POSTURE OF THE TRUNK DURING THE LIFTING OF WEIGHTS*

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This paper is an attempt to answer briefly three questions, and then to suggest an explanation of the answers based on the relevant anatomy. The questions are: (1) How are heavy weights lifted ? (2) What part does the trunk play in this ? (3) What damage may be produced ? The answers to the first two questions stem from personal observation of a large number of people engaged in their everyday tasks.

Ways of Lifting Weights

One can say at once that people seem to lift their burdens in almost as many ways as there are burdens to be lifted. One familiar heavy weight is the suitcase, which may be lifted either by stooping down, grasping the handle, and then straightening the hips and lumbar vertebrae; or by bending the hips and knees and lifting the case with the trunk held erect. That awkward load, a sack of potatoes lying on the ground, is often first lifted by stooping, clasping it to the bosom and lifting it on a bench, and then humping it on to the back. When first becoming house-owners, many people remove stumps of bushes or trees from the garden by loosening the roots, and then hauling the stump out of the ground with the hands between the knees and the back a little stooping, a large upwards pull being obtained by extending the hips and knees.

In modern industry, most heavy weights are handled by machines, but one still sees barrows full of wet concrete being lifted off the ground by the handles, and hods of bricks carried on the shoulders, and so on. In Covent Garden the barrow has largely replaced porter carriage, but towers of baskets are still, on occasion, lifted on to the head from a stand, the bottom basket being grasped by the hands in front of the chest after first bending the legs, and then placed on the head and the legs extended. This list could go on *ad infinitum*, but it serves the purpose of illustrating this first point—that the manner in which a weight is lifted is dependent upon its size, its shape, its position in space, and the habits of the person lifting it.

The Part Played by the Trunk

When considering the trunk, there is at first sight just as large a variety of parts that it can play. However, after watching numbers of people lifting weights of various kinds, one can say that the part played by the trunk appears to depend more upon the magnitude of the weight than upon other factors. When the weight is small the trunk may be flexed or extended, bent sideways or rotated; but as the weight increases the amount of rotation or lateral flexion becomes less, until there comes a time when the trunk is held in a limited range of positions between the two extremes of simple flexion and straight. Moreover, the heavier the weight the more likely it is that it will be lifted with the trunk held in this straighter position.

It must be emphasized that, although the straight trunk is usually held erect, this is not necessarily so. In the straight position the long axis of the trunk is normally placed parallel with, and as close as possible to, the line of pull of the weight, but this line of pull is not always at right angles to the ground. Anyone who has pulled a large weight up a sloping chute by means of a rope is aware that the trunk is held straight but is also held at an angle to the ground.

So one can say that, although with light weights the trunk may be placed in any position, with the greatest loads it is nearly always held erect in a straightened posture. One further observation is relevant, and that is, with large weights the active movement of lifting appears usually to be achieved by movements of the limbs rather than of the trunk.

Lesions Caused by Weight-lifting

A review of the literature makes it apparent that lesions caused by weight-lifting rarely appear in the limbs, but are not uncommon in the trunk. We all know that herniae and prolapses can be precipitated by weight-lifting, and anyone who does a bit of spare-time gardening can testify that repeatedly lifting a weed- and clay-laden spade can cause lesions of the soft tissues of the back even though an exact diagnosis cannot always be achieved in such cases. Our orthopaedic and neurosurgical colleagues spend much of their time dealing with patients who have lesions of their intervertebral disks, disorders in which acute symptoms often first appear when the patient tries to lift some large and heavy article.

There thus appear to be two basic types of injury to the trunk. There is an anterior, *extrusive* group of injuries, which includes visceral herniae and prolapses; and a *spinal* group, including such lesions as lumbosacral strain, prolapsed intervertebral disks at the lumbar and cervical levels, tears of posterior ligaments and spinal muscles, and the less frequent crush fractures of the bodies of the lower thoracic and upper lumbar vertebrae.

Anatomical Considerations

In trying to give an anatomical explanation of these various observations it is convenient to divide the analysis into two stages. Firstly, by examining the forces exerted on the trunk when weight-lifting in the different positions; and, secondly, by examining the mechanisms whereby the trunk may sustain these forces. For the sake of brevity this analysis has been limited to the two extreme positions which may be adopted when lifting heavy weights—namely, the straight or erect position and the flexed or stooping position; in each case it has been assumed that the weight is divided equally between the two hands.

Forces Acting on the Trunk

By palpating the muscles of subjects lifting weights in different positions, one can assess the relative strengths of contraction of the various muscles involved. In theory, it would be better to do this with the electromyograph, but in practice the movements of the trunk grossly disturb the record and render it nearly useless. The descriptions given here are based on palpation alone. There appear to be very different patterns of contraction in the two positions.

In the *erect* position the weight is transferred to the humerus by the forearm muscles, and then appears to

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be carried to the pectoral girdle mainly by the deltoid (Fig. 1). From the lateral part of the pectoral girdle most of the weight is then transferred to the middle and lower cervical vertebrae through trapezius and other muscles. Rotation of the scapula is prevented by the muscles attached to the chest wall. So that, in this erect position, the weight is transferred principally to the neck vertebrae, some reaching the upper thoracic spine.

In the *stooping* position the weight is transferred to the humerus as before, but from the humerus it takes a very different path. The deltoid plays little part (Fig. 2). Anteriorly, a small part of the weight is transferred to the thoracic cage by the pectoral muscles, and thence through the ribs to the thoracic vertebrae. Posteriorly, some of the weight is transferred to the scapula by the rotator cuff muscles and thence reaches the thoracic vertebrae through the lower parts of the trapezius and allied muscles. Below this level the latissimus dorsi can be felt to contract strongly, passing some of the weight to the lower reaches of the spine and the back of the pelvis. In essence, these posterior muscles form a broad sheet which suspends the weight and passes it to the whole length of the thoracic and lumbar spine.

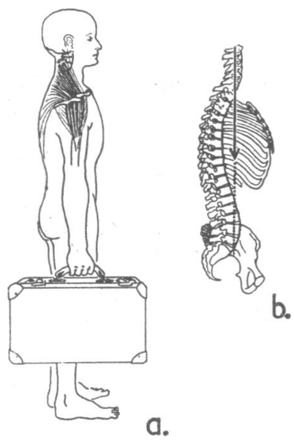

FIG. 1. — In the upright position much of the weight is transferred through the shoulder muscles to the pectoral girdle, and thence to the cervical vertebrae (*a*); it thus exerts a vertical compression upon the trunk (*b*), little muscular contraction being needed for the trunk to sustain the weight. (Drawn by Mrs. M. Besterman.)

When the two paths are compared, it is obvious that in the erect position most of the weight is being transferred to the upper part of the vertebral column. On the other hand, in the stooping position the weight is being transferred to the thoracic and lumbar series and the pelvis itself.

From the mechanical aspect, in the erect position there is a force applied to the cervical vertebrae which acts in the long axis of the trunk, whereas when stooping there is a flexing force acting at right angles to the long axis of the trunk, with its centre at about the level of the fourth or fifth thoracic vertebra.

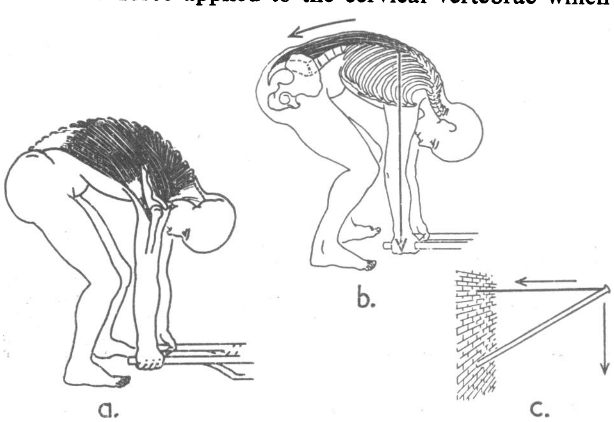

FIG. 2.—In the flexed position much of the weight is transferred direct from the humerus to the lower thoracic and lumbar spine, the remainder passing to the scapula and thence to the upper and middle thoracic vertebrae (*a*); the weight thus exerts a flexing force upon the trunk, and this is resisted by the erector spinae muscles and the vertebral column (*b*), which act together in a manner similar to the ropes and pole of a gaff-staff (*c*). (Drawn by Mrs. M. Besterman.)

Mechanisms Resisting the Different Forces

There is general agreement that vertical forces are resisted by the chain of vertebral bodies and intervertebral disks, a chain well adapted to sustain considerable compression. In the erect position much of the weight acts vertically on the cervical vertebrae, the weight passing directly down the bodies to the thoracic vertebrae. Morphological studies suggest that in some cases the chain of oblique articular facets may well carry some of the vertical force downwards as far as the last cervical or first thoracic vertebra, whence the weight probably passes forwards along the relatively large pedicles to reach the upper thoracic vertebral bodies. This suggestion requires experimental confirmation before it can be accepted. The ribs and sternum brace the thoracic kyphos, and thus sustain some of the weight in the upper thorax, but below mid-thoracic level the chain of vertebral bodies and intervertebral disks is the only apparent means of sustaining vertical forces, for the thoracic and lumbar articular facets lie in a nearly vertical plane and under experimental conditions merely slide up and down if vertical forces are applied.

The lumbar lordosis places the vertebral bodies in the centre of the lower part of the trunk, and Floyd and Silver (1950, 1951) have shown electromyographically that little or no muscular effort is needed to maintain the erect trunk in a position of balance, so that it seems unlikely that much muscular contraction is needed to maintain the erect position of the trunk when carrying weights. The lower lumbar series of disks are wedge-shaped, as are the lowest one or two vertebral bodies, so that vertical forces tend to slide the column forwards on the sacrum and deposit it in the pelvis. This tendency is resisted by the ilio-lumbar ligaments, and by the articular facets of the lumbo-sacral joint, which face principally forwards in most cases.

Since little or no contraction of the lumbar muscles is involved, one can quite easily make an estimate of the downwards force acting on the lower lumbar vertebrae. This force consists principally of the weight of the body above this level, plus the weight being carried by the arms, plus any additional force arising from the acceleration of the weight during the lift.

In the stooping position two mechanisms appear to be involved. The weight, acting as a flexing force on the trunk, is sustained in part by the contraction of the erector spinae group of muscles, which over simply may be thought of as suspending the vertebral column in the same way as wire stays suspend a horizontal flagpole. The fibres of the erector spinae pass obliquely between their attachments, so that the force of their contraction can be split into two components—a dorsal extending force, which is the component used to lift the weight, and a longitudinal component compressing the vertebral bodies. Owing to the complexity of the muscle, it is very difficult to assess the magnitude of these components in the middle reaches of the spine, but a much simpler computation can be achieved for the forces acting at the lower lumbar joints, provided always that it is assumed that the spinal mechanism is the only one which is in action when lifting in the stooping position.

This last is a false assumption, but it is none the less illuminating to compare the theoretical forces acting on the lower lumbar vertebrae in the two extreme positions (Table I). There is thus in theory a fivefold increase in pressure in the stooping position when compared with the pressure in the erect position.

It has been shown experimentally by Hirsch (1951), Virgin (1951), Hirsch and Nachemson (1954), and others that normal lumbar vertebral bodies are crushed by pressures equivalent to about 1,000 lb. (454 kg.) weight, and that such a pressure may well result in permanent deformation of the intervertebral disks. And yet weights greater than 70 lb. (32 kg.) can be lifted by normal male adults in the stooping position.

The answer to this apparent enigma is simple, and is suggested by the extrusive group of lesions and by the suppressed grunt or gasp that accompanies heavy lifts. Measurements of intra-abdominal pressure in the stooping position show that large increases in pressure occur during the initial heave of a lift, and that a smaller sustained rise of pressure occurs while the weight is held against gravity. With large weights the pressure can rise by up to 100 cm. H_2O. Intra-oesophageal measurements have shown that pressures of a similar order are induced within the thorax. Serial measurements of this rise in pressure show that, for a given weight, there is an almost linear relationship between the pressure induced in the trunk cavities and the angle between the trunk and the ground, there being no significant rise in pressure in the erect position. It would appear that in the stooping position the pressure in the trunk, produced by contraction of the abdominal wall muscles, presses upwards on the ribs and downwards on the pelvic floor to act as an extensor of the trunk and thus to sustain a considerable portion of the flexing force induced by the weight. It can be calculated that about one-sixth of the weight is supported in this way, so that a more real estimate of the pressure on the spine can be obtained, as is shown in Table II.

TABLE I.—*Theoretical Pressure (lb.; kg. Weight) on Body of Fourth Lumbar Vertebra During Weight-lifting. It Has Been Assumed that Only the Spinal Mechanism is in Action. (Based on an Average Normal Male, 5 ft. 10 in. (152 cm.) in Height)*

	Erect		Stooping	
	lb.	kg.	lb.	kg.
Holding 70 lb. (32 kg.) still against gravity	140	63·5	700	317·5
Pressure induced by initial acceleration of weight	80	36·5	350	159
Total pressure during early stage of lift	220	100	1,050	476·5

It must be stressed that these figures are only rough estimates, but they accord well with the observed facts. On the basis of two mechanisms in the flexed position, the theoretical maximum lift is of the order of 140 lb. (63.5 kg.), and few people can lift more than this when stooping. When erect, the theoretical maximum lift is of the order of 500 lb. (227 kg.), and this figure is achieved by professional weight-lifters. It is interesting to note that these sportsmen are trained to keep their trunks as erect as possible when engaging in maximum lifts.

There thus appear to be two mechanisms in the trunk which act together during weight-lifting, the *spinal* mechanism and the pressure or *pneumatic* mechanism; it is suggested that these are involved respectively in the production of the spinal and extrusive groups of lesions. In the spinal group, lesions of the disks would appear to be precipitated by the "nutcracker" effect of large compression forces, and are thus more apt to occur in the stooping position. Similarly, the increase in the longitudinal compression force when stooping will increase the liability to ilio-lumbar strain, and the increased tension in the post-vertebral muscles and ligaments may well predetermine soft-tissue injury. In the extrusive group, any potential weakness of the abdominal wall is apt to be broken down by the considerable increase in intra-abdominal pressure, an increase which occurs only when the trunk is flexed.

TABLE II.—*Theoretical Pressure (lb.; kg. Weight) on Body of Fourth Lumbar Vertebra During Weight-lifting, Taking the Raised Intra-abdominal and Intrathoracic Pressure Into Account. (Based on Average Normal Male, 5 ft. 10 in. (152 cm.) in Height)*

	Erect		Stooping	
	lb.	kg.	lb.	kg.
Holding 70 lb. (32 kg.) still against gravity	140	63·5	580	263
Pressure induced by initial acceleration of weight	80	36·5	220	100
Total pressure during early stage of lift	220	100	800	363

One must therefore re-emphasize the dictum of former teachers, and say that when weight-lifting it is better to bend the knees than bend the back.

One possible exception to this rule is the person liable to injury of the cervical disks and intervertebral facets. In theory there is less compression force exerted on the neck when stooping than when lifting weights in the erect position: however, the flexion of the cervical spine which accompanies stooping may exacerbate other symptoms present, and it is doubtless best for such unfortunates to refrain from weight-lifting of any kind.

Conclusion

In final summary, one can say that there is evidence that two complementary mechanisms are in action when large flexion forces are resisted by the human trunk, these being the spinal column and its muscles on the one hand, and the "pneumatic" mechanism on the other. Each is affected by its own group of disorders, and in theory it appears that the more flexed the trunk when lifting the more likely is it that damage will occur.

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Although interest in Russian medical work has greatly increased in recent years, the language barrier and unfamiliarity with the existing sources of approach have made difficult the full exploitation of Russian medical literature. This second obstacle has been overcome by the *Guide to Russian Medical Literature* (Public Health Service Bulletin No. 602. Govt. Printing Office, Washington, D.C. 89 pp.; 40 cents). It is edited by Scott Adams and F. B. Rogers and includes chapters describing available Western- and Russian-language sources for Russian medical literature, English translation sources, Russian medical bibliography, medical libraries, medical publishing activities, and a list of current medical journals.