HUMAN LOWER LUMBAR VERTEBRAE: SOME MECHANICAL AND OSTEOLOGICAL CONSIDERATIONS

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INTRODUCTION

In man, the vertebral column supports the weight of the trunk and upper limbs, and also sustains much of the weight of burdens borne upon these parts of the body. The structure of the chain of vertebral bodies and intervertebral discs (Wyman, 1857; Wagstaffe, 1874; Gallois & Japiot, 1925) and mechanical considerations (Rauber, 1876; Petter, 1933; Bradford & Spurling, 1945; Davis, 1959) indicate that these weights subject this chain mainly to vertical compression forces, the magnitude of which increase from the axis to the lumbo-sacral joint. Therefore one would expect the size of the vertebral bodies to increase in the same direction, the lowest lumbar vertebra being the largest. In general this assumption is supported by serial measurements of the vertebral bodies, the linear dimensions increasing down to the level of the third or fourth lumbar vertebra. In the last two lumbar vertebrae, however, some variation occurs, and in some cases the linear diameters of the vertebral bodies are decreased: for example, in Aeby's (1879) series, two out of twenty-eight columns had a smaller transverse diameter in L5 than in L4; in Cunningham's (1886) series of sagitto-vertical indices in fifty-seven columns from many races, twenty-two had a larger index for L5 as compared with L4, it being equal or smaller in the remaining thirty-five; Anderson (1883), giving average dimensions from a series of twenty-eight columns, found that the antero-posterior diameter of L4 was less than that of L3, and that on average this diameter of L5 equalled that of L3. However, since resistance to pressure by a uniform structure depends upon its cross-sectional area, linear dimensions alone might give a false impression. Vertebral bodies are fairly uniform in internal structure (Gallois & Japiot, 1925), and it is therefore to be expected that their cross-sectional areas, or more simply the areas of the upper or lower surfaces of the vertebral bodies, would better represent their ability to resist longitudinal compression than do their linear dimensions. Davis (1955, 1958) has measured the areas of the upper surfaces of the vertebral bodies in nineteen columns, and his findings support those of the previous authors, for in eight out of the nineteen the area of L4 was equal to or larger than that of L5.

Reduction in size of the lower one or two lumbar vertebral bodies suggests that less compressive force is exerted upon them than on those immediately above; this being so, part of the total compressive force must be transmitted to the pelvis by some other mechanism. The inaccessibility of the lumbar vertebrae and of the lumbo-sacral joint makes direct assessment of the forces acting in this region extremely difficult. If, however, one assumes that the size of a given portion of a vertebra is related to the magnitudes of the forces acting upon it, then comparison of the size of that portion in different vertebrae from one individual should provide an assessment of the relative magnitudes of those forces at different levels.

In most subjects the normal lumbar lordosis present in the upright position places the disc surfaces of the lower lumbar vertebral bodies at an angle to the vertical (Fig. 1) so that the vertical compression from above (*A* in Fig. 1) can be resolved into two components, one acting obliquely downwards and backwards (*B*) the other acting forwards (*C*). Component *B* is clearly supported by the vertebral bodies; component *C*, which tends to slide the fifth lumbar vertebra forwards into the pelvis,

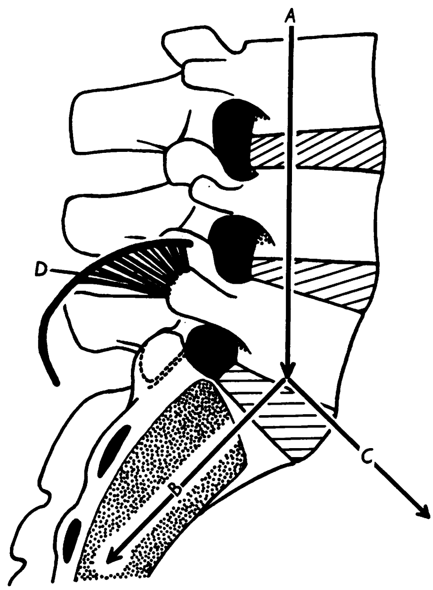

Fig. 1. Diagram to show the mechanical considerations. *A* is the vertical compression force, which can be divided into postero-inferior (*B*) and antero-inferior (*C*) components. *D* is the superimposed outline of the posterior part of the right iliac crest with the posterior part of the ilio-lumbar ligament attaching it to the sacrum. The plane of the lumbo-sacral zygopophyseal joint surfaces are shown in broken outline. (The right ala of the sacrum has been removed.)

would appear to be resisted by appendages of the fifth lumbar neural arch: the lumbar and lumbo-sacral zygopophyseal joint surfaces (broken line in Fig. 1) are so placed that normally they can prevent forward sliding of L 5 upon the sacrum, and as the ilio-lumbar ligaments pass obliquely forwards from ilium to transverse process they too may resist such a tendency. Since the fifth lumbar vertebra is exposed to both components, one might expect two structural modifications. First, an increase in relative size of its pedicles to transmit forces from the vertebral body to the neural arch, and secondly, should the ilio-lumbar ligaments be mainly responsible one would expect also an increase in relative size of its transverse processes.

For these reasons measurements have been made of the areas of the lower lumbar vertebral bodies and of the sizes of the pedicles and transverse processes in a series of late juvenile and adult West African vertebral columns, and the results collated.

MATERIAL

Through the kindness of Prof. Smith at Ibadan it was possible to examine his very large collection of West African material.

Forty-two male and thirty female West African vertebral columns were selected from over 200 adult and young adult columns available as being those which were free from artefacts, pathological changes and numerical and other anomalies. While the stated ages at death were available for most of these skeletons, little reliance could be placed upon them as births are not registered, and precise age plays little part in West African society; this series has therefore been divided into adult (35♂, 24♀) and young adult (7♂, 6♀) groups; those in which not all, but at least eight vertebrae have their epiphyseal rings fused to the bodies have been classified as young adults. A juvenile series of seven columns was also examined, including those in which the rings were present but had fused in less than eight vertebrae.

METHODS

The areas of the lower vertebral body surfaces have been obtained by tracing their outline on to paper with a sharp hard pencil, and then measuring the areas in square centimetres with an architectural planimeter.

The size of the pedicles was assessed by obtaining the pedicle index (Davis, 1955) which is the product of the greatest and least diameters of a pedicle at its most slender portion. These were measured with callipers. The mean of the indices of the two sides was then calculated to give the *mean pedicle index* for each vertebra.

The size of the transverse processes was assessed by obtaining the product of the greatest and least diameters at a point one-third of the distance from the lateral aspect of the superior articular process to the tip of the transverse process, measured with calipers. The buttress for the articular process terminates medial to this point and most of the muscular attachments lie laterally; the dimensions at this point are thus those best suited to mechanical analysis. The mean of the values of the two processes in each vertebra was then calculated, and called the *mean transversal index*.

Thus, three figures were obtained in each of the lower three lumbar vertebrae in each column, namely the area of the lower surface of the vertebral body, the mean pedicle index, and the mean transversal index.

In order to allow comparison of these indices in different individuals, in each column the ratios (L3 × 100)/L4 and (L4 × 100)/L5 were then calculated for each of these indices. In the adult and young adult series the ratios of the areas were compared with those derived from the pedicles, and then with those derived from the transverse processes, by graphic means and by regression calculations.

RESULTS

The measurements

(*a*) *The areas of the lower surfaces of the vertebral bodies* (Table 1)

In all groups the mean area of the lower surface of the body of L4 is slightly greater than that of L3. The mean area of L5 is smaller than that of L4. In both

Table 1. *The areas in square centimetres of the lower surfaces of the lower three lumbar vertebrae in seventy-two West Africans*

	Males				Females			
	Mean area (cm.^{2})	Range	Standard deviation	No. of columns	Mean area (cm.^{2})	Range	Standard deviation	No. of columns
				Adults				
L3	13·4	11·1–16·1	1 1		11·3	9·3–13·6	1·0	
L4	14·0	11·6–17·0	1·2	35	11·9	9·6–13·8	1·0	24
L5	12·8	10·2–16·4	1·3		11·3	8·8–12·5	1·0	
				Young adults				
L3	12·9	10·4–15·0	1·5		11·0	9·0–14·8	2·1	
L4	13·3	10·7–16·0	1·6	7	11·9	9·9–16·3	2·2	6
L5	12·2	10·2–14·7	1·4		11·1	9·0–14·9	2·0	

male groups the mean area of L5 is smaller than that of L3 also. The findings in the two sexes do not differ significantly from each other.

Summarizing the results for individual columns the area of L3 was greater than that of L4 in five out of forty-two males, and one out of thirty females; that of L4 was greater than that of L5 in thirty-five out of forty-two males and twenty-five out of thirty females: the differences in frequency in the two sexes is not significant in either case.

Table 2. *The mean pedicle indices in square centimetres in adult and young adult West Africans*

	Males				Females			
	Mean area (cm.^{2})	Range	Standard deviation	No. of columns	Mean area (cm.^{2})	Range	Standard deviation	No. of columns
				Adults				
L3	1·40	0·89–1·73	0·18		1·23	0·88–1·62	0·21	
L4	1·61	1·10–2·10	0·25	35	1·37	1·02–1·83	0·26	24
L5	2·17	1·44–3·23	0·42		1·90	1·35–2·58	0·31	
				Young adults				
L3	1·32	1·00–1·84	0·28		1·12	0·78–1·59	0·29	
L4	1·59	1·23–2·34	0·36	7	1·32	0·94–1·75	0·29	6
L5	2·01	1·49–2·64	0·40		1·68	1·50–2·08	0·21	

(*b*) *The mean pedicle indices* (Table 2)

The mean pedicle indices have a constant pattern in all groups, there being an increase from L3 to L5. The magnitudes of the standard deviations indicate the considerable variability in individual measurements, this being most marked in the fifth lumbar vertebra. Again the findings in the two sexes did not differ significantly.

(*c*) *The mean transversal indices* (Table 3)

The mean transversal indices show that the fifth lumbar transverse processes are much stouter than their higher counterparts, and that on average the fourth lumbar

Table 3. *The mean transversal indices in square centimetres in adult and young adult West Africans*

	Males				Females			
	Mean area (cm.²)	Range	Standard deviation	No. of columns	Mean area (cm.²)	Range	Standard deviation	No. of columns
				Adults				
L3	0·36	0·24–0·50	0·07	35	0·29	0·20–0·56	0·08	24
L4	0·26	0·14–0·55	0·09		0·26	0·15–0·50	0·09	
L5	1·20	0·52–2·87	0·53		0·78	0·25–1·41	0·99	
				Young adults				
L3	0·32	0·17–0·50	0·10	7	0·26	0·19–0·32	0·05	6
L4	0·25	0·20–0·30	0·04		0·19	0·14–0·28	0·05	
L5	0·87	0·45–1·55	0·41		0·77	0·19–1·54	0·42	

process is less stout than the third in all the four groups. As with the pedicle indices, the greatest individual variation occurs in the fifth lumbar vertebra.

(*d*) *Juveniles* (Table 4)

Although the differences are not so striking in these young specimens, they do have an over-all pattern similar to that of the adults, with the exceptions of the transversal indices in J 3 and J 4, in which the fifth lumbar transverse processes are less robust than in those above.

Table 4. *The measurements in five male and two female juvenile West African columns*

		Male columns					Female columns	
		J 1	J 2	J 3	J 4	J 5	J 6	J 7
Stated age (years) ...		6	7	9	9	10	8	12
Vertebral body area (cm.²)	L 3	7·3	7·9	9·0	9·2	9·6	8·5	6·3
	L 4	7·4	8·9	9·5	10·3	10·2	9·2	6·4
	L 5	7·0	9·2	9·3	9·7	9·4	9·0	6·2
Mean pedicle index (cm.²)	L 3	1·20	0·99	0·86	1·03	0·94	0·65	0·60
	L 4	1·19	1·29	0·90	1·10	1·05	0·85	0·61
	L 5	1·26	1·30	0·98	1·19	1·23	1·24	0·87
Mean transversal index (cm.²)	L 3	0·37	0·35	0·25	0·28	0·27	0·22	0·22
	L 4	0·22	0·35	0·21	0·15	0·20	0·20	0·20
	L 5	0·42	0·36	0·21	0·13	0·72	0·64	0·85

One can summarize these results by saying that most frequently the area of the lower surface of the body of L 4 is larger than in either L 3 or L 5, that the pedicles increase in size from above downwards, and that the transverse process of L 5 is usually much larger than that of L 3 or L 4, L 3 being larger than L 4.

The ratios

(1) Comparisons between the relative sizes of the vertebral pedicles and the areas of the bodies are presented graphically in Figs. 2 and 3.

It will be noted that in Fig. 2, which compares the ratios (L 3 × 100)/L 4 for pedicles and areas, there is no clear correlation between the differences in the areas and those in the pedicles in these two vertebrae in any group. Fig. 3, which compares the ratios (L4 × 100)/L5 for pedicles and vertebral body areas, shows an apparent inverse correlation between the ratios, that is to say that the smaller the area of L5 in relation to L4, the bigger the size of the L5 pedicle relative to L4. Statistical tests of this show that this correlation is significant. Comparing the two sets of figures in both males and females, one obtains for males $r = -0{\cdot}633$, $t = 10{\cdot}00$, $P < 0{\cdot}001$; for females $r = -0{\cdot}798$, $t = 11{\cdot}62$, $P < 0{\cdot}001$. The correlation does not differ significantly between the two groups ($z♂ - z♀ = 0{\cdot}353$, S.E. $= 0{\cdot}248$). Regression lines for the male and female groups have been inserted in the figure.

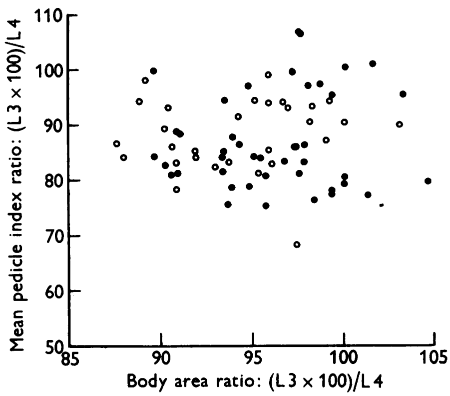

Fig. 2

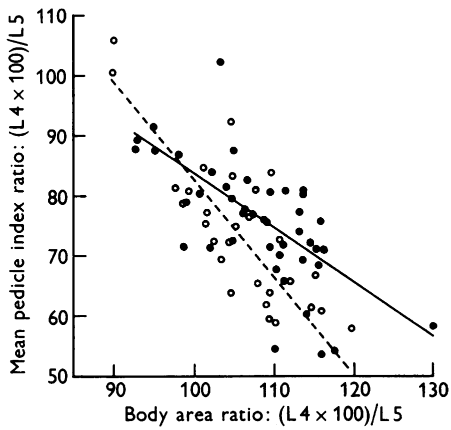

Fig. 3

Fig. 2. Comparison of the mean pedicle index ratios and body area ratios (L3 × 100)/L4 in West Africans. (For description see text.) Males, ●; females, ○.

Fig. 3. Comparison of the mean pedicle index ratios and body area ratios (L4 × 100)/L5 in West Africans. (For description see text.) Males, ●; females, ○. Male regression line, ——; female regression line, - - - -.

This significant negative correlation shows that, on average, the smaller the relative area of the vertebral body of L5, the greater is the thickness of its pedicle.

(2) Comparisons of the mean transversal index ratios (L3 × 100)/L4 with the area ratios (L3 × 100)/L4 are given in Figs. 4 and 5.

As with the pedicle indices, there is no significant relationship between the changes in size of the 3rd and 4th lumbar vertebral body areas and those of the transverse processes (Fig. 4).

The (L4 × 100)/L5 ratios, shown in Fig. 5, suggest that when the area of L5 is small relative to that of L4, the thickness of the L5 transverse process is relatively large. Again, statistical treatment of the data gives significant results; for males $r = -0{\cdot}549$, $t = 5{\cdot}17$, $P < 0{\cdot}001$; for females $r = -0{\cdot}449$, $t = 2{\cdot}658$, $P < 0{\cdot}002$. The correlations in the two sets of figures do not differ significantly from each other ($z♂ - z♀ = 0{\cdot}134$, S.E. $= 0{\cdot}250$).

(3) The results therefore show that, in both sexes, the relative sizes of the pedicles and transverse processes of L3 and L4 are not dependent on the relative sizes of

their vertebral body areas; there is, on the other hand, a significant inverse relationship between the relative sizes of both the pedicles and the transverse processes of L4 and L5 when compared with the relative sizes of their vertebral body areas.

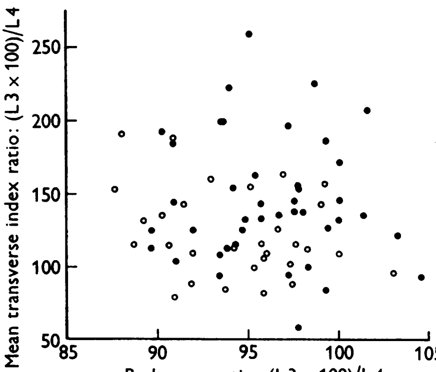

Fig. 4

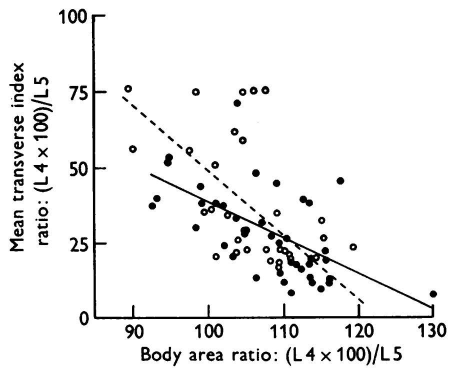

Fig. 5

Fig. 4. Comparison of the mean transverse index ratios and body area ratios (L3 × 100)/L4 in West Africans. (For description see text.) Males, ●; females, ○.

Fig. 5. Comparison of the mean transverse index ratios and body area ratios (L4 × 100)/L5 in West Africans. (For description see text.) Males, ●; females, ○. Male regression line, ——; female regression line, - - - -.

DISCUSSION

In this series of West African skeletons the finding that the area of the vertebral body of L5 is less than that of L4 in sixty out of seventy-four adult and young adult columns confirms the findings in other smaller series from different races, and suggests strongly that this is the common condition in man as a whole.

The significant inverse relationship between pedicle size and area of L5 when compared with L4 supports the view that the neural arch is responsible for transmission of part of the vertical compressive force from the vertebral column to the pelvis, and the similar relationship in size of the transverse processes suggests that part of this neural arch transmission is carried through the transverse process and, by inference, through the ilio-lumbar ligaments.

In most subjects it would appear that, in the upright position, pressure on the lumbo-sacral intervertebral disc is less than on the one above, the pressure on L5 being in part resisted by the neural arch. The neural arch components may be resisted by either the lumbo-sacral zygopophyseal joint surface or by the ilio-lumbar ligaments, and the significant inverse relationship between body size and thickness of transverse process in L5 suggests that these ligaments play a considerable part. Brailsford (1929) found that some 12% of 3000 subjects had lumbo-sacral zygopophyseal facets which faced inwards and could not therefore resist such a forward force; it would appear that in such individuals the ilio-lumbar ligaments are the sole mechanism resisting this tendency.

The lumbo-sacral intervertebral disc is the one most frequently affected by lumbar disc lesions (O'Connel, 1951; Armstrong, 1958). The present findings suggest strongly that in the upright position the pressure on the lumbo-sacral disc is less than on those above; clinical findings (Armstrong, 1958) show that lumbar disc lesions are most commonly sustained with the spine flexed. In this flexed position the lumbo-sacral angle is reduced so that the anterior component of the compression force is of less importance, and there is an increase in magnitude of the vertical component. This increase in the vertical component, coupled with the relatively smaller cross-sectional area of the vertebral body surface (and hence of the disc) may well play an important part in prejudicing the integrity of the lumbo-sacral disc in the flexed position, particularly when it is remembered that Virgin (1951) has shown that the upper lumbar discs can sustain a greater compression force per unit area than can the lower ones.

I wish to record my gratitude to Prof. A. Smith of University College, Ibadan, for allowing me access to his magnificent skeletal material. My thanks are due to Dr and Mrs A. J. Palfrey for their liberal hospitality, assistance and advice, to Prof. R. E. M. Bowden for her constant encouragement, and to the staff of the Photographic Department of the Royal Free Hospital School of Medicine. The work was made possible by generous financial assistance from the Royal Society and Nuffield Foundation.

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