P<0,0005 and P0,005) between the sexes at all levels, except at L5, where this difference is almost certainly significant (P<0,01).

TABLE 9.17

t-Values of Sex Differences in the Mean Pedicle Index Values of Zulu Thoracic and Lumbar Vertebrae

Vertebra	t-Value	P<
T1	6,072	0,0005
T2	7,647	0,0005
T3	5,732	0,0005
T4	5,995	0,0005
T5	4,458	0,0005
T6	5,272	0,0005
T7	5,763	0,0005
T8	5,959	0,0005
T9	4,832	0,0005
T10	4,832	0,0005
T11	5,098	0,0005
T12	2,906	0,005
L1	4,132	0,0005
L2	5,517	0,0005
L3	4,010	0,0005
L4	4,781	0,0005
L5	2,57	0,01

1.1.2 Mean Pedicle Index/Inferior Body Area Ratio

Compared to vertebral body area, Zulu male pedicles are largest at the T1 and T2 levels (Table 9.18). Presented graphically (Fig. 9.27) the ratio shows a biphasic curve with a sharp decline in pedicle size from T1 to T6, T7, T8 and T9. From T9 the pedicle size increases in relation to the inferior vertebral body area to T11, followed by a decrease to L2-L4 and a sharp increase from L4 to L5. The ratio follows the same general pattern in the female columns.

TABLE 9.18

The Mean Pedicle Index/Inferior Body Area Ratio Values of Zulu Thoracic and Lumbar Vertebrae

Vertebra	Males	Females
T1	0,19	0,16
T2	0,18	0,15
T3	0,13	0,12
T4	0,11	0,10
T5	0,10	0,09
T6	0,09	0,08
T7	0,09	0,08
T8	0,09	0,08
T9	0,09	0,09
T10	0,13	0,12
T11	0,15	0,14
T12	0,13	0,14
L1	0,11	0,10
L2	0,10	0,10
L3	0,11	0,11
L4	0,11	0,10
L5	0,16	0,16

1.2 Comparative Series

1.2.1 Mean Pedicle Index (gped x lped)

The results of Davis (1961) on the last three lumbar vertebrae in 35 male and 24 female West-African columns and those of Pal and Routal (1986, 1987) on certain thoracic and the lumbar vertebrae in 44 Indian males are available for comparison. These data, with the results of the present study, are listed in Table 9.19 and presented graphically in Fig. 9.28.

The mean pedicle index values in the Zulu males are highly significantly greater (P<0,0005 and P<0,005) than in the Indian males at the levels reported by Pal and Routal (1986, 1987). Exceptions are the index values for T9 and L5 which show no significant difference between these samples. The

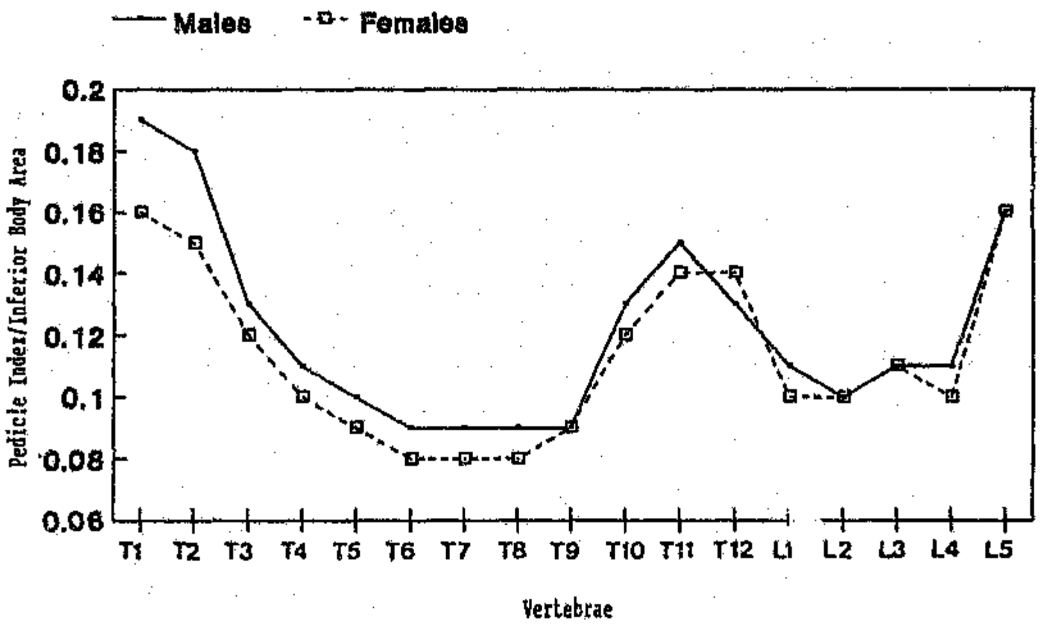

Fig. 9.27 The Pedicle Index/Inferior Body Area Ratio Values of Zulu Thoracic and Lumbar Vertebrae

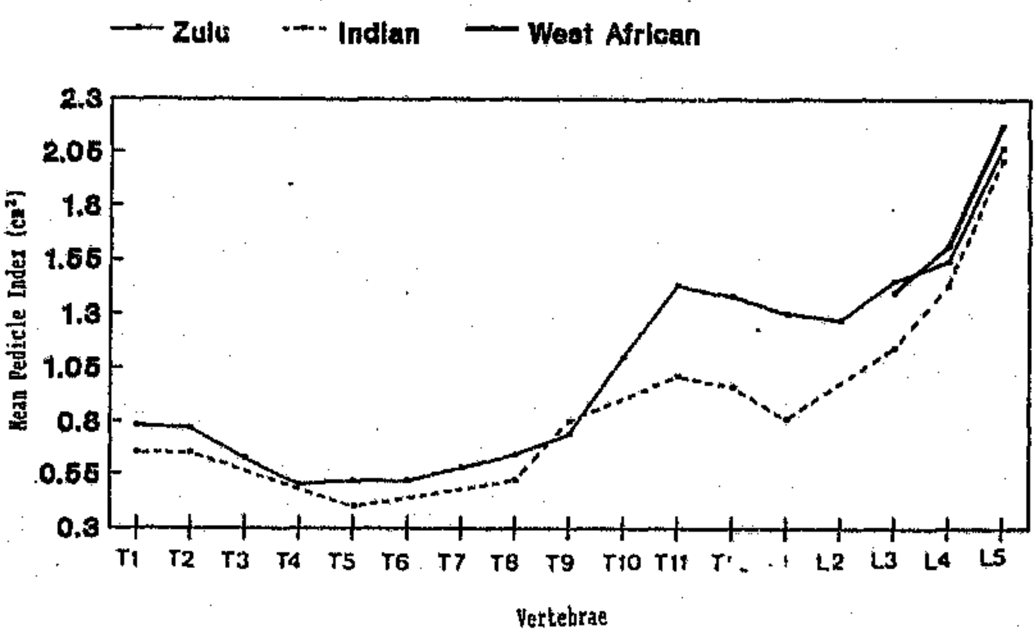

Fig. 9.28 The Mean Pedicle Index Values of Modern Human Male Thoracic and Lumbar Vertebrae

index values of the last three lumbar vertebrae in West African spinal columns are not significantly different from those of Zulu males. On the other hand, the mean index values of L3 and L4 in the West African males are highly significantly greater (P<0,0005) than those of Indian males. The values of L5 show no significant difference among these populations.

TABLE 9.19

The Mean Pedicle Index Values of the Thoracic and Lumbar Vertebrae in the Males of Various Populations (cm^2)

Vertebra	Present Study Zulu (n=30) Mean ± SD	Pal and Routal (1986, 1987) Indian (n = 44) Mean ± SD	Davis (1961) West-African (n=35) Mean ± SD
T1	0,78 ± 0,11	0,65 ± 0,09	
T2	0,77 ± 0,11	0,65 ± 0,13	
T3	0,62 ± 0,11		
T4	0,50 ± 0,10		
T5	0,52 ± 0,10	0,40 ± 0,07	
T6	0,52 ± 0,09		
T7	0,58 ± 0,12		
T8	0,64 ± 0,14	0,52 ± 0,15	
T9	0,74 ± 0,15	0,80 ± 0,33	
T10	1,10 ± 0,26		
T11	1,43 ± 0,24	1,01 ± 0,26	
T12	1,38 ± 0,26	0,96 ± 0,24	
L1	1,30 ± 0,26	0,81 ± 0,18	
L2	1,27 ± 0,19		
L3	1,45 ± 0,21	1,14 ± 0,02	1,40 ± 0,18
L4	1,54 ± 0,20	1,43 ± 0,08	1,61 ± 0,25
L5	2,07 ± 0,33	2,01 ± 0,37	2,17 ± 0,42

The mean pedicle index values of the last three lumbar vertebrae in Zulu and West African female columns (Table 9.20) show no significant difference.

TABLE 9.20

The Mean Pedicle Index Values of the Last Three Lumbar Vertebrae in Zulu and West African Females (cm^2)

Vertebra	Zulu n = 30 Mean ±SD	West-African n = 24 Mean ±SD
L3	1,23 ± 0,22	1,23 ± 0,21
L4	1,29 ± 0,20	1,37 ± 0,26
L5	1,83 ± 0,37	1,90 ± 0,37

1.2.2 Mean Pedicle Index/Inferior Body Area Ratio

Comparison of the mean ratio values shows the same biphasic curve in Zulu and Indian males (Table 9.21, Fig 9.29), but the values of the ratio are smaller in Indian males. The pedicle sizes of the last three lumbar vertebrae in West African males present the same tendency to increase in relation to the body area as in Zulu and Indian males.

The ratio of the pedicle size of the last three lumbar vertebrae increase in West African females. Zulu females present a decrease in this ratio from L3 to L4 followed by an increase to L5. The ratio values of the last three West African lumbar vertebrae have been calculated from Davis's (1961) results.

TABLE 9.21

The Mean Pedicle Index/Inferior Body Area Ratio Values in the Thoracic and Lumbar Vertebrae of the Comparative Modern Human Series

Vertebra	Zulu Males n=30	West African Males n=35	Indian Males n=44	Zulu Females n=30	West African Females n=24
T1	0,19		0,15	0,16	
T2	0,18		0,13	0,15	
T3	0,13			0,12	
T4	0,11			0,10	
T5	0,10		0,07	0,09	
T6	0,09			0,08	
T7	0,09			0,08	
T8	0,09		0,07	0,08	
T9	0,09		0,10	0,09	
T10	0,13			0,12	
T11	0,15		0,11	0,14	
T12	0,13		0,09	0,14	
L1	0,11		0,07	0,10	
L2	0,10			0,10	
L3	0,11	0,10	0,08	0,11	0,11
L4	0,11	0,12	0,10	0,10	0,12
L5	0,16	0,17	0,14	0,16	0,17

2 African and Asian Great Ape Series

2.1 Present Study

2. 1 Pedicle Index (gped x lped)

The size of the pedicles decreases from T1 to T5 in Za 95, a *Gorilla* male vertebral column. From T5 it increases gradually to T10 followed by a sharp increase to L2, a decrease at L3 and a sudden sharp increase from L3 to L4 (Table 9.22, Fig 9.30). In Za 1312 a slight increase in pedicle size occurs from T1 to T2 and T3 followed by a decrease to T4 and an increase to L1. A decrease in pedicle size is seen from L1 to L2 followed by a sharp increase to L4.

TABLE 9.22

The Pedicle Index Values in Individual Sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae (cm^2)

Vertebra	*Gorilla*		*Pan*		*Pongo*
	Za 1312 Male	Za 95 Male	Za 1071 Male	Za 94 Male	Za 93 Female
T1	0,85	0,94	0,59	0,38	0,40
T2	0,88	0,73	0,46	0,37	0,40
T3	0,88	0,65	0,53	0,41	0,40
T4	0,77	0,63	0,55	0,39	0,34
T5	0,91	0,61	0,51	0,45	0,31
T6	0,93	0,71	0,54	0,41	0,32
T7	1,01	0,70	0,54	0,50	0,33
T8	1,29	0,75	0,50	0,48	0,43
T9	1,34	0,88	0,58	0,53	0,38
T10	1,89	0,84	0,53	0,55	0,38
T11	2,13	1,14	0,77	0,65	0,46
T12	2,18	1,46	0,76	0,80	0,61
T13		1,85	1,09	1,00	
L1	3,29	1,88	1,22	1,05	0,96
L2	2,98	2,03	1,36	1,10	1,02
L3	3,55	1,79	1,22	1,16	0,87
L4	4,62	2,38	1,32	1,41	1,09

The *Pan* male columns show a decrease in pedicle size from T1 to T2 followed by a gradual increase to T10. From this level Za 94 presents an increase in pedicle size through to L4. Za 1071 shows an increase in pedicle size from T10 to L2 followed by a decrease to L3 and an increase to L4. L2 presents, however, the largest pedicles in this vertebral column (Fig 9.31).

In the *Pongo* female vertebral column, the pedicle size is equal over the first three thoracic vertebrae. This is followed by a decrease to L5 and an increase to T8. A second decrease in pedicle size occurs from T8 to T9. T9 and T10 have pedicles of equal size. From T10 the mean pedicle index value increases by 60,4 mm^2 to L2, followed by a decrease of 10,5 mm^2 to L3 and an increase of 22 mm^2 to L4 (Fig. 9.32).

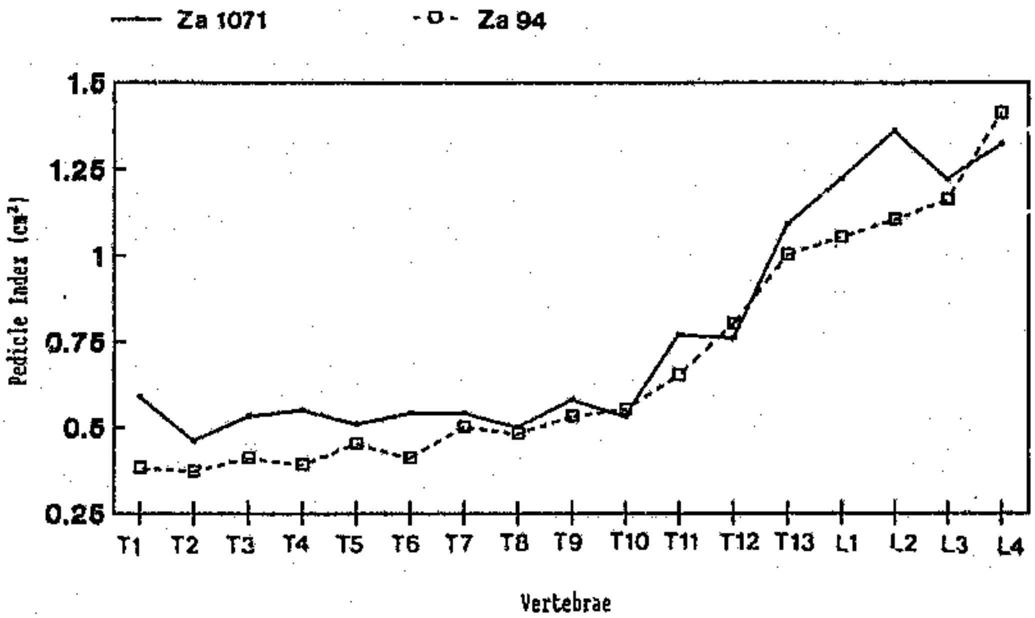

Fig. 9.31 The Pedicle Index Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

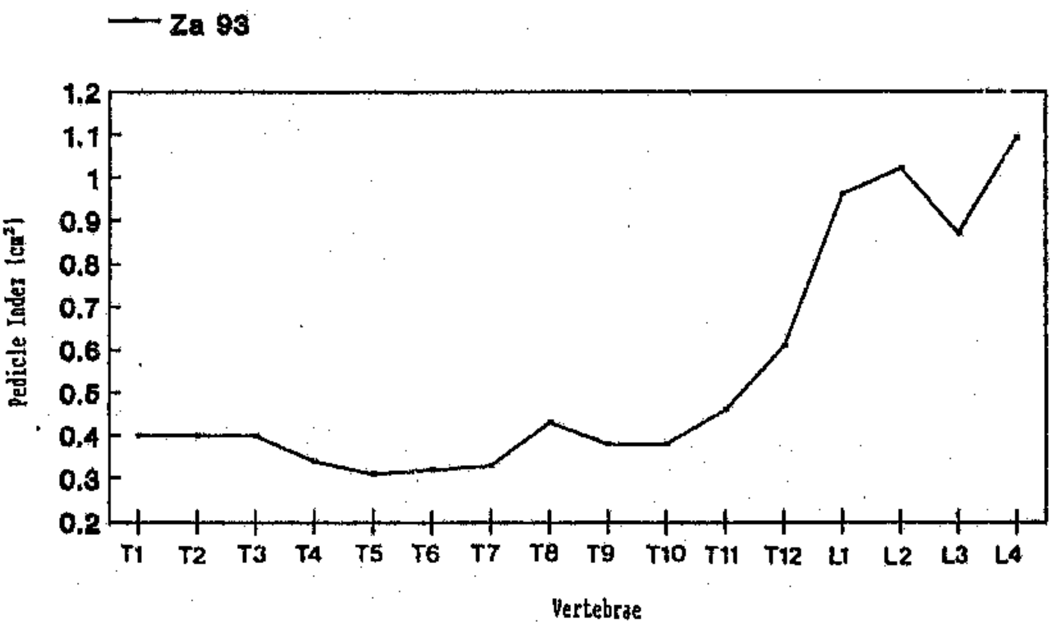

Fig. 9.32 The Pedicle Index Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

2.1.2 Pedicle Index/Inferior Body Area Ratio

The graphs of the relationship between the pe 'ıle size and the inferior body area in the two *Gorilla* male spinal columns differ markedly (Fig. 9.33). Unfortunately, the inferior vertebral body areas of the last two lumbar vertebrae of Za 95 are damaged. In this column a sharp decline occurs from T1 to T3, followed by an increase to T4. Between T5 and T9 the ratio fluctuates between 0,11 and 0,12 and then declines to 0,10 in T10. The ratio increases from T10 to T13 and L1 followed by a decrease to L2. The lumbar region of Za 1312 also shows a decline from L1 to L2, which is followed by a sharp incline to L4 (Table 9.23).

TABLE 9.23

The Pedicle Index/Inferior Body Area Ratio Values in Individual Sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae

Vertebra	*Gorilla*		*Pan*		*Pongo*
	Za 1312 Male	Za 95 Male	Za 1071 Male	Za 94 Male	Za 93 Female
T1	0,12	0,21	0,19	0,20	0,13
T2	0,11	0,15	0,14	0,17	0,12
T3	0,11	0,12	0,15	0,17	0,11
T4	0,10	0,14	0,15	0,15	0,09
T5	0,11	0,11	0,12	0,16	0,08
T6	0,11	0,12	0,12	0,14	0,07
T7	0,10	0,11	0,11	0,16	0,07
T8	0,12	0,11	0,10	0,15	0,08
T9	0,11	0,12	0,10	0,15	0,07
T10	0,14	0,10	0,09	0,13	0,06
T11	0,13	0,13	0,12	0,14	0,07
T12	0,12	0,14	0,10	0,15	0,09
T13		0,15	0,14	0,18	
L1	0,17	0,15	0,14	0,17	0,13
L2	0,14	0,13	0,13	0,17	0,12
L3	0,15	*	0,11	0,17	0,10
L4	0,23	*	0,13	0,25	0,14

* Inferior vertebral body area unknown

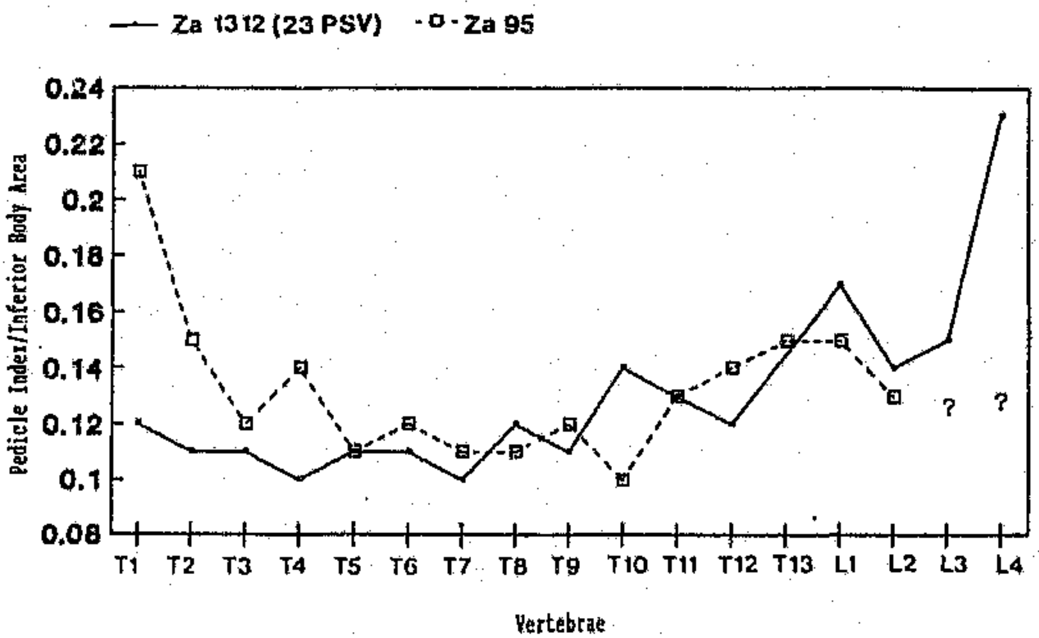

Fig. 9.31 Pedicle Index/Inferior Body Area Ratio Values in Two Sets of *Gorilla* Male Thoracic and Lumbar Vertebrae

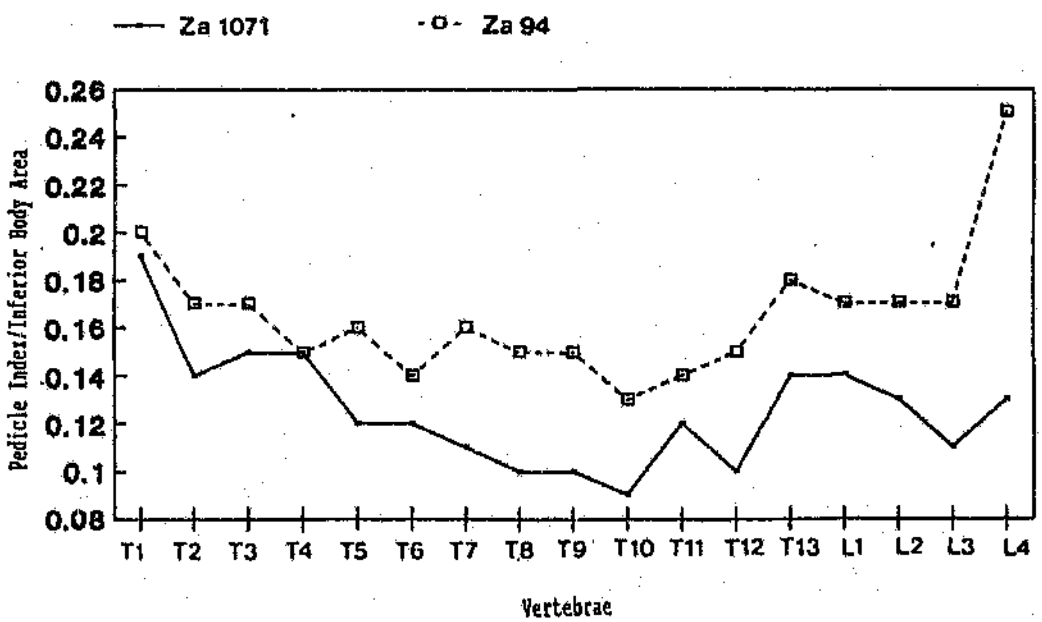

Fig. 9.34 The Pedicle Index/Inferior Body Area Ratio Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

In the two *Pan* vertebral columns this ratio shows a gradual, though more distinct decline to the T10 level which is followed by an incline to T13 (Fig. 9.34). In the lumbar region of Za 1071, the ratio of L1 is equal to that of T13, followed by a decline to L3 and an incline to L4. In Za 94 the ratio declines from T13 to L1, L2 and L3 in which it is equal, followed by a sharp incline to L4.

The pedicle index/inferior body area ratios of the *Pongo* female thoracic and lumbar vertebrae (Fig 9.35) decrease from 0,13 in T1 to 0,07 in T6 and T7, followed by an increase to 0,08 in T8. From T8 the ratio decreases to 0,06 in T10 followed by an increase to 0,13 in L1. In the lumbar region the ratio decreases from L1 to L3 and increases to L4. L4 (0,14) presents the largest pedicles in relation to the body area and T10 the smallest.

3. Australopithecine Series

3.1 Present Study

3.1.1 Pedicle Index (gped x lped)

In this series one of the pedicles of a vertebra is frequently damaged or broken away. The index value of the remaining pedicle is then, for the purposes of this study, treated as the mean index value. These values are all clearly marked in the tables.

With the exception of the third last thoracic vertebra of which the pedicle index values are unknown, the pedicle size increases from the seventh last thoracic vertebra to L1 in Sts 14, an *A. africanus* female partial column. From L1 a sharp decline occurs to L2, followed by a gradual increase to L6. The pedicle size of L1 is however greater than that of L6 (Table 9.24, Fig. 9.36).

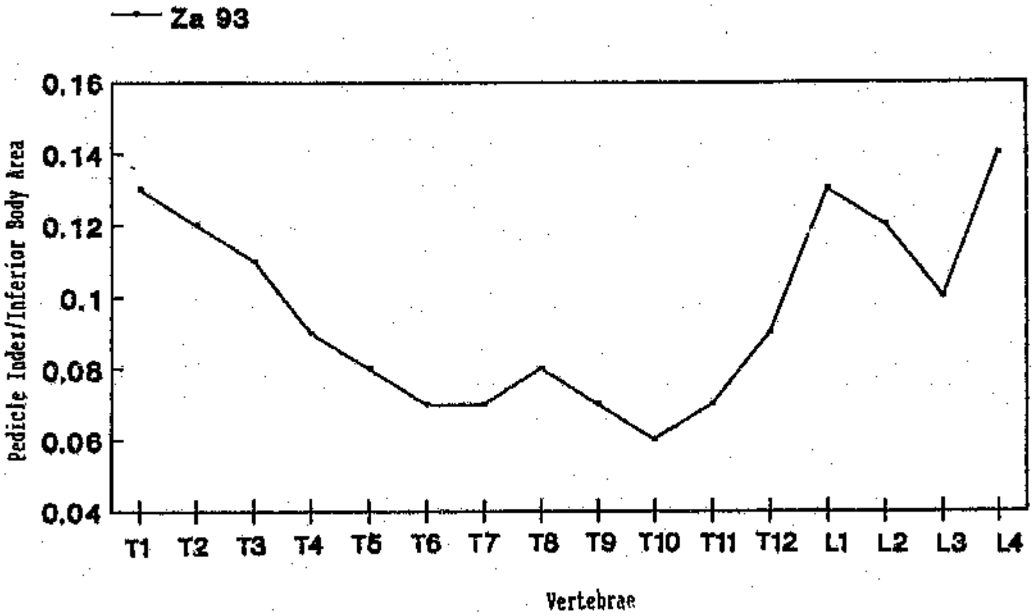

Fig. 9.35 The Pedicle Index/Inferior Body Area Ratio Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

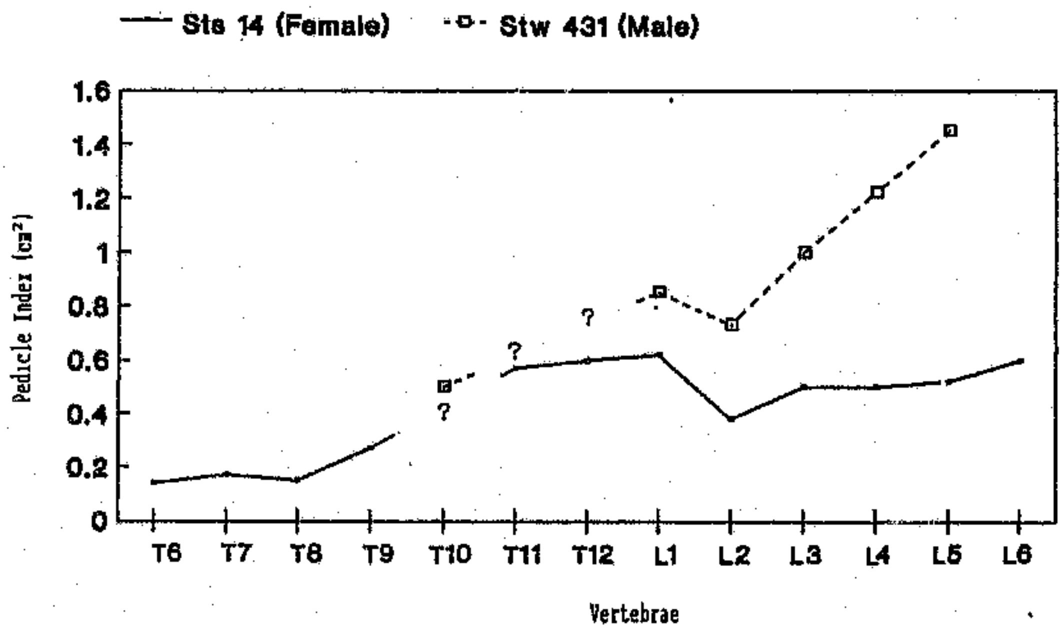

Fig. 9.36 The Pedicle Index Values in Two Sets of *A. africanus* Thoracic and Lumbar Vertebrae

TABLE 9.24

The Pedicle Index Values in Individual Sets of *A. africanus* Thoracic and Lumbar Vertebrae (cm^2)

Vertebrae	Sts 14	Stw 431	Stw 8b
Thoracic:			
7th last	0,14		
6th last	0,17		
5th last	0,15		
4th last	0,27		
3rd last	-	0,50	
2nd last	0,57	-	
last	0,60	-	
Lumbar:			
L1	0,62	0,85*	
L2	0,38	0,73	0,72*
L3	0,50	1,00*	
L4	0,50	1,22*	
L5	0,52$	1,45$	
L6	0,60*		

* Only right side is preserved
$ Only left side is preserved

Stw 431, an *A. africanus* male partial vertebral column, shows a decrease in pedicle size from L1 to L2 followed by a sharp increase to L5, the last lumbar vertebra. A comparison of the two partial columns reveals larger pedicles in the male than in the female. The male partial column also shows a sharp increase in pedicle size in the lumbar region with the pedicles of the last lumbar vertebra the largest. In contrast the female partial column shows a gradual increase, but the size of the L1 pedicles is the largest. Stw 8b is either a second or third male lumbar vertebra. The pedicle size of the right pedicle correponds with that of L2 in Stw 431.

The pedicle index values of the two *A. robustus* vertebrae are 0,60 cm^2 in the last thoracic, SK 3981a, and 1,15 cm^2 in the last lumbar, SK 3981b.

3.1.2 Pedicle Index/Inferior Body Area Ratio

This ratio is high in the last thoracic vertebra of Sts 14. From here a sharp decline occurs to L2 and L3 which are equal. From L3 a sharp incline occurs in the pedicle size in relation to the inferior body area. In the first three lumbar vertebrae of Stw 431 in which this ratio is known a decrease occurs to L2 followed by an increase to L3 (Table 9.25, Fig. 9.37).

The ratios of the two *A. robustus* vertebrae are 0,16 in the last thoracic and 0,22 in the last lumbar vertebra.

TABLE 9.25

The Pedicle Index/Inferior Body Area Ratio Values in Individual Sets of *A. africanus* Thoracic and Lumbar Vertebrae

Vertebrae	Sts 14	Stw 431
Thoracic:		
7th	0,06	
6th	0,07	
5th	0,06	
4th	0,09	
3rd	-	
2nd	-	
last	0,18	
Lumbar:		
L1	0,16	0,12
L2	0,10	0,10
L3	0,10	0,13
L4	0,11	
L5	0,14	
L6	0,18	

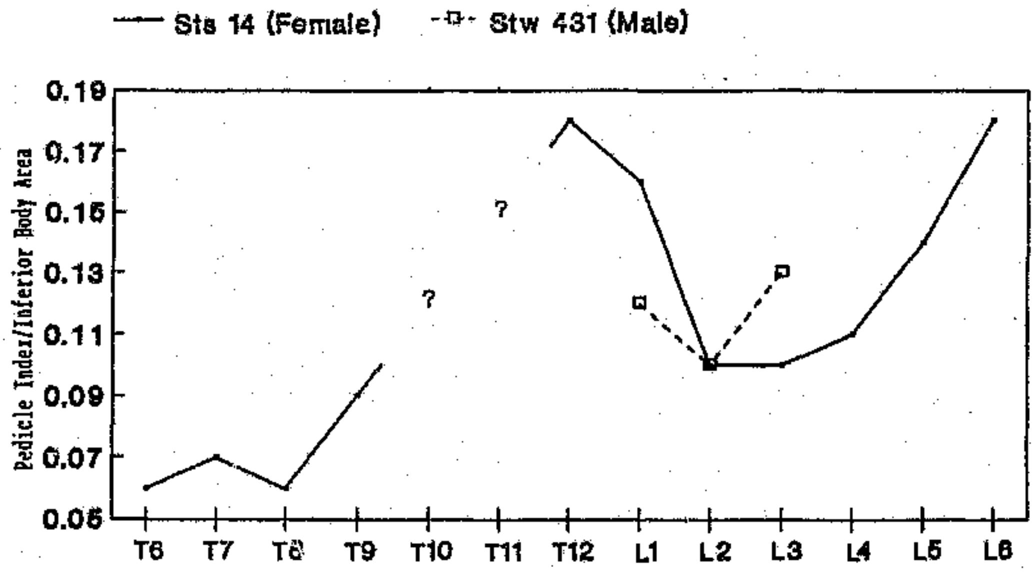

Fig. 9.37 The Pedicle Index/Inferior Body Area Ratio Values in Two Sets of *A. africanus* Thoracic and Lumbar Vertebrae

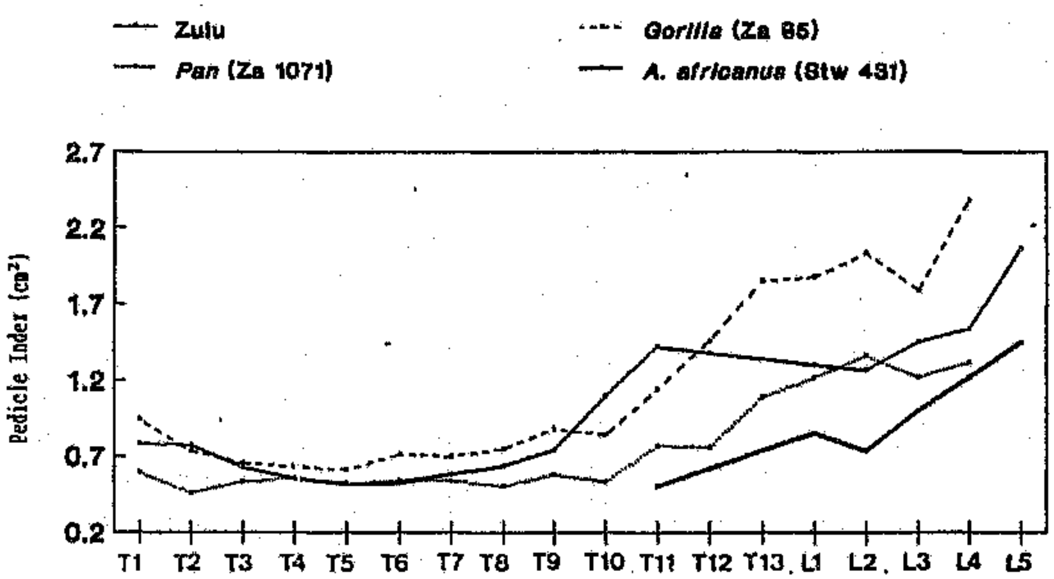

Fig. 9.38 The Pedicle Index Values of Modern Human (n=30), *Gorilla* (n=1), *Pan* (n=1) and *A. africanus* (n=1) Male Thoracic and Lumbar Vertebrae

4. Intergroup Comparisons

4.1 Pedicle Index (gped x lped)

In both modern man and the anthropoid apes the pedicle size decreases in the upper thoracic region followed by an increase in the lower thoracic region (Figs. 9.38 and 9.39). In the lumbar region of modern man a decrease occurs from T11 to L2 followed by a sharp increase to the last lumbar vertebra. The lumbar pedicle index values of Stw 431 show the same pattern as modern man. Sts 14 shows an increase in pedicle size up to L1, which is in accordance with the pedicle index values of the anthropoid apes, followed by a decrease from L1 to L2, as seen in Stw 431 and modern man, and a gradual increase to the last lumbar vertebra. In the anthropoid apes L1 presents larger pedicles than the last thoracic vertebra and, with the exception of Za 1312, the pedicle size increases to L2 in these columns. From here three columns show a decrease in pedicle size at the second last lumbar vertebra, L3. In the other two columns, one (Za 1312) shows this decrease at L2 while Za 94 does not present a decrease. In all the great ape columns, modern man and Stw 431, there is a sharp increase in the pedicle size of the last lumbar vertebra. Sts 14 is the only one of all the hominoid columns in which the pedicles of the last lumbar vertebra are not the largest.

4.2 Mean Pedicle Index/Inferior Body Area Ratio

From Figs. 9.33, 9.34 and 9.35 it seems as if this ratio decreases from T1 to T10 in the African and Asian great ape spinal columns, Za 1312 being the only exception. Modern human spinal columns (Fig. 9.27) also show a marked decrease in pedicle size in relation to the inferior body area in the upper thoracic region. The difference is that in modern man the ratio decreases from T1 to T5 or T6 and stays equal to T8

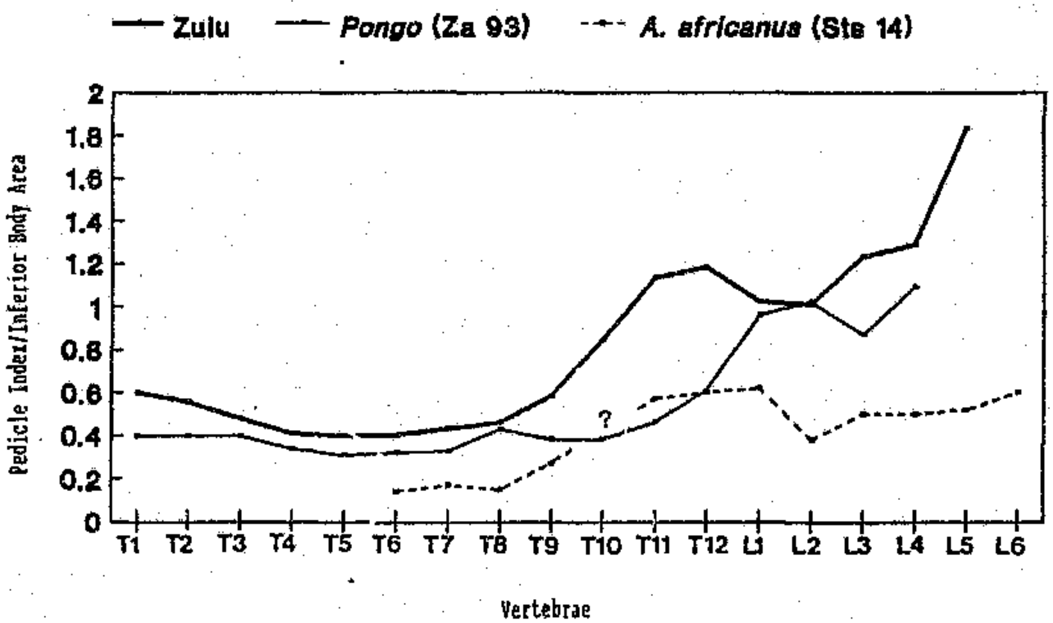

Fig. 9.39 The Pedicle Index Values of Modern Human (n=30), *Pongo* (n=1) and *A. africanus* (n=1) Female Thoracic and Lumbar Vertebrae

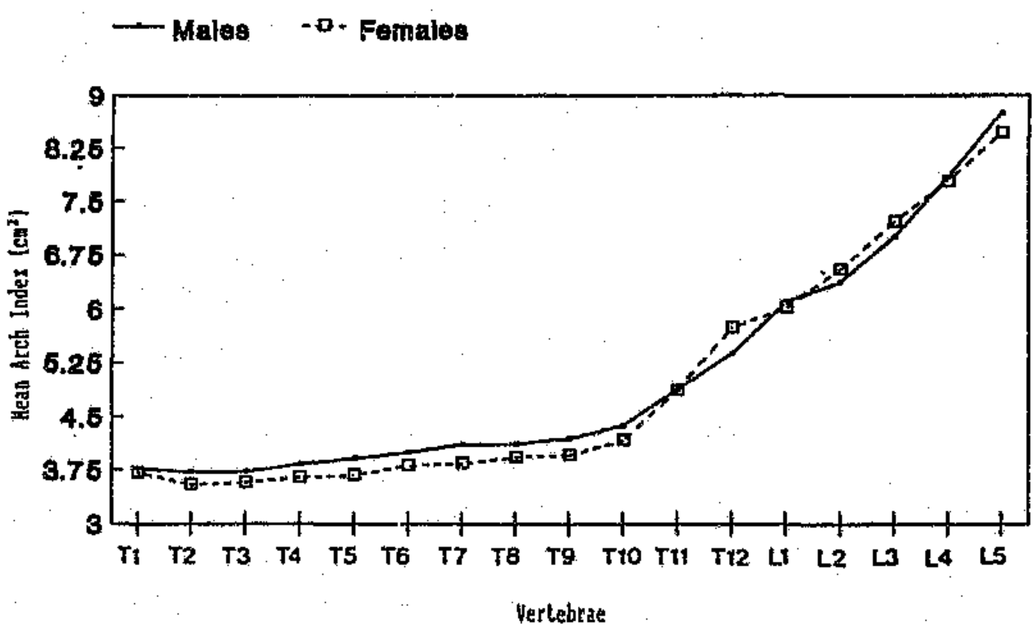

Fig. 9.40 The Mean Arch Index Values of Zulu Thoracic and Lumbar Vertebrae

or T9, whereas T10 presents the smallest pedicle size in relation to the inferior body area of the anthropoid ape thoracic vertebrae.

The decline in the upper thoracic region of modern man is followed by an increase in the ratio values to T1. The anthropoid apes also show an increase in these values from T10 to the last thoracic or first lumbar vertebra. Unfortunately the ratios of the second and the third last Sts 14 thoracic vertebrae are unknown, but the ratio for the last thoracic vertebra is considerably larger than the ratio for the fourth last thoracic vertebra (Fig. 9.37).

In the lumbar regions of the five anthropoid ape columns the ratio values show three patterns. One *Pan* column presents a decrease from T13 to L1, L2 and L3, which have equal values, followed by an increase at L4 (Fig. 9.34). In the other *Pan* and the *Pongo* (Fig. 9.35) columns the ratio values decrease from L1 to L3 followed by an increase at L4. One *Gorilla* column presents a decrease from L1 to L2 followed by an increase to L4 (Fig. 9.33). The inferior surfaces of the bodies area of the last two lumbar vertebrae of the remaining *Gorilla* column are damaged. In modern man a decrease occurs from T12 to L1 (Fig. 9.27). The ratio values of L1 to L4 are more or less equal followed by a sharp increase at L5. In Sts 14 this ratio decreases from the last thoracic vertebra to L2 and L3 followed by an increase in the last three lumbar vertebrae (Fig. 9.37). The ratio of the pedicles of L1 to the vertebral body are thus greater than or equal in size to those of the last thoracic vertebra in the anthropoid apes. In contrast a decrease in this ratio occurs from the last thoracic to the first lumbar vertebra in modern man and in Sts 14. All three groups present a sharp increase in the ratio of the last lumbar vertebra.

Thus, the pedicle size increases from the midthoracic vertebrae to T11 in modern man and to L2 in three of the five pongid spinal columns. Sts 14 presents an increase down to

L1. From T11 in modern man and L1 in Sts 14 and Stw 431, a decrease occurs to L2 followed by an increase to the last lumbar vertebra. In the three pongid spinal columns, with the same pattern, the increase down to L2 is followed by a decrease at L3 and an increase at L4.

D. The Arch Distance

1 Modern Human Series

1.1 Zulu Series

1.1.1 Arch Index (mfd x mdfb)

The arch index is the product of the maximum distance between the articular facets and the sagittal distance between these articular facets and the posterior aspect of the vertebral body, measured both superiorly and inferiorly. The mean of the superior and inferior indicial values is then calculated to give the mean arch index for each vertebra. This mean arch index indicates approximately the position of the articular facets in relation to the body.

The mean arch index values of both the Zulu males and females decline a little over the cranial two or three thoracic vertebrae and then increase gradually to T10. From this level downwards the increase is more rapid to the level of L5. The articular facets and the laminae are thus placed furthest away from the vertebral body in the last lumbar vertebra (Table 9.26, Fig. 9.40).

TABLE 9.26

The Mean Arch Index Values of Zulu Thoracic and Lumbar Vertebrae (cm²)

Vertebrae	Males			Females		
	Mean	±SD	Observed Range	Mean	±SD	Observed Range
T1	3,77	0,52	2,91 - 4,85	3,71	0,52	2,89 - 4,95
T2	3,72	0,49	2,84 - 4,89	3,55	0,44	2,89 - 4,66
T3	3,72	0,47	2,95 - 5,16	3,57	0,44	2,76 - 4,41
T4	3,83	0,45	2,96 - 5,09	3,64	0,49	2,75 - 5,04
T5	3,91	0,44	3,250 - 5,35	3,68	0,40	2,94 - 4,57
T6	3,99	0,47	3,15 - 5,57	3,80	0,48	2,74 - 4,79
T7	4,11	0,49	3,33 - 5,81	3,84	0,43	2,95 - 4,75
T8	4,11	0.42	3,22 - 5,59	3,92	0,47	2,97 - 4,97
T9	4,19	0,47	3,49 - 5,59	3,95	0,51	3,21 - 4,87
T10	4,37	0,58	3,23 - 5,64	4,16	0,51	2,90 - 5,23
T11	4,87	0,86	3,62 - 7,28	4,86	0,83	3,51 - 7,06
T12	5,39	0,84	3,80 - 7,00	5,74	1,01	4,10 - 8,99
L1	6,10	0,71	4,54 - 7,14	6,01	0,76	4,25 - 7,53
L2	6,40	0,74	5,04 - 8,67	6,54	0,69	4,99 - 7,72
L3	7,00	1,12	5,56 - 9,59	7,21	0,93	6,[illegible] - 9,97
L4	7,83	1,26	5,79 - 10,03	7,77	0,94	6,31 - 9,698
L5	8,74	1,44	6,73 - 13,09	8,46	1,10	6,28 - 11,21

Sex differences: No significant differences in the mean arch index values are found between male and female Zulu thoracic and lumbar vertebrae.

1.1.2 Arch Index/Inferior Body Area Ratio

The distance of the articular facets and the laminae as indicated by the mean arch index decreases gradually from T1 to T10 in relation to inferior body area in both Zulu males and females (Table 9.27, Fig. 9.41). From this level the ratio stays almost the same to L3 in the male and L4 in the female columns. (The female columns present an increase of 0,07 at T12.) At L5 an increase of this ratio occurs in both sexes which indicates an increase in the distance of the posterior arch from the vertebral body.

TABLE 9.27

The Mean Arch Index/Inferior Body Area Ratio Values of Zulu Thoracic and Lumbar Vertebrae

Vertebrae	Males	Females
T1	0,90	1,00
T2	0,87	0,93
T3	0,81	0,87
T4	0,75	0,85
T5	0,72	0,80
T6	0,68	0,74
T7	0,60	0,69
T8	0,56	0,65
T9	0,53	0,59
T10	0,50	0,57
T11	0,50	0,59
T12	0,52	0,66
L1	0,52	0,61
L2	0,51	0,63
L3	0,51	0,63
L4	0,55	0,63
L5	0,68	0,74

Sex differences: An interesting feature of this ratio is that the distance of the articular facets and laminae from the vertebral body is greater in the female columns than in the male columns, when expressed in relation to the inferior body area. The mean arch index values show no significant difference between the sexes. The inferior body area values of the Zulu female thoracic and lumbar vertebrae are significantly smaller than those of the corresponding male vertebrae. The larger arch index/inferior body area ratio values in the female spinal columns thus depend upon the smaller values of the denominator.

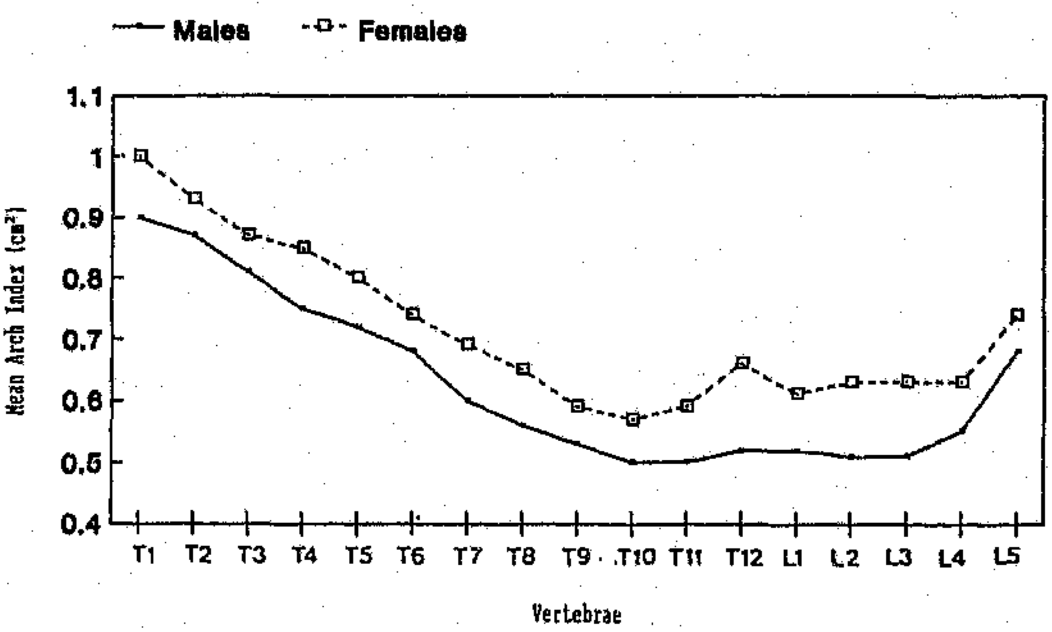

Fig. 9.41 The Arch Index/Inferior Body Area Ratio Values of Zulu Thoracic and Lumbar Vertebrae

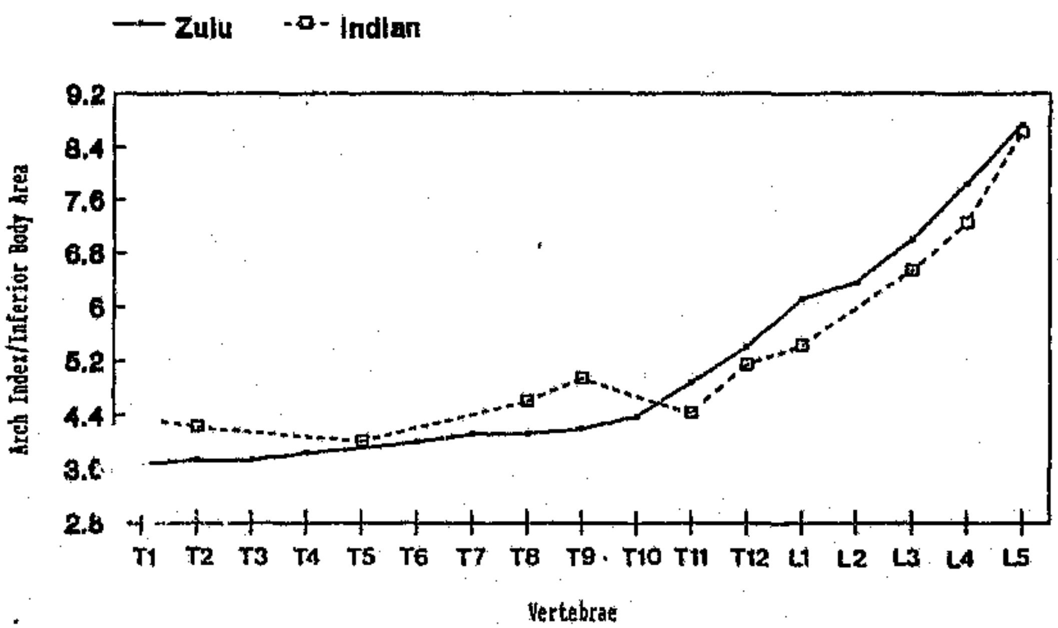

Fig. 9.42 The Mean Arch Index Values of Modern Human Male Thoracic and Lumbar Vertebrae

1.2 Comparative Series

1.2.1 Arch Index (mfd x mdfb)

A comparison of the mean arch index values of Zulu males (present study) and Indian males (Pal and Routal, 1987) reveals highly significant differences (P>0,005) at the T1, T2, T8, T9 and L1 levels. The articular facets of T11 are almost certainly significantly (P>0,01) further from the vertebral body in Zulu than in Indian males (Table 9.28, Fig. 9.42). The difference in mean arch index values between these males is probably significant (P>0,025) at the L4 level. The articular facets of the Indian thoracic vertebrae are situated more posteriorly or further from the vertebral body, than those of Zulu male vertebrae. The opposite is found in the lumbar region.

TABLE 9.28

The Mean Arch Index Values of Zulu and Indian Male Thoracic and Lumbar Vertebrae (cm^2)

Vertebrae	Zulu males Present study n = 30 Mean ± SD	Indian males Pal and Routal (1986, 1987) n = 44 Mean ± SD
T1	3,68 ± 0,52	4,35 ± 0,60
T2	3,72 ± 0,49	4,21 ± 0,93
T3	3,72 ± 0,47	
T4	3,83 ± 0,45	
T5	3,91 ± 0,44	4,00 ± 0,67
T6	3,99 ± 0,47	
T7	4,11 ± 0,49	
T8	4,11 ± 0,42	4,60 ± 1,01
T9	4,19 ± 0,47	4,94 ± 0,47
T10	4,37 ± 0,58	
T11	4,87 ± 0,86	4,43 ± 0,50
T12	5,39 ± 0,85	5,14 ± 0,89
L1	6,10 ± 0,71	5,42 ± 0,09
L2	6,35 ± 0,74	
L3	7,00 ± 1,12	6,52 ± 1,05
L4	7,83 ± 1,26	7,25 ± 1,00
L5	8,74 ± 1,43	8,61 ± 0,57

1.2.2 Arch Index/Inferior Body Area Ratio

The values for this ratio form the same pattern in Zulu and Indian males (Table 9.29, Fig. 9.43). The values for the Indian male vertebrae are greater than those for the Zulu male columns between T1 and T11. The posterior arch of the Zulu male T12 vertebra and of the lumbar vertebrae are placed further away from the body than those of the Indian males in relation to the inferior body area.

TABLE 9.29

The Mean Arch Index/Inferior Body Area Ratio Values of Zulu and Indian Male Thoracic and Lumbar Vertebrae

Vertebrae	Zulu males Present study n = 30	Indian males Pal & Routal (1986, 1987) n = 44
T1	0,90	1,02
T2	0,87	0,88
T3	0,81	
T4	0,75	
T5	0,72	0,74
T6	0,68	
T7	0,60	
T8	0,56	0,63
T9	0,53	0,62
T10	0,50	
T11	0,50	0,50
T12	0,52	0,50
L1	0,52	0,47
L2	0,51	
L3	0,51	0,47
L4	0,55	0,51
L5	0,68	0,61

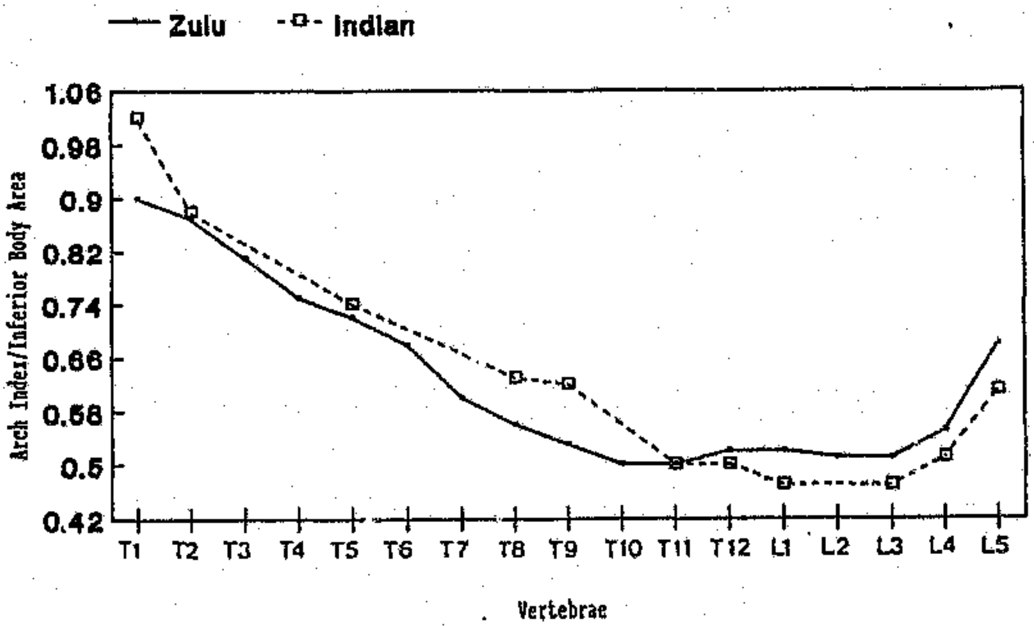

Fig. 9.43 The Mean Arch Index/Inferior Body Area Ratio Values of Modern Human Male Thoracic and Lumbar Vertebrae

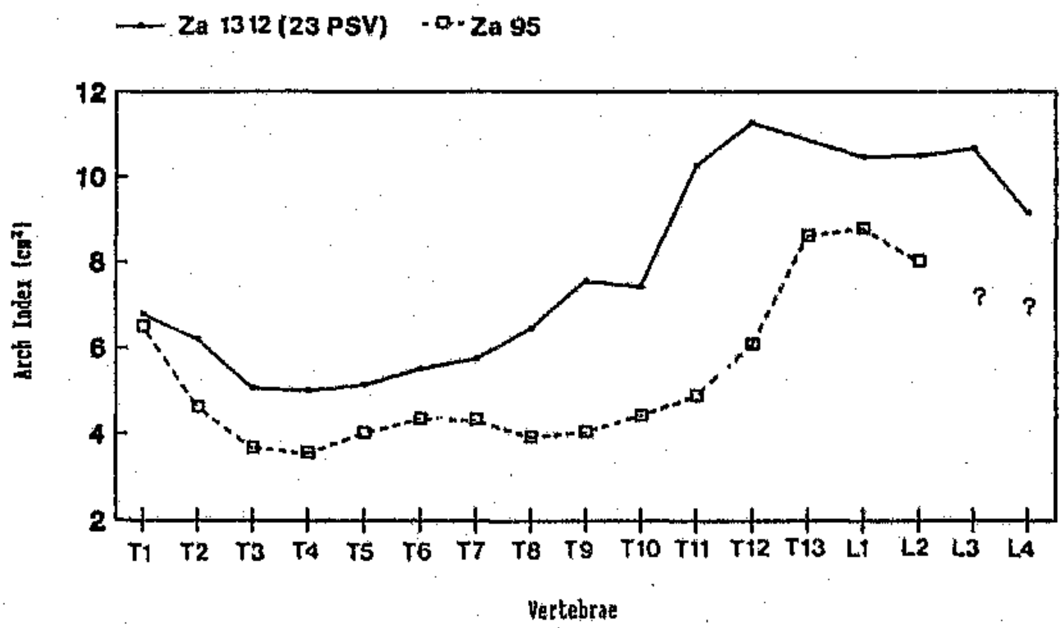

Fig. 9.44 The Arch Index Values in Two Sets of *Gorilla* Male Thoracic and Lumbar Vertebrae

2. African and Asian Great Ape Series

2.1 Present Study

2.1.1 Arch Index (mfd x mdfb)

The arch index values which indicate the distance between the vertebral body and the articular facets and laminae, decrease from T1 to T4 in the *Gorilla* male columns (Table 9.30, Fig. 9.44). This decrease is followed by a moderate increase to T9 and a sharp increase from T10 to T12 in Za 1312. In Za 95 the values increase from T4 to T6, decrease slightly to T8 and increase sharply to T13. The lumbar region of Za 1312 shows a decrease in the index values from T12 to L1 followed by a slight increase to L3 and a marked decrease of 1,5cm² at L4.

TABLE 9.30

The Arch Index Values in Individual Sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae in (cm²)

Vertebrae	*Gorilla* Za 1312 Male	*Gorilla* Za 95 Male	*Pan* Za 1071 Male	*Pan* Za 94 Male	*Pongo* Za 93 Female
T1	6,77	6,48	3,29	2,19	2,60
T2	6,20	4,62	3,32	1,86	2,60
T3	5,06	3,67	3,34	1,65	2,78
T4	5,01	3,55	3,25	1,69	2,42
T5	5,15	4,01	3,18	1,69	2,43
T6	5,51	4,35	3,28	1,76	2,34
T7	5,75	4,33	2,79	1,81	2,14
T8	6,45	3,92	2,61	1,84	2,13
T9	7,54	4,04	2,65	2,06	1,97
T10	7,42	4,42	2,80	2,05	2,14
T11	10,24	4,88	2,63	2,02	2,62
T12	11,26	6,08	3,08	2,47	2,89
T13		8,59	4,99	3,23	
L1	10,45	8,77	5,65	4,23	3,18
L2	10,47	8,00	5,23	4,23	3,21
L3	10,66	*	4,23	3,68	3,31
L4	9,14	*	3,32	2,84	2,78

* Posterior surface of vertebral body damaged

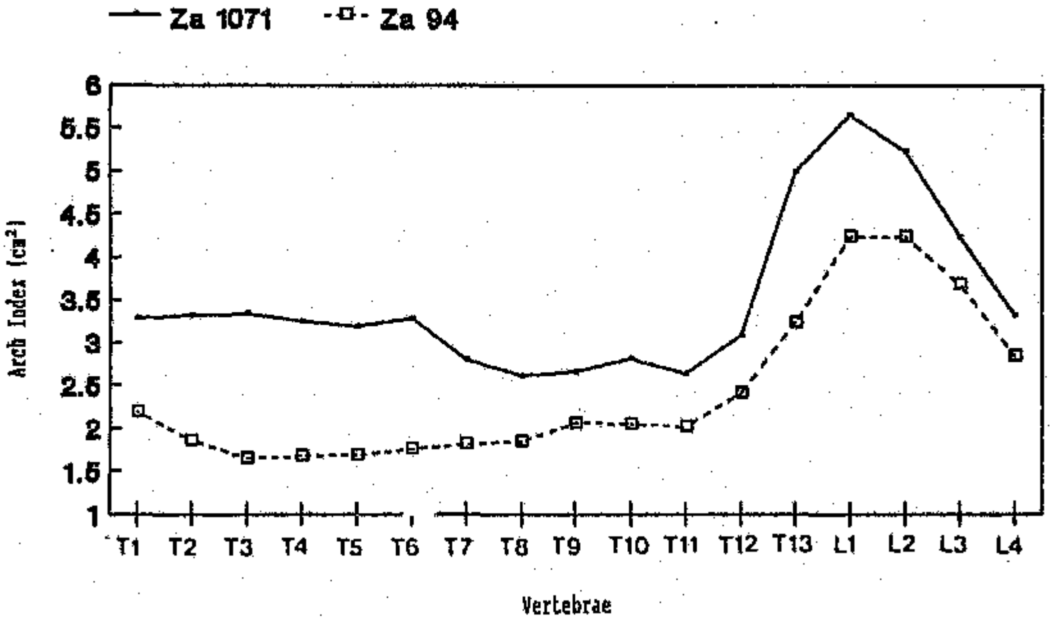

Fig. 9.45 The Arch Index Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

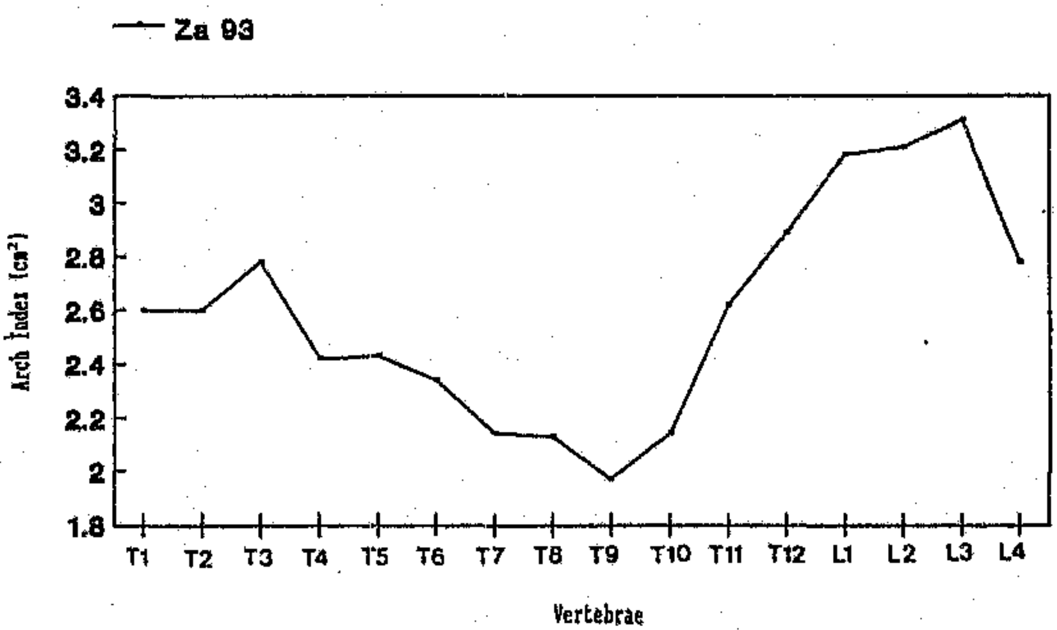

Fig. 9.46 The Arch Index Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

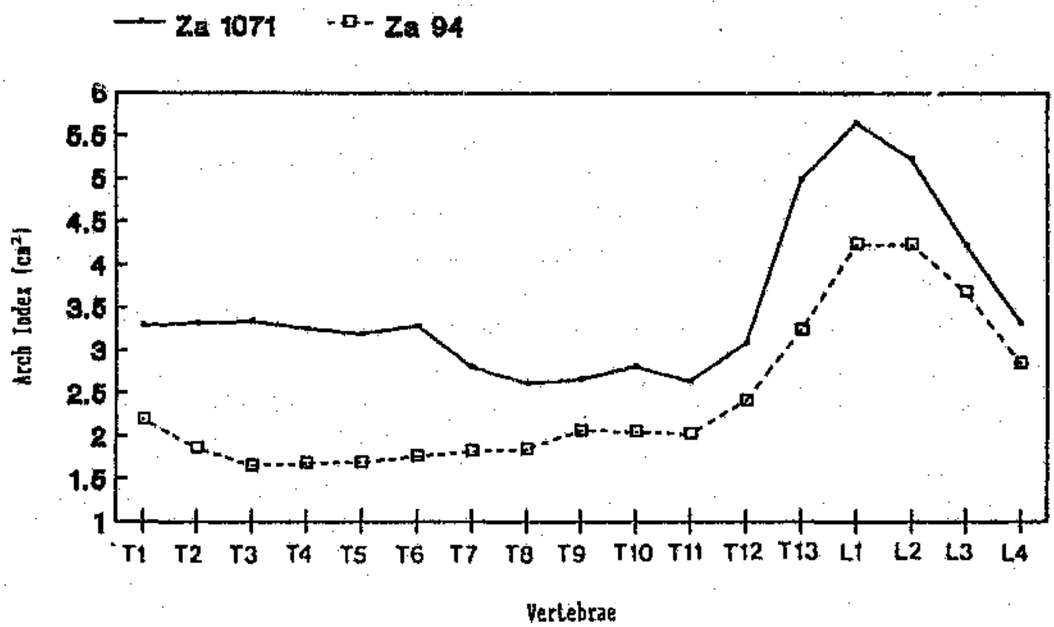

Fig. 9.45 The Arch Index Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

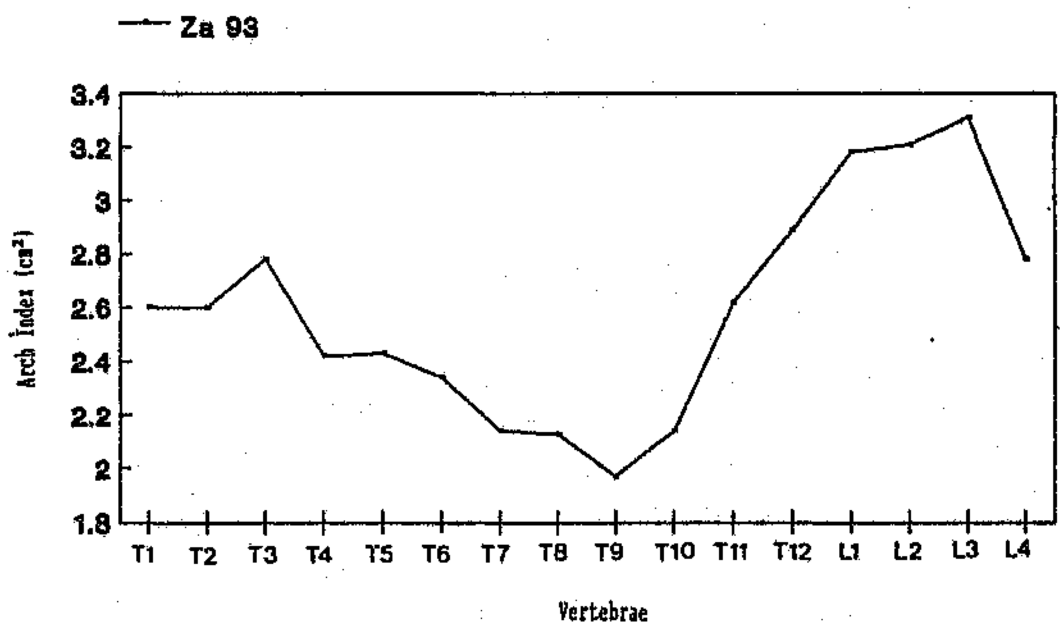

Fig. 9.46 The Arch Index Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

The two *Pan* vertebral columns do not show the same distinct decrease followed by a definite increase in the index values of the thoracic region (Table 9.30, Fig. 9.45). Instead, the articular facets and laminae of the first eleven thoracic vertebrae are placed at an almost equal distance from the vertebral bodies. Both spinal columns present a sharp increase in this index from T11 to L1 in which the articular facets and laminae are placed furthest from the body. From L1 in Za 1071 and L2 in Za 94, the distance between the vertebral body and the articular facets and laminae decreases to L4.

The arch index values of the *Pongo* thoracic and lumbar vertebrae present the same basic pattern as those of the *Pan* vertebrae. Scarcely any change occurs before T10. From this level the index values increase to L3 followed by a slight decrease at L4 (Table 9.30, Fig. 9.46).

2.1.2 Arch Index/Inferior Body Area Ratio

This ratio decreases sharply in the first three *Gorilla* male thoracic vertebrae (Table 9.31, Fig. 9.47). From this level a gradual decrease occurs to T10. Za 1312 presents an increase to T11 followed by a gradual decrease to L3. The ratio of L4 in this column indicates a greater distance between the vertebral body and the articular facets and laminae in relation to the inferior body area. Za 95 presents an increase from T10 to L1 followed by a decrease to L2. Unfortunately the ratios of the last two lumbar vertebrae are unknown, but the pattern presented by Za 95 is in accordance with the pattern which is presented by the *Pan* male columns (Table 9.31, Fig. 9.48). These spinal columns show a decrease in this ratio to the level of T12. The decrease is followed by an increase to L1 and a decrease to L4.

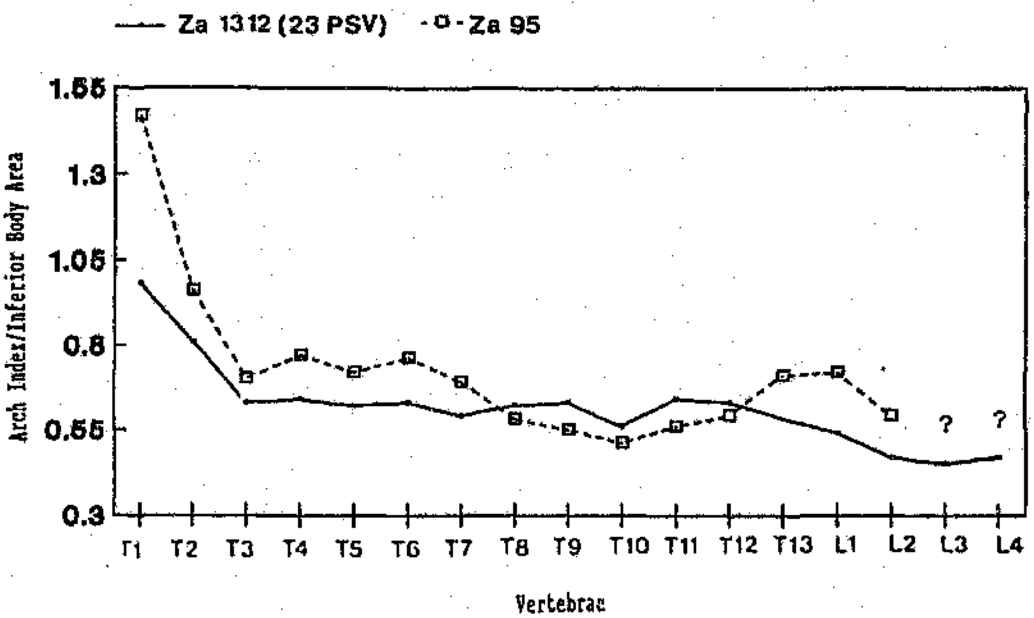

Fig. 9.47 The Arch Index/Inferior Body Area Ratio Values in Two Sets of *Gorilla* Male Thoracic and Lumbar Vertebrae

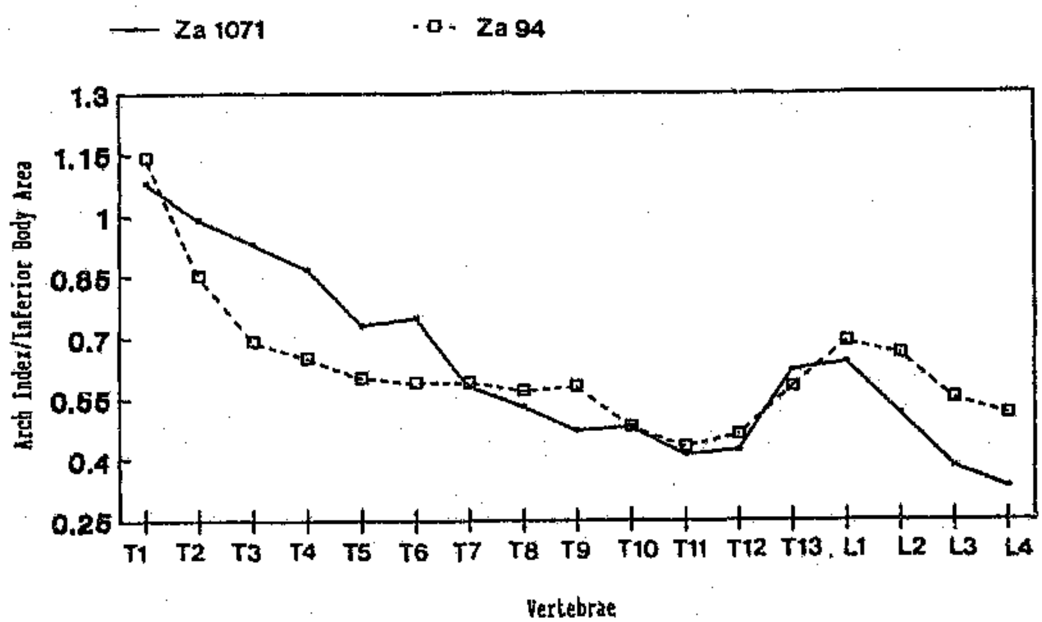

Fig. 9.48 The Arch Index/Inferior Body Area Ratio Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

With the exception of an increased ratio at T3, the *Pongo* female vertebral column also shows a decrease to T9 followed by a mild increase to L1 (Fig. 9.49). This increase in the distance in relation to the inferior body area is however not as sharp as in the African great ape spinal columns. In the lumbar region the ratio decreases from L1 to L2, increases to L3 and decreases to L4. In the *Pan* and *Pongo* lumbar regions the distance between the vertebral body and the articular facets and laminae, in relation to the inferior body area, is thus smallest in the last lumbar vertebra.

TABLE 9.31

The Arch Index/Inferior Body Area Ratio Values in Individual Sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae

Vertebrae	*Gorilla*		*Pan*		*Pongo*
	Za 1312 Male	Za 95 Male	Za 1071 Male	Za 94 Male	Za 93 Female
T1	0,98	1,47	1,08	1,14	0,87
T2	0,81	0,96	0,99	0,85	0,75
T3	0,63	0,70	0,93	0,69	0,79
T4	0,64	0,77	0,87	0,65	0,64
T5	0,62	0,72	0,73	0,60	0,59
T6	0,63	0,76	0,75	0,59	0,52
T7	0,59	0,69	0,58	0,59	0,45
T8	0,62	0,58	0,53	0,57	0,41
T9	0,63	0,55	0,47	0,58	0,36
T10	0,56	0,51	0,48	0,48	0,37
T11	0,64	0,56	0,41	0,43	0,42
T12	0,63	0,59	0,42	0,46	0,41
T13	-	0,71	0,62	0,58	-
L1	0,54	0,72	0,64	0,69	0,43
L2	0,47	0,59	0,51	0,66	0,37
L3	0,45	*	0,38	0,55	0,41
L4	0,47	*	0,33	0,51	0,37

* Inferior vertebral body area unknown

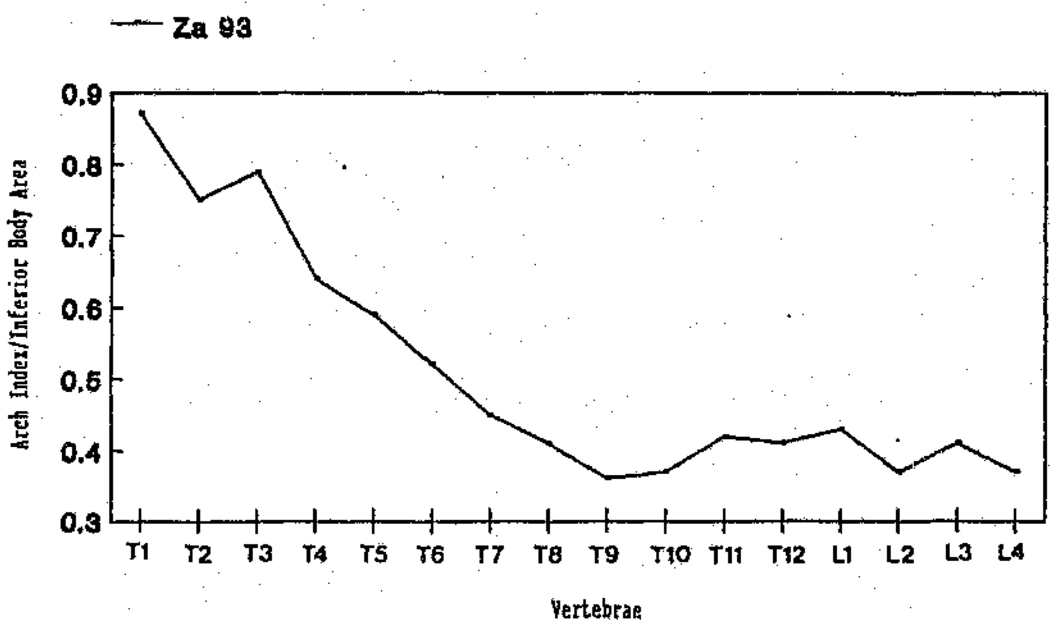

Fig. 9.49 The Arch Index/Inferior Body Area Ratio Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

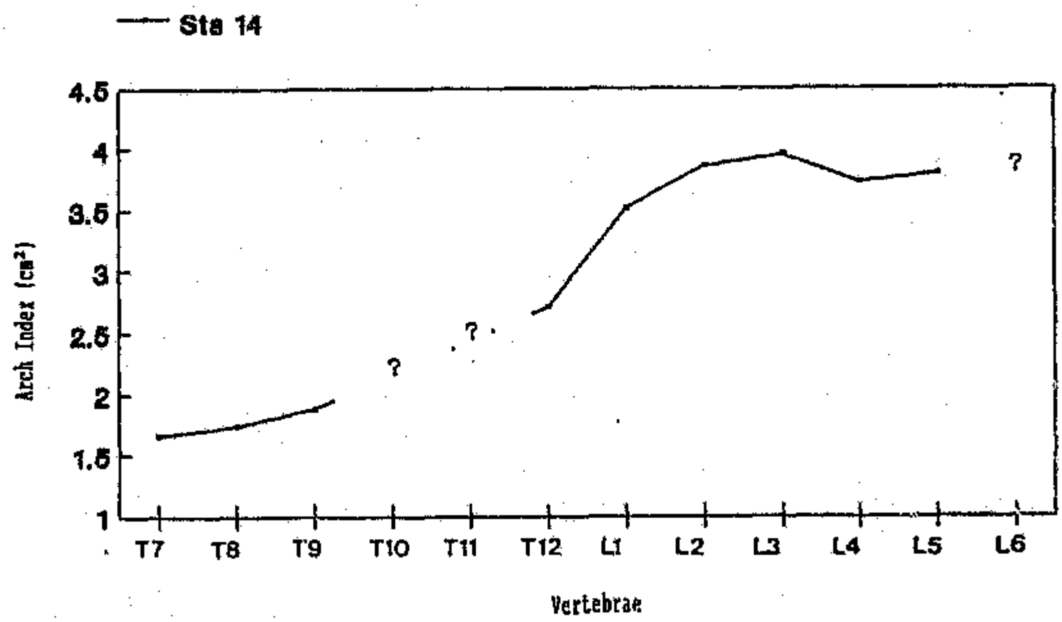

Fig. 9.50 The Arch Index Values in a Single Set of *A. africanus* Female Thoracic and Lumbar Vertebrae

3. Australopithecine Series

3.1 Present Study

3.1.1 Arch Index (mfd x mdfb)

The inferior articular facets of all six Sts 14 lumbar vertebrae have suffered damage to some extent, but the missing parts have been reconstructed. In the superior five lumbar vertebrae the mean arch index is calculated from the superior arch index and the inferior arch index, which also is calculated from the reconstructed parts. The mean arch index value of the last lumbar vertebra has not been calculated, for the inferior articular facets are broken away and the reconstruction is thus not a mere filling of a missing piece but a total restoration. Table 9.32 and Fig. 9.50 show an increase in the index values from the last thoracic vertebra to L3, a decrease to L4 and a slight increase to L5, the second last lumbar vertebra.

TABLE 9.32

The Arch Index Values in Individual Sets of *A. africanus* Thoracic and Lumbar Vertebrae (cm^2)

Vertebrae	Sts 14 Female	Stw 431 Male
Thoracic:		
6th last	1,66	
5th last	1,74	
4th last	1,88	
3rd last	-	
2nd last	-	
last	2,71	
Lumbar:		
L1	3,51	
L2	3,86	4,83
L3	3,95	
L4	3,72	
L5	3,79	
L6	-	

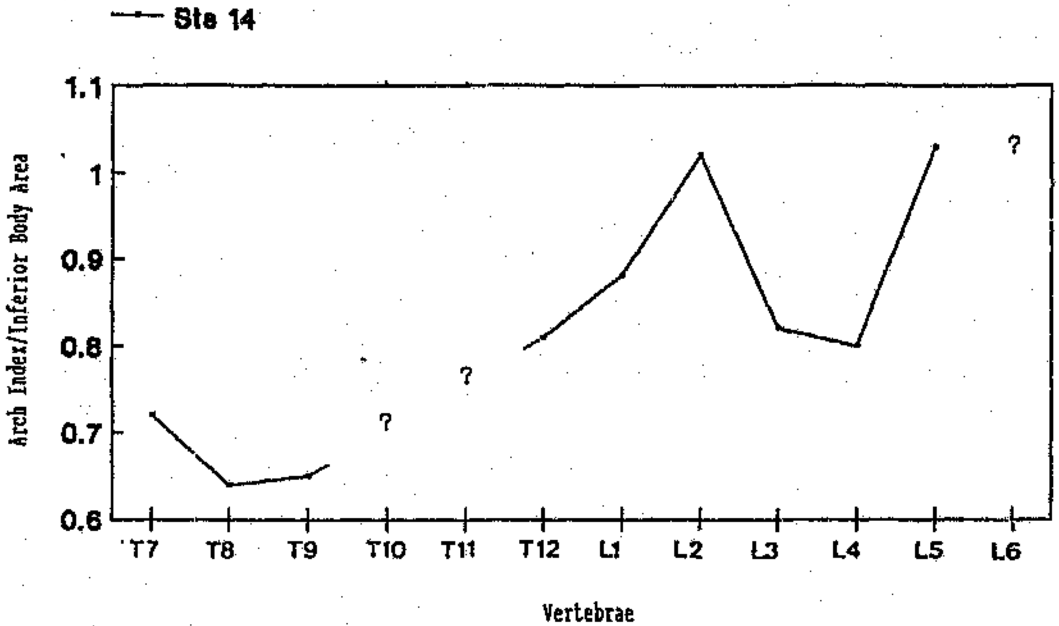

Fig. 9.51 The Arch Index/Inferior Body Area Ratio Values in a Single Set of *A. africanus* Female Thoracic and Lumbar Vertebrae

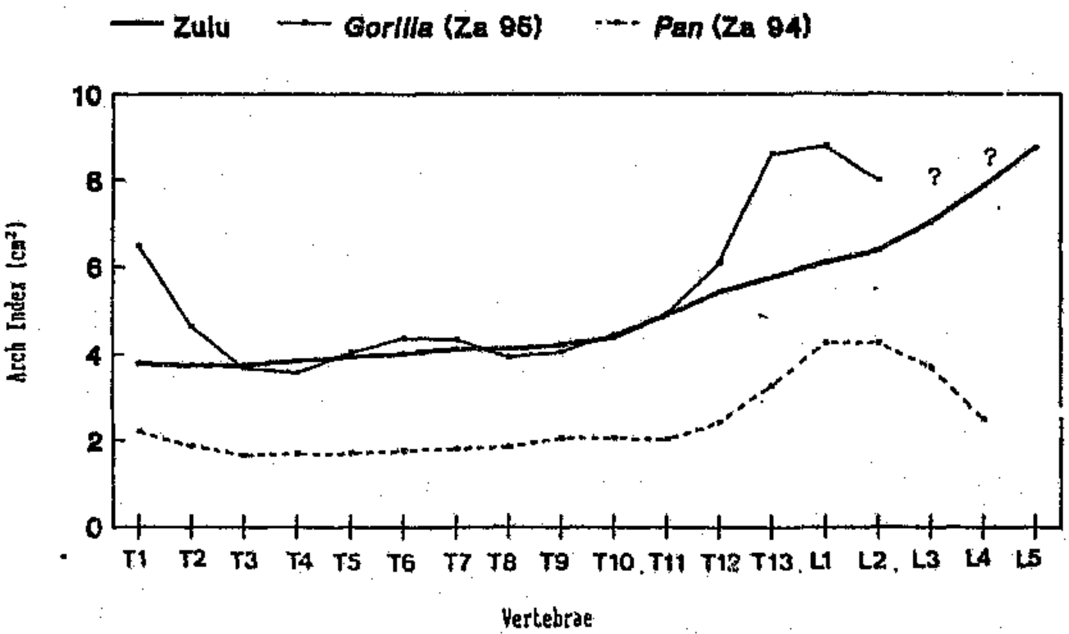

Fig. 9.52 The Arch Index Values of Modern Human (n=30), *Gorilla* (n=1) and *Pan* (n=1) Male Thoracic and Lumbar Vertebrae

3.1.2 Arch Index/Inferior Body Area

This ratio, which indicates the distance between the vertebral body and the articular facets and laminae, in relation to the inferior body area, increases in Sts 14 from the last thoracic vertebra to L2 (Table 9.33, Fig. 9.51). From L2 a decrease occurs to L4. An increase in the ratio then occurs from L4 to L5 and, though the ratio for L6 is unknown, the ratio value which is based on the diameters of the reconstructed parts suggests a further increase at this level.

TABLE 9.33

The Arch Index/Inferior Body Area Ratio Values of Sts 14 Thoracic and Lumbar Vertebrae

Vertebrae	Sts 14
Thoracic:	
6th last	0,72
5th last	0,64
4th last	0,65
3rd last	-
2nd last	-
Last	0,81
Lumbar:	
L1	0,88
L2	1,02
L3	0,82
L4	0,80
L5	1,03
L6	-

4. Intergroup Comparisons

4.1 Arch Index (mfd x mdfb)

The mean arch index values of the upper eleven thoracic vertebrae show little change in modern man, the *Pan* and the *Pongo* vertebral columns (Figs. 9.52, 9.53). The two *Gorilla*

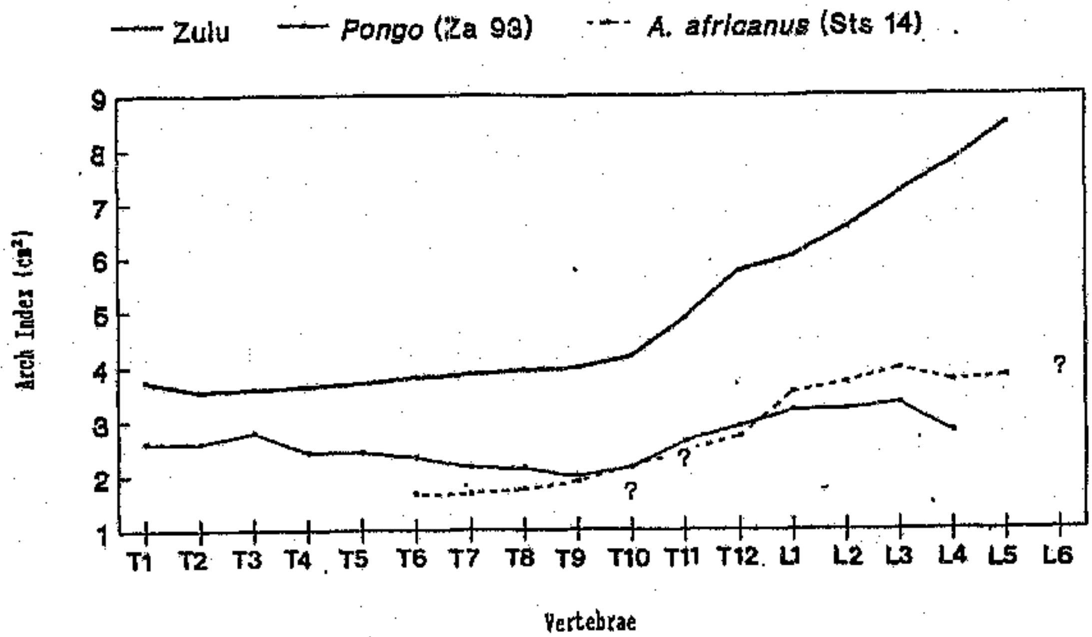

Fig. 9.53 The Arch Index Values of Modern Human (n=30), *Pongo* (n=1) and *A. africanus* (n=1) Female Thoracic and Lumbar Vertebrae

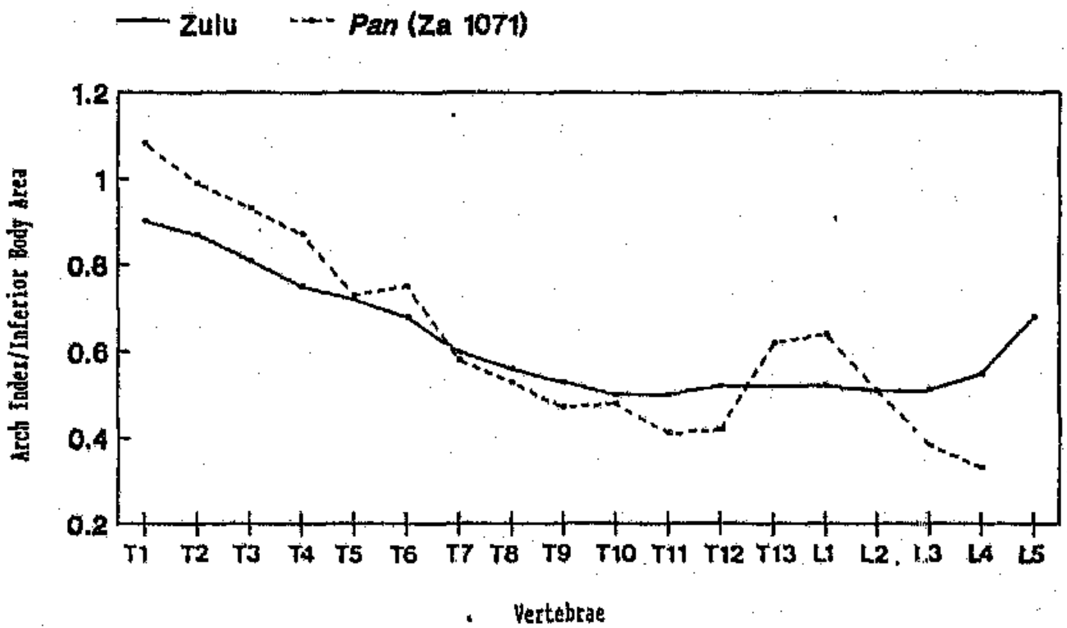

Fig. 9.54 The Arch Index/Inferior Body Area Ratio Values of Modern Human (n=30) and *Pan* (n=1) Male Thoracic and Lumbar Vertebrae

columns present a decrease from T1 to T4. The African apes then show a sharp increase in index values from T11 to T13 or L1, which is followed by a decrease to the last lumbar vertebra. The *Pongo* female spinal column shows the same tendency, though less prominently, (Fig. 9.53). The modern human columns show a gradual increase in index values from T2 to T10, followed by a sharper increase through to L5. Sts 14 index values increase from the last thoracic vertebra to L3, followed by a decrease to L4 and a slight increase to L5. This pattern seems to be the same as those of the anthropoid apes to the level of L4. The slight increase at L5 is more in line with the modern human pattern. Unfortunately the index value of L6 is unknown but the reconstructed part, which is made with the articular facets of the sacral piece as guidelines, suggests an increased index value of this level.

4.2 Arch Index/Inferior Body Area Ratio

The difference in the arch index/inferior body area values between modern human and the pongid spines is best illustrated in Fig. 9.54. The ratio values of Zulu and *Pan* (Za 1071) male vertebrae present a decrease from T1 to the second last thoracic vertebra. The difference between the two groups lies in the definite increase in this ratio in the last thoracic and first lumbar vertebrae of pongids, followed by a decrease from L1 to L4, whereas modern man shows a plateau from the last thoracic to the third lumbar vertebrae followed by a striking increase from L3 to L5.

Sts 14 (Fig. 9.55) shows a sharp increase in this ratio from the last thoracic vertebra to L2, followed by an even sharper decrease to L3 and L4, in which the ratio is equal. From L4 this ratio increases again to L5 and, though the ratio for L6 of Sts 14 is unknown, the ratio value which includes the diameters of the reconstructed parts suggests a further increase at this level. The pattern presented by the ratio values of the last thoracic and the upper four lumbar verte-

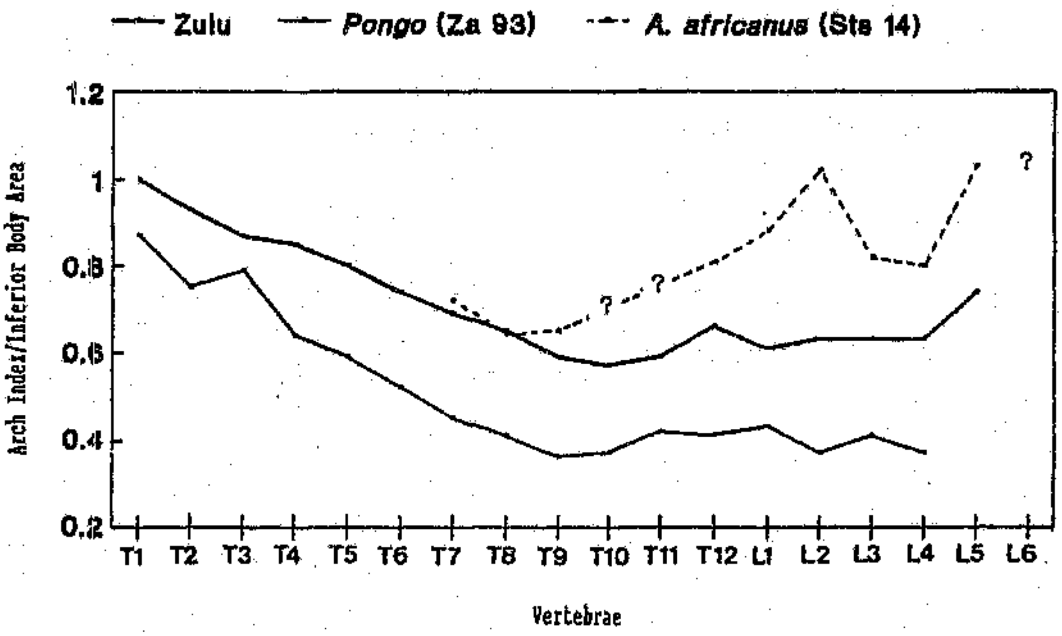

Fig. 9.55 The Arch Index/Inferior Body Area Ratio Values of Modern Human (n=30), *Pongo* (n=1) and *A. africanus* (n=1) Thoracic and Lumbar Vertebrae

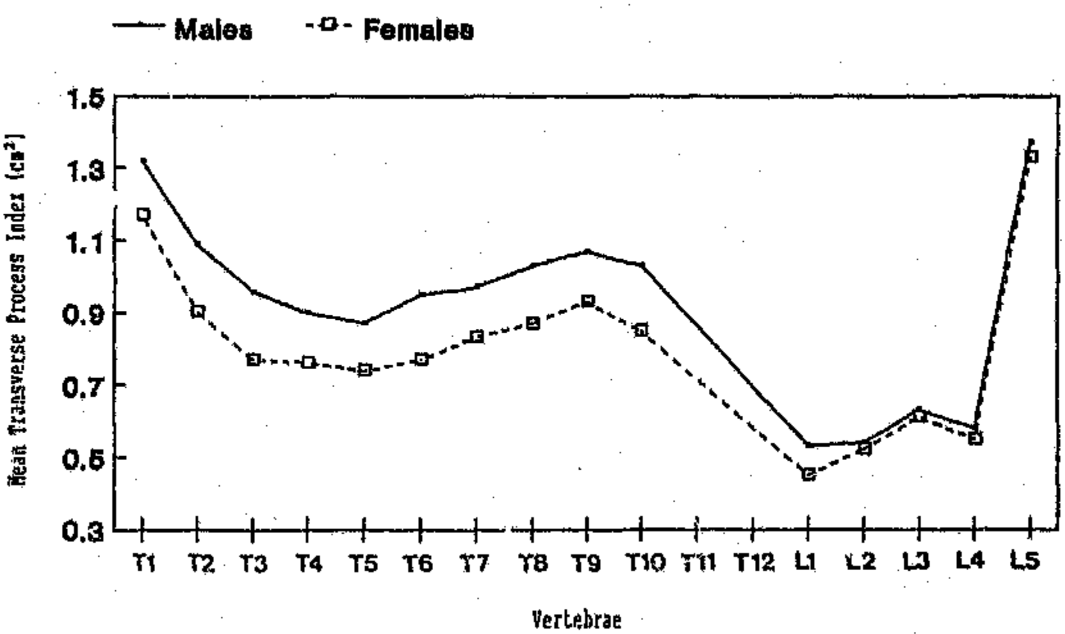

Fig. 9.56 The Mean Transverse Process Index Values of Zulu Thoracic and Lumbar Vertebrae

brae of Sts 14 is thus in accordance with the pattern presented by the anthropoid ape vertebrae. The increase in the ratio values in the last two lumbar vertebrae is, on the other hand, a modern human-like characteristic.

E. The Transverse Process Size

1. Modern Human Series

1.1 Zulu Series

This series lacks the index values of T11 and T12 since the morphology of these transverse processes differs from that of the rest of the thoracic region. The greatest and least transverse process diameters of T11 and T12 do not reflect the size of these processes in the same manner as in the rest of the thoracic region and they are thus excluded from this part of the study.

1.1.1 Transverse Process Index (gtp x ltp)

The mean transverse process index value is determined as an indicator of the mean transverse process size of both sides. In the Zulu male spinal columns a decrease in the index values occurs from T1 to T5 followed by a gradual increase to T9. From this level a decrease occurs to T10 (Table 9.34, Fig. 9.56).

The transverse processes of the upper four lumbar vertebrae are much smaller than the thoracic transverse processes. From L1 the size increases to L3, decreases slightly to L4, followed by a very sharp increase at L5. Thus, the transverse processes of L5 are the largest in the Zulu male vertebral columns. The Zulu female columns present smaller transverse processes than the male columns, but the pattern of variation in the regions corresponds.

TABLE 9.34

The Mean Transverse Process Index Values of Zulu Thoracic and Lumbar Vertebrae (cm^3)

Vertebra	Zulu Males (n = 30)			Zulu Females (N = 30)		
	Mean	±SD	Range	Mean	±SD	Range
T1	1,32	0,23	0,84 - 1,72	1,17	0,16	0,86 - 1,58
T2	1,09	0,24	0,76 - 1,69	0,90	0,17	0,55 - 1,24
T3	0,96	0,19	0,70 - 1,41	0,77	0,10	0,53 - 0,99
T4	0,90	0,16	0,62 - 1,29	0,76	0,11	0,57 - 0,97
T5	0,87	0,14	0,62 - 1,14	0,74	0,11	0,50 - 0,99
T6	0,95	0,15	0,67 - 1,33	0,77	0,13	0,54 - 1,03
T7	0,97	0,15	0,73 - 1,34	0,83	0,11	0,56 - 1,02
T8	1,03	0,17	0,73 - 1,34	0,87	0,13	0,62 - 1,12
T9	1,07	0,18	0,81 - 1,66	0,93	0,13	0,66 - 1,16
T10	1,03	0,20	0,65 - 1,49	0,85	0,17	0,58 - 1,21
T11	-	-	-	-	-	-
T12	-	-	-	-	-	-
L1	0,53	0,18	0,22 - 1,26	0,45	0,11	0,26 - 0,77
L2	0,54	0,13	0,27 - 0,78	0,52	0,11	0,29 - 0,71
L3	0,63	0,15	0,32 - 0,94	0,61	0,12	0,33 - 0,89
L4	0,58	0,15	0,33 - 0,89	0,55	0,17	0,35 - 1,02
L5	1,37	0,33	0,79 - 1,93	1,33	0,30	0,73 - 1,81

Sex differences: The thoracic transverse processes are highly significantly larger (P<0,005) in the Zulu male than female columns (Table 9.35). In the lumbar region the transverse processes of L1 are almost certainly significantly larger (P<0,05) in the male columns, whereas the transverse process index values of the last four lumbar vertebrae show no significant differences between the sexes.

TABLE 9.35

t-Values of Sex Differences in the Transverse Process Index Values of Zulu Thoracic and Lumbar Vertebrae

Vertebra	t-Value	P<
T1	2,903	0,005
T2	3,491	0,0005
T3	4,976	0,0005
T4	4,073	0,0005
T5	3,938	0,0005
T6	5,023	0,0005
T7	3,979	0,0005
T8	3,900	0,0005
T9	3,404	0,0005
T10	5,655	0,0005
T11	-	-
T12	-	-
L1	1,920	0,05
L2	0,634	0,30
L3	0,801	0,25
L4	0,823	0,25
L5	0,462	0,30

1.1.2 Transverse Process Index/Inferior Body Area Ratio

In relation to the inferior body area, the size of the transverse processes decreases from T1 to T10 in both male and female Zulu vertebral columns (Table 9.36, Fig. 9.57). The ratios of the first four lumbar vertebrae, which are almost equal to one another are less than those of the thoracic region while an increase occurs at the L5 level.

TABLE 9.36

The Mean Transverse Process Index/Inferior Body Area Ratio Values in Zulu Thoracic and Lumbar Vertebrae

Vertebra	Males	Females
T1	0,31	0,32
T2	0,25	0,24
T3	0,21	0,19
T4	0,17	0,18
T5	0,16	0,16
T6	0,16	0,15
T7	0,14	0,15
T8	0,14	0,15
T9	0,14	0,14
T10	0,12	0,12
T11	-	-
T12	-	-
L1	0,04	0,05
L2	0,04	0,05
L3	0,05	0,05
L4	0,04	0,04
L5	0,11	0,12

1.2 Comparative Series

1.2.1 Transverse Process Index (gtp x ltp)

Davis (1961) reports the mean transverse process index of the last three lumbar vertebrae in male and female West African columns. A comparison between these data and the results of the present study on Zulus (Table 9.37) shows the same pattern of a decrease to L4 and an increase to L5 in both groups. The transverse processes of L3 and L4 Zulu male vertebrae are highly significantly greater (P<0,0005) than those of the West African males, while no significant difference is found between the last lumbar vertebrae of these groups. The transverse processes of the last three Zulu female lumbar vertebrae are highly significantly greater (P<0,005) than those of the West African female vertebrae.

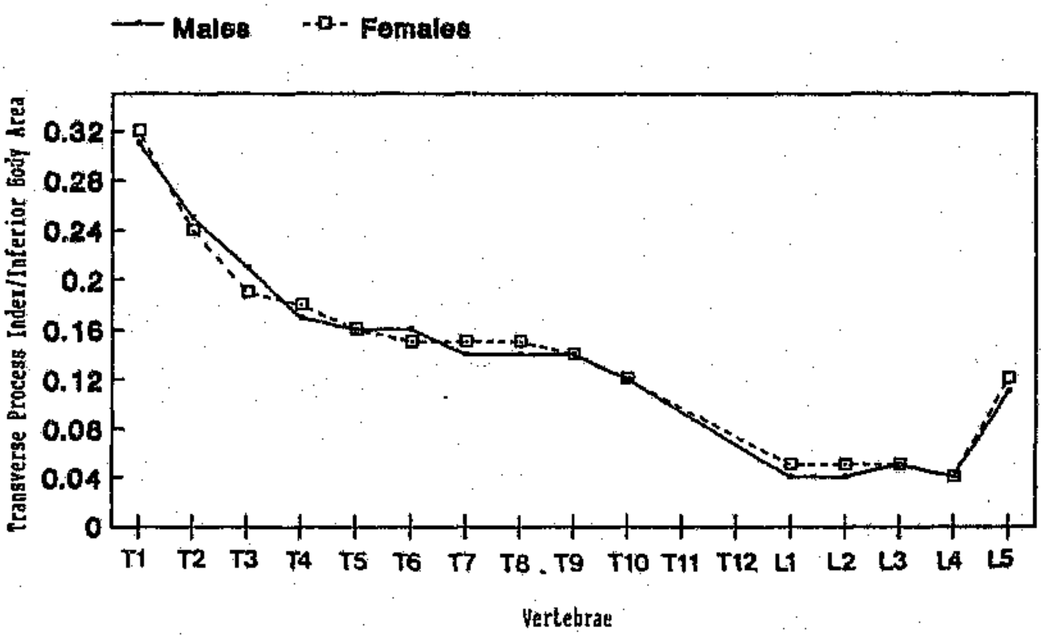

Fig. 9.57 The Transve: : Process Index/Inferior Bo· Area Ratio Values of Zulu Thoracic and Lumbar Vertebrae

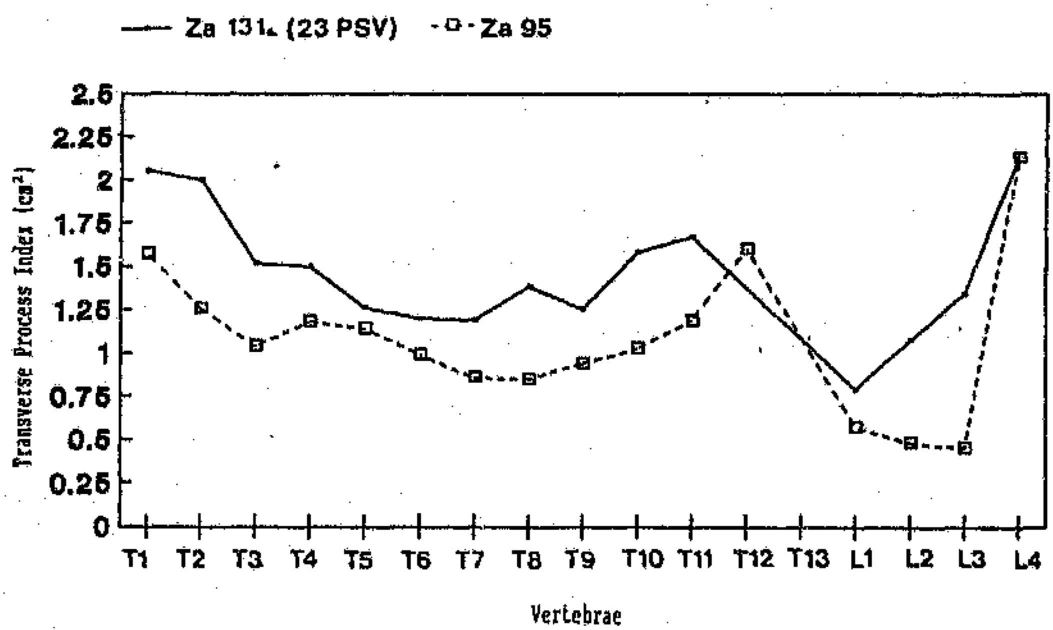

Fig. 9.58 The Transverse Process Index Values in Two Sets of *Gorilla* Male Thoracic and Lumbar Vertebrae

TABLE 9.37

The Mean Transverse Process Index Values of the Last Three Lumbar Vertebrae in Zulu and West African Male Spines (cm^2)

Vertebra	Zulu			West African		
	Mean	±SD	Observed Range	Mean	±SD	Observed Range
Males:						
L3	0,63	0,15	0,32 - 0,94	0,36	0,07	0,24 - 0,50
L4	0,58	0,15	0,33 - 0,69	0,26	0,09	0,14 - 0,55
L5	1,37	0,33	0,79 - 1,93	1,20	0,53	0,52 - 2,87
Females:						
L3	0,61	0,12	0,33 - 0,89	0,29	0,08	0,20 - 0,56
L4	0,55	0,17	0,35 - 1,02	0,26	0,09	0,15 - 0,50
L5	1,33	0,30	0,73 - 1,81	0,78	0,99	0,25 - 1,41

Zulu males: n = 30
Zulu females: n = 30
West African males: n = 35
West African females: n = 24

1.2.2 Transverse Process Index/Inferior Body Area Ratio

This ratio has here been calculated for West African spinal columns from Davis's (1961) results on the last three lumbar vertebrae and compared with the results of the present study (Table 9.38). Though the Zulu transverse processes are larger in relation to the inferior bod. area, both groups present the same pattern of a slight decrease from L3 to L4 followed by an increase to L5.

TABLE 9.38

The Mean Transverse Process Index/Inferior Body Area Ratio Values of the Last Three Lumbar Vertebrae of Zulu and West African Male Spines

Vertebra	Males		Females	
	Zulu	West African	Zulu	West African
L3	0,05	0,03	0,05	0,03
L4	0,04	0,02	0,04	0,02
L5	0,11	0,09	0,12	0,07

2 African and Asian Great Ape Series

2.1 Present Study

2.1.1 Transverse Process Index (gtp x ltp)

The two *Gorilla* male vertebral columns show a decrease in index values of the upper thoracic vertebrae, followed by an increase to the second last thoracic vertebra. The transverse processes of L1 are much smaller than those of the thoracic vertebrae (Table 9.39, Fig 9.58). In Za 1312 the transverse process size increases from L1 to L4 while Za 95 shows a decrease in this size in the upper three lumbar vertebrae followed by a sharp increase at L4. The T1 transverse processes are the largest in the thoracic region, while those of L4 are the largest in the thoracolumbar region.

TABLE 9.39

The Transverse Process Index Values in Individual Sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae (cm^2)

Vertebra	*Gorill*		*Pan*		*Pongo*
	Za 1312	Za [illegible]5	Za 1071	Za 94	Za 93
T1	2,05	1,57	0,61	1,02	0,67
T2	2,00	1,25	0,42	0,59	0,52
T3	1,52	1,04	0,33	0,56	0,56
T4	1,50	1,18	0,35	0,59	0,58
T5	1,26	1,14	0,38	0,56	0,57
T6	1,20	0,99	0,42	0,60	0,58
T7	1,19	0,86	0,45	0,62	0,61
T8	1,38	0,85	0,47	0,64	0,79
T9	1,25	0,94	0,55	0,64	0,78
T10	1,58	1,03	0,47	0,63	0,94
T11	1,67	1,19	0,51	0,74	1,07
T12	-	1,60	0,59	0,74	-
T13	-	-	-	-	-
L1	0,79	0,57	0,38	0,38	0,21
L2	1,07	0,48	0,26	0,32	0,42
L3	1,34	0,45	0,17	0,34	0,36
L4	2,14	2,13	1,16	1,35	0,72

The two *Pan* male spinal columns present a decrease in the transverse process size from T1 to T3, followed by a gradual increase to the second last thoracic vertebra (Table 9.39, Fig. 9.59). The transverse processes of L1 in these columns are smaller than those of the thoracic vertebrae. In the lumbar region Za 1071 shows a decrease in size from L1 to L3 followed by a sharp increase at L4. Za 94, on the other hand, shows a decrease from L1 to L2 followed by a sharp increase at L4.

In the *Pongo* female vertebral column, the size of the transverse processes decreases from T1 to T2, increases gradually to T7 and then sharply to T11 (Table 9.39, Fig. 9.60). This spinal column differs from the African great ape columns in that the transverse processes of T11 are the largest among the thoracic vertebrae, not those of T1. In the lumbar

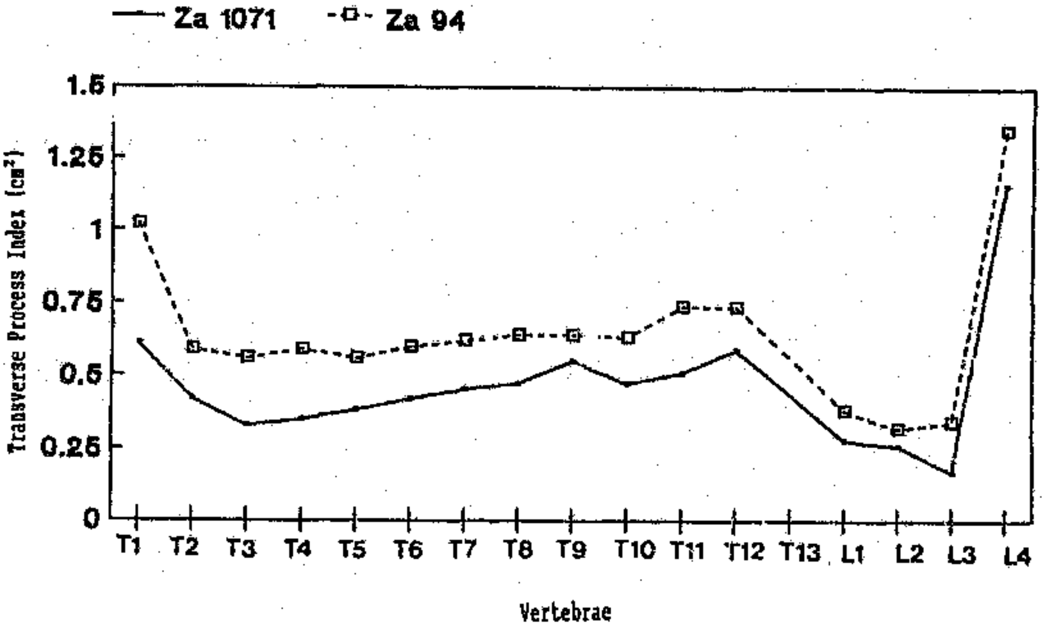

Fig. 9.59 The Transverse Process Index Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

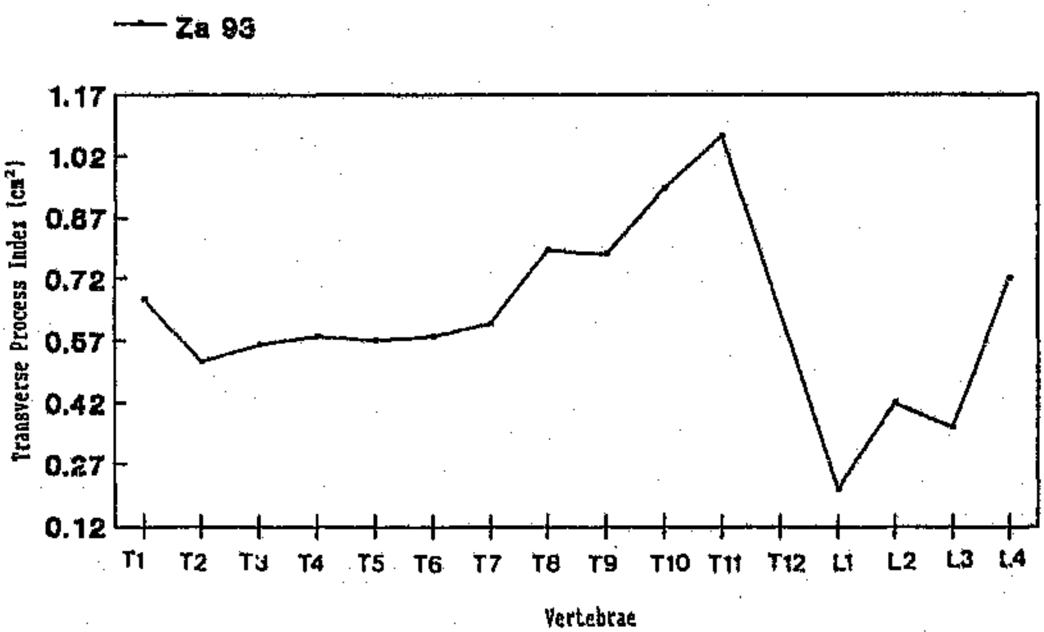

Fig. 9.60 The Transverse Process Index Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

region, the transverse processes of L1 are the smallest. The size of the lumbar transverse processes increases to L2, followed by a slight decrease to L3 and a sharp increase at L4. The increase in size at L4 is however smaller than that which occurs in the African great ape columns. In these ape columns the transverse processes of L4 are the largest, whereas T11 presents the largest transverse processes in this *Pongo* column.

2.1.2 Transverse Process Index/Inferior Body Area Ratio

This ratio decreases sharply between the first two thoracic vertebrae and then gradually to the second last thoracic vertebra in the *Gorilla* male columns (Table 9.40, Fig. 9.61). The ratios of the first three lumbar vertebrae, which present little variation among them, are lower than in the thoracic region. The sizes of the transverse processes of the last lumbar vertebrae, in relation to the inferior body area, are larger than those of the rest of the lumbar vertebrae.

The two *Pan* vertebral columns show the same pattern as the *Gorilla* columns for this ratio (Table 9.40, Fig. 9.62). In the *Pongo* female column this ratio decreases more gradually to the level of T6 (Table 9.40, Fig 9.63). From there it increases gradually and slightly to T11. The transverse processes of the lumbar region are smaller in relation to the inferior body area than in the thoracic region. The ratio for L4 is the largest in the lumbar region.

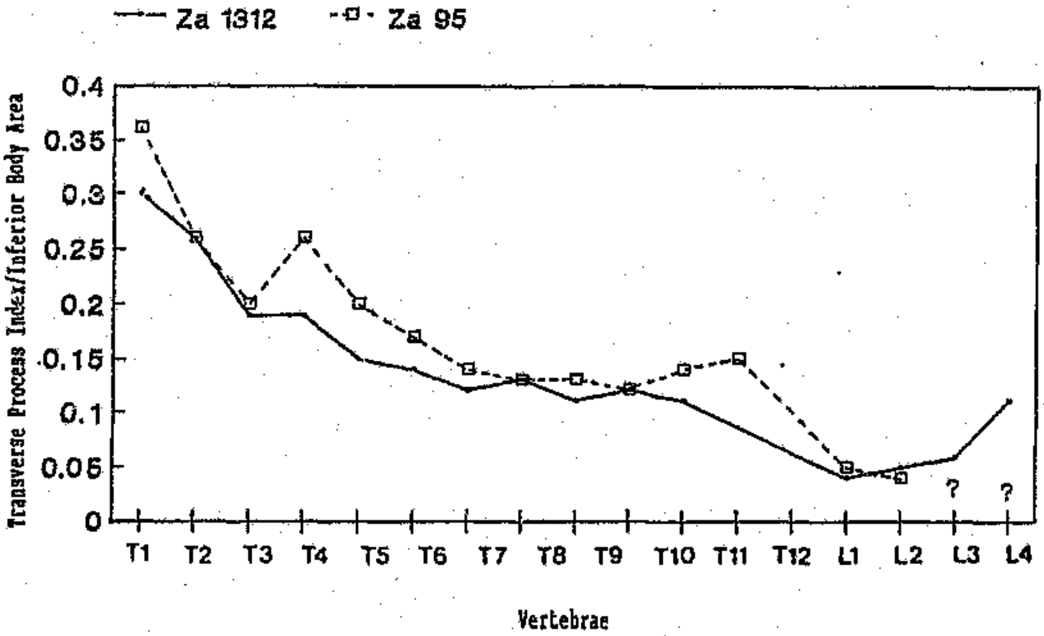

Fig. 9.61 The Transverse Proses Index/Inferior Body Area Ratio Values in Tw^ Sets of *Gorilla* Male Thoracic and Lumbar Vertebrae

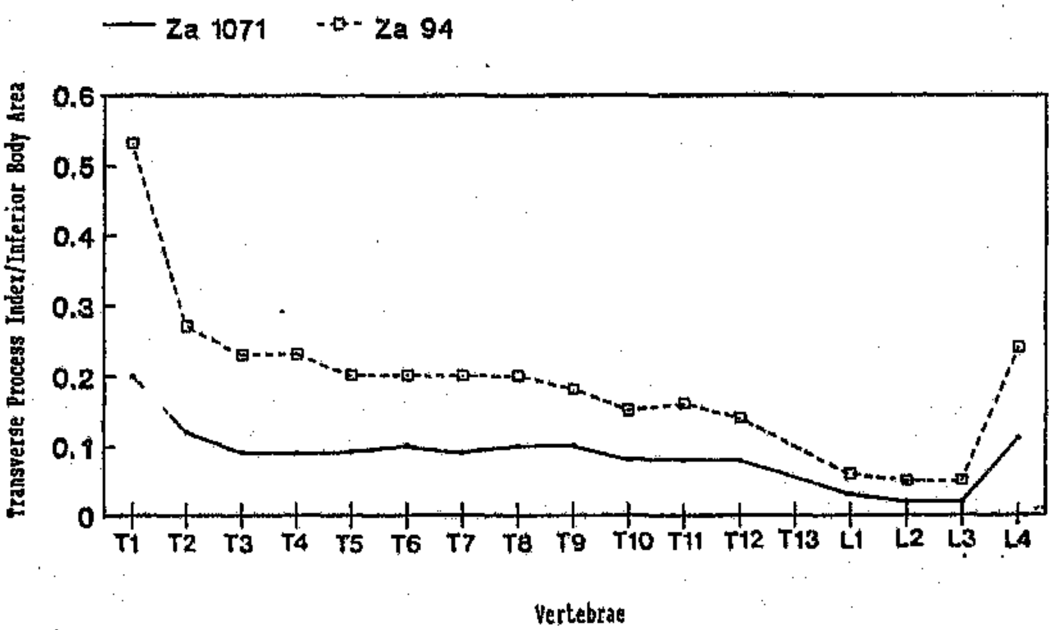

Fig. 9.62 The Transverse Process Index/Inferior Body Area Ratio Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

TABLE 9.40

The Transverse Process Index/Inferior Body Area Ratio Values in Individual sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae

Vertebra	*Gorilla*		*Pan*		*Pongo*
	Za 1312	Za 95	Za 1071	Za 94	Za 93
T1	0,30	0,36	0,20	0,53	0,22
T2	0,26	0,26	0,12	0,27	0,15
T3	0,19	0,20	0,09	0,23	0,16
T4	0,19	0,26	0,09	0,23	0,15
T5	0,15	0,20	0,09	0,20	0,14
T6	0,14	0,17	0,10	0,20	0,13
T7	0,12	0,14	0,09	0,20	0,14
T8	0,13	0,13	0,10	0,20	0,15
T9	0,11	0,13	0,10	0,18	0,14
T10	0,12	0,12	0,08	0,15	0,16
T11	0,11	0,14	0,08	0,16	0,17
T12	-	0,15	0,08	0,14	-
T13	-	-	-	-	-
L1	0,04	0,05	0,03	0,06	0,03
L2	0,05	0,04	0,02	0,05	0,05
L3	0,06	*	0,02	0,05	0,04
L4	0,11	*	0,11	0,24	0,09

* Inferior body area unknown

3 Australopithecine Series

3.1 Present Study

3.1.1 Transverse Process Index (gtp x ltp)

Sts 14 presents an increase in transverse process size from the eighth last to the sixth last thoracic vertebrae, followed by a decrease to the next vertebra and an increase to the fourth last thoracic vertebra (Table 9.41, Fig. 9.64). The sizes of the lumbar transverse processes are smaller than those of the thoracic vertebrae. Though the transverse processes of L5 are broken away, an increase occurs between L4 and L6. Stw 431 shows an increase in transverse process size between the last two lumbar vertebrae (Table 9.41, Fig. 9.64).

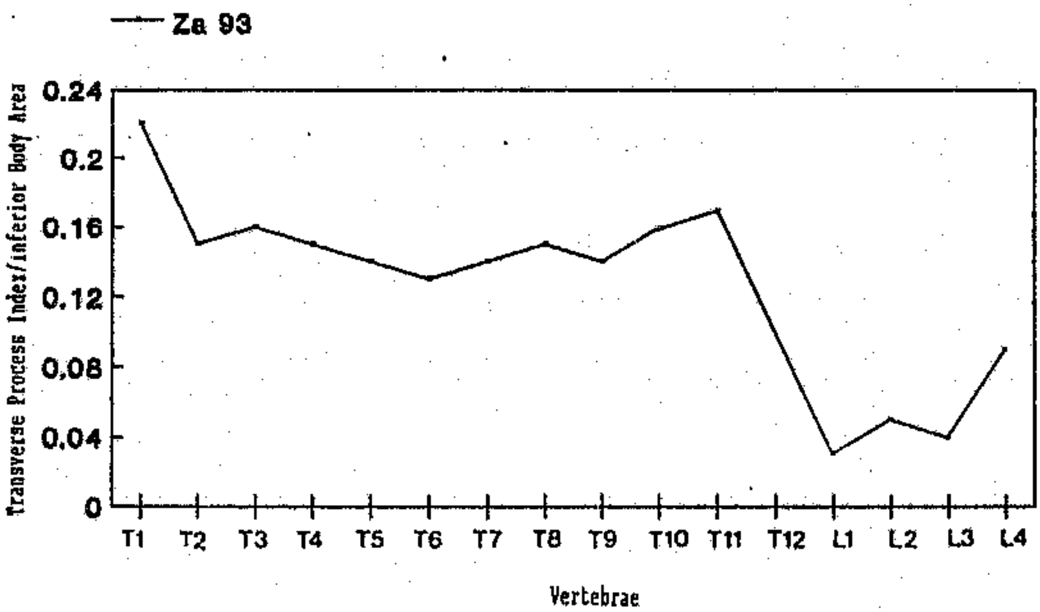

Fig. 9.63 The Transverse Process Index/Inferior Body Area Ratio Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

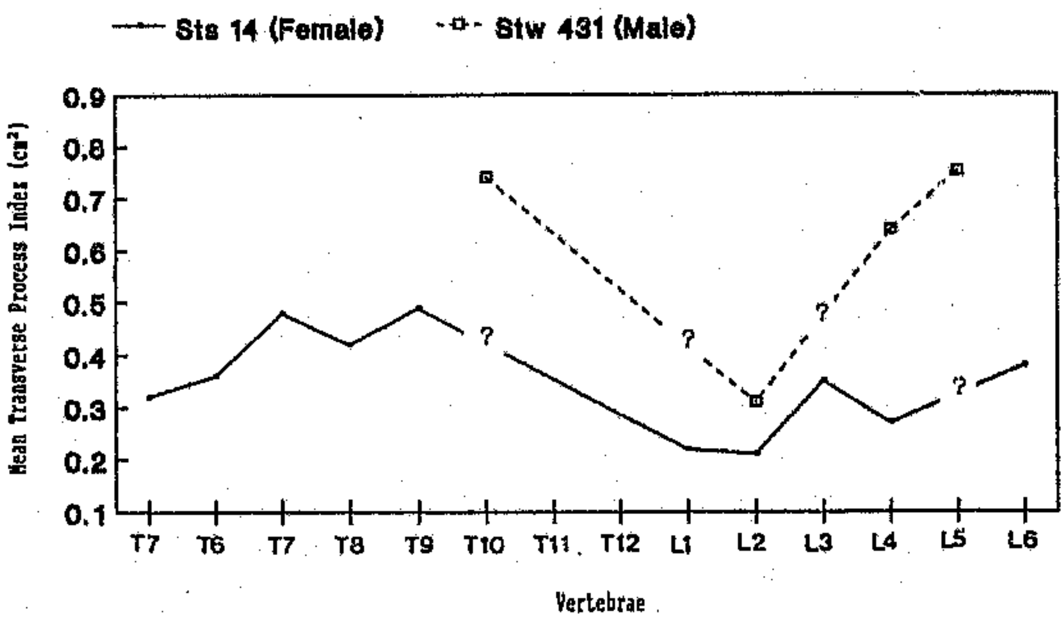

Fig. 9.64 The Transverse Process Index Values in Two Sets of *A. africanus* Thoracic and Lumbar Vertebrae

TABLE 9.41

The Transverse Process Index Values in Individual Sets of *A. africanus* Thoracic and Lumbar Vertebrae (cm^2)

Vertebra	Sts 14	Stw 431	Stw 8b
Thoracic:			
8th	0,32*		
7th	0,36*		
6th	0,48*		
5th	0,42*		
4th	0,49		
3rd	-	0,74$	
2nd	-	-	
last	-	-	
Lumbar:			
L1	0,22*	-	
L2	0,21	0,32	
L3	0,35*	-	0,82#
L4	0,27*	0,64$	
L5	-	0,75*	
L6	0,38		

* Only left side preserved
$ Only right side preserved
# Either L2 or L3

3.1.2 Transverse Process Index/Inferior Body Area

In relation to the inferior body areas, the Sts 14 lumbar transverse processes are smaller than those of the thoracic vertebrae (Table 9.42, Fig. 9.65). The ratio for the last lumbar vertebra, L6, is higher than those of the first four lumbar vertebrae, which show little variation. The only Stw 431 vertebra for which a ratio can be calculated is L2 in which the ratio value is 0,04.

TABLE 9.42

The Transverse Process Index/Inferior Area Ratio Values of Sts 14 Thoracic and Lumbar Vertebrae

..rtebra	Sts 14
Thoracic:	
7th	0,15
6th	0,21
5th	0,16
4th	0,17
3rd	-
2nd	-
last	-
Lumbar:	
L1	0,06
L2	0,06
L3	0,07
L4	0,06
L5	-
L6	0,12

4 Intergroup Comparisons

4.1 Transverse Process Index (gtp x ltp)

In the thoracic region, the anthropoid apes present an initial decrease in transverse process size from T1 to T2 in *Pongo*, to T3 in *Pan* and to T7 or T8 in *Gorilla* vertebral columns (Figs. 9.58, 9.59 and 9.60). This decrease is followed by an increase to the second last thoracic vertebra. The most important feature in the lumbar region is the enlarged transverse processes of the last lumbar vertebrae.

In modern human columns the size of the transverse processes decreases from T1 to T5 followed by an increase to T9. It differs from the pattern of the anthropoid apes in that the

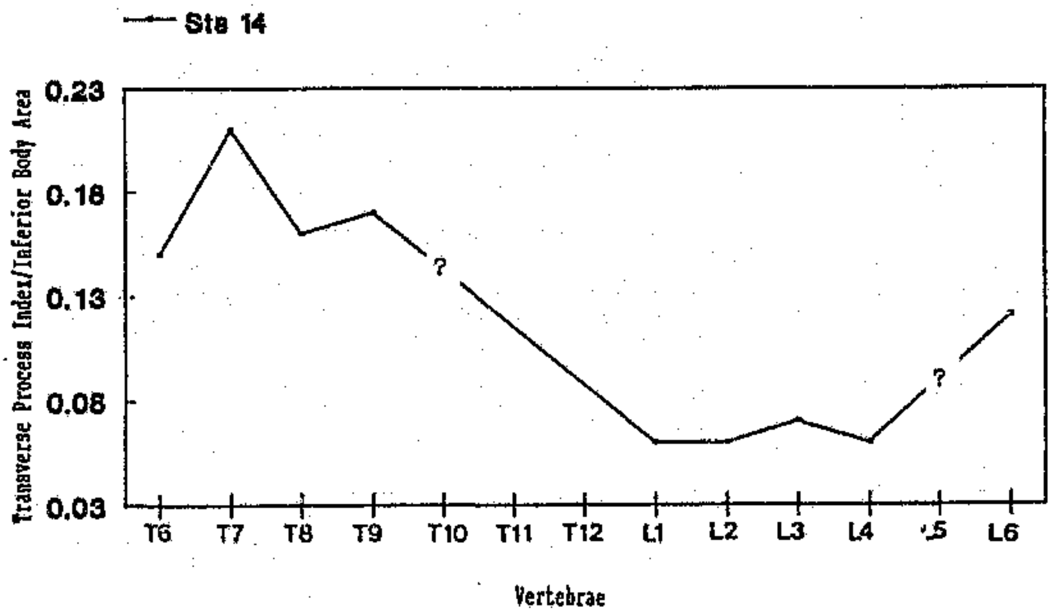

Fig. 9.65 The Transverse Process Index/Inferior Body Area Ratio Values in a Single Set of *A. africanus* Female Thoracic and Lumbar Vertebrae

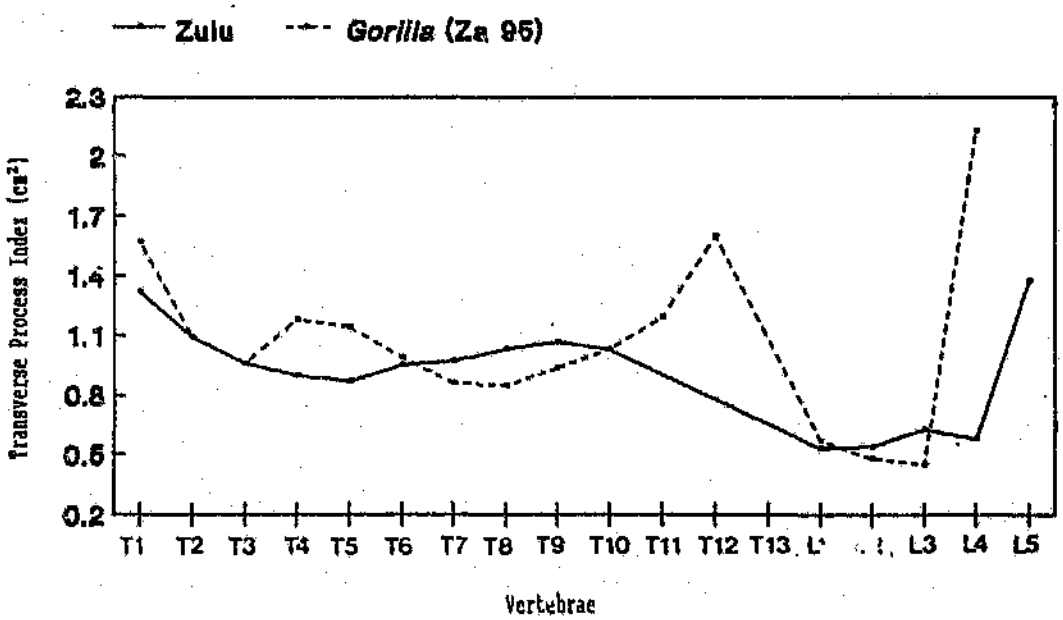

Fig. 9.66 The Transverse Process Index Values in Modern Human (n=30) and a Single Set of *Gorilla* Male Thoracic and Lumbar Vertebrae

transverse processes diminish from T9 to T10 (Fig. 9.66). The lumbar transverse processes enlarge gradually to L4 followed by a rapid increase in size at L5.

The size of the Sts 14 thoracic transverse processes is smaller than those in modern human and the anthropoid ape columns, but the pattern of a gradual increase is in accordance with that of these columns (Fig. 9.67). In the lumbar region the increase in the size of the last australopithecine vertebra is smaller than in the modern human and pongid vertebrae.

4.2 Transverse Process Index/Inferior Body Area Ratio

The values of this ratio present the same pattern of a gradual decrease from T1 to the second last thoracic vertebra, followed by an increase at the last lumbar vertebra in modern human, pongid and australopithecine vertebrae. The only difference is that in one *Pan* and the *Pongo* spinal columns, a slight increase occurs in the ratio values of the lower thoracic vertebrae (Fig. 9.68).

F The Body-Pedicle Angle

1 Modern Human Series

1.1 Zulu Series

In the thoracic regions of both Zulu males and females the pedicles are directed upwards and backwards from the body towards the laminae. A sudden decrease in the angle occurs between T12 and L1 (Table 9.43, Fig 9.69). In the lumbar regions, the angle decreases from L1 to L4 and increases at L5. The pedicles of L3 and L4 are nearly horizontal in both groups.

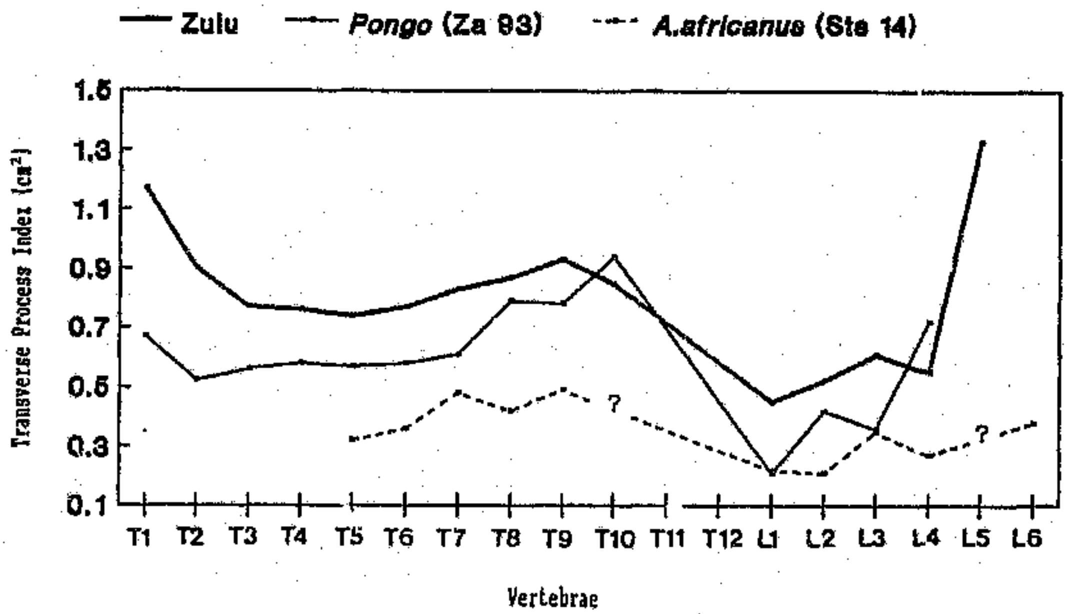

Fig. 9.67 The Transverse Process Index Values of Modern Human (n=30), *Pongo* (n=1) and *A. africanus* (n=1) Female Thoracic and Lumbar Vertebrae

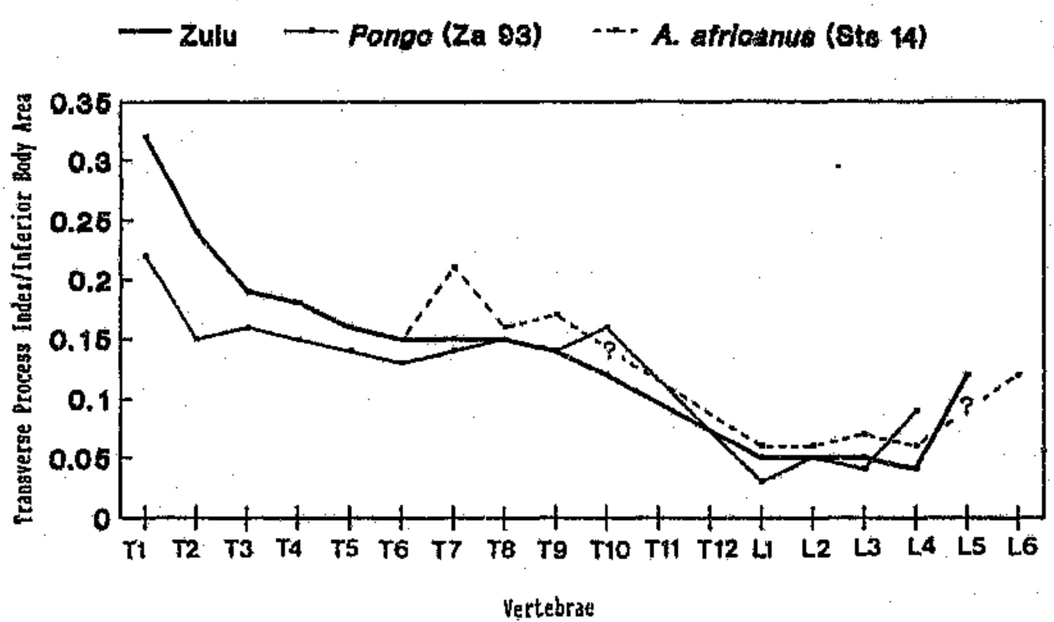

Fig. 9.68 The Transverse Process Index/Inferior Body Area Ratio Values of Modern Human (n=30), *Pongo* (n=1) and *A. africanus* (n=1) Female Thoracic and Lumbar Vertebrae

Sex differences: No significant difference is found between the body-pedicle angles of corresponding Zulu male and female thoracic and lumbar vertebrae.

TABLE 9.43

The Mean Body-Pedicle Angle Values of Zulu Thoracic and Lumbar Vertebrae

Vertebrae	Males			Females		
	Mean	±SD	Range observed	Mean	±SD	Range observed
T1	110,1	3,25	100,0 - 117,0	111,5	2,15	109,0 - 118,0
T2	110,4	2,33	102,5 - 116,0	110,6	1,50	107,0 - 114,0
T3	110,1	1,63	107,0 - 113,0	110,4	1,72	105,0 - 113,5
T4	110,2	1,61	105,0 - 113,0	110,3	1,64	105,0 - 113,0
T5	110,0	1,79	103,5 - 113,5	110,0	1,68	105,0 - 113,0
T6	110,3	1,35	107,0 - 114,0	110,1	1,45	108,0 - 113,0
T7	110,4	1,30	107,5 - 112,5	110,0	1,39	107,0 - 113,0
T8	109,6	1,78	106,5 - 114,5	109,7	1,23	107,0 - 112,0
T9	109,3	1,44	107,0 - 112,5	109,2	1,18	107,0 - 111,0
T10	109,1	1,53	106,0 - 113,0	109,2	0,97	107,0 - 110,5
T11	108,7	1,96	106,0 - 112,5	109,4	0,94	107,0 - 110,0
T12	108,3	2,18	101,5 - 112,0	108,9	2,31	98,0 - 110,0
L1	98,9	2,61	94,0 - 104,5	100,4	2,56	94,0 - 105,0
L2	95,9	2,44	90,5 - 102,0	96,4	2,44	90,0 - 100,0
L3	93,4	2,53	87,0 - 100,0	94,0	1,73	90,0 - 97,0
L4	92,5	1,50	91,0 - 95,0	92,7	2,00	88,0 - 96,0
L5	94,8	2,43	88,0 - 98,0	95,4	2,04	90,0 - 98,0

1.2 Comparative Series

The results of the present study confirm for the Zulu spines the pattern of superoposterior sloping of the pedicles in the thoracic region, followed by a sudden decrease in this angle till the pedicles of L3 and L4 which are nearly horizontal, as found by Pal and Routal (1986, 1987). These data are listed in Table 9.44 and presented graphically in Fig. 9.70.

The Zulu males present highly significantly larger angles ($P<0,0005$) than the Indian males, at the levels of T8 and L1, while the difference at the L4 level is almost certainly

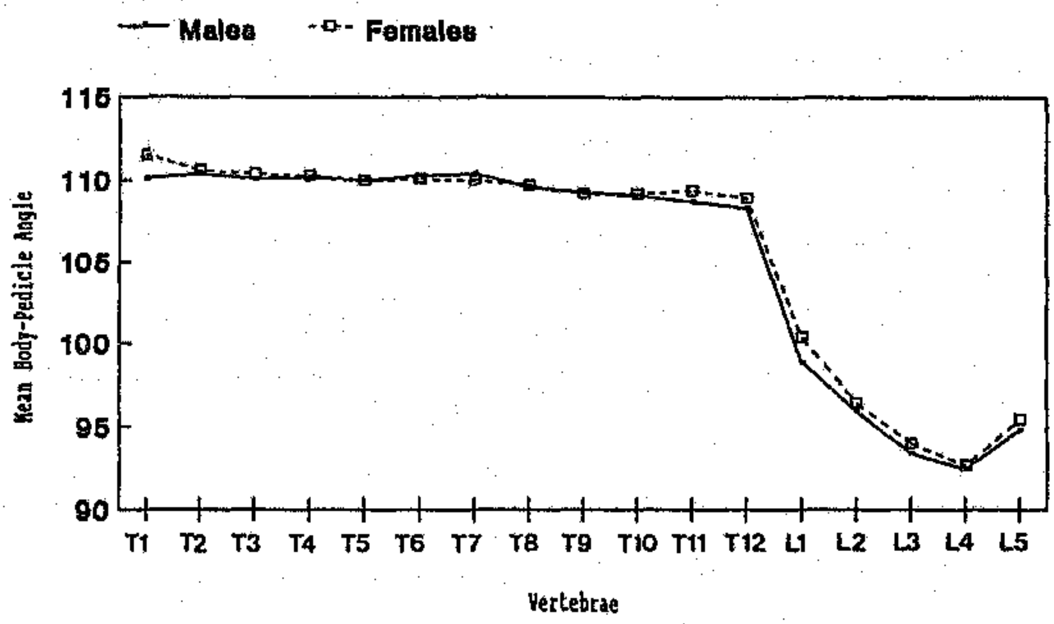

Fig. 9.69 The Mean Body-Pedicle Angle Values of Zulu Thoracic and Lumbar Vertebrae

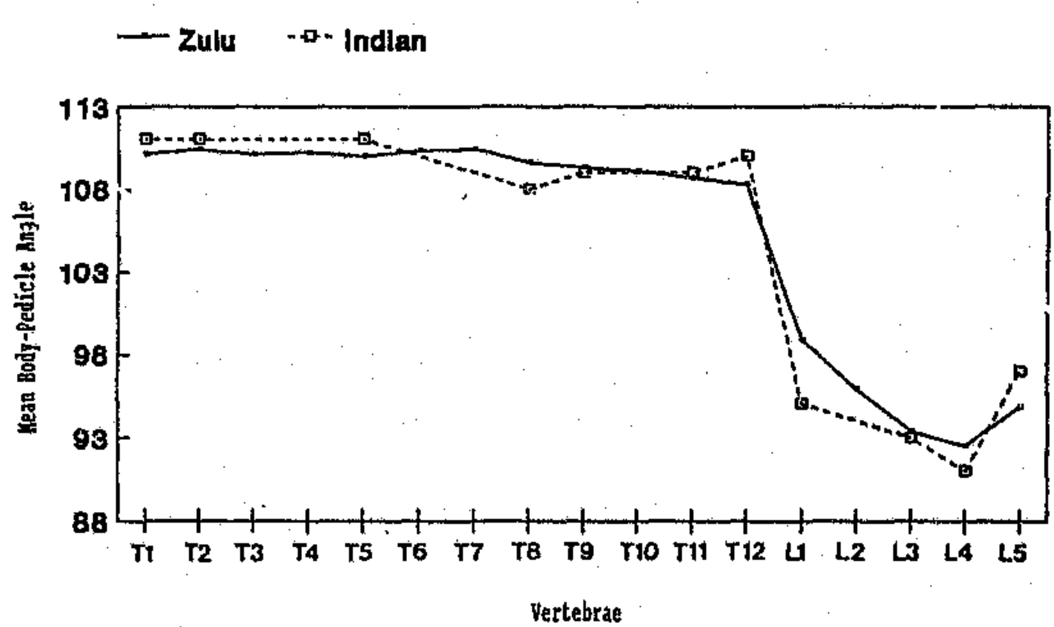

Fig. 9.70 The Mean Body-Pedicle Angle Values of Modern Human Male Thoracic and Lumbar Vertebrae

significant (P<0,01). The body-pedicle angles of Indian males at the T12 and L5 levels are probably significantly greater (P<0,025) than those of the Zulu males.

TABLE 9.44

The Mean Body-Pedicle Angle Values of Zulu and Indian Male Thoracic and Lumbar Vertebrae

Vertebrae	Zulu Present Study n = 30	Indian Pal & Routal (1986, 1987) n = 44
T1	110,1	111
T2	110,4	111
T3	110,1	
T4	110,2	
T5	110,0	111
T6	110,3	
T7	110,4	
T8	109,6	108
T9	109,3	109
T10	109,1	
T11	108,7	109
T12	108,3	110
L1	98,9	95
L2	95,9	
L3	93,4	93
L4	92,5	91
L5	94,8	97

2. African and Asian Great Ape Series

2.1 Present Study

In both *Gorilla* male columns the pedicles are directed posterosuperior in the thoracic region. An initial decrease occurs in the upper thoracic vertebrae followed by a more gradual decrease to L2. The angle increases at L3 and decreases again at L4 (Table 9.45, Fig. 9.71).

Conspicuous features of this angle in the *Pan* columns are an increase from T1 to T2 and a decrease from T5 to T8 and T9 in both columns. From this level Za 94 shows an increase in the

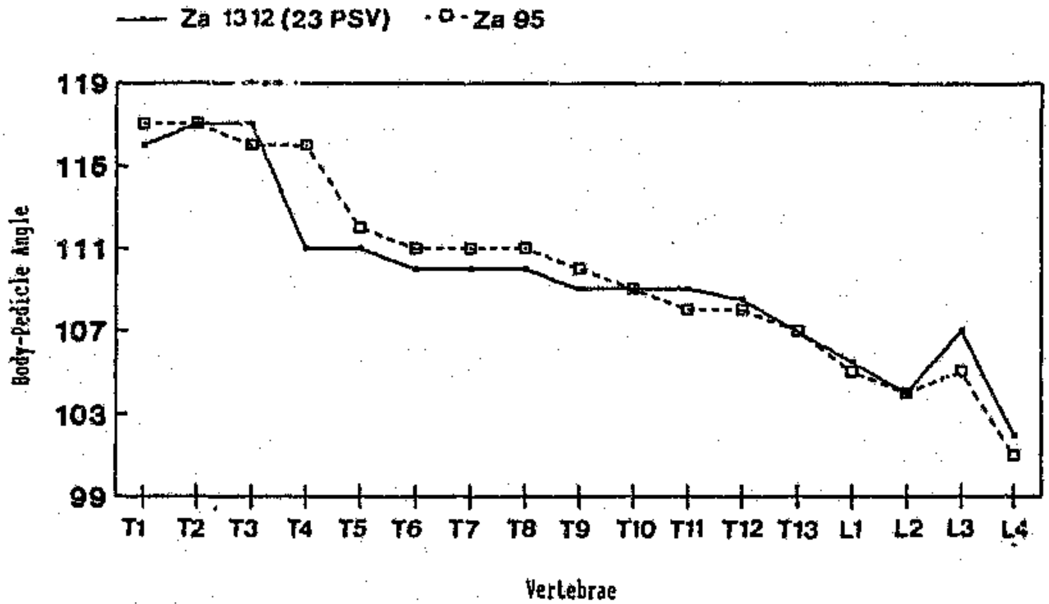

Fig. 9.71 The Body-Pedicle Angle Values in Two Sets of *Gorilla* Male Thoracic and Lumbar Vertebrae

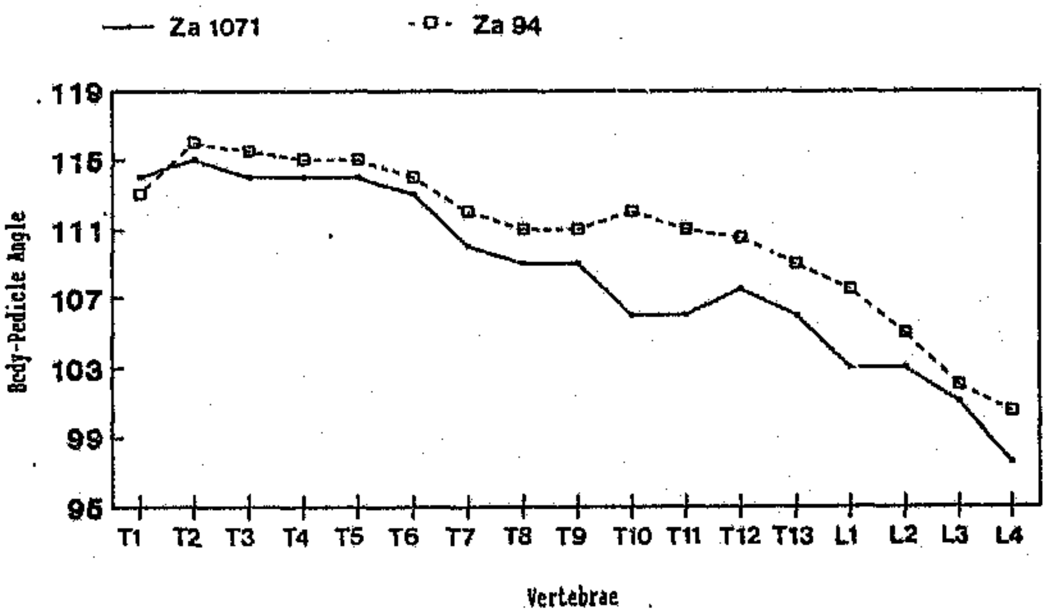

Fig. 9.72 The Body-Pedicle Angel Values in Two Sets of *Pan* Male Thoracic and Lumbar Vertebrae

body-pedicle angle from T9 to T10, followed by a sharp decrease to L4. Za 1071 presents a decrease from T9 to T10 and T11 followed by an increase to T12 and a strong decline to L4 (Table 9.45, Fig. 9.72).

In the *Pongo* vertebral column this angle increases from T1 to T3 and then decreases to L2. An increase occurs at L3 followed by a sharp decrease at L4 (Table 9.45, Fig. 9.73).

TABLE 9.45

The Body-Pedicle Angle Values in Individual Sets of African and Asian Great Ape Thoracic and Lumbar Vertebrae

Vertebra	*Gorilla*		*Pan*		*Pongo*
	Za 1312 Male	Za 95 Male	Za 1071 Male	Za 94 Male	Za 93 Female
T1	116,0	117,0	114,0	113,0	111,0
T2	117,0	117,0	115,0	116,0	112,0
T3	117,0	116,0	114,0	115,5	113,0
T4	111,0	116,0	114,0	115,0	112,0
T5	111,0	112,0	114,0	115,0	109,0
T6	110,0	111,0	113,0	114,0	108,0
T7	110,0	111,0	110,0	112,0	107,0
T8	110,0	111,0	109,0	111,0	107,0
T9	109,0	110,0	109,0	111,0	106,0
T10	109,0	109,0	106,0	112,0	106,0
T11	109,0	108,0	106,0	111,0	105,0
T12	108,5	108,0	107,5	110,5	105,0
T13	-	107,0	106,0	109,0	-
L1	105,5	105,0	103,0	107,5	104,0
L2	104,0	104,0	103,0	105,0	102,0
L3	107,0	105,0	101,0	102,0	105,0
L4	102,0	101,0	97,5	100,5	96,0

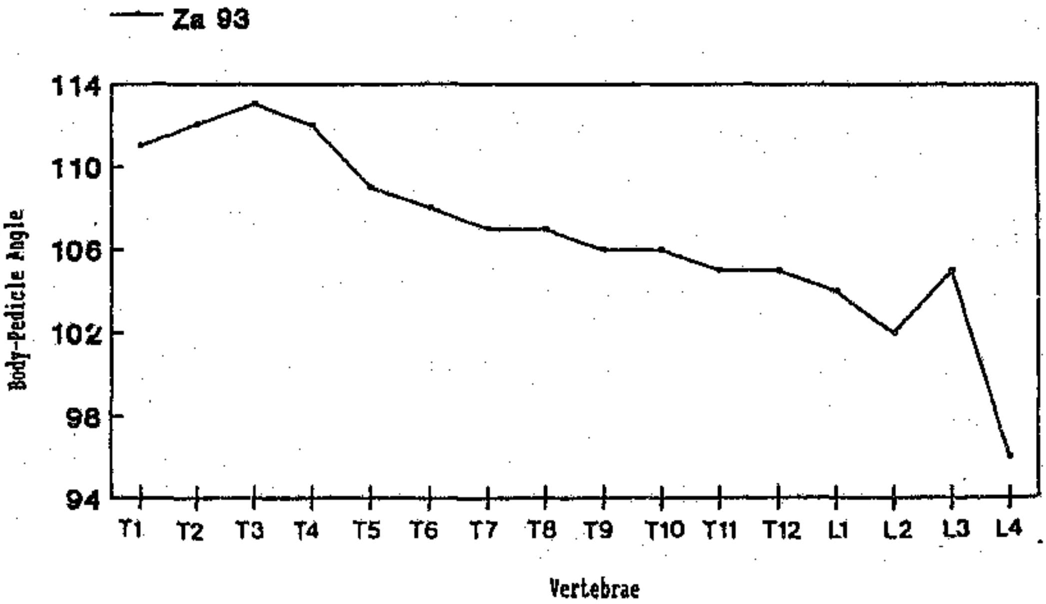

Fig. 9.73 The Body-Pedic' ;le Values in a Single Set of *Pongo* Female Thoracic and Lumbar Vertebrae

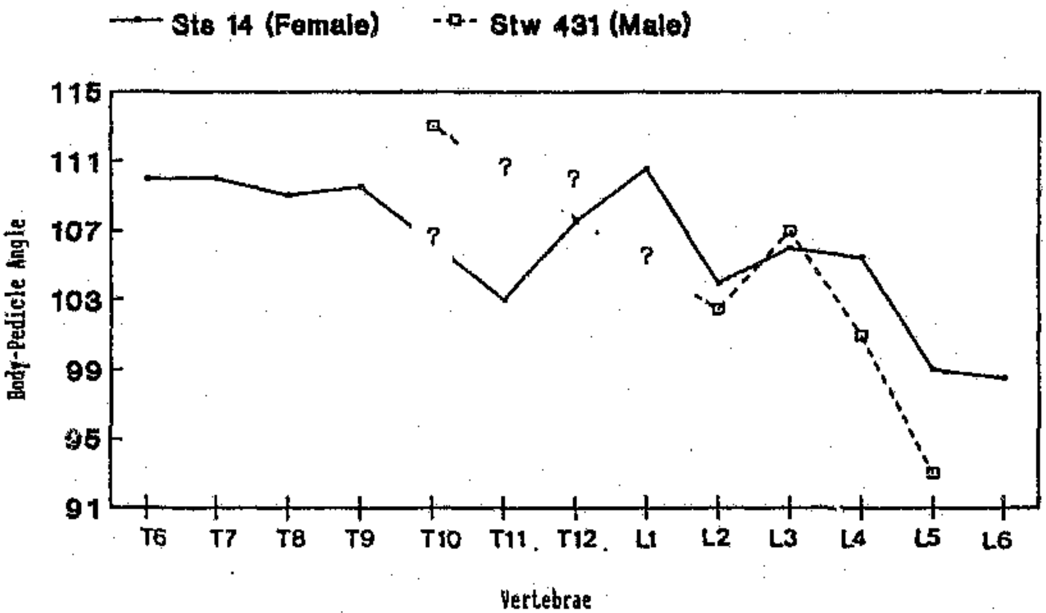

Fig. 9.74 The Body-Pedicle Angle Values in Two Sets of *A. africanus* Thoracic and Lumbar Vertebı.

3 Australopithecine Series

3.1 Present Study

In the preserved thoracic vertebrae of Sts 14 the pedicles are directed backwards and upwards from the body towards the laminae. The angle of the second last thoracic vertebra is considerably smaller than those in the rest of the preserved thoracic vertebrae. From this level the angle increases to L1 and decreases to L2. Both Sts 14 and Stw 431 show an increase in this angle from L2 to L3 followed by a decrease to the last lumbar vertebra (Table 9.46, Fig. 9.74).

TABLE 9.46

The Body-pedicle Angle Values in Individual Sets of *A. africanus* Thoracic and Lumbar Vertebrae

Vertebrae	Sts 14	Stw 431
Thoracic:		
7th last	110	
6th last	110	
5th last	109	
4th last	109,5	
3rd last	-	113
2nd last	103	-
last	107,5	-
Lumbar:		
L1	110,5	-
L2	104	102,5
L3	106	107*
L4	105,5	101*
L5	99	93$
L6	98,5	

* Only right side preserved
$ Only left side preserved

4 Intergroup Comparisons

A comparison of the three series shows larger body-pedicle angles, which indicates a larger superoposterior slope, in the upper thoracic vertebrae of the anthropoid apes than in modern man (Figs. 9.75 and 9.76). In the lower thoracic region, the anthropoid ape vertebrae present a sharper decline in this angle to slope less superoposteriorly than in modern man. The difference between the angles of the last thoracic and first lumbar vertebrae is larger in the modern human than in the anthropoid ape columns, so that the pedicles of L1 are more horizontal in modern man. In contrast to the decrease in body-pedicle angle between these two vertebrae in modern human and anthropoid ape columns, Sts 14 presents an increase from the second last thoracic vertebra to L1. In the modern human lumbar region the slope of the pedicles declines from L1 to L4, followed by a slight incline at L5. In the anthropoid ape series, the *Gorilla* and *Pongo* vertebral columns present a decline in this angle from L1 to L2, followed by an incline at L3 and a decline to L4 whereas the *Pan* columns show a decline from L1 to L4. The *A. africanus* partial spinal columns present an incline between L2 and L3 followed by a decline to the last lumbar vertebra. The pedicles with the most horizontal slope in relation to the vertebral body are thus those of the second last lumbar vertebra in modern man and those of the last lumbar vertebrae in anthropoid apes and in *A. africanus*. The general pattern of the *A. africanus* graph (Fig. 9.76) seems to be closer to that of *Pongo* than to modern man.

G. Discussion

The inferior body surface area increases from T1 to the second last lumbar vertebra and decreases then at the last lumbar vertebra in both the modern human (Zulu) and our small anthropoid ape series. The increase in the inferior body area of consecutive vertebrae is expected since the compressive force increases as each vertebra bears the weight of

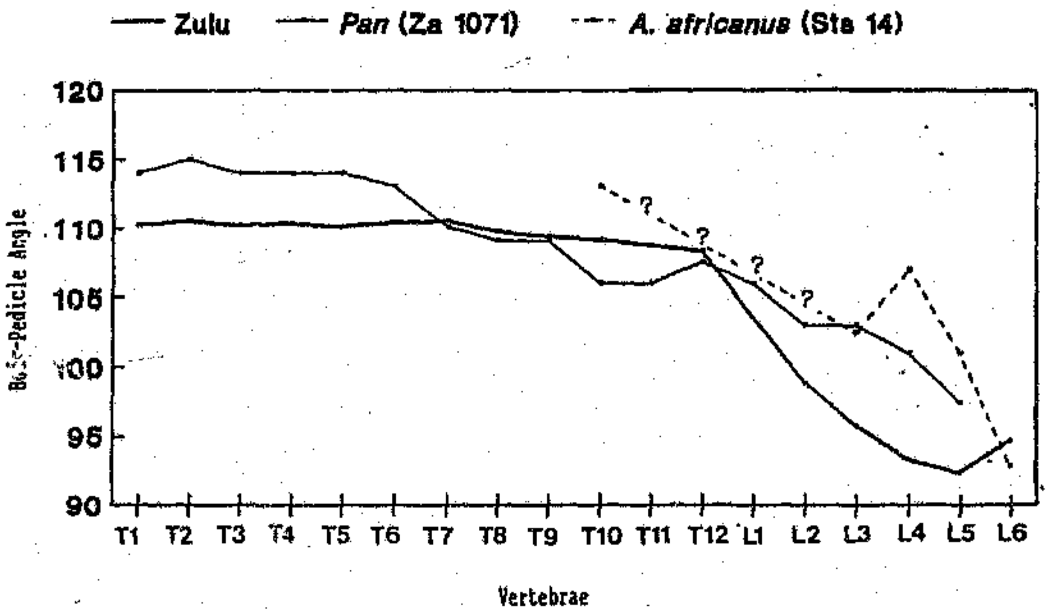

Fig. 9.75 The Body-Pedicle Angle Values of Modern Human (n=30), *Pan* (n=1) and *A. africanus* (n=1) Male Thoracic and Lumbar Vertebrae

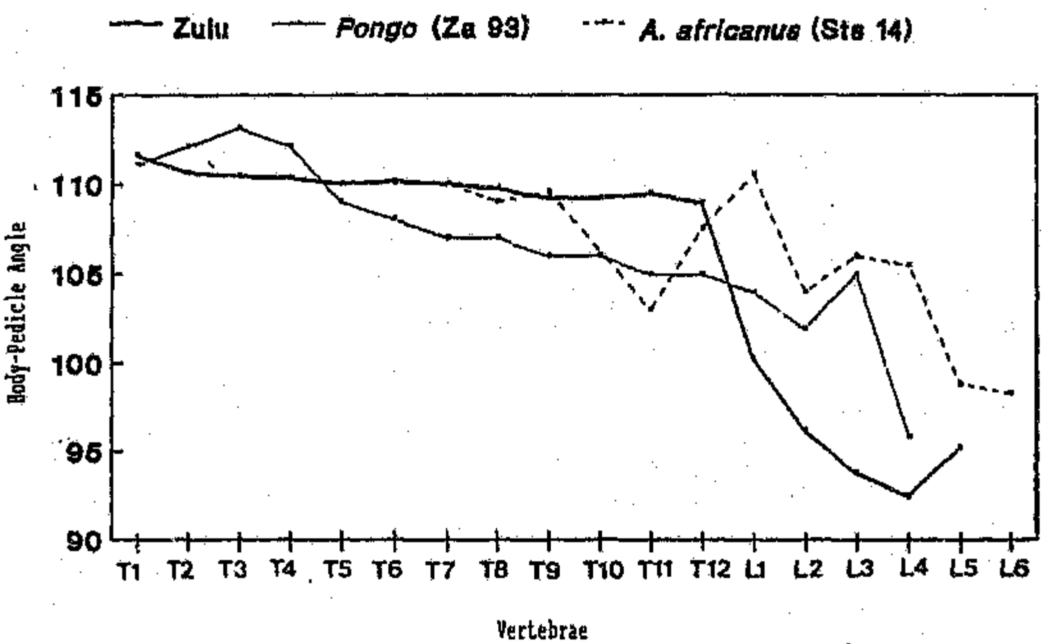

Fig. 9.76 The Body-Pedicle Angel Values of Modern Human (n=30), *Pongo* (n=1) and *A. africanus* Thoracic and Lumbar Vertebrae

all of the body above it. In keeping with this reasoning, the last lumbar vertebra should present the greatest inferior surface area. Yet we have found a reduction in the inferior area for the last lumbar bodies. Such reduction suggests that less compressive force is exerted upon the lowest lumbar bodies than on those immediately above. Part of the total compressive force must thus be transmitted to the pelvis (os coxae) cranial to the inferior body surface of the last lumbar vertebra.

Davis (1961) has studied the mode of weight transmission from L5 to the pelvis in modern human spinal columns. He concludes that the decrease in body area from L4 to L5, associated with an increase in the pedicle and transverse process size, suggests that part of the vertical compressive force is transmitted through the strong pedicles to the neural arch, and that part of this neural h force is transmitted through the transverse processes and, by inference, through the iliolumbar ligaments to the iliac crest.

Increased interest in low back pain recently has served to spur on research into the biomechanics of the posterior elements of the lumbar vertebrae. Indirect measuring methods show that lumbar articular facet joints are capable of transmitting compressive forces. Nachemson (1960) has measured the intradiscal pressure, with and without the posterior elements. He at first concluded that the facets were capable of carrying 18 to 20% of the vertical load, but this conclusion was later retracted (Nachemson, 1963). Lin *et al.* (1978) have studied the load-bearing rôle of the posterior vertebral elements of the lumbar vertebrae through strain gauges placed on the laminae of the upper of two vertebrae in a motion segment. The gauges recorded the strain in the laminae. They state from their results:

> "These data reaffirm the importance of the posterior elements and lumbar articular processes, which tend to maintain the lumbar spine in hyperextension and thereby to increase the loadbearing capacity". (op.cit., p 51)

Adams and Hutton (1980) also use an indirect method to study the rôle of the articular facets in resisting intervertebral compressive forces. They use a specially designed angle plate to load lumbar segments at specific angles and conclude that, after the intervertebral disc has been reduced in height by a period of sustained loading, the apophysial joints resist about 16% of the compressive forces in the erect standing and thus lordotic posture. Yang and King (1984) use an intervertebral load cell to measure load transmitted by lumbar articular facets indirectly. They conclude that normal lumbar articular facets carry 3 to 25% of the axial load and if a facet joint is arthritic the load could be as high as 47%.

Louis (1983, 1985), on the basis of morphological studies on dry skeletons, also emphasises the weight-bearing function of the articular facet joints. He has included this function of the facets in the three-pillar spine concept for spinal stability and weight-bearing which he has proposed. According to this concept descending forces between C2 and L5 are transmitted through three pillars, arranged in a triangle. The anterior pillar is formed by the vertebral bodies and intervertebral discs and the two posterior pillars by successive articular processes. The three pillars are reinforced by horizontal bars, the pedicles and laminae. This three-pillar concept does not however take into account the spinal curves and the form and position of the articular facets.

Pal and Routal (1986, 1987) have recently developed an hypothesis on weight transmission through the vertebral column on the basis of morphological and mechanical features of the dry vertebral column. They are of the opinion that between C2 and C7 weight is transmitted through the three pillars postulated by Louis (1983, 1985); an anterior pillar formed by the bodies and intervertebral discs, and two posterior pillars formed by the strong bar-like articular facets. At C7 and below, the articular facets are incorporated into the laminae and do not form separate bar-like masses as in the cervical region, but constitute one posterior pillar, flattened anteroposteriorly and strengthened in the living state, by the posterior ligamentous complex. This two-pillar system, an anterior and a posterior pillar, of weight transmission is proposed also for the lumbar region, since the morphological structure of the neural arch remains the same in the thoracic and lumbar regions (Fig. 9.77). The pedicles, where they are inclined towards the vertical, play an important rôle in the transfer of load between the posterior and anterior pillars. Pal and Routal (1986) are also of the opinion that the anteriorly convex curves of the cervical and the lumbar regions tend to increase the load which is carried by the *posterior* pillar, whereas the anteriorly concave thoracic curve tends to concentrate the load in the *anterior* pillar.

The present study uses the studies of Pal and Routal (1986, 1987) as a basis for a comparative study, to determine if the dimensions of the thoracic and lumbar vertebrae of anthropoid apes and of the australopithecines reflect the same weight-bearing system as those of modern man.

In the axis (C2) Pal and Routal (1986) find a significant correlation between the areas of the superior articular surfaces, on one hand, and the total area of the body and of the two inferior articular facets, on the other hand. This indicates that the compressive force exerted on the superior articular surfaces is transferred to the inferior body surface and the inferior articular facets. The mechanism they describe is that weight from the atlas passes to the two superior articular facets of the axis. On each side this

Fig. 9.77 Diagrammatic Representation of the Positions of the Weight Bearing Pillars in the Cervical (A), Thoracic (B) and Lumbar (C) Regions (after Pal and Routal, 1986)

compressive force resolves into two components; one acts downwards and medially to the inferior surface of the body and the other dowawards, backwards and laterally, through the strong and inclined pedicles to the inferior articular facets. The load is thus carried downwards to C6 in three pillars. The surface areas indicate that approximately 54% of the compressive force applied on the superior articular surfaces is transmitted through the vertebral bodies and approximately 46% through the inferior articular facets. The strong bar-like articular facets form two strong pillars, situated wide apart, posterolateral to the bodies. These pillars corroborate this high percentage of compressive force which, it is suggested, is carried by them.

Below C7 the two strong bar-like articular facets are incorporated into the laminae to form one posterior pillar of successive articulations of laminae at their articular facets. The mechanism of weight transmission which is described by Pal and Routal (1986, 1987) is that compressive forces which act on the superior articular facets of thoracic and lumbar vertebrae will diffuse on to the laminae before passing through the inferior articular facets. Hence, the compressive force transmitted through the inferior articular facets of a vertebra should be the same as that transmitted through the cross-sectional area of the laminae. Pal and Routal (1986) find a decrease in inferior articular facet area from C7 to T1 which suggests that part of the load received from the posterior pillars of C7 is transferred to the anterior pillar. The strong pedicles of T1 and T2 which are inclined downward and forward from the laminae to the body provide supporting evidence for such a transfer.

The results of the present study, on the inferior body area, the pedicle size, the lamina size, the arch index and the body-pedicle angle in Zulu thoracic and lumbar vertebrae, corroborate the tendencies which emerge from Pal's and Routal's (1986, 1987) results for modern human (Indian) vertebrae.

In the thoracic region of the Zulu spines the inferior body surface area increases gradually from T1 to T12. This indicates a gradual increase in weight transmission by the anterior pillar from above downwards. The cross-sectional area of the laminae decreases from T1 to T5 or T6. The larger laminae of the uppermost thoracic vertebrae indicate that they transmit a greater load than the laminae of the midthoracic vertebrae. Part of the initial weight received by T1 must thus be transferred to the anterior pillar formed by the vertebral bodies. The posterior elements of T1 receive the weight transmitted through the cervical region via the inferior articular facets of C7 plus the additional weight transmitted by the first ribs. These ribs would be expected to transmit more weight than the remaining ribs, due to their close association with the appendicular skeleton of the upper limb. Based on the decrease in lamina size,the strong and vertically inclined pedicles and the change in direction of the spinal curvature, Pal and Routal (1987) suggest that most of the load through the laminae of T1 is transmitted to the laminae of T2 and T3 from where a large part of this load is transmitted to the anterior pillar. The decrease in the size of the upper thoracic transverse processes found in the present study underlines the increased load which is transmitted to T1 via the first ribs.

The lamina area increases from T5 or T6 to T10. If the decrease in the load transmitted through the upper thoracic laminae is kept in mind, this increase points to the laminae receiving additional weight from another source. The present study shows an increase in the size of the transverse processes of T5 to T9: this confirms Pal's and Routal's (1987) hypothesis that the lower ribs may transfer more weight to the lower thoracic vertebrae than the middle ribs do. At this level (between T5 and T10), the only difference occurs between the trend shown by the index values and that shown by the index/inferior body area ratios. The lamina and the arch index values show an *increase*, while the lamina index/inferior body area and the arch index/inferior body area ratios *decrease*. It seems thus that, though the laminae increase gradually from T5 to T10, additional load is transmitted through the vertebral bodies. In association with the increase in the pedicle size and the pedicle index/inferior area ratios in this region, it seems as if most of the additional weight from the ribs is transferred to the vertebral bodies. The mechanism of weight transfer suggested by Pal and Routal (1987) is that the weight is received from the ribs via the costotransverse articulation and transmitted through the laminae and articular facets to the next vertebra. Here the strong, inclined pedicles transfer part of the weight to the vertebral body.

In the modern human (Zulu) spines, the lamina index values decrease from T9 or T10 to L1. This would indicate that the laminae of T11 and T12 transmit less weight than those of the preceding vertebrae. The laminae of T11 and T12 do not receive additional weight from the last two ribs which are rudimentary and do not articulate with the transverse processes. In addition the decreases in pedicle index values from T11 or T12 to L2, and in the pedicle index/inferior body area ratio from T11 or T12 to L1 or L2, indicate that less weight is transferred to the anterior pillar, although the inclination of the pedicles indicates that part of the posterior pillar load can still be transferred to the anterior pillar.

In the lumbar region the lamina index and the lamina index/ inferior body area increase gradually from L1 to L3 followed by a sharp increase at L4 and L5. Apart from the additional segmental load which is added at each level, the gradual increase in the first three lumbar vertebrae seems to reflect the downward transmission of weight received from the laminae of T12. This is corroborated by the weak and horizontal pedicles which do not enhance weight transfer between the two pillars.

The large increase in the lamina size of L4 is accompanied by strong pedicles and by an increase in the inferior body area. This increase is however smaller than the increase in the inferior area of L3. At the level of L5 the inferior body area decreases in relation to that of L4. This decrease is accompanied by a large increase in pedicle, lamina and transverse process size. In both L4 and L5 the dimensions of the posterior elements suggest that weight is transferred from the anterior to the posterior pillar, moderately in L4 but markedly in L5. The inclination of the pedicles is almost horizontal, but, due to the inclined position of the L5 vertebral body, the pedicle inclination is increased. Load through these inclined pedicles should however pass upwards opposite to the direction of inclination. Pal and Routal (1987) use the following principle to explain the mechanism of weight transfer between the anterior and posterior pillars at this level:

> "In an inclined beam which is connecting the two columns load will only pass towards gravity. But if such a beam is free towards its lower end it will transmit the load even against gravity".
> (op.cit. p 102)

If the body and pedicles of L5 are considered to form an inclined beam which is free at the lower end and is fixed posteriorly at the lumbosacral articular facets, part of the load received by the body will be transferred, according to this principle, upwards against gravity, through the strong pedicles to the laminae of L5 (Fig. 9.78).

Pal and Routal (1987) do not mention the increase in the size of the L5 transverse processes reported by Davis (1961) and observed in the present study. Davis (1961) finds that the smaller the body area of L5 in relation to L4, the bigger the size of L5 pedicles relative to those of L4. This would suggest that part of the vertical compressive force is transmitted to the pelvis via the neural arch. The same signifi-

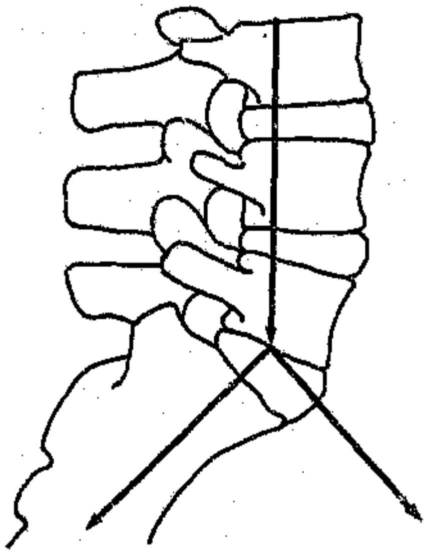

Fig. 9.78 The Inclined Position in L5 of Modern Man and the Resolution of the Vertical Downward Force (after Davis, 1961)

cant inverse relationship is found between the transverse process size and the inferior area of L5 relative to L4. He suggests that, in modern man, the normal lumbar lordosis present in the upright posture places the disc surfaces at an angle to the vertical, so that the compressive force from above can be resolved into two components (Fig. 9.78). One component, acting obliquely downwards and backwards, is supported by the vertebral bodies. The other component acts forwards and tends to slide L5 forwards into the pelvis. This tendency is resisted by the lumbar and lumbosacral articular facets and by the iliolumbar ligaments which pass obliquely forwards from the transverse processes to the iliac crests. The significant inverse relationship between the pedicle size and inferior area of L5 relative to L4 supports his view that in the human spine *the neural arch is responsible for transmission of part of the vertebral compressive force from the vertebral column to the pelvis*. The similar relationship in the size of the transverse processes found in this study suggests that part of this neural arch transmission is carried through the transverse processes and thus, by inference, through the iliolumbar ligaments.

The author is thus of the opinion that the principle proposed by Pal and Routal (1987) to explain the transfer of weight through the pedicles of L5 applies also to the transverse processes and iliolumbar ligaments. The so-called anterior iliolumbar ligament is described by Bogduk and Twomey (1987) as forming a thick bundle beyond the tip of the transverse process of L5 which passes posterolaterally, in line with the long axis of the transverse process, to attach to the iliac crest. If the body and the transverse process, which spreads its base forward on to the body, and the anterior iliolumbar ligament of L5 are considered to form an inclined beam which is free at the lower end and is fixed posteriorly at the ilium, part of the load received by the vertebral body will be transferred upwards through the strong transverse processes and the iliolumbar ligaments to the ilium. It is thus suggested that both the laminae and the transverse processes take part in the transmission of part of the load transferred from the anterior pillar, though the laminae may carry a larger percentage.

Before the results of a comparison between modern human and the African and Asian great ape spinal columns are discussed, it must again be emphasized that in the present study only five anthropoid ape vertebral columns have been available for mensuration. The results must thus be regarded as highly tentative.

The inferior body surface area, in pongids as in modern man, increases from the first thoracic to the second last lumbar vertebra, followed by a decrease at the last lumbar vertebra. In the thoracic region the lamina index values of the apes present the same pattern as modern human vertebrae. These values decrease from the upper to the middle, followed by an increase in the lower, and a decrease in the last two or three thoracic vertebrae. The lamina index/inferior body area ratio, as in modern man, differs from the lamina index in that this ratio decreases from the first to the last thoracic vertebra. The pedicle size tends to decrease from T1 to ± T5 and then to increase to L1 or L2. These data present thus the same tendencies as modern man up to T10. The mechanisms of weight transmission downwards and of load transfer between the anterior and posterior pillars in this region of anthropoid ape spinal columns thus probably correspond with those described for modern human columns.

In the last two or three thoracic vertebrae the pedicle size of apes differs from that of modern humans. In modern man the pedicle size decreases from T11 or T12 to L2, whereas this size increases to L1 or L2 in the pongid spinal columns. Associated with the increase in pedicle size are an increase in the transverse process size and a decrease in lamina size, down to the second last thoracic vertebra of the pongids. In all five ape spinal columns, the second last ribs still articulate with the transverse processes and thus transfer load to it. The laminae do not however increase, which may indicate that more weight is transferred to the anterior pillar through the strong inclined pedicles than is received by the transverse processes.

The results for the lumbar region differ considerably between the ape series and modern man. Whereas the <u>lamina size increases</u> from L1 to L5 in modern man, in all five spines of anthropoid apes a <u>decrease</u> occurs from L1 to L3, while in three of the five columns a further decrease occurs at L4. In the other two ape columns a slight increase occurs at L4. Though the pattern which is presented by the pedicle size in the apes is not very clear, the general trend seems to be an increase down to L2, followed by a decrease at L3 and an increase at L4. The arch index also decreases [illegible] to L4 which indicates that the posterior pillar [illegible] the anterior pillar downwards. With the vertebral column in the oblique position, the pedicles represent inclined beams between the anterior and posterior pillars and load is thus transferred from posterior to anterior by gravity.

At the level of the last lumbar vertebra both the body area and the lamina size in the apes decrease, in contrast to the increase in lamina size of the last modern human lumbar vertebra. In association with these decreases in the pongid series, the pedicle index and the transverse process size increase in the last lumbar vertebra. In relation to the decreased body area of this vertebra these dimensions also show an increase. In modern man part of the vertical compressive force is thought to be transmitted to the posterior arch via the strong pedicles. This force is transferred partly to the sacrum through the articular facet joints and partly to the pelvis via the strong transverse processes and the iliolumbar ligaments. From the data on the pongids it is evident that the laminae do not transmit additional load at this level. It seems thus that a different mechanism of weight transfer to the pelvis characterizes the apes: the major mechanism for weight transfer would seem to involve enlarged transverse processes of the last lumbar vertebra.

The pongid vertebral columns do not present a lumbar lordosis and therefore the abrupt change in direction between the last lumbar vertebra and the sacrum which occurs in modern man, is not present. The last two lumbar vertebrae lie embedded between the supero-inferiorly elongated iliac bones. Recently, an opportunity has arisen for the author to dissect the iliolumbar ligaments of a female *Gorilla*. It has been found that these ligaments consist of an upper horizontal ligament between the transverse process of the second last lumbar vertebra and the inner lip of the crest of the ilium and a lower fan-shaped ligament which radiates from the transverse process of the last lumbar vertebra to the inner lip of the crest and the inner surface of the ilium (Fig. 9.79). The fibres of these ligaments and those of the sacro-iliac ligament below are continuous to form a virtually single functional unit judged by appearance. These results correspond with the description of the iliolumbar ligaments in *Pan* (Sonntag, 1923) and in rhesus monkeys (Pun *et al.*, 1987).

The decrease in inferior body area of L4 in our pongid spines suggests that part of the weight received from above does not reach the sacrum through the inferior surface of the body. The enlarged pedicles suggest transfer of weight, but not to the posterior pillar (the laminae), as in modern man, since the lamina size decreases and the lamina size/inferior body area ratio also shows no increase. The transverse processes of the last lumbar vertebrae show tremendous increases in most of the pongid columns. From these results and the presence of strong iliolumbar ligaments which attach the last lumbar vertebrae to the ilia in much the same manner as the sacrum, it is suggested that part of the weight receiv d by the vertebral body of L4 is transferred to the pelvis via the enlarged transverse processes and the iliolumbar ligaments.

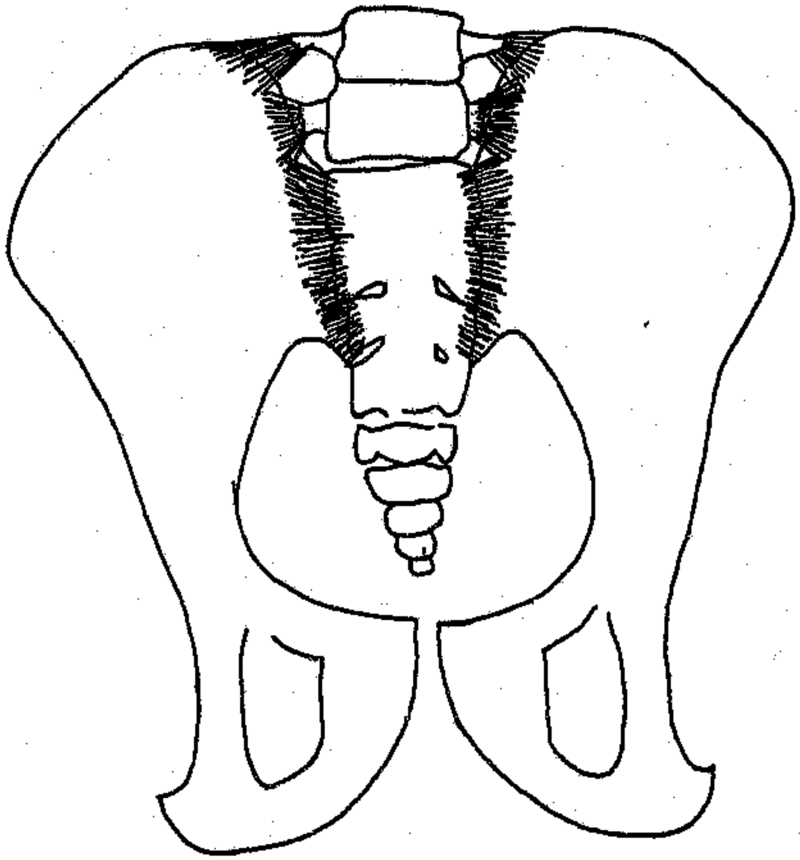

Fig. 9.79 Observed Iliolumbar Ligaments in a Dissected *Gorilla* Female

The relation between the iliolumbar ligaments and the upright posture has been stressed in recent studies. Pun *et al.* (1987) compare rats, rabbits, dogs and rhesus monkeys and show that only the latter, which are able to sit in an upright position, possess iliolumbar ligaments. Luk *et al.* (1986) find that the iliolumbar ligament is not present in modern man at birth. It develops gradually from metaplasia of muscle fibres of the quadratus lumborum muscle into collagen fibres during the first two decades of life. Both these studies suggest that the development of the iliolumbar ligament is directly related to stress created across the lumbosacral junction when the erect posture is assumed.

A comparison of the *A. africanus* results with those of the modern human and pongid vertebral columns shows that the same tendencies, and thus presumably the same weight-bearing mechanism, occur in the middle thoracic region of all three groups.

At the thoracolumbar junctional area the pedicle size of Sts 14 increases from the second last thoracic vertebra to L1. This increase resembles the pattern presented by the anthropoid apes. Modern human columns, on the other hand, show a decrease in pedicle size from T11 to L2. In relation to the inferior body area, the pedicle sizes of Sts 14 vertebrae show a sharp decrease from the last thoracic vertebra to L1. This decrease closely resembles the tendency in modern human vertebrae at this level. The increase in the pongid pedicle sizes down to L2 suggests that, in the thoracolumbar junctional area, of the load transmitted through the posterior pillar, a larger part is transferred to the anterior pillar in pongid columns than in Sts 14 and in modern human columns.

In the upper lumbar region, the inferior body areas of Stw 431 vertebrae increase from L1 to L3. Unfortunately the inferior body areas of the last two lumbar vertebrae of Stw 431 are not available. Sts 14 shows a slight decrease from L1 to L2 followed by an increase at L3. Relative to the body area, the lamina sizes of L1 and L2 of Sts 14 are equal, followed by a slight increase at L3, while the pedicle size decreases from L1 to L2 and L3, the latter two of which have equal values. These data indicate that no transfer of weight occurs from the posterior to the anterior pillar in Sts 14 at L1 to L3. Each pillar thus transmits the load from the vertebrae above, plus the segmental load which is added at each level and seems to influence the anterior pillar to a greater degree in Sts 14. The mechanism of weight transmission at the level of the upper lumbar vertebrae of Sts 14 is thus in accordance with the mechanism found in modern human columns.

At the level of L4 in Sts 14 a slight decrease in inferior body area and lamina size occurs, while the pedicle sizes of L3 and L4 are equal. Relative to the inferior body area, the lamina size, the pedicle size and the transverse process size present equal ratio values from L1 and L4. Although the author is able to offer no explanation for the apparent slight decrease in both the anterior and posterior pillars in Sts 14, it seems that very little if any weight transfer occurs through the pedicles or transverse processes.

In the <u>last two</u> lumbar vertebrae of Sts 14 the inferior body area decreases. In modern human and ape spinal columns a decrease is found only in the <u>last</u> lumbar vertebra. Associated with this decrease in body area in Sts 14, the lamina index increases from L1 to L5. An increase is expected also in L6, as suggested by the reconstructed laminae. The lamina index/inferior body area ratio also shows an increase from L1 to L5. An increase is expected also in L6. The pedicle index and pedicle index/inferior body area ratio in Sts 14 also present an increase from L3 to L6. It seems thus as if weight is transferred from the vertebral bodies (anterior pillar) to the laminae (posterior pillar).

It is interesting to note that, in the last two lumbar vertebrae, apart from the values of the inferior body areas, the data for Sts 14 are the same as for L4 and L5 in modern human spinal columns. The same mechanism of weight transfer from the anterior pillar to the posterior pillar, as in modern human columns, may thus be inferred for *A. africanus*. The strong decrease in the inferior body areas of the last two lumbar vertebrae of Sts 14 implies that this transfer of weight, from the anterior to the posterior pillar, starts already in the second last lumbar vertebra.

In the last lumbar vertebra of modern human spinal columns, the transfer of weight from the anterior to the posterior pillar, in an 'antigravity' direction through the pedicles, is possible because of the inclined position of the body of L5. If weight is transferred from the anterior to the posterior pillar to a marked extent in the last two lumbar vertebrae of Sts 14, it may reasonably be inferred that both of these vertebrae were most likely carried in an inclined position (Fig. 9.80). In other words, L5 was probably situated at an angle relative to L6, and L6 at an angle relative to the sacrum. Instead of the abrupt angle between the last lumbar vertebra and the sacrum present in modern human vertebral columns (Fig. 9.78), Sts 14 seems to have presented a more gradual transition through a more gently curved lower lumbar region.

In the previous chapter it was recorded that both of the last two lumbar vertebrae of Sts 14 are markedly wedge-shaped: this observation would seem to support this hypothesis.

Unfortunately, the transverse processes of the second last lumbar vertebra of Sts 14 are broken. Whereas the transverse processes of the modern human second last lumbar vertebra show a slight decrease in cross-sectional area, an increase would be expected in Sts 14,since a decrease in the inferior body area is associated with an increase in lamina size. The attachment of a more rostral part of the iliolumbar ligament

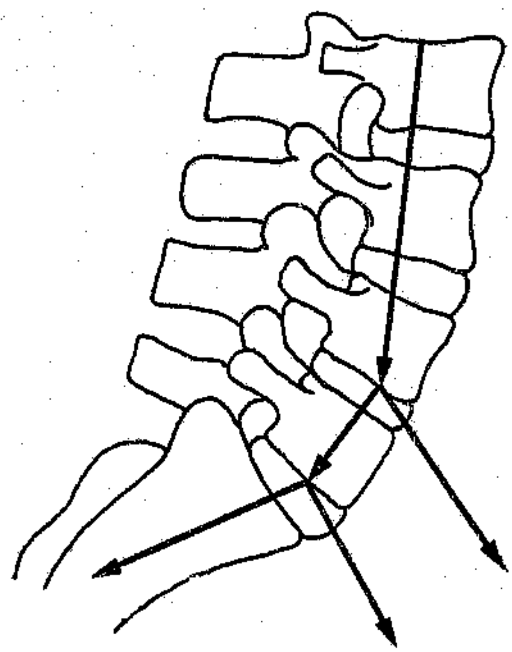

Fig. 9.80 Proposed Inclined Position of the Last Two Lumbar Vertebrae of Sts 14

to the transverse processes of the second last lumbar vertebra (L5) may have helped prevent the anterior slipping (or spondylolisthesis) of the inclined second last lumbar vertebra of Sts 14.

To confirm whether or not the presence of the "extra" lumbar vertebra in Sts 14 is the reason for this proposed more gradually curved lower lumbar region, the inferior body areas of the lumbar vertebrae of six Zulu male spinal columns with six lumbar vertebrae each have been calculated. In these columns a decrease in the inferior body area occurs only at the last lumbar vertebra.

In Stw 431, the second last lumbar vertebra is of equal anterior and posterior vertical heights, while the last lumbar vertebra is anteriorly wedge-shaped. Unfortunately, the inferior vertebral body areas of these two lumbar vertebrae are not available. It is thus not known whether an *A. africanus* vertebral column with only five lumbar vertebrae would have presented the same, less marked, elongated curvature due to the inclination of the last two lumbar vertebrae as Sts 14. The only indirect evidence available is the pedicle size of the last three lumbar vertebrae of Stw 431 which increase sharply, much in the manner of modern human pedicle sizes and appreciably more rapidly than those of Sts 14.

The mechanism of weight transfer between the last lumbar vertebra and the pelvis seems to be the same in Sts 14 and in modern human spinal columns. The decrease in inf[illegible]r body area is associated with an increase in the pedicle [illegible], the lamina index, the transverse process index and the arch index. Relative to the inferior body area these index values also show an increase. Weight is transferred from the last lumbar vertebral body to the posterior arch. Part of this neural arch transmission is carried through the laminae and inferior articular facets, while [illegible] is carried through the transverse processes and, by inference, through the iliolumbar ligaments.

H. Summary and Conclusion

1. The metrical trends shown by Zulu vertebral columns are similar to those of Indian spines (Pal and Routal, 1986, 1987).

2. In the thoracic region the transverse process index and transverse process index/inferior body area ratio confirm for the Zulu spine the mechanisms of weight transfer between the anterior and posterior pillars suggested by Pal and Routal (1987).

3. In the thoracic region, down to the level of T10, the trends presented by the lamina, pedicle, transverse process and arch indices and by the ratios of these individual values to the inferior body areas suggest that at this level human and pongid vertebral columns are adapted to the same mechanisms of weight transmission downwards and of weight transfer between the anterior and posterior pillars of the spinal columns.

4. The apes differ from the two hominid groups in the thoracolumbar junctional area, in that weight is transferred from the posterior to the anterior pillar through the strongly inclined pedicles. Such transfer is associated with a decrease in pongid lamina size in this region.

5. In the lumbar region the laminae of apes decrease in size from L1 to L4, while those of modern man and of Sts 14 present an increase. More weight is thus transmitted through the <u>posterior</u> pillar in the two hominid groups. This may be associated with the lordotic curve which in these hominids tends to transmit more load to the posterior pillar.

6. At the last lumbar vertebra in modern human spinal columns, a decrease in inferior body area is associated with an increase in pedicle size, in lamina area, in transverse process size and in the arch index. At this level the ape spinal columns show an increase in the pedicle and transverse process sizes, but a <u>decrease</u> in the lamina size and in the arch index. The mechanism of weight transfer to the pelvis thus differs between the two groups. In the modern human columns, part of the weight received by the vertebral body of L5 is transferred to the neural arch. The increased sizes of the transverse processes and the laminae suggest that part of this neural arch transmission is transferred to the pelvis through the laminae and part through the transverse processes and the iliolumbar ligaments. In the ape spinal columns, part of the weight received by the body of the last lumbar vertebra is thought to be transferred to the ilia through the transverse processes and the iliolumbar ligaments, but not through the laminae. The absence of a lordotic curve and the enclosure of the last two lumbar vertebrae between the ilia are thought to play a rôle in the increased transfer through the transverse processes.

7. The last lumbar vertebra of Sts 14 presents the same metrical features as those of modern human vertebral columns. This suggests the same mechanism of weight transfer to the pelvis at that level. However, the transmission of load <u>through the lumbar region</u> differs from that of modern man, in that in Sts 14 the inferior area of L4 decreases slightly, followed by a more definite decrease in the last <u>two</u> lumbar vertebrae. From the increasing pedicle and lamina size, it is suggested that part of the weight received by the vertebral bodies of the last two lumbar vertebrae is transferred to the neural arch. It is found that both these vertebrae are anteriorly wedge-shaped. Accordingly the author proposes that in Sts 14 L5 might have been situated at an angle

relative to L6, and L6 at an angle relative to the sacrum. These results suggest that Sts 14 displayed a more gradually curved lower lumbar region and a less abrupt lumbosacral transition than obtains in modern man.

CHAPTER 10

GENERAL CONCLUSIONS

Contents of Chapter:

A. Differences between African and Asian Great Apes

The outstanding difference between African and Asian great ape vertebral columns is the modal number of presacral vertebrae (PSV). Phylogenetically shortening of the vertebral column by evolutionary migration of the pelvis in a cephalic direction has gone distinctly further in the Asian than in African great apes. *Pongo* vertebral columns present a modal number of 23 PSV with almost equal (no significant difference) tendencies towards lengthening and shortening. The African and Asian great ape vertebral columns, on the other hand, show a modal number of 24 PSV with a significantly greater tendency towards shortening than lengthening.

In the thoracic region *Pongo* vertebral columns present a modal number of twelve thoracic vertebrae in contrast with the modal number of thirteen thoracic vertebrae in African great ape columns. The frequencies of variation in the numbers of thoracic vertebrae show a tendency to an increased number of fourteen thoracic vertebrae in *Pan* columns while *Gorilla* columns present an almost equal distribution of the plus- and minus-variants. *Pongo* vertebral columns, on the other hand, present a tendency towards a decreased number of eleven thoracic vertebrae.

The numbers of lumbar vertebrae range between three and five with four the modal number in both African and Asian great ape vertebral columns. The frequencies of the specific variants show a strong tendency towards shortening of African great ape lumbar region. *Pongo* presents a greater, though not significantly so, incidence of five than of three lumbar vertebrae. This apomorphic trend to shortening seems to link the African apes, *Gorilla* and *Pan*, closer together.

B. Differences between African and Asian Great Apes and Modern Man

1. Numerical Traits

The modal number of PSV suggests a closer relationship between modern man (24 PSV) and the African great apes (24 PSV) than between modern man and *Pongo* (23 PSV). *Gorilla* and *Pan*, however, show a higher tendency to departures from the mode than *Homo sapiens*. In the frequencies of variations of the numbers of PSV and of the numbers of lumbar vertebrae, modern man shows greater tendencies to lengthening in contrast with *Pan* and *Gorilla* which tend to shorten both the vertebral column and the lumbar region. *Pan*, however has a definitely stronger tendency to 25 PSV than *Gorilla*.

Phylogenetically shortening of the vertebral column thus has gone distinctly further in *Pongo* than in African great apes and in modern man. It corroborates the current opinion on the cladistic relationships of the living apes and modern man as shown by morphological and molecular studies (Andrews and Cronin, 1982). The evolution of hominoids involved first the divergence of the gibbons, followed by the orang-utans, followed by a split between hominids, chimpanzees and gorillas. Evidence as to the order of the last divergence is at present equivocal. The higher frequency of 25 PSV in *Pan* than in *Gorilla* vertebral columns, supports evidence from the amino acid sequence data which hints at the possibility that *Pan* is more closely related to *Homo* than to *Gorilla*.

2. Other Non-metrical and Metrical Traits

The general vertical vertebral index values of modern human lumbar regions indicate moderately good bony adaptation to an anteriorly convex lumbar curve (lordosis). In contrast the *Gorilla* and the *Pan* columns present good bony adaptation to an anteriorly <u>concave</u> lumbar region.

Differences in the morphology of the articular facets of modern human and anthropoid ape lumbar vertebrae are closely associated with the difference in curvature. In modern man the lumbar superior articular facets face progressively more backwards from the first to the last lumbar vertebra. The lower lumbar vertebrae tend to be anteriorly displaced in the anteriorly convex lumbar region due to their oblique positions. The more backwardly orientated articular facets of these vertebrae are effective in the resistance to anterior displacement. In contrast, the pongid lumbar superior articular facets face progressively more medially from the first to the last lumbar vertebra. The tendency to anterior displacement of the lower lumbar vertebrae is considerably less in the pongid anteriorly concave lumbar region. The last two lumbar vertebrae are furthermore embedded between the supero-inferiorly elongated ilia to which they are attached by strong iliolumbar ligaments in much the same manner as the sacrum. This strong arrangement resists the possible tendency of forward displacement of the last two lumbar vertebrae due to the oblique posture of the vertebral column and thus reduces the need for backward facing lower lumbar superior articular facets.

The configuration of the lumbar articular facets when viewed from behind shows that the inferior articular facets of the modern human last lumbar vertebra are placed as widely or even more widely apart as the superior articular facets. In contrast, it is found that the inferior articular facets tend to be placed nearer to each other than the superior articular facets in the pongid last lumbar vertebra. The modern human facets are probably placed further apart to carry a larger part of the vertical load, as part of the load carried by the vertebral bodies is transferred to the laminae of L5 due to the oblique position of this vertebra in the lordosis (discussed under the next heading).

3. Weight-bearing Mechanism

The results of the present study on the inferior vertebral body area, the pedicle size, the lamina size, the arch index and the body-pedicle angle in Zulu thoracic and lumbar vertebrae corroborate the tendencies which emerge from Pal's and Routal's (1986, 1987) results for modern human (Indian) vertebrae. The transverse process size corroborates some of their explanations of weight transfer to the pelvis. It thus agrees with the mechanism of weight transmission through the vertebral column proposed by them, except at the level of L5. In essence two weightbearing pillars, an anterior formed by the vertebral bodies and a posterior formed by the laminae and articular facets are proposed, with the pedicles playing an important rôle in the transfer of load between the pillars.

The pongid thoracic regions present the same tendencies as modern man between T1 and T10. This suggests the same mode of weight transmission through this region in pongid and modern human vertebral columns. The posterior elements of T1 receive the weight transmitted through the cervical region (Pal and Routal, 1986) via the inferior articular facets of C7 plus the additional weight transmitted by the first ribs. Between T1 and T10 additional weight received from the ribs is transmitted through the laminae and inferior articular facets of the receiving vertebra to the next. Here the strong, inclined pedicles transfer part of the weight to the vertebral body.

The pongid last two or three thoracic vertebrae present an increase in pedicle size in contrast with the decrease shown by modern human vertebrae. This increase in pedicle size is associated with an increase in the transverse process size and a decrease in lamina size, down to the second last thoracic vertebra. It is found that, in contrast with modern man, the second last ribs still articulate with the transverse processes in all five pongid spinal columns and thus transfer load to it. This weight is transferred to the anterior pillar through the strong inclined pedicles of the last thoracic and first lumbar vertebrae.

The results of the lumbar region differ considerably between the ape series and modern man. In a comparison of the upper three lumbar vertebrae modern man shows an increase in the anterior pillar size, the posterior pillar size and the distance between the two pillars. These results seem to reflect the downward transmission of weight received from T12 and the additional segmental load added at each level in the two pillars with no weight transfer between them as indicated by the relatively weak and horizontal pedicles. The pongid columns, on the other hand, present an increase in the anterior pillar and pedicle sizes of L1 to L3 associated with decreases in the posterior pillar sizes and the distance between the pillars. It is suggested that the pedicles represent inclined beams between the anterior and posterior pillars due to the oblique position of the pongid vertebral columns and that load is thus transferred from the posterior to the anterior pillar by gravity.

The large increase in the lamina size of L4 in modern man is accompanied by a small increase in the inferior body area and strong pedicles. The dimensions of the posterior elements suggest moderate transfer of weight from the anterior to the posterior pillar.

At the level of the last lumbar vertebra both pongid and modern man present a decrease in the inferior vertebral body area. In modern man this decrease in the anterior pillar is accompanied by marked increases in the lamina size, in the pedicle size, in the size of the transverse processes and in the distance between the two pillars (arch index). Pal's and Routal's (1987) proposed mechanism of weight transfer to the pelvis is supported. It states that if the body and pedicles of L5 are considered to form an inclined beam which is free at the lower end and it is fixed posteriorly at the lumbo-sacral articular facets, part of the load received will be transferred upwards against gravity, through the strongly inclined pedicles to the laminae. It is however suggested that part of the load to the posterior pillar is transferred to the pelvis via the strong transverse processes and, by inference through the iliolumbar ligaments as proposed by Davis (1961).

The decrease in the inferior body area of the last lumbar vertebrae of the pongid vertebral columns is associated with decreases in the lamina size and the distance between the two pillars and by marked increases in the pedicle and transverse process sizes. The oblique pongid vertebral columns do not present a lumbar lordosis and therefore the abrupt change in direction between the last lumbar vertebra and the sacrum which occurs in modern man, is not present. Instead, the last two lumbar vertebrae lie embedded between the supero-inferiorly elongated iliac bones and strong iliolumbar ligaments attach the last lumbar vertebra to the ilia in much the same manner as the sacrum. The results associated with this morphology suggest that part of the weight received by the vertebral body of L4 is transferred to the pelvis via the enlarged transverse processes and the strong iliolumbar ligaments.

To summarise it may be said that load is transferred from the posterior to the anterior pillar in both modern human and pongid thoracic regions where the curvature is anteriorly concave. In the modern human lumbar region where the curvature is concave posteriorly, the load is transferred from the anterior to the posterior pillar and to the transverse processes in L5. Pongid lumbar regions present anteriorly concave curvatures and load is seen to be transferred from the posterior to the anterior pillar in the upper three vertebrae. In the last lumbar vertebra which is embedded between the supero-inferiorly elongated ilia, weight is transferred from the anterior pillar to the transverse processes.

C. The Posture of *Australopithecus*

The general vertical index values indicate good bony adaptation to an anteriorly convex lumbar curve in Sts 14 (between L2 and L6), an *A. africanus* female partial vertebral column. Moderate to good bony adaptation to an anteriorly convex lumbar region is expressed by Stw 431, an *A. africanus* male, partial column. These results correspond with those of modern human male and female vertebral columns. The curvature, orientation and configuration of the lumbar articular facets correspond with those of the modern human lumbar articular facets. The lumbar superior articular facets are less curved, and face progressively more backwards than medialwards from the first to the last lumbar vertebra. Less curved superior articular facets probably allow a greater possibility of rotation, while the more backwards facing facets of the lower lumbar vertebrae resist forward displacement of these obliquely placed vertebrae in a lordosis more effectively. The presence of the same tendencies of these features in the *A. africanus* superior articular facets as in modern man, suggests that these vertebrae suffered the same stresses as do modern human vertebrae, in a lumbar lordosis.

The articular facets of the *A. africanus* last lumbar vertebrae seem to be placed wide apart so as to form a rectangle with its long sides horizontal, when viewed from behind. This corresponds with the configuration of the articular facets of a modern human last lumbar vertebra and is in contrast with the trapezium with its base narrower than its top shown by the pongid vertebral columns. It is thought that the more widely placed inferior articular facets in *A. africanus*, as in modern man, carry larger part of the vertical load. Yang and King (1984) found that modern human normal lumbar articular facets carry 3 to 25% of the axial load.

The bony adaptation to a developed lumbar lordosis in the *A. africanus* partial vertebral columns and the posteriorly wedged individual lumbar vertebrae of *A. robustus* and *A. afarensis*, which indicate that they might have taken part in the formation of an anteriorly convex lumbar region, lead the author to conclude that the australopithecines probably carried the trunk erect. Because of the close association between extended lower limbs and the formation of the lumbar lordosis, as shown by Abitbol (1987a), it is further concluded that the australopithecines used extended lower limbs. Thus our results suggest a mode of bipedalism in these early hominids that corresponds with that of modern humans.

D. The Weight-bearing Mechanism of *A. africanus*

The metrical data associated with the weight-bearing mechanism of *A. africanus* thoracic and lumbar vertebrae present the same tendencies as those of modern human vertebrae. The only exception is the sharp decrease in the inferior vertebral body areas of the last two Sts 14 lumbar vertebrae while a decrease occurs only at the last lumbar vertebral level in modern man. Corroborated by the demonstrated presence of a lumbar lordosis in *A. africanus*, the same mechanism of weight transmission as in modern man may be inferred for *A. africanus* vertebral columns.

In the thoracic region load is transferred from the posterior to the anterior pillar. Weight received from the last thoracic vertebra and the additional segmental load added at each level are transmitted downwards in the two pillars of the upper lumbar vertebrae with no weight transfer between the pillars. In the last two lumbar vertebrae of Sts 14, associated with the decrease in the inferior vertebral body area, are an increase in lamina size and an increase in pedicle size. It seems thus as if weight is transferred from the vertebral bodies (anterior pillar) to the laminae (posterior pillar). This corresponds with the mechanism of weight transfer through the pedicles of the last lumbar vertebra in modern man which is possible because of the inclined position of the body of L5 in the modern human lumbar lordosis. It is found that both L5 and L6 of Sts 14 are anteriorly wedge-shaped. It is thus suggested that in Sts 14 L5 might have been situated at an angle relative to L6, and L6 at an angle relative to the sacrum. Sts 14 thus seems to have presented a more gradually curved lower lumbar region and a less abrupt lumbosacral transition than obtains in modern man.

The mechanism of weight transfer between the last lumbar vertebra and the pelvis seems to be the same in Sts 14 and in modern human spinal columns. The decrease in inferior body area is associated with an increase in the pedicle index, the lamina index, the transverse process index and the arch index. Relative to the inferior body area these index values also show an increase. Weight is transferred from the last lumbar vertebral body to the posterior arch. Part of this neural arch transmission is carried through the laminae and inferior articular facets, while part is carried through the transverse processes and, by inference, through the iliolumbar ligaments.

Unfortunately, the transverse processes of the second last lumbar vertebra of Sts 14 are broken. Whereas the transverse processes of the modern human second last lumbar vertebra show a slight decrease in cross-sectional area, an increase would be expected in Sts 14, since a decrease in the inferior body area is associated with an increase in lamina size. The attachment of a more rostral part of the iliolumbar ligament to the transverse processes of the second last lumbar vertebra (L5) may have helped prevent the anterior slipping (or spondylolisthesis) of the inclined second last lumbar vertebra of Sts 14. This will also explain the less marked increase in the size of the transverse processes of the last lumbar vertebra of Sts 14 compared with the marked increase in modern man.

The inferior vertebral body areas of the last two lumbar vertebrae of Stw 431, which are anteriorly wedge shaped, are unfortunately not available. It is thus not known whether an *A. africanus* vertebral column with only five lumbar vertebrae would have presented the same, less marked, elongated curvature due to the inclination of the last two lumbar vertebrae as Sts 14. The only indirect evidence available is the pedicle size of the last three lumbar vertebrae of Stw 431 which increase sharply, much in the manner of modern human pedicle sizes and appreciably more rapidly than those of Sts 14.

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