Physiological Considerations in Bracing of the Spine[1]

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It is well recognized that braces in current use cannot produce complete immobilization of the spine, especially in the lumbosacral region. In fact, it has been shown that motion at the lumbosacral joint may be increased during trunk flexion when a long spinal brace is worn, since there is compensation for decreased motion of the thoracolumbar region.[1]

Clinically, however, despite the obvious incompleteness of immobilization, bracing frequently results in symptomatic improvement of low-back disorders. Apparently, either partial immobilization or the support provided, in some manner, to this region brings about the improvement. In this regard, it has been observed that in certain cases of low-back pain caused by disc degeneration or so-called mechanical instability, compression of the abdominal viscera often relieves the pain. This compression may be accomplished by use of a circumferential bandage, a well-fitting corset, a brace with an abdominal pad which can be tightened, or a snug plaster body jacket.

In an effort to expand our understanding of the physiological factors in support of the spine and their possible application to orthotics, a study of the mechanics of stability and support of the spine was undertaken at the Biomechanics Laboratory. In particular, the role of the compartments of the trunk (thorax and abdomen) in helping to provide stability of the spine was investigated.

The spinal column, which serves as a sustaining rod for the maintenance of the upright position of the body, may be considered to have both an intrinsic and an extrinsic stability. Intrinsic stability is provided by the alternating rigid and elastic components of the spine which are bound together by ligaments, while extrinsic stability is provided by the paraspinal and trunk muscles. The trunk muscles, especially those of the abdomen, form a contractile muscular wall about the body compartments which is capable of compressing the viscera. With the contraction of these muscles, the intracavitary pressures are increased, aiding in many bodily functions such as childbirth, respiration, return of venous blood, and, as will be shown, stabilization or support of the spine.

The isolated ligamentous spine behaves like a modified elastic rod.[2] When it is fixed at the base, its critical load—i.e., the greatest load it can sustain without buckling—is approximately 4½ pounds, or much less than the body weight alone.[2] The stability of the spine in the living is therefore dependent largely on the extrinsic support provided by the trunk muscula-

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ture. The lack of inherent or intrinsic stability of the vertebral column and the importance of the trunk muscles are clearly demonstrated if one tries to hold an unconscious person upright.

The maintenance of the upright position, however, depends upon a finely balanced and co-ordinated mechanism that requires a minimal amount of muscular effort. This has been demonstrated by basal metabolic studies in which the metabolic rate was found to be only slightly greater during standing[3] than the standard rate in the recumbent position (about 1200 cal/min). The same conclusion has been reached on the basis of electromyographic studies of the intrinsic back muscles,[4] in which slight activity has consistently been found in only one muscle, the longissimus, which is the largest of the back muscles. Activity in other back muscles is sporadic and occurs only with shifting of the body weight.

During the act of lifting a heavy weight with the hands, the nucleus of the lumbosacral disc may be considered as a fulcrum of movement and the arms and trunk as a long anterior lever. The weight being lifted and the weight of the upper part of the body are balanced by the contraction of the deep muscles of the back and the glutei maximi acting through a much shorter lever arm, the distance from the center of the lumbosacral disc to the center of the adjacent spinous process. If a 200-pound weight is lifted by a male of average size, the theoretical force on the lumbosacral disc—with the body weight also taken into consideration—can be calculated to be 2,071 pounds (Fig. 1).[5]

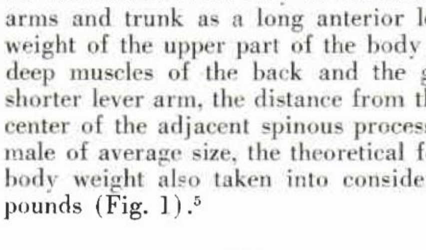


Fig. 1. Theoretical force on lower lumbar part of spine, with role of trunk omitted.

Experimental studies of the isolated ligamentous spine[6,7] and investigation of injuries sustained by catapult ejection of jet pilots[8] have shown that such great forces cannot be tolerated. Compression tests on two vertebral bodies and intervening disc have indicated that failure occurs in specimens from young subjects at compressive loads ranging from 1,000 to 1,700 pounds.[6,7] In specimens from older subjects the critical level was sometimes reduced to as little as 300 pounds. Catapult ejection of young jet fliers with a force of 20 G, or less than 2,000 pounds, has resulted in vertebral compression fractures in 27 per cent of the cases.[8] Evidence of failure is often difficult to see either on gross examination or by x-ray. It may consist of compression of a few spicules of bone, cracks in the end plate, or, sometimes, collapse of the plate. It is interesting to note that fracture of the vertebra always occurs before herniation of a normal disc.[7]

When one compares the force calculated earlier (2,071 lb.), to which the lumbosacral area is apparently subjected during heavy lifting, with the force that the isolated spine is able to tolerate experimentally, a discrepancy is evident. It is obvious that the lumbar vertebrae and discs alone are not able to withstand the amount of force that may be imposed during exertion; additional support of the spine is necessary.

This additional support may be provided by the thorax and abdomen. Let us consider the spine as a segmented elastic column supported by the paraspinal muscles. This column is attached to the sides of and within two chambers: the thoracic and abdominal cavities. The thoracic cavity is filled largely with air and the abdominal cavity with a semifluid mass. The action of the trunk musculature converts these chambers into nearly rigid-walled cylinders containing (1) air and (2) liquid and semisolid material. Both these cylinders are capable of resisting a part of the force generated in loading the trunk and thereby of relieving the load on the spine itself.

EXPERIMENTAL PROCEDURE

To test this hypothesis, the action and effects of the musculature of the thorax and abdomen were investigated in 10 healthy male subjects under various conditions of loading of the trunk.

The intrathoracic pressure was obtained by means of an open-tip polyethylene catheter placed within the esophagus and the intra-abdominal pressure by means of a similar catheter placed within the stomach.

Copper-wire electrodes were embedded in the trunk muscles—specifically, the intercostals, the abdominal obliques, the rectus abdominis, and the deep muscles of the back—and the electrical activity of these muscles was recorded simultaneously with the pressures.

Loading of the trunk was accomplished by two methods. In the first (dynamic), the subject lifted from 0 to 200 pounds, in increments of 50 pounds. The weights were lifted from the floor to the height of the freely-hanging hand with the subject in the erect position.

In the second (static) method of loading the trunk, the subject pulled against a measurable fixed resistance (strain ring) up to a maximum of 200 pounds. This was done with the trunk of the subject in four positions: vertical, then flexed at 30, 60, and 90 degrees. The amount of pull or tension

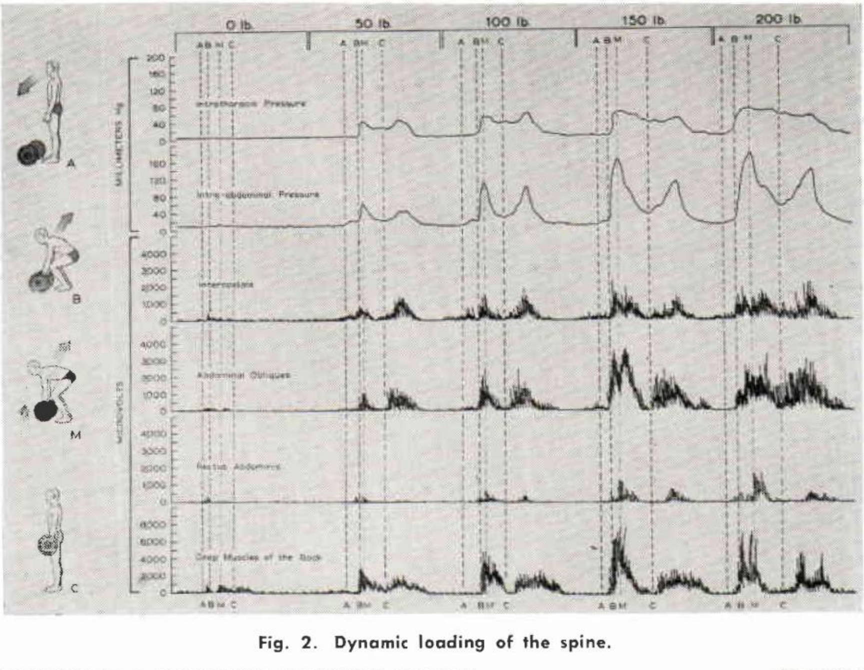


Fig. 2. Dynamic loading of the spine.

exerted on the strain ring was recorded simultaneously with the intracavitary pressures and electromyographic activity.

RESULTS

Figure 2 illustrates the data obtained. It can be seen that when the subject bends over but lifts no weight there is little increase in the intracavitary pressures. As heavier weights are lifted, the maximum pressures in both abdomen and thorax are progressively increased. The intra-abdominal pressure rises more than the intrathoracic, but the latter is more sustained and fluctuates less during lifting. Apparently the rib cage becomes "fixed" by inspiration and muscle activity and remains so throughout the loading.

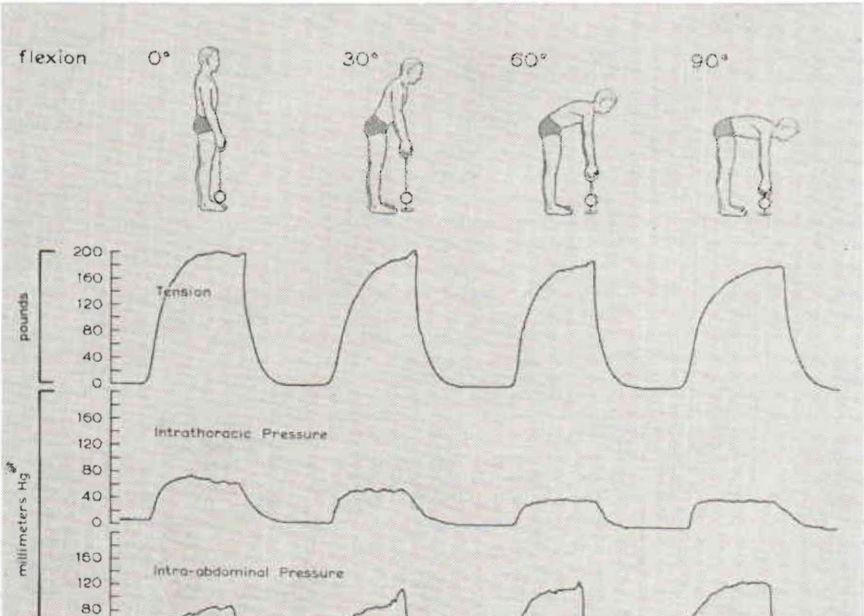


Fig. 3. Static loading of the spine.

Motion pictures taken to correlate the subject's position with pressures and electromyographic activity demonstrate (Fig. 2) that there is little increase of pressure or muscle activity as the subject bends forward (position *A*). The pressures rise rapidly as the subject begins to strain to lift the weight (position *B*), and the maximum peak of pressure occurs at the moment the inertia of the weight is overcome and it is lifted from the floor (position *M*). With the subject in the upright position the pressures again drop toward resting levels (position *C*). The second peak of pressure occurs as the weight is set down.

As is also shown, the trunk musculature becomes active simultaneously with the elevation of pressure and obviously is important in the generation of these pressures. As the weights and the force on the spine are increased, the activity of these muscles is increased.

Tension imposed on a strain ring with the trunk vertical or in various degrees of flexion was recorded simultaneously with the intracavitary pressures and the electromyographic activity of the muscles (Fig. 3). It can be seen that as the tension on the ring is increased the pressures and electromyographic activity are increased proportionately.

When the subject pulled on the ring while he was in the upright position, the intra-abdominal and intrathoracic pressures were, in general, identical or nearly so. Evidently, equilibrium of pressures was established across the diaphragm with the subject in this position. As the subject progressively flexed the trunk on the thighs, the pressure in the abdomen tended to increase when any specific tension on the ring was maintained. The pressure in the thorax, however, remained the same or tended to decrease with progressive flexion of the trunk.

It was apparent from preliminary runs that the intracavitary pressure produced by loading the trunk played an important part in the stability of the spine. It was therefore decided to evaluate the effects of increasing the intra-abdominal pressure by means of externally applied pressure. For this purpose, a rubber bladder surrounding the abdomen was placed within a non-elastic lumbosacral corset and inflated to the limit of comfort.

The resting abdominal pressure was elevated from 5 to 25 mm Hg. The intrathoracic pressure was elevated only slightly (Fig. 4).

It is interesting to note that, while the resting intra-abdominal pressure was considerably elevated by the corset, the maximum intra-abdominal pressures generated in loading of the spine were quite comparable with those obtained without the corset.

However, when the activity of the trunk musculature is compared during loading with and without the corset, a marked difference is obvious. The activity of the abdominal muscles was consistently and considerably decreased when the corset was worn, despite the fact that the intra-abdominal pressures might be the same. The intercostal activity was also noted to be decreased if the corset came high up on the chest over the intercostal muscles being studied. It appears, therefore, that the contracted muscles of the abdominal wall or the rigid external-pressure apparatus acts to contain the abdominal contents in a compressed state capable of transmitting force. When the compression or restraint is accomplished by an external apparatus, there is little need for contraction of the abdominal muscles.

To illustrate the role of the trunk in the support of the spine, it is possible, using the data obtained in this study, to calculate the approximate forces on the lower thoracic and lumbar spine in the living subject when a weight of 200 pounds is lifted.[5]

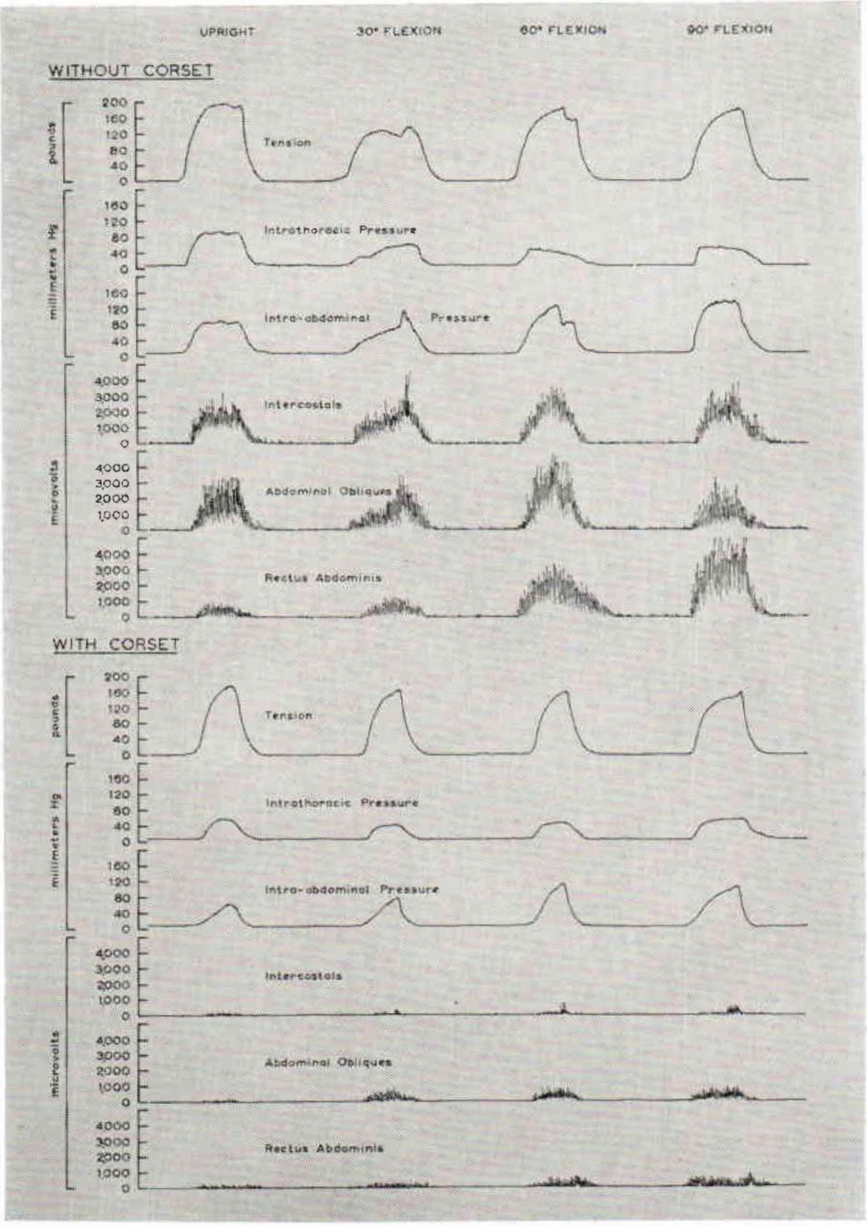


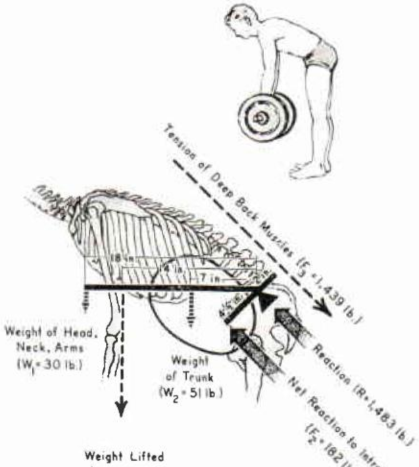
Fig. 4. Effect on muscle activity of external compression of abdomen by inflatable corset.

The spinal column may be considered as a flexible beam fixed at its base (the pelvis) and eccentrically loaded at its free end. The thoracic and abdominal cavities may be considered as modified inflatable supporting structures for the beam.

With use of basic mechanical principles, the amount of force at the base (lumbosacral junction) of this beam can be calculated (Fig. 5). For purposes of computation, we may consider a section just above the brim of the pelvis. The forces acting at this level include the weight lifted, the body weight, the tension of the deep muscles of the back and posterior thigh muscles acting on the back, and the net upward force exerted by the pelvis to counteract the net downward force of the intra-abdominal pressure. The last value is obtained by multiplying the average intra-abdominal pressure recorded during the lifting of 200 pounds (3 pounds per square inch) by the cross-sectional area of the abdomen at this level, and subtracting the longitudinal component of the tension of the abdominal muscles.

When all the forces, their directions, and the distances from the fulcrum are determined, the reaction at the lumbosacral disc can be calculated. Thus, instead of the theoretical force, calculated earlier, of approximately 2,071 pounds at the base of the beam, there is, if one takes into account what might be called the "inflatable support" of the trunk, a force of about 1,483 pounds—a reduction of about 600 pounds.

The theoretical force on the lower thoracic region of the spine, omitting the effect of the intracavitary pressure, may also be calculated as it was for that at the base of the spine; it is found to be 1,568 pounds. However, by the relatively simple mechanism of the upward push on the diaphragm by the increased intra-abdominal pressure acting through a lever system, the force on the lower thoracic and lumbar spine is reduced to only 791 pounds (Fig. 6).



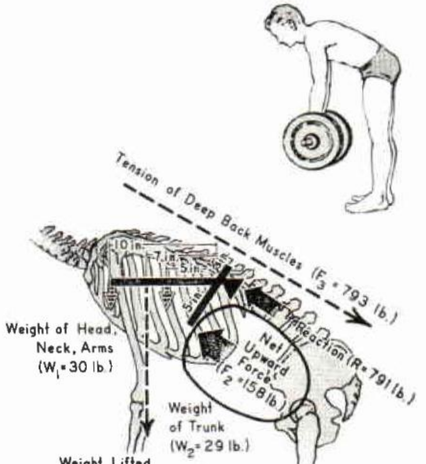


Fig. 5. Force on lower lumbar part of spine, with role of trunk included.

Fig. 6. Force on lower thoracic part of spine, with role of trunk included.

DISCUSSION

The answer to the question of how the vertebral column in a living subject is able to withstand a far greater force than can the isolated spine must be found by consideration of the extrinsic supporting structures of the trunk.

These studies have substantiated the hypothesis that the additional support is provided as follows: The spinal column is attached to the sides of and within two chambers, the abdominal and thoracic cavities; the action of the trunk musculature converts these chambers into nearly rigid-walled cylinders capable of transmitting part of the forces generated in loading the trunk and thereby of relieving the load on the spine itself.

It should be emphasized that what occurs here is the result of a reflex mechanism. When a load is placed on the spine, the trunk musculature is involuntarily called into action to "fix" the rib cage and to restrain or compress the abdominal contents. The intracavitary pressures are thereby increased, aiding in support of the spine.

It may be concluded, from the calculations presented, that the actual force on the spine is much less than that considered to be present when support by the trunk, or the effect of the intracavitary pressures, is omitted. The actual force on the lumbosacral disc is approximately 30 per cent less, and that on the lower thoracic portion of the spine is about 50 per cent less than would be present without support by the trunk.

In addition to contributing to support of the spine, the increased intra-abdominal pressure may well produce an analgesic effect, since, as was mentioned earlier, it has been observed clinically that patients with low-back pain may be relieved by abdominal compression. Orthopedic surgeons regularly rely on abdominal strengthening exercises as a means of pain control for lumbosacral arthralgia. From the orthotist's viewpoint, abdominal compression is a built-in feature in most conventional low-back supports.

Studies are currently under way on the effects of air-pressure bracing which provides, in addition to the compression, partial immobilization by the rigidity of the apparatus. Obvious advantages include comfort, adequate distribution of pressure, variability of pressure, and consequent rigidity and ease of fitting because of lack of localized pressure areas.

Disadvantages are present also, such as heat-transfer problems and potential muscle atrophy resulting from disuse. Only extensive clinical trials and modification of apparatus will determine the value of and specific indications for this type of bracing.

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