

THE INFLUENCE OF WEIGHT-BEARING ON THE LUMBAR SPINE A RADIOLOGICAL STUDY

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Throughout Africa it is customary for Africans of the labourer class to transport objects of any appreciable weight by balancing these on the head. Considerable weights are often carried in this fashion without any discernible detrimental effect. These considerations, coupled with the presumption that the spines of these labourers are better equipped to withstand the compressive and tensile forces to which they are subjected than those of the European, have prompted the present investigation.

Most of the research done with weight-bearing was aimed at determining in how far the body posture is influenced by its relationship to the centre of gravity.¹ In the cases that were examined points of reference on the external surface of the body alone were used; thus reference points were applied to the knee, the hip and the shoulder. By this means only a relative impression of the adaptability of the body under conditions of weight-bearing was obtained. The adaptation is also influenced by the amount of dorsal placing of the weight.²

No literature or any references have been encountered which point to a radiological examination of the lumbar region where radiographs were made while the subjects were actually supporting the weights on their heads.

When a team of labourers carry bags of grain, etc. on their heads, they take turns in pairs to lift the bags on the heads of the others carrying the load.

The aim of the present study was to determine the adaptation of the lumbo-sacral region in the Bantu under the influence of weight-bearing, and why they prefer the bags on their heads rather than lifting them on the heads of others.

MATERIALS AND METHODS

A total of 77 Bantu men employed by flourmills were examined radiologically without and with weight-bearing directly on the head. The ages of the subjects who were examined varied from 23 to 45 years. Their period of service, during which they carried loads on the head, ranged from 3 weeks to 21 years. Radiographs of 54 of these subjects were found to be suitable for radiological measurements.

The following measurements were carried out on the X-rays (Fig. 1).

1. The movements between 2 adjacent vertebrae according to the method of Begg and Falconer.³

2. The sacral angle, i.e. the inclination of the superior surface of the sacrum, was determined by measuring the angle which the superior surface of the sacrum subtends with the horizontal in the erect position. This is an important measurement in view of its association with forces tending to cause forward slipping of one vertebra on another.

3. The inclination of sacrum relative to the horizontal plane which is known as the sacral inclination.⁴ It is the angle which a line joining the mid-points of the superior surface of S.1 and the inferior surface of S.2 makes with the horizontal plane (Fig. 1, /cde).

4. The lumbo-sacral angle which, according to the method of Mitchell,⁵ is formed by the lines which bisect the first sacral segment and the fifth lumbar vertebra (Fig. 1, /aob).

5. The inclination of the upper surface of L.5 relative to the horizontal plane, as well as the inclination of the other lumbar vertebrae, were noted. Particular attention was paid to the possible presence of any abnormalities which could be ascribed to the effect of carrying weights in this fashion.

Since the normal posture of an individual is determined by ligaments, articular facets and muscular systems, the X-rays were taken of the erect posture. It was thus possible to determine, firstly, the natural movements which are permitted in a specific region under the influence of normal body weight and, secondly, the changes occurring with weight-carrying. Only the antero-posterior projection of the lumbar region was done in the supine position.

For the purpose of standardizing the technique and guarding against any unnecessary radiation, all the exposures were made under personal supervision. After the tube height had been adjusted to centre on the iliac crests for any particular case, at a focal film distance of 3 feet, no further adjustments were made. Lateral view radiographs of the lumbar region were then taken both without and with weight-carrying on the head, the one immediately following the other. The X-rays and any measurements made on them were thus found to be comparable for any specific case. Where movements of the spine were examined, an attempt was made in each case to obtain the maximum possible movement.

The forces to which the 2 groups were subjected, namely those who lift the bags and those who carry them on their heads, were calculated according to the data supplied by Thieme.⁴

FINDINGS

The average lumbo-sacral angle in the Bantu was found to be 137° with a range of 124-153 degrees. The mean sacral angle showed an average of 37.4° and varied from 22° to 56°.

A correlation was found to exist between sacral inclination, sacral angle and the inclination of the upper surface of the lumbar vertebrae.

Table I demonstrates clearly that with decrease in the sacral inclination, the sacral angle and the inclination of

TABLE I. ANGLES AND INCLINATIONS

Sacral angle	Lumbo-sacral angle	Average inclination of L.5	Mean sacral inclination
(20-29) Mean 24°	138°	5.5°	50°
(30-39) Mean 34°	135°	11°	40°
(40-49) Mean 43°	136°	16°	31°
(50-) Mean 56°	132°	23°	21°

the upper surface of L.5 increase accordingly, while the lumbo-sacral angle remains more or less constant.

When considering the forces which act upon the various lumbar vertebrae and the lumbo-sacral junction with weight-carrying on the head, the presence of the lumbar lordosis requires particular attention. In the presence of the lumbar lordosis it is obvious that the upper surfaces of the lumbar vertebrae and the first sacral segment cannot all be horizontal, but must of necessity be inclined anteriorly in the lower lumbar region and posteriorly in the upper lumbar region (Fig. 1).

A downward-sliding force is thus created at those levels where the vertebral surfaces slope downwards and ante-

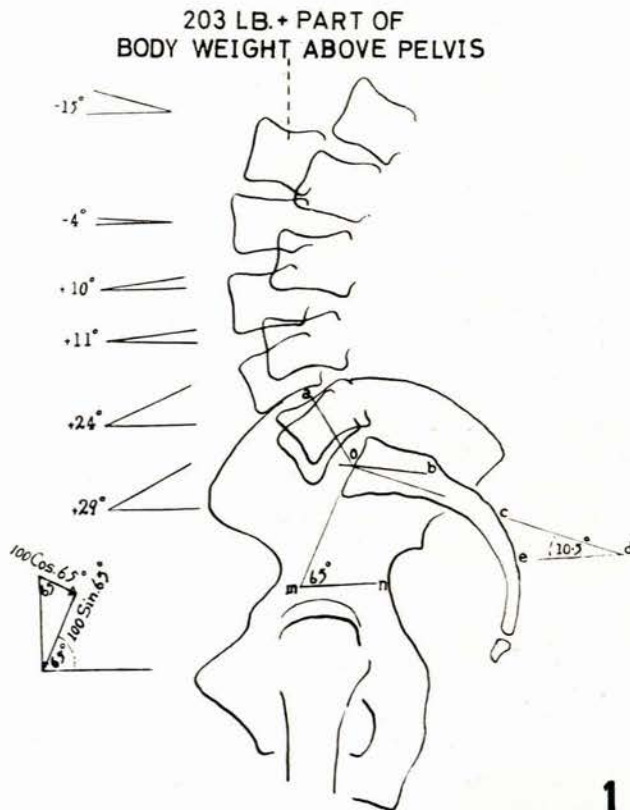


Fig. 1. Tracings of X-rays with and without weight-carrying; they demonstrate the inclination of the lumbar vertebra with weight-carrying. /aob. = lumbo-sacral angle, /omn. = sacral angle, and /cde. = sacral inclination.

riorly. The magnitude of this force is determined not only by the amount of vertical loading on the vertebrae above, but also by the obliquity of the upper surface of the vertebra in question.

Based on the findings of Thieme⁴ and others it appears that forces which act on the lumbar region during the process of lifting a bag of grain by 2 men is much greater than when such a bag is carried on the head of one person. This can be ascribed mainly to the greater leverage which comes into play in the former cases as compared to the latter.

When standing erect the proportion of the body weight which is transmitted through the lumbar spine is estimated at approximately 47 lb. Adding to this the weight of a bag of grain of 203 lb., which is carried on the head, it is clear that the total weight which acts on the lumbar spine is in the region of 250 lb. The mean downward-sliding force in the group examined was found to be 141.6 lb. at the S.1 level with a maximum of 220.7 lb. The corresponding figures for L.5 were 81.4 lb. and 170.6 lb. respectively. This force decreases progressively upwards in the lumbar segments up to L.3, where it reaches an average of 8.7 lb. Above L.3 the downward-sliding force is directed posteriorly and reaches an average of 34.8 lb. on the upper surface of L.1.

TABLE II. THE DOWNWARD-SLIDING FORCE WHICH ACTS UPON THE VARIOUS LUMBAR SEGMENTS WHEN A TOTAL WEIGHT OF 250 LB. IS TRANSMITTED THROUGH THE LUMBAR SPINE

Vertebrae	Mean inclination of upper surface of vertebrae	Downward-sliding force	Maximum inclination of upper surface of vertebrae	Downward-sliding force
S.1	+ 34.5°	+ 141.6 lb.	+ 62°	+ 220.7 lb.
L.5	+ 19.0°	+ 81.4 lb.	+ 40°	+ 160.7 lb.
L.4	+ 10.0°	+ 43.4 lb.	+ 24°	+ 101.7 lb.
L.3	+ 2.0°	+ 8.7 lb.	+ 10°	+ 43.4 lb.
L.2	- 1.3°	- 5.6 lb.	- 11°	- 47.7 lb.
L.1	- 8.0°	- 34.8 lb.	- 17°	- 73.1 lb.

A plus (+) sign indicates a forward-sliding tendency
A minus (-) indicates a backward-sliding tendency.

The most striking phenomenon in the adaptation of the lumbar spine to weight-carrying is the partial obliteration of the lumbar lordosis with simultaneous rotation of the sacrum into a slightly more vertical position (Fig. 4a). The maximum adaptation occurs at the lumbo-sacral junction where the lumbo-sacral angle becomes more obtuse (Fig. 2b). At the higher levels in the lumbar spine only minor adaptation changes of this nature occur.

TABLE III. THE MEAN DEGREE OF FLEXION AND EXTENSION TO WHICH THE SPINE IS CAPABLE AT THE DIFFERENT LUMBAR LEVELS IN 54 BANTU MEN, AND THE ADAPTATION OF THE LUMBAR SPINE WHEN A WEIGHT OF 203 LB. IS CARRIED ON THE HEAD

	S.1-L5	L.5-4	L.4-3	L.3-2	L.2-1	Total
The mean degree of possible flexion and extension	20.15°	19.24°	16.32°	14.16°	10.72°	80.59°
The adaptation of the lumbar spine under weight-carrying	11.11°	2.66°	0.89°	0.46°	—	15.12°
Percentage of total adaptation	73.5%	17.6%	5.9%	3.0%	—	

When the movements of adjacent segments are examined, it is found that under the influence of weight-carrying a total mean compensatory flexion of 15.12° occurs in the lumbar region, which serves as an index of the reduction of the lordosis. This represents 18.8% of the amount of flexion and extension movement of which this region is capable, namely 80.59°. Of this compensation

73.5% occurs at the lumbo-sacral junction and 17.6% at the L.4-5 junction, while only 8.9% is contributed by the remainder of the lumbar region (Table III). The move-

tion of 12.4° . Under weight-carrying this inclination increases to 21° , owing to the compression of the L.5-S.1 disc, with a consequent increase in the downward-sliding force on L.5 (Table IV).

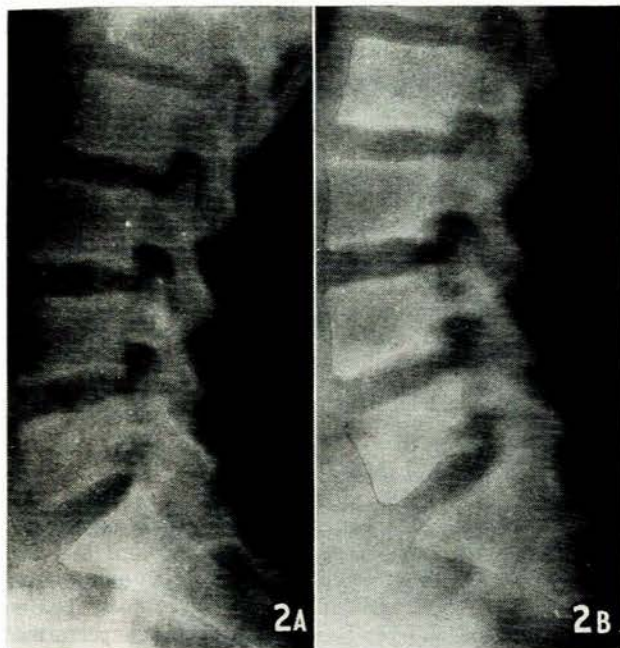


Fig. 2. (a) Radiograph of lumbo-sacral region without weight-carrying, (b) Radiograph demonstrating the adaptation of the lumbo-sacral spine under influence of weight-carrying. Note especially the changes in the lumbo-sacral disc, viz. posterior widening with compression anteriorly.

ment at the lumbo-sacral level under weight-carrying represents fully 55.1% of the amount of flexion and extension of which this level is capable. The 17.6% compensation at the L.4-5 level represents only 13.8% of the amount of flexion and extension that can be achieved here.

In the absence of weight-carrying the 2 superior sacral segments form a mean angle of 36° with the horizontal, representing the mean sacral inclination. Under conditions of weight-carrying this angle is increased to 40.5° , indicating a posterior vertical rotation of the sacrum which amounts to 4.5° . The extremes of sacral inclination varied from 22° to 56° with weight-carrying.

The more vertical placing of the sacrum under the influence of weight-carrying diminishes the downward-sliding forces on the upper surface of the sacrum. The opposite occurs at the level of L.5 vertebra. In the erect posture the upper surface of L.5 has an average inclina-

TABLE IV. THE MEAN ADAPTATION OF THE LUMBAR REGION TO WEIGHT-CARRYING IN 54 BANTU MEN

Lumbo-sacral angle	Inclination of sup. surface of vertebrae						Sacral inclination	
	S.1	L.5	L.4	L.3	L.2	L.1		
Without weight	136°	37.4°	12.4°	0.6°	-10.5°	-15°	-21°	36°
With weight-carrying	146°	36°	21°	9°	2°	-1.5°	-8.5°	40.5°

A further change found was that of slight downward sliding of the fifth vertebra on the upper surface of S.1 (Fig. 3c). The position that L.5 now occupies cannot be explained only on the grounds of being the normal displacement of one vertebra on another that occurs with the flexion-extension movement, but is also to be correlated with disc compression under conditions of weight-carrying.

In ventro-flexion and with weight-carrying, the intervertebral foramina increase in size. This enlargement occurs between L.4 to S.1, and in this way ample provision is made for avoiding compression on the nerves during

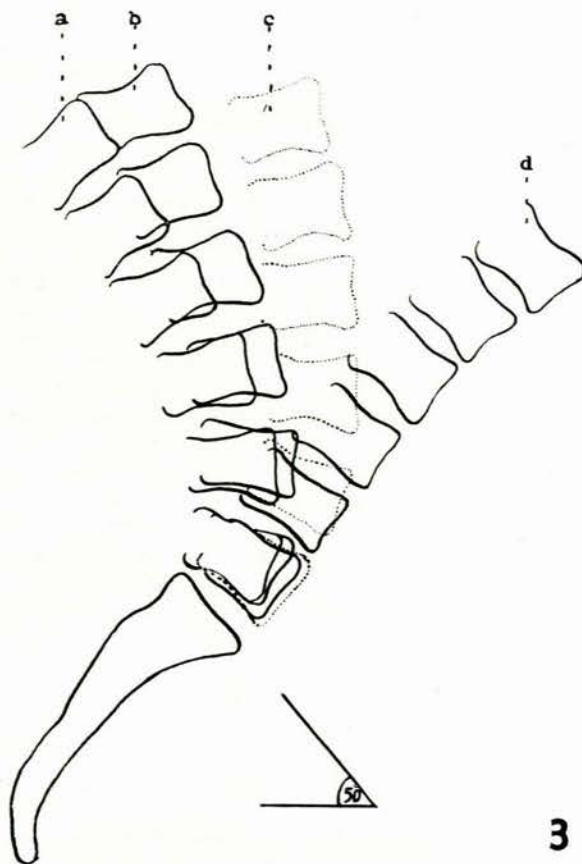


Fig. 3. Superimposed tracings of radiographs of lumbar spine in: (a) hyperextension, (b) erect posture, (c) with weight-carrying, and in (d) flexion. Note the position of the 5th lumbar vertebra relative to the sacrum under conditions of weight-carrying as compared to the other positions.

the head-carrying of weights (Fig. 2b). In hyperextension the intervertebral foramina diminish in size owing to the fact that the superior articular processes are forced upwards into the inferior notches of the vertebra above.

In contrast to the findings in Whites⁶ no abnormalities in the lumbar spines, which could be unequivocally attributed to the carrying of heavy weights on the heads of the Bantu, were encountered. Of the 54 men who carried

heavy weights 6 had disc-space narrowing, 6 presented articular tropism; 2 cases had spondylolysis, but no Schmörl's nodes were encountered.

DISCUSSION

The cause of lumbar instability is practically universally ascribed to the assumption of the erect posture of man.^{5, 7-9} The instability is mainly ascribed to the slope of the upper surface of the first sacral vertebra, thus emphasizing the importance of the sacral angle and of the fact that the lumbo-sacral junction is a junction of a moveable column supported on a stable base, the sacrum.

The weight-carrying experiments in the Bantu show that the lumbo-sacral joint is definitely not a junction of a flexible column and a rigid base. On the contrary, it has been found that the movements in the lumbar region are closely correlated with the movements of the pelvis on the hip joints in the erect posture.

It would appear a logical argument that the most stable position of the spine, and more especially of the lumbo-sacral junction, is attained when the vertical line of weight-bearing coincides with the superior border of the sacrum. One might justifiably modify this by stating that the most stable position is attained when the vertical line of weight-bearing* passes through the upper surfaces of both the sacrum and the hip joints, i.e. with the lumbo-sacral junction vertically above the hip joints. On the basis of this argument Meschan and Farrer-Meschan¹⁰ conclude that when the working line of vertical forces passes through the sacrum, the lumbo-sacral angle is regarded as being stable, while it is unstable when this line passes in front of the sacrum, irrespective of the size of the sacral angle.

If this classification of spines, according to Meschan and Farrer-Meschan,¹⁰ is rigidly applied to the Bantu, most of their spines would be classified as unstable, especially under conditions of weight-carrying. Furthermore, the finding of Brailsford¹¹ that the lumbo-sacral angle increases in the labourer class who carry heavy loads, is contradicted

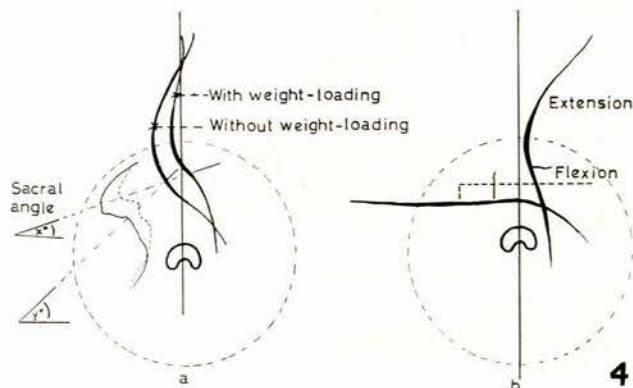


Fig. 4. Diagrammatic representation of the lumbo-sacral mechanism. The movements of the lumbar spine are closely correlated with the movements of the pelvis around the hip joints. (a) With weight-loading the sacral angle decreases owing to a posterior rotation of the pelvis around the hip joint. (b) flexion and extension.

*Line of weight-bearing is represented by a perpendicular dropped from the centre of L.3.¹⁴

in the case of the Bantu where the opposite is found.

The adaptation of the sacrum into a more vertical position is accomplished by posterior rotation of the upper part of the pelvis round the hip joints. The sacral angle changes accordingly. The promontorium must of necessity move away from the vertical line of weight-bearing (Fig. 4a). This is regarded by Meschan¹⁰ as an unstable condition. In the Bantu, however, it is a normal adaptation mechanism of a stable spine under the influence of weight-carrying.

The theory that the centre of gravity is a physiological constant, which cannot be disturbed in the erect position,^{12, 13} is thus amply corroborated by the findings in the Bantu whose spine adapts itself to the centre of gravity. This adaptation is mainly affected by the movements of the pelvis on the hip joints.

Theoretically one would expect the lumbo-sacral angle to become more acute under the influence of weight-carrying associated with the posterior narrowing of the disc space. In practice the opposite is however found (compare Figs. 2a & b). With weight-carrying the disc space widens posteriorly.

These findings are of importance in the approach to the problem of low back pain. In the first instance, with weight-handling directly on the head, 73.5% of the compensatory movement takes place at the lumbo-sacral junction. The significance of this figure becomes apparent when fusion of the lumbo-sacral junction is performed. As a result of this procedure not only is the spine-pelvis junction transferred to the next level, but there is also a resultant change in the spine-pelvis relationship. Thus the mechanics of this area, which under normal conditions constitute an effective shock-absorbing mechanism, are to a great extent altered.

Secondly, it is of practical importance when considering the problem of low back pain that with weight-carrying directly on the head there is a widening of the posterior aspect of the disc with resulting enlargement of the intervertebral foramina of the lower lumbar region. This finding may be of value in a conservative approach to the problem of low back pain of the spine.

The forces to which the lumbar region is subjected as a result of the greater leverage which comes into play when a bag of grain is lifted by 2 men is fully 4 times greater than when the bag is handled by 1 person directly on his head. In the latter case a much smaller muscular force is needed to counteract the downward-sliding tendency and thus to maintain the erect posture, than when lifting the bags. This explains why Africans prefer to handle any appreciable weight directly on the head.

On calculating the magnitude of the forces which act on the lumbo-sacral junction in the erect posture, one arrives at a figure of 30-40 lb. as representing the downward-sliding force in the White.⁴ In the Bantu who carry bags of grain on their heads, the usual downward-sliding force to which their lumbo-sacral junction is subjected is in the region of 140-220 lb. (Table II).

The forces to which the Bantu lumbar spine is subjected without apparent detrimental effect makes it doubtful whether the downward-sliding forces to which the lumbo-sacral region is subjected constitutes an important aetiological factor in the causation of lumbar instability.

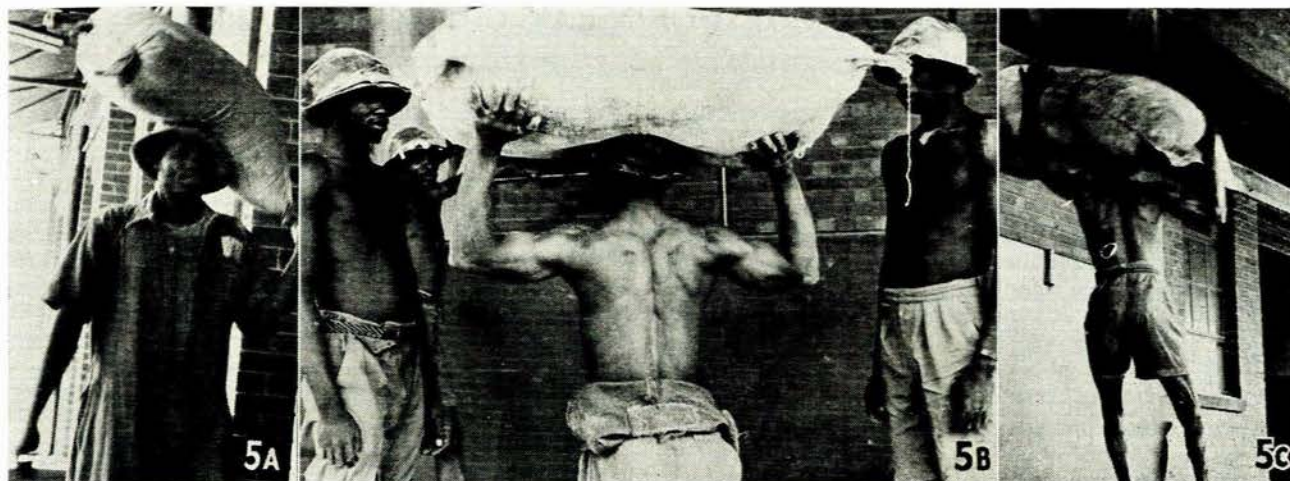


Fig. 5. The favourite method of handling heavy weights directly on the head. (a) The bag of grain (203 lb.) is supported solely on the head at a slight tilt. (b) The bag is lifted on the head of a fellow worker. (c) The favourite method of handling the bags of grain as they arrive from the chute from an upper storey. Note the body posture under these conditions.

Furthermore the 2 cases of spondylolysis showed no evidence of spondylolisthesis, notwithstanding the fact that one of them had been handling bags of grain on the head for 6 years and the other for 14 years. In both these cases an excessively big range of movement was possible in the relative segments without in any way influencing the stability of the body posture.

Two important features of the Bantu spine are illustrated by these 2 cases; firstly that in accordance with the findings of Müller¹⁵ and Hirsch¹⁶ the paravertebral joints perform no weight-bearing function. Secondly that the intervertebral disc is the crucial structure during weight-bearing, while at the same time it constitutes the most important factor in maintaining the stability of the body posture.

The absence of signs and symptoms of low back pain in the Bantu, who continually handle heavy weights in this fashion, is in striking contrast to the condition in the White where low backache is an extremely common complaint. The greater stability in the Bantu as compared to the White is undoubtedly due to greater muscular development.

SUMMARY AND CONCLUSIONS

The effect on the lumbar spines of the custom of carrying heavy weights on the head was investigated in a selected group of Bantu men whose occupation involves this type of work.

Weight-carrying leads to a reduction of the lumbar lordosis. This adaptation is limited mainly to the lower lumbar region, and results in a slight decrease in the downward-sliding force at the S.1 level. On the other hand, owing to disc compression, there is an increase in the downward-sliding force at the upper surface of L.5.

No abnormalities which could be directly attributed to the carrying of heavy weights on the head were encountered.

The findings confirm the premise that the paravertebral joints have no weight-bearing function.

It appears that the most efficient way of transporting heavy objects is by balancing them on the head, since the stresses and strains to which the spine is subjected are reduced to a minimum under these conditions.

Contrary to the commonly accepted view that lumbar instability results from the junction of a mobile column (the spine) and a relatively rigid base (the pelvis), it was found that the movements of the lumbar spine are closely correlated with the movements of the pelvis on the hip joints. This close association is responsible for the creation of a very effective shock-absorbing mechanism, a fact which deserves consideration where spinal fusion is contemplated.

The fact that the lumbo-sacral junction can effectively cope with the stresses and strains to which it is subjected under conditions of weight-carrying as described, casts doubt on the importance of the downward-sliding force as an aetiological factor in the causation of lumbar instability.

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