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Role of the Trunk in Stability of the Spine*†

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The human spine may be frequently subjected to large forces. The mechanisms of muscular support which normally enable it to tolerate these forces have not been well understood. The role of the compartments of the trunk (thorax and abdomen) in helping to provide stability of the spine has therefore been investigated.

The spinal column serves as a sustaining rod for maintenance of the upright position of the body and, as such, is subjected to a complex system of forces and stresses of different types. This column 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 the systems of ligaments, whereas extrinsic stability is provided by the paraspinal and other trunk muscles.

It has been shown that the ligamentous spine may be considered to be a modified elastic rod. As such, it obeys the physical laws which apply to elastic rods. It has also been shown that the critical load value for the isolated ligamentous spine, fixed at the base, is approximately four and a half pounds, or much less than the weight of the body above the pelvis. If the load is increased further, buckling occurs [6]. The stability of the spine is therefore dependent largely on the action of the extrinsic support provided by the trunk muscles.

When one compares the forces to which the back (especially the lumbosacral area) is subjected with the force that the spine is able to tolerate experimentally, there is a discrepancy that is difficult to explain.

If the nucleus pulposus of the fifth lumbar disc is considered as the fulcrum of movement and a heavy weight is lifted with the hands, the arms and trunk form a long anterior lever. The weight being lifted and the weight of the head, arms, and upper part of the trunk are balanced by the contraction of the deep muscles of the back acting through a much shorter lever arm—the distance from the center of the disc to the center of the spinous process. With these factors in mind, the force that results when a 170-pound man lifts a 200-pound weight may

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be computed. Conditions that may be assumed are that the weight is lifted at a distance of fourteen inches from the lumbosacral disc and that flexion of the spine at the pelvis is 40 degrees. It may also be assumed that in a man of this weight the head, neck, and upper limbs weigh thirty pounds (17.7 per cent of body weight) and that the portion of the trunk above the disc between the fifth lumbar and the first sacral vertebrae weighs fifty-one pounds (30 per cent of body weight)[3]. The head, neck, and upper limbs are attached to the top of the spine and may be considered to act at a distance of approximately eighteen inches from the fulcrum. The weight of the trunk may be considered to act seven inches from the fulcrum. Then, with use of these measurements alone, omitting the role of the trunk, the force on the lumbosacral disc can be calculated to be 2,071 pounds (Appendix 2 and Fig. 10).

In experimental studies of segments of the isolated ligamentous spine, structural failure occurred when forces of considerably less magnitude were applied [2,7]. Compression tests on two vertebral bodies with their intervening disc resulted in failure of the segments of spines, from subjects under forty years of age, under compressive loads ranging from 1,000 to 1,710 pounds. In older subjects the critical level was sometimes reduced to as little as 300 pounds.

Evidence of failure is often difficult to see either on gross examination or on the roentgenogram. It may consist of compression of a few spicules of bone, cracks in the end-plate, or, sometimes, collapse of the plate.

It is noteworthy that when the annulus is complete, its elastic limits cannot be exceeded without vertebral fracture. The end-plate is most susceptible to the forces on the spine, and it is generally this structure which gives way first.

The vertebral body itself is the next most susceptible portion of the segment under study and usually collapses before herniation of the nucleus through the annulus [7].

STATEMENT OF HYPOTHESIS AND SCOPE OF STUDY

The question arises how the lumbar vertebrae and discs are able to withstand the amount of force that can be imposed. One possible explanation lies in considering 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, separated by the diaphragm. The thoracic cavity is filled largely with air, and the abdominal cavity with a semifluid mass. The action of the trunk muscles converts these chambers into nearly rigid-walled cylinders of (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.

To test this hypothesis, the action and effects of action of the muscles of the thorax and abdomen have been investigated under various conditions of loading of the trunk. These conditions may be divided into two categories: dynamic loading (lifting weights) and static loading (pulling on a strain ring). The intrathoracic and intra-abdominal pressures generated during loading were recorded simultaneously, as was the electrical activity of the trunk muscles. For dynamic loading the subjects' angles of trunk flexion for given portions of the recorded data were determined photographically, and for static loading four positions of trunk flexion were used.

METHODS AND MATERIALS

Ten healthy male subjects took part in these experiments.

The intrathoracic pressure was obtained by means of an open-tip polyethylene catheter (No. 190) placed within the esophagus, and the intra-abdominal pressure by means of a similar catheter placed within the stomach. The ends of these catheters were covered with small rubber esophageal balloons which were partially inflated with a small amount of air to prevent occlusion of the openings of the catheter by the mucosal lining of the organs.

It is realized that the pressures obtained from the esophagus and stomach may not be exactly the same as the intrathoracic and intra-abdominal pressures. It is, however, reasonable to assume that the pressure changes as recorded from within these organs reflect those that occur within the two body cavities.

The placement of the catheters was determined by having the subject inspire maximally. The catheter within the lower part of the esophagus recorded a negative pressure, while that within the stomach recorded a positive pressure. In addition, the changes of pressure within the lower part of the esophagus, caused by the heart beat, frequently could be used to help determine the placement of the catheter.

Records of the electrical activity of the trunk muscles were obtained by use of embedded wire electrodes consisting of insulated fine copper wire (No. 34). This wire was threaded through a No. 25 hypodermic needle, the insulation removed from the tip of the wire, and a small hook made in the end of the wire over the short side of the bevel of the needle. The needles with their contained wire electrodes were then sterilized.

After suitable preparation and local anesthetization of the skin, two needles and electrodes were inserted approximately two centimeters apart into each muscle to be studied. The needles were then withdrawn, leaving the wire electrodes with their hooks embedded within the muscles. These were easily removed subsequently by gently pulling on the wires and straightening out the hooks.

The activity of the intercostals, the abdominal obliques, the rectus abdominis, and the deep muscles of the back was recorded simultaneously. The intercostal space between the fifth and sixth or sixth and seventh ribs on the right side was used for obtaining the intercostal activity. The activity of the abdominal obliques was obtained from the right upper quadrant of the abdomen. No attempt was made to estimate depth of the needle so as to differentiate activity of the external oblique from the internal oblique or transversus abdominis. The activity of the rectus abdominis was obtained in the right epigastrium and that of the deep muscles of the back from the main muscle mass of the sacrospinalis at the level of the second to third lumbar vertebra.

Loading of the trunk was accomplished by two methods. In the first (dynamic), the subject lifted weights, in the form of bar bells, of from zero to 200 pounds, in increments of fifty pounds. The weights were lifted from the floor to the height of the freely hanging hand with the subject in the erect position. The lifting was done both with the knees flexed and the spine relatively straight and with the knees straight and the spine flexed. When the heavy weights (150 to 200 pounds) were lifted, the subjects were frequently unable to maintain the second position and lifting was accomplished by partially flexing the knees and spine.

In order to fix the subject's angle of flexion with reference to a given portion of the recorded data, motion pictures of two subjects were made with a thirty-five-millimeter camera which simultaneously photographed a clock in the field of view and a frame on which there were vertical and horizontal lines in a plane parallel to the subject's sagittal plane. The clock had one-second, six-second, and thirty-second sweep hands; the one-second sweep hand triggered a pulse every second which was recorded together with the other data.

The one-second dial was divided into intervals of 1/100 second. The camera

TABLE I

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES STRAIGHT, SPINE FLEXED

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	10	32	83	102	143
JM	2	4	36	58	112	122
JM	3	4	36	84	104	128
MK	1	8	20	30	42	80
MK	2		20	42	44	72
BG	1		24	36	68	104
BG	2	8	24	48	70	104
CC	1		34	62	90	
CC	2	10	26	64	90	108
HL	1	14	16	50	90	172
BB	1	4	36	58	80	80*
RW	1	8	34	66	80	112
RD	1		28	52	120	120
BS	1	10	20	56	80	76
BE	1	8	46	118	148	168
BE	2	20	46	112	160	170
Mean		9	30	64	93	120

* 175 pounds lifted.

TABLE II

RELATIONSHIP OF INTRATHORACIC PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES STRAIGHT, SPINE FLEXED

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	2	20	53	63	62
JM	2	4	46	46	50	60
JM	3	2	30	38	56	52
MK	1	7	18	19	38	48
MK	2				28	40
BG	1		28	16	72	62
BG	2	2	14	30	40	36
CC	1		28	46	48	
HL	1		16			100
BB	1	10	60	70	38	37*
RW	1	6	16	36	60	66
RD	1		32	28	48	52
BS	1	6	18	34	64	46
BE	1	14			60	88
Mean		6	27	38	51	59

* 175 pounds lifted.

speed was thirty-two frames per second, allowing indexing of the position of the subject to the corresponding portion of the recording. By counting down from the one-second mark made by the clock, it was possible to fix the subject's position to within 1/100 second on the recorded data.

The second (static) method of loading the trunk was by means of pulling against a measurable fixed resistance (strain ring) up to a maximum of 200 pounds. Pulling on the ring was done with the trunk of the subject in four positions. In all positions the knees were held straight. The trunk was held first vertical and then flexed at 30, 60, and 90 degrees. The amount of pull or tension exerted on the strain ring was recorded simultaneously with the intracavitary pressures and electromyographic activity.

TABLE III

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES FLEXED, SPINE RELATIVELY STRAIGHT

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	10	108	118	136	134
JM	2	16	44	120	154	158
JM	3	12	50	92	144	156
MK	1	14	44	84	110	136
MK	2	20	30	94	116	144
BG	1	14	30	108	140	140
BG	2	15	38	110	144	150
CC	1	10	38	92	120	116
CC	2	16	44	140	124	148
HL	1	6	38	78	114	162
BB	1	6	40	80	86	88*
RW	1	18	92	104	108	118
RD	1	12	50	76	136	
BS	1	10	40	80	88	96
BE	1	10	66	138	186	200
BE	2	32	116	172	196	208
Mean		14	54	105	131	148

* 175 pounds lifted.

TABLE IV

RELATIONSHIP OF INTRATHORACIC PRESSURE (MILLIMETERS OF MERCURY) TO DYNAMIC LOADING OF THE SPINE: WEIGHTS LIFTED WITH KNEES FLEXED, SPINE RELATIVELY STRAIGHT

Subject	Run No.	0 Lb.	50 Lbs.	100 Lbs.	150 Lbs.	200 Lbs.
JM	1	4	44	44	56	47
JM	2	12	24	48	60	
JM	3	12	36	44	56	60
MK	1	10	40	44	58	60
MK	2	11	20	25	34	60
BG	1	8	20	34	64	60
BG	2	6	10	38	44	54
CC	1	8	34	48	50	56
HL	1		18	22	38	84
BB	1	0	22	26	26	26*
RW	1		22	62	42	54
RD	1	8	36	58	42	84
BS	1	8	20	40	48	56
BE	1		60	66	120	138
Mean		8	29	43	53	68

* 175 pounds lifted.

It was apparent from preliminary runs that the intracavitary pressure produced by loading the trunk must be considered in studying the forces acting on 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 extending across the abdomen from one mid-axillary line to the other and from the xiphoid to the pubis was constructed. This bladder was placed within a non-elastic lumbosacral corset and inflated to the limit of comfort. The resting intra-abdominal pressure was thereby increased by approximately ten to fifteen millimeters of mercury.

RESULTS AND DISCUSSION

Although the weights lifted (dynamic loading) and the pull on the strain ring (static loading) may both exert a force of 200 pounds, there are, of course, a number of differences between these two methods. These differences are primarily in the positioning of the body components and the center of gravity, the amount of movement of the trunk, and the effects of inertia. The results obtained by the two methods of loading, as would be expected, reflect these differences.

Dynamic Loading of the Spine

A total of sixteen experimental runs was carried out on ten healthy male subjects. One subject was used for three runs, four subjects for two runs, and the remainder for one run each.

The intrathoracic and intra-abdominal pressures generated during the loading are given in Tables I through IV. Figure 1 is taken from a typical run as an illustration of the data obtained, with position *A* that of bending forward; *B*, beginning to lift the weight; *M*, lifting the weight from the floor; and *C*, standing upright with the weight at arm's length. It can be seen that when the subject bends over but lifts no weight there is little increase in the intra-abdominal and intrathoracic pressures. The small amount that may be present is probably due to passive compression of the viscera. As larger weights are lifted, the maximum pressures in both abdomen and thorax are progressively increased. The intra-abdominal pressure, however, rises more than that of the thorax with the heavier weights. As weights of 150 to 200 pounds are lifted, the amount of increase of pressure drops off as though a maximum limit were being approached.

As the weights are lifted, the pressures rapidly rise to the maximum and then drop when the upright position is reached. With all but the heaviest weights, the pressure in the abdomen drops almost to the resting level. With the heaviest weights a moderate pressure elevation is maintained in the upright position. These findings are similar to those of Bartelink. The spine seems to be able to tolerate the force of the smaller weights in the upright position with little support by the trunk, but with the heavier weights the trunk is needed to aid in the transmission of the force. As the weights are lowered, there is a second but lower peak of intracavitary pressures.

The intrathoracic pressure, although much less than the intra-abdominal, 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. The fact that the rib cage is not easily compressed beyond this fixed, stable position may account for the generally lower thoracic pressures.

The moving pictures made to correlate the position of the subject with the pressures and with the electromyographic activity demonstrated (as shown in Figure 1) that (1) there is little increase of pressure or muscle activity as the subject bends forward, (2) the pressures rise rapidly as the subject begins to strain to lift the weight, and (3) the maximum peak of pressure occurs at the moment the inertia of the weight is overcome and the weight is lifted from the floor. With the subject in the upright position and the weight at arm's length, the pressures again drop toward resting levels.

As is also shown in Figure 1, the trunk muscles become active simultaneously with the elevation of pressure. The activity of the investing trunk muscles obviously is important in the generation of these pressures. The activity of the rectus abdominis was generally noted to be less than that of the obliques or transversus, which have transverse components and compress the viscera by their con-

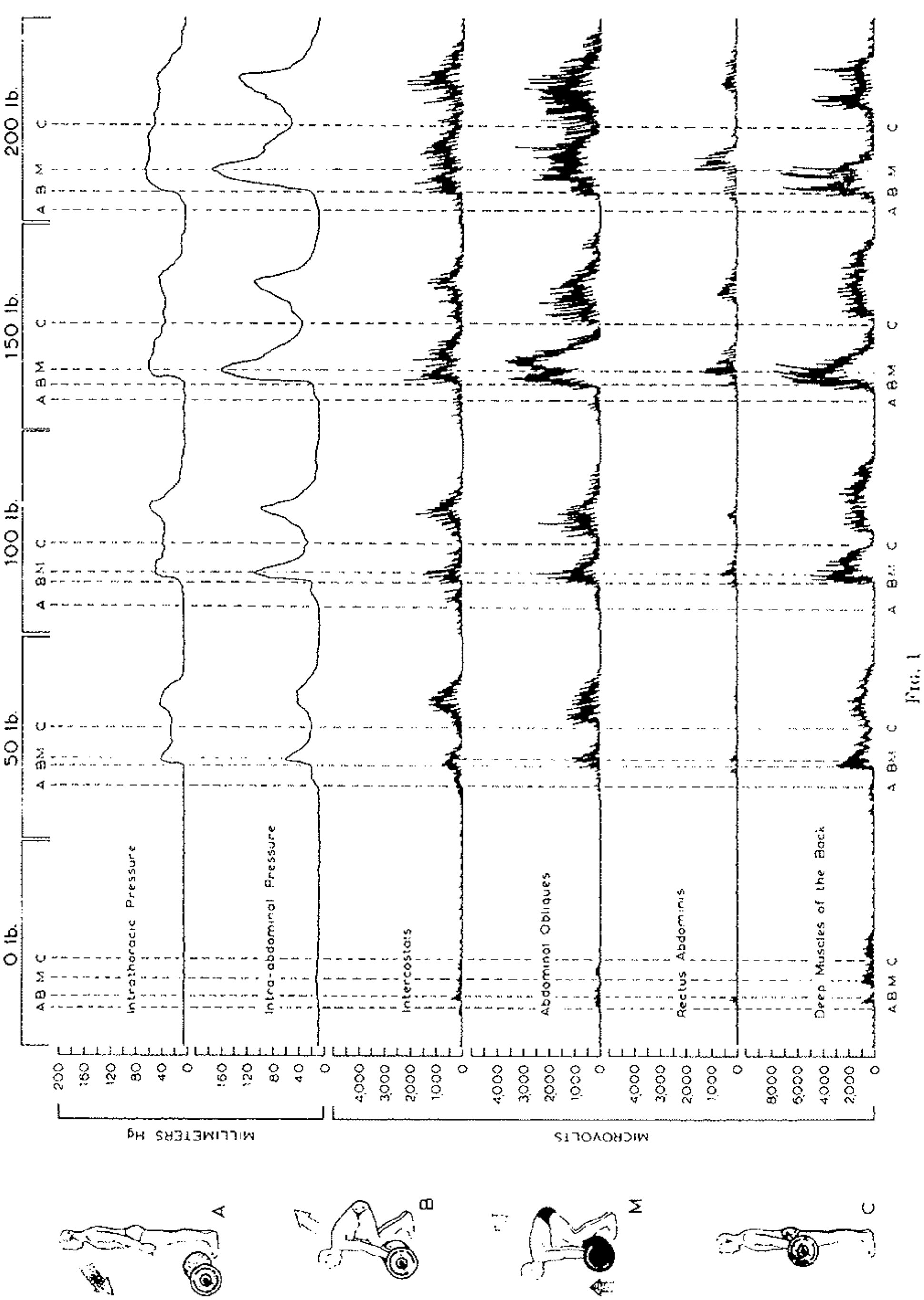

FIG. 1

Dynamic loading of the spine.

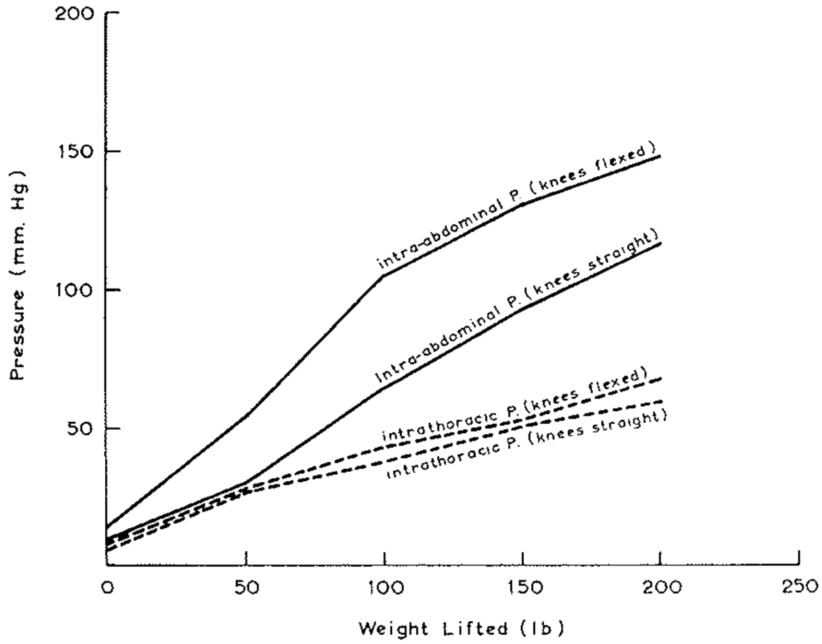

FIG. 2

Relationship of intracavitary pressures to dynamic loading of the spine.

traction. This was especially true when small weights were lifted or when the trunk was in a nearly vertical position. When the trunk was flexed and heavier weights were lifted, however, the activity of the rectus abdominis increased considerably. Presumably, it acts as a stabilizer, binding the rib cage to the pelvis and preventing pouching out of the abdominal viscera. The increase of activity in the flexed position was especially evident in tall subjects. (It should be noted that the electromyographic activity of a muscle increases when the muscle is shortened, even though there is no increase in tension.) The deep muscles of the back are, of course, seen to be active in extending the trunk and lifting the weights. As the weights and thereby the moment of the anterior lever and the force on the spine are increased, the activity of these muscles is increased. However, since none of these muscles contracts isometrically [5], the level of electrical activity as recorded cannot be accurately correlated with the amount of tension developed.

The two positions for the dynamic loading studies (knees flexed and spine relatively straight, knees straight and spine flexed) were fairly easily held by the subjects while lifting weights of up to 100 pounds. However, with weights of 150 to 200 pounds this was more difficult and most of the subjects found it necessary to flex the spine partially with the first method of lifting, and the knees with the second method.

The means of the maximum pressures generated during lifting of the various weights by the two methods are plotted in Figure 2. There was a considerable and consistent difference in the amount of intra-abdominal pressure generated during these two methods of lifting. It was more elevated when the weight was lifted with the knees flexed than with the knees straight. The intrathoracic pressures, however, were quite similar and much less than the intra-abdominal pressures.

No conditions of lifting the weights were imposed on the subjects other than that they lift in the two positions just outlined. No instructions were given as to holding the breath, inspiring maximally, or expiring. Much of the variability of

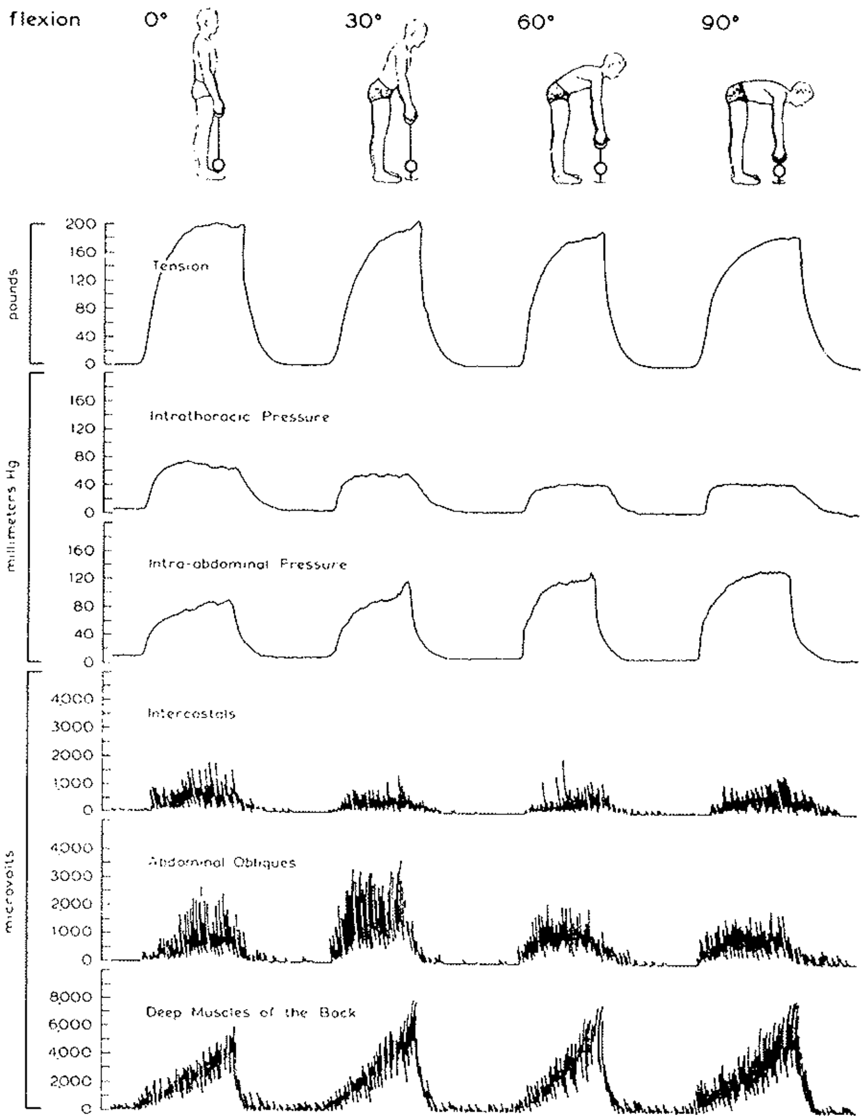

FIG. 3

Static loading of the spine.

the data presented in Tables I through IV may be accounted for by the fact that the subjects were allowed to lift the weights as naturally and easily as possible. Especially with the lighter weights, the amount of inspiration and holding of the breath affected the pressures. With the heavier weights, the conditions under which they could be lifted became more limited; for example, the depth of the inspiration became uniformly greater as the lift began, and the breath was held throughout the lift. Consequently, there is much better agreement in results of separate runs by the same subject when heavy weights were lifted than when lighter weights were lifted.

As can also be seen in the Tables, there is a considerable range in the values of the pressures for different subjects lifting the same weight (±30 to 35 per cent from the mean). There appears to be fairly good correlation between the size of

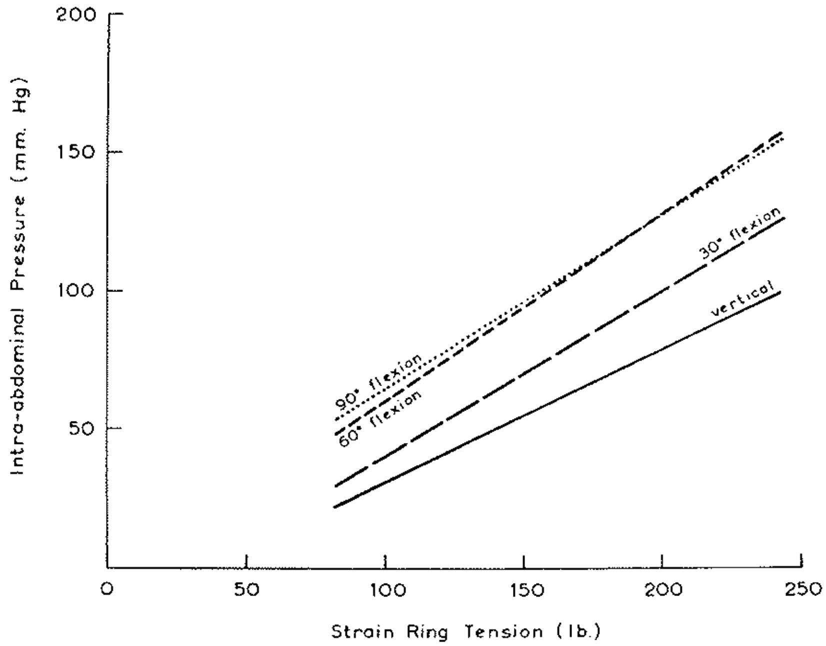

FIG. 4

Relationship of intra-abdominal pressure to static loading of the spine (without inflatable corset).

the subject and the amount of pressure generated. The lowest pressures were generally found in BB and BS, both of whom weighed between 120 and 130 pounds and who were five feet, three inches and five feet, four inches tall. The highest pressures were obtained in BE, who weighed 220 pounds and was six feet, two inches tall.

Static Loading of the Spine

For the study of static loading, sixteen experimental runs were performed with seven subjects. Tension imposed on a strain ring with the trunk vertical or in various degrees of flexion was simultaneously recorded with the intra-abdominal and intrathoracic pressures and the electromyographic activity of the muscles. It can be seen in Figure 3 that as the tension on the ring (or loading of the spine) is increased, the intracavitary pressures and electromyographic activity increase proportionately.

With the subject pulling on the ring in the upright position, the intra-abdominal and intrathoracic pressures were generally 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. The action of the obliques was generally fairly constant in the various positions, remaining proportionate to the pressure. The rectus abdominis was only slightly active in the vertical position, but its activity increased progressively with flexion of the trunk. The activity of the intercostals remained approximately the same or decreased slightly in the more flexed positions. The activity of the deep muscles of the back increased progressively with loading of the spine; it was somewhat less in the upright than in the flexed positions.

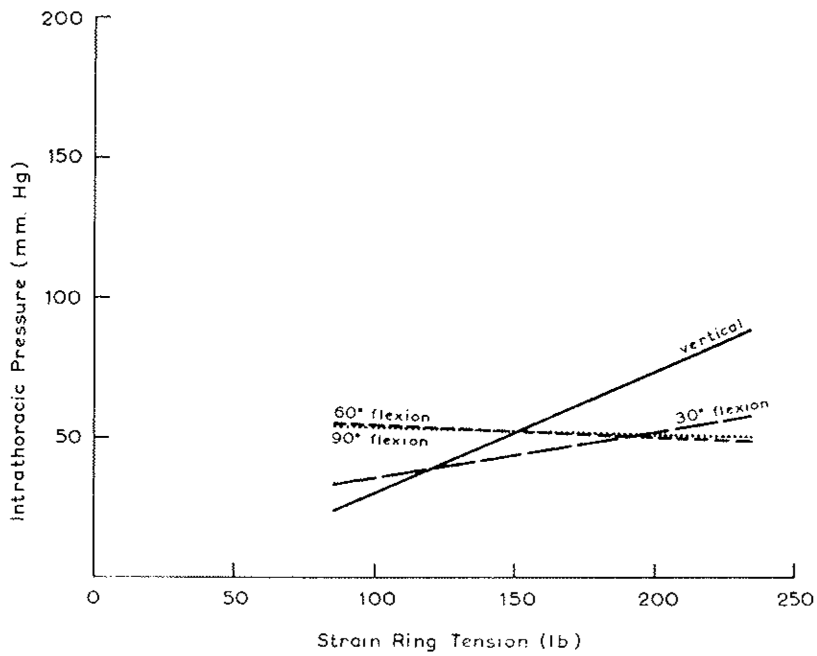

FIG. 5

Relationship of intrathoracic pressure to static loading of the spine (without inflatable corset).

The data obtained from the subjects in this series are difficult to compare and analyze for several reasons: (1) Both the amount of tension on the ring and the pressures generated were variable; (2) it was quite difficult to have a single subject pull exactly the same way on successive runs and even more difficult to have different subjects do so—frequently, there was a tendency for the subject to lean backward while pulling, thus using body weight in place of muscle activity to impose tension on the ring; and (3) small differences occurred in the amount of inspiration and of holding of the breath. The variability of the data was primarily due to the second factor—the position of the subject while pulling. The third factor played only a small role and then mainly when the load was small.

Despite this variability, a relationship between the intra-abdominal pressure and the position of the trunk during static loading is evident. The lines on the graph in Figure 4 were obtained from the data (maximum strain-ring tensions and maximum pressures in the four different positions) by the method of least squares. It can be seen that, for any specific tension on the ring, the intra-abdominal pressure increases with flexion of the trunk. There is, however, virtually no difference in the pressures obtained with the trunk flexed at 60 and 90 degrees.

This finding is clarified when it is recalled that when a weight is lifted in the flexed position, the spine forms a long anterior lever with the fulcrum in the lower lumbar part of the spine (Appendix 2 and Fig. 10). As the spine is progressively flexed, the length of the anterior component of this lever is increased, increasing the force on the lower part of the spine. The increased abdominal pressure in the flexed positions presumably reflects the larger forces being transmitted through the abdomen.

The slopes of the lines indicating the relationship between the intrathoracic pressure and tension on the strain ring were also determined by the method of least squares for each of the four positions studied (Fig. 5). In the upright posi-

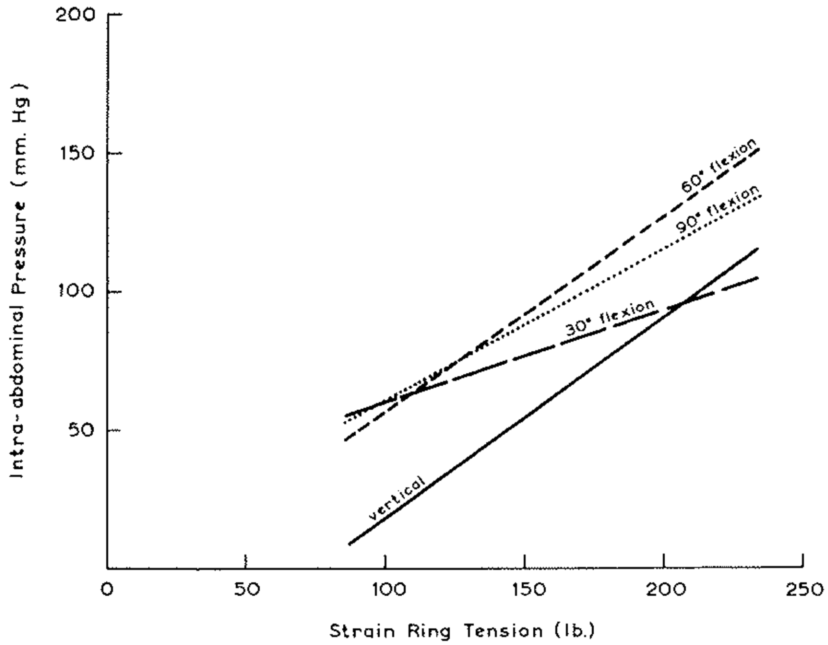

FIG. 6

Relationship of intra-abdominal pressure to static loading of the spine (with inflatable corset).

tion the relationship between the intrathoracic pressure and the tension is almost identical with that between the intra-abdominal pressure and the tension. Thus, equilibrium of the pressures of the two cavities occurs across the diaphragm in this position. When the trunk is flexed, however, the intrathoracic pressures are considerably lower than the intra-abdominal. It can also be seen that as the trunk assumes a more flexed position the degree of increase of intrathoracic pressure with further loading is diminished. When the trunk is flexed to 60 or 90 degrees, there is essentially no change in the intrathoracic pressure over the range of strain-ring tension studied here (100 to 200 pounds). Apparently, in these positions the thorax becomes fixed quickly during the act of pulling and remains so while further tension is applied to the ring.

The smaller amounts of intrathoracic pressure in the more flexed positions, as compared with those in the upright position, may be at least partially accounted for by the fact that in the upright position all the force on the strain ring is transmitted through the rib cage and thoracic part of the spine. In the flexed positions, however, the force on the strain ring is distributed from the arms by way of the trapezius and latissimus dorsi along the thoracic and even the lumbar portions of the spine. Therefore, since there is less total force transmitted through the thorax, there is less increase of intrathoracic pressure and less need for rigidity and fixation of the rib cage.

Effects of an Inflatable Corset

It has been observed for some time that, in cases of pain in the lower part of the back due to disc degeneration or so-called mechanical instability of the back, compression of the abdominal viscera often relieves the pain. This compression may be accomplished by a tight corset, a brace with an abdominal pad which can be tightened, or a snug plaster body jacket.

As part of the study of the support of the spinal column, an investigation of the effects of externally applied pressure and support for the trunk was begun. The first apparatus to be studied was a corset inflated to the limit of comfort. At

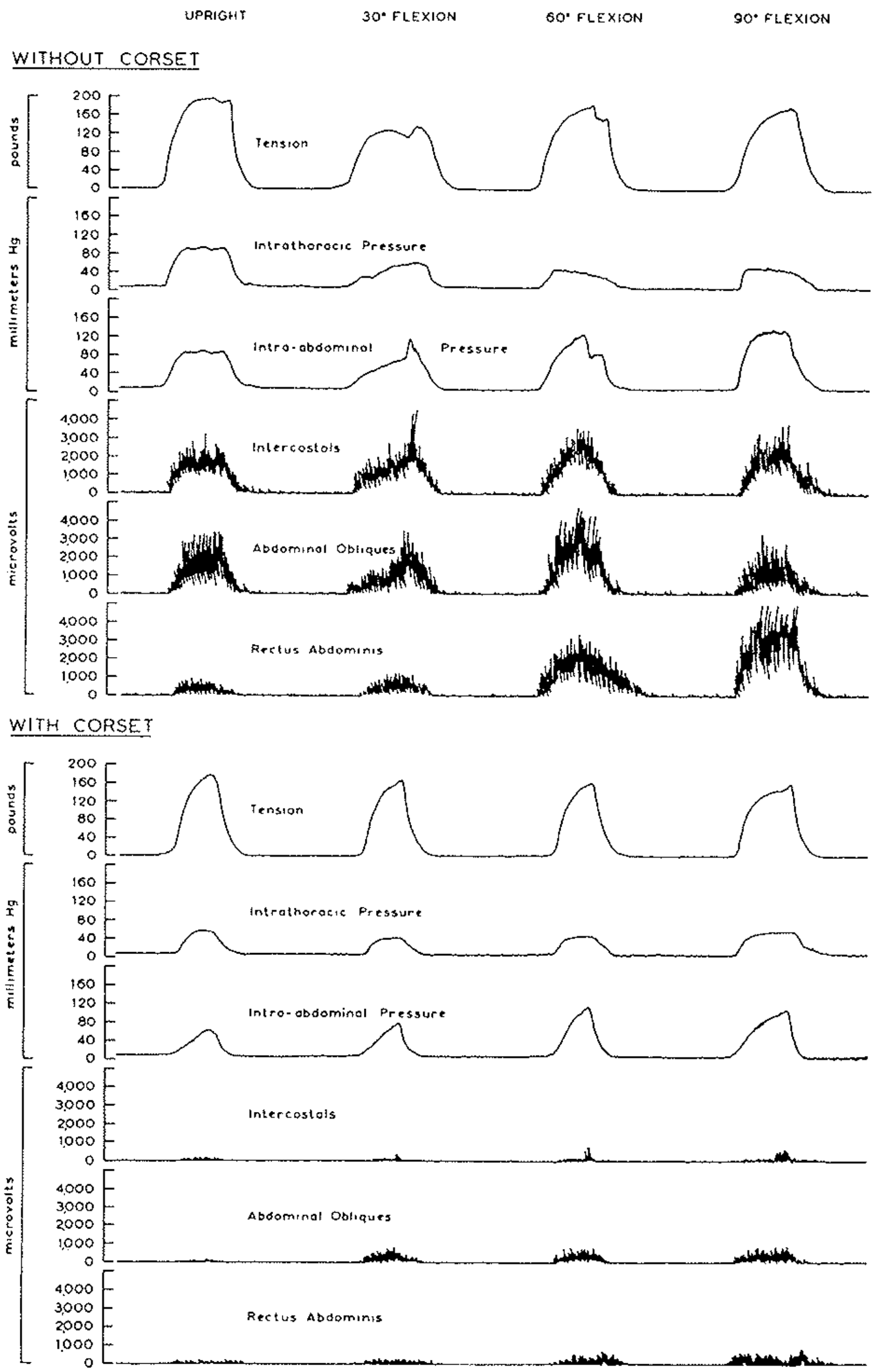

FIG. 7

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

TABLE V

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE TO STATIC LOADING OF THE SPINE WITHOUT INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*) 30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	204	50	120	60	114	80	136	84
MK	2	228	100	212	136	200	130	204	136
RD	1	90	24	114	56	132	136	124	108
RD	2	64	80	176	108	170	148	180	148
CC	1	140	42	112	32	116	44	86	40
CC	2	120	24	128	32	116	50	136	96
CC	3	188	56	204	60	170	100	136	100
CC	4	200	88	208	72	176	120	166	132
JM	1	200	88	174	120	196	128	194	136
JM	2	182	84	184	112	182	122	188	128
BS	1	136	40	124	50	122	86	120	74
BG	1	104	50	140	74	140	78	140	80
BG	2	128	44	136	58	146	72	168	94
BG	3	198	74	210	100	200	100	200	92
BG	4	202	96	188	96	188	124	176	90
BE	1	206	84	170	94	164	94	156	80

TABLE VI

RELATIONSHIP OF INTRATHORACIC PRESSURE TO STATIC LOADING OF THE SPINE WITHOUT INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*) 30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	228	100	212	50	200	60	204	56
RD	1	90	32	114	50	132	72	124	70
RD	2	164	52	176	66	170	56	180	64
CC	1	140	50	112	28	116	44	86	48
CC	2	120	10	128	20	116	32	136	28
JM	1	200	88	174	44	196	42	194	44
JM	2	182	68	184	50	182	40	188	42
BS	1	136	30	124	30	122	44	120	40
BG	1	104	56	140	62	140	70	140	82
BG	2	128	48	136	48	146	72	168	84
BG	3	198	56	224	56	204	36	200	42
BG	4	202	62	188	40	188	50	176	36

this point there was no weakness or paresthesia of the lower limbs (such as would occur with an increase of the pressure), and there was a subjective feeling of rigidity and support of the trunk.

Eight experimental runs were carried out on six subjects, with certain significantly consistent results despite the small number. The resting abdominal pressure was elevated from five to eight millimeters of mercury to twenty to twenty-five millimeters of mercury. With normal inspiration there was an increase of five to ten millimeters of mercury in the abdominal pressure, and when the trunk was flexed an increased elevation of the pressure occurred because of the restraint given by the apparatus. The intrathoracic pressure was elevated only slightly, if at all.

TABLE VII

RELATIONSHIP OF INTRA-ABDOMINAL PRESSURE TO
STATIC LOADING OF THE SPINE WITH INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*)					
				30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	220	80	220	80	186	122	192	110
MK	2					200	120		
RD	1	184	92	140	100	170	110	168	100
CC	1	144	48	116	50	96	50	108	54
CC	2	160	56	180	90	176	120	152	96
JM	1	172	48	164	66	160	88	152	80
BS	1	154	68	156	88	148	96	96	80
BG	1	168	68	132	68	116	68	122	70
BG	2	220	128	210	114	200	124	196	116

TABLE VIII

RELATIONSHIP OF INTRATHORACIC PRESSURE TO
STATIC LOADING OF THE SPINE WITH INFLATABLE CORSET

Subject	Run No.	Trunk Vertical		Trunk in Flexion (*Degrees*)					
				30		60		90	
		Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*	Tension *Lbs.*	Pressure *Mm. Hg*
MK	1	228	70	240	72	186	80	192	50
RD	1	184	88	140	74	170	74	168	64
JM	1	172	40	164	42	160	44	152	52
BS	1	154	50	156	66	148	62	96	50
CC	1	144	56	116	54	96	60	108	48
BG	1	168	68	132	60	116	60	122	60
BG	2	220	56	216	60	200	54	196	48

It is interesting to note that, while the resting intra-abdominal pressure was considerably elevated by the corset, the maximum pressures generated in static loading of the spine were quite comparable to those obtained without the corset (compare Figs. 4 and 6). The slope of the lines indicating the relationship of the intra-abdominal pressure to the strain-ring tension (Fig. 6) was determined by the method of least squares. Because of the small amount of data, more observations might change the slopes of the lines in Figure 6. This possibility may account for the discrepancy in the slopes in Figures 4 and 6.

It would appear that there is little if any difference in the maximum pressures in the abdomen or thorax with and without the corset during static loading of the spine. The slightly lower pressures occasionally seen with the corset may be due to the fact that some of the force normally transmitted through the trunk is transmitted instead through the apparatus.

However, when the activity of the trunk muscles is compared during loading with and without the corset, a marked difference is obvious (Fig. 7). The activity of the abdominal obliques and the rectus abdominis is consistently and considerably decreased when the corset is worn, despite the fact that the intra-abdominal pressures may 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. In tall subjects, however, on whom the corset did not extend as high as on the shorter subjects, there was no effect on the intercostal activity.

CALCULATION OF ACTUAL FORCES ON THE SPINE

To illustrate the role of the trunk in the support of the spine, the data obtained experimentally may be used to calculate the approximate forces on the spine in the living human being when a weight of 200 pounds is lifted. Since by far the largest forces are imposed on the lumbar and lower thoracic regions, these will be considered, along with the effect of the intra-abdominal pressure.

The influence of the trunk muscles and the intra-abdominal pressure on the forces transmitted by the spine can be demonstrated by considering the static equilibrium of the upper part of the body. The forces which must be considered in

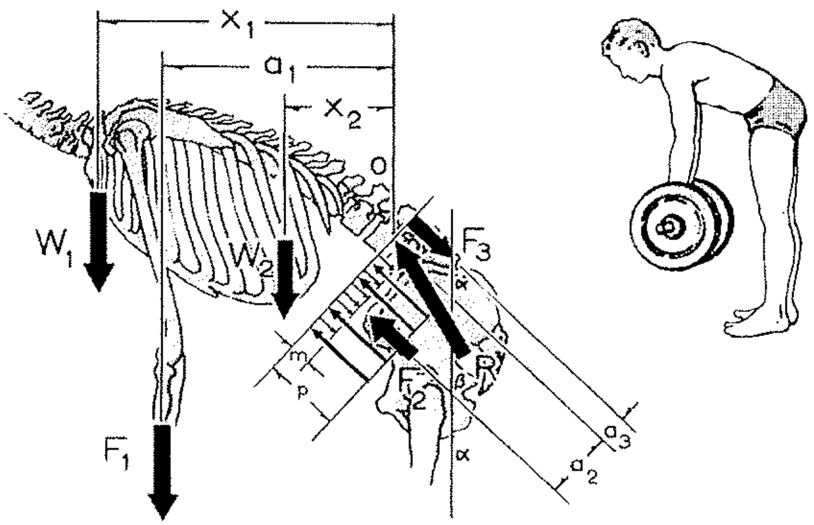

FIG. 8
Forces used in calculations.

this idealized system are (1) gravity forces—the body weight and any additional external weight carried by the body, (2) the tension in the deep muscles of the back and in the muscles of the abdominal wall, (3) the pressure (p) in the internal cavities of the trunk (intra-abdominal and intrathoracic), and (4) the force transmitted by the spinal column. The spinal column may be considered to act as a flexible segmental column, whereas the thoracic and abdominal cavities may be considered as inflatable structures contained within the trunk and restrained by the thoracic cage and abdominal muscles.

To determine the force on the spine at a given level, it is necessary to consider the external (gravity) forces acting on the body above this level and the internal forces resisting or supporting the external forces (Fig. 8). The external forces can be grouped together or divided into several components. For convenience, the weights of head, neck, and arms are grouped together for calculation as one force (W_1) and the weight of the torso above the given level is considered separately as another force (W_2); both act through their respective centers of gravity. The weight lifted by the arms is considered as a separate force (F_1) acting through its center of gravity.

The resisting internal forces are the net force of the intra-abdominal pressure and tension of the longitudinal component of the abdominal muscles (F_2), the tension in the deep muscles of the back (F_3), and the reaction (R) on the spine at the given level. (Although the tension of the transverse component of the abdominal muscles contributes to the increase of abdominal pressure, it has little effect on the static equilibrium and therefore has been neglected in the following equations.)

The magnitudes of the forces W_1, W_2, and F_1 and their position in space relative to the disc 0 (Fig. 8), defined by distances x_1, x_2, and a_1, are known for a subject in a given posture and activity. For a given set of external forces, the magnitudes of the forces F_2, F_3, and R cannot be defined solely by considerations of equilibrium, since they depend on the activity of the abdominal muscles, the back muscles, and the intra-abdominal pressure. If the activity of the abdominal muscles in terms of developed tension forces and the intra-abdominal pressure are

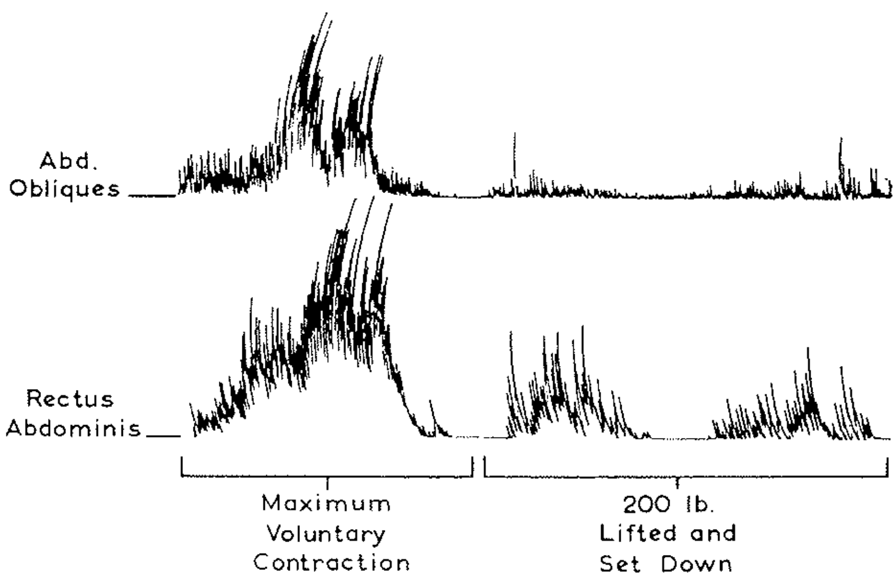

FIG. 9

Electromyographic activity during maximum voluntary contraction and during lifting.

measured, then the net resultant force F_2 can be determined. If p is the intensity of intra-abdominal pressure acting on an effective abdominal cross section, A_a, and m is the estimated intensity of longitudinal muscle tension on an effective muscle cross section A_m, then

$$F_2 = pA_a - mA_m \qquad (1)$$

The remaining unknown forces F_3 and R can be calculated under conditions of static equilibrium. In most cases it is sufficient to assume that the net abdominal force F_2 and the tension in the back muscles F_3 are parallel, making an angle α with the vertical.

The tension in the back muscles (F_3) is an unknown. However, for static equilibrium, the sum of the moments about the fulcrum (0) must equal zero, or

$$W_1x_1 + W_2x_2 + F_1a_1 - F_2a_2 - F_3a_3 = 0$$

from which F_3 may be obtained:

$$F_3 = \frac{W_1x_1 + W_2x_2 + F_1a_1 - F_2a_2}{a_3} \qquad (2)$$

The reaction (R) is of most interest in this study. Its magnitude and direction are unknown and may be determined in a similar way, by considering the conditions of equilibrium. The resultant sum of forces acting at the fulcrum 0 must be zero (this includes R). This condition may now be divided into two parts: (1) The sum of the vertical components of the forces must equal zero, or

$$W_1 + W_2 + F_1 - F_2 \cos \alpha + F_3 \cos \alpha - R \cos \beta = 0$$

from which

$$R \cos \beta = W_1 + W_2 + F_1 + (F_3 - F_2) \cos \alpha \tag{3}$$

(2) The sum of the horizontal components of the forces must equal zero, or

$$F_2 \sin \alpha - F_3 \sin \alpha + R \sin \beta = 0$$

or

$$R \sin \beta = (F_3 - F_2) \sin \alpha \tag{4}$$

Values of the reaction R and the angle β can be determined as follows: Dividing Equation 3 by Equation 2,

$$\frac{R \sin \beta}{R \cos \beta} = \tan \beta = \frac{(F_3 - F_2) \sin \alpha}{W_1 + W_2 + F_1 + (F_3 - F_2) \cos \alpha} \tag{5}$$

Solving for tan β, and hence β, from Equation 5, the magnitude of the force R can be calculated from Equation 4:

$$R = \frac{(F_3 - F_2) \sin \alpha}{\sin \beta} \tag{6}$$

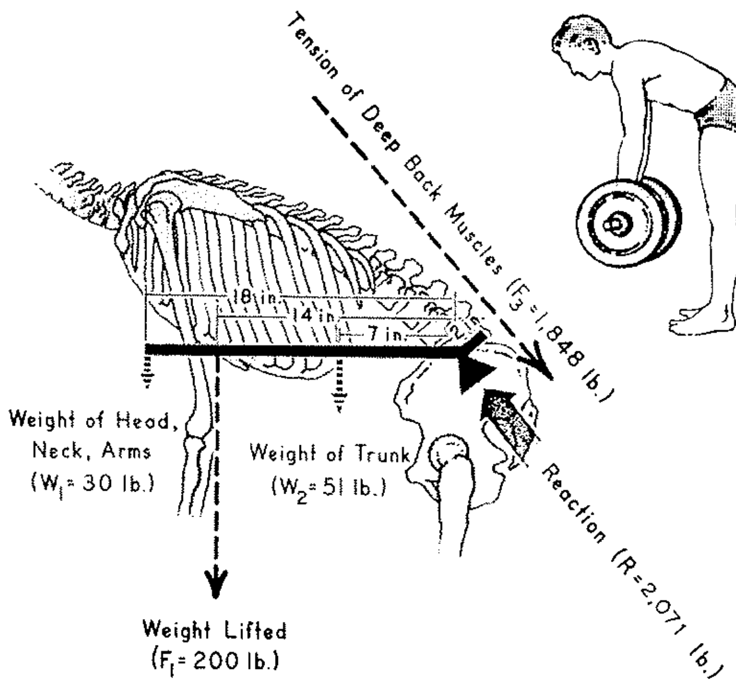

FIG. 10

Force on lower lumbar part of spine, omitting role of trunk.

With use of the equations thus derived, the force at the base (lumbosacral junction) of the spine can be determined.

With knowledge of the amount of weight lifted, the body weight, the reaction to the intra-abdominal pressure, and the distances from the lumbosacral disc or fulcrum at which the forces act, the tension of the deep back muscles can be calculated. When all the forces and their directions are known, the reaction at the lumbosacral disc can be determined (see Appendix 2). Thus, instead of a force to

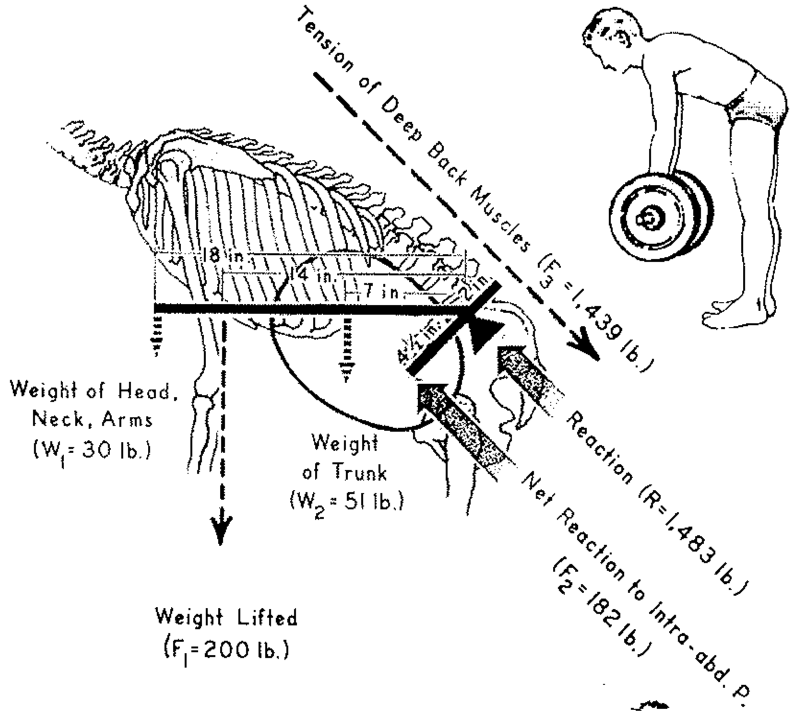

FIG. 11

Force on lower lumbar part of spine, including role of trunk.

2,071 pounds (Fig. 11) at the base of the beam, there is, because of the "inflatable support", a force of only 1,483 pounds—a reduction of 600 pounds.

Next, the force on the lower thoracic part of the spine can be calculated, again with the example of a weight of 200 pounds being lifted in the flexed position.

The total force acting on the diaphragm can be calculated by multiplying the area of the diaphragm by the intra-abdominal pressure. This upward force is partially counteracted, however, by the downward pull on the rib cage by the longitudinal components of the abdominal-wall muscles during compression of the viscera (see Appendix 1 for calculation).

When the spine is heavily loaded, the diaphragm contracts and becomes relatively flattened and rigid. It may be thought of as a lever attached to the lower thoracic vertebrae through the ribs and to the upper three lumbar vertebrae by means of the crura. If the upward force is assumed to act at the center of the diaphragm, the ratio between the diaphragmatic lever (distance from center of diaphragm to fulcrum, which for practical purposes is assumed to be the center of the nucleus pulposus of the disc between the tenth and eleventh thoracic vertebrae) and the posterior lever acted on by the deep back muscles (distance from mid-point of spinous process to fulcrum) is approximately four to one. The upward force is transformed through the lever system into a force about four times larger acting in the same direction as the contraction of the deep muscles of the back and forming a force couple with the tension developed in these muscles.

If the role of thorax and abdomen is ignored, the force on the lower thoracic region of the spine may be calculated as it was for that at the base of the spine, except that the lever arm acted on by the weight lifted is considerably shorter than the lever arm at the base of the spine and that the posterior lever is also

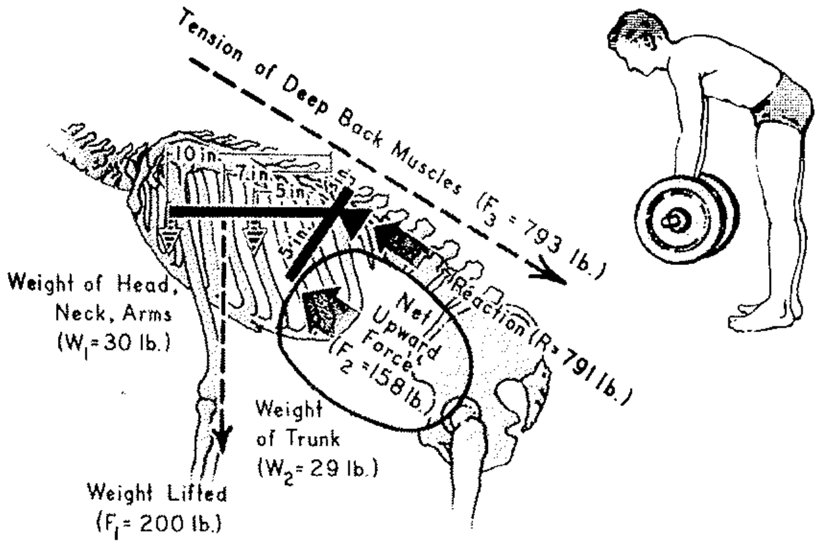

FIG. 12

Force on lower thoracic part of spine, including role of trunk.

somewhat shorter. The force on this region of the spine thus obtained is 1,568 pounds. By the relatively simple mechanism of an upward push on the diaphragm by increased intra-abdominal pressure, the force on the lower thoracic and upper lumbar vertebrae and discs is reduced to 791 pounds (Appendix 2).

CONCLUSIONS

There is a great discrepancy between the force that can theoretically be applied to the spine if the role of intracavitary pressures is ignored and the force that can be tolerated experimentally by the isolated ligamentous human spine.

In estimating that a force of approximately 2,071 pounds is imposed on the lower lumbar part of the spine when a weight of 200 pounds is lifted in the flexed position, the vertebral column is considered only as an isolated unit being acted on by the forces of the weight lifted, the body weight, and the contraction of the deep muscles of the back. Such a picture, however, is quite simplified, since no account is taken of the important role of the trunk—thorax and abdomen—in support of the spine. ("Support" is used here in its broadest sense, meaning maintenance of stability of the column against deformity and against structural damage of its components.) The answer to the question of how the vertebral column in a living subject is able to withstand a far greater force than the isolated column must be found by consideration of the extrinsic supporting structures of the trunk.

In this study, data on the mechanism of support of the spine by the trunk have substantiated the hypothesis made at the beginning of the study: The spinal column is attached to the sides of and within two chambers, the abdominal and thoracic cavities; the action of the trunk muscles converts these chambers into nearly rigid-walled cylinders containing (1) air and (2) liquid and semisolid material. Both these cylinders are capable of transmitting part of the forces generated in loading the trunk and thereby of relieving the load on the spine itself.

When large forces are applied to the spine—for example, lifting weights of 100 to 200 pounds—there is generalized contraction of the trunk muscles, including the intercostals, the muscles of the abdominal wall, and the diaphragm. The muscles about the shoulder girdle and those of the back are, of course, active during lifting, just as the muscles of the thighs help maintain body balance and the erect position.

The action of the intercostals and of the muscles of the shoulder girdle renders the thoracic cage a quite rigid structure firmly bound to the thoracic part of the spine. When inspiration and the action of the intercostal muscles, which stabilize the rib cage, increase intrathoracic pressure, the thoracic cage and spine become a solid, sturdy unit capable of transmitting large forces. By the contraction of the diaphragm, attached at the lower margin of the thorax and overlying the abdominal viscera, and of the muscles of the abdominal wall, especially the transversus abdominis, the abdominal contents are compressed into a semirigid cylinder.

The force of weights lifted by the arms is thus transmitted to the spinal column by the shoulder-girdle muscles, principally the trapezius, and then to the abdominal cylinder and to the pelvis, partly through the spinal column but also through the rigid rib cage.

When larger forces are involved, there is need for increased rigidity of the rib cage and compression of the abdominal contents. This accounts for the increased activity of the trunk muscles and the increase in intracavitary pressures when greater forces are applied. Thus, an increased intra-abdominal pressure is due to the contraction of the abdominal muscles and to the compression of the abdomen by the force which is transmitted through the trunk.

This view is well substantiated by the fact that when an air-pressure corset is worn, although the resting abdominal pressure is considerably elevated (by approximately twenty millimeters of mercury), the pressures recorded during loading of the spine are similar to those recorded without the corset. However, the activity of the abdominal muscles is markedly decreased when the inflatable corset is worn. It appears, therefore, that the contracted muscles of the abdominal wall or the rigid external-pressure apparatus act 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. However, a small amount of activity is noted in the abdominal muscles even when the corset is worn, especially when greater forces or heavier loads are applied. The amount of compression of the viscera necessary to transmit these great forces can be tolerated briefly but not for prolonged periods. Since, in this study, the apparatus was inflated to the limit of comfort for extended periods, the abdomen was not compressed enough to obviate entirely the need for muscle activity with the larger forces.

It should be emphasized that the mechanism discussed here is a reflex mechanism. When a load is placed on the spine, the trunk muscles are 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 this calculation of the contribution of the trunk compartments to the support of the spine, 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 calculated force on the lumbosacral disc is about 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.

These particular results are applicable under the conditions described in this report—near-maximum loading of the trunk (lifting a 200-pound weight) in the flexed position. However, with appropriate consideration of the surrounding structures, the position of the spine, and the forces acting at a specific level, the general principles illustrated by this investigation can be used to determine the force at any level of the spine under a variety of situations.

APPENDIX 1

The approximate value of the longitudinal component of the tension of the abdominal muscles was calculated as follows:

The cross-sectional areas of the abdominal obliques and the recti were determined with values obtained from Weber's tables [8].

	Longest fibers (*centimeters*)	Weight (*grams*)
Rectus abdominis	29.7	131.65
External oblique	18.4	115.05
Internal oblique	12.4	107.12

The following formula was used:

$$\text{Cross section} = \frac{W}{\rho L} = \frac{V}{L}$$

where

W = weight in grams

ρ = density of muscle (1.06 grams per cubic centimeter)

L = length of muscle (longest fibers) in centimeters

V = volume in cubic centimeters

The values thus obtained were as follows:

Rectus abdominis 4.2 square centimeters

External oblique 5.9 square centimeters

Internal oblique 8.2 square centimeters

Since only the longitudinal component of these muscles is active in holding the rib cage down, this component was arrived at by considering the two oblique muscles as fan-shaped with some fibers running transversely, some longitudinally, and some obliquely. For ease of calculation, a mean obliquity of 45 degrees to the longitudinal was assumed for the fibers of each muscle as a whole. One-half of the cross section was assumed to act in the transverse direction and one-half in the longitudinal direction. The rectus abdominis, of course, acts only in the longitudinal direction.

The cross-sectional area of the abdominal-wall muscles acting in a longitudinal direction was calculated as follows:

Rectus abdominis (both sides): 4.2 square centimeters $\times 2 = 8.4$ square centimeters

External oblique (longitudinal component): 5.9 square centimeters $\times \frac{1}{2} \times 2 = 5.9$ square centimeters

Internal oblique (longitudinal component): 8.2 square centimeters $\times \frac{1}{2} \times 2 = 8.2$ square centimeters

Total cross-sectional area acting in a longitudinal direction = 22.5 square centimeters

On the basis of the value four kilograms per square centimeter [4], the maximum voluntary longitudinal force which could theoretically be produced by this muscle mass is ninety kilograms (198 pounds).

Since these muscles were not maximally active during the weight lifting, an attempt was made to determine the degree of activity by comparing electromyographic activity during maximum voluntary contraction and during the act of lifting. The position in which the voluntary contraction was performed was the same as that in lifting the weights. Isometric contractions were also compared, with the strain ring used as the method of loading.

The results were similar and are illustrated in Figure 9.

As can be seen, the degree of activity in the abdominal obliques during loading is approximately one-sixth of that obtained with maximum voluntary contraction. The activity of the rectus abdominis with loading is somewhat less than one-half of the maximum voluntary activity.

The maximum longitudinal force which can theoretically be generated by the abdominal obliques is the cross-sectional area of the longitudinal components of the muscles, 14.1 square centimeters, multiplied by four kilograms per square centimeter or 56.4 kilograms. However, when the muscles function at only one-sixth of their maximum, the longitudinal force is only 9.4 kilograms. Similarly, the force produced by the rectus abdominis is calculated by multiplying the area 8.4 square centimeters by four kilograms per square centimeter and dividing by two (degree of activity), which equals 16.8 kilograms. The total longitudinal force generated by the obliques and the rectus abdominis while lifting 200 pounds is therefore 26.2 kilograms or 57.64 pounds.

APPENDIX 2

Force on Lumbosacral Disc

In determination of the reaction of force at the lumbosacral disc, to be considered are the weight lifted (F_1), the reaction of the pelvis to the net downward force of the intra-abdominal pressure (F_2), the tension of the deep muscles of the back (F_3), and the body weight as divided into two parts (W_1 and W_2).

Omission of Intracavitary Pressures: In this calculation, which is illustrated in Figure 10, the reaction of the pelvis to the net downward force of the intra-abdominal pressure is omitted.

Let M_1 denote the moment resulting from a force of 200 pounds acting at 14 inches (the distance, in a subject flexing his spine to lift the weight, from the arm to the center of the fifth lumbar disc); then $M_1 = 2{,}800$ pound-inches.

Let M_4 denote the moment resulting from the body weight. Body weight has been divided into two parts: W_1 and W_2. W_1 (head, neck, and arms) is thirty pounds (17.7 per cent of the total body weight) and acts at a distance of eighteen inches from the fulcrum. W_2 (the weight of that part of the trunk above the lumbosacral disc) is fifty-one pounds (30 per cent of the total body weight) and acts seven inches from the fulcrum. Addition of the moments of these two components of body weight gives $M_4 = (30 \text{ pounds} \times 18 \text{ inches}) + (51 \text{ pounds} \times 7 \text{ inches}) = 897$ pound-inches.

The force exerted by the back muscles (F_3) is treated as an unknown, as in the reaction (R) of the pelvis to the net resultant of forces acting on the spine at the lumbosacral junction.

For static equilibrium, $\Sigma M = 0$. With use of this fact, F_3 may be solved for (with M_3 being the moment of this force acting at 2 inches—the distance from the center of the lumbosacral disc to the mid-point of the spinous process of the fifth lumbar vertebra, the level at which most of the deep muscles of the back are attached).

M_1 and M_4 are negative by convention. Transposing and substituting known values,

$$F_3 = \frac{2{,}800 \text{ pound-inches} + 897 \text{ pound-inches}}{2 \text{ inches}} = 1{,}848.5 \text{ pounds}$$

Further, the resultant sum of the forces acting at 0 (lumbosacral disc) must be in equilibrium with the reaction (R). This condition may be conveniently expressed as follows: The resultant sum of the forces acting at 0 should be zero. (Note that this includes R.) This condition may be divided into two parts: The sum of the vertical components of forces at 0 should be zero, and the sum of horizontal components of forces at 0 should also be zero. Then, algebraically, the conditions are as follows:

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos \alpha - R \cos \beta = 0$

Angle β is an unknown. Angle α is assumed to be 40 degrees. Substituting known values, 200 pounds + 30 pounds + 51 pounds + 1,848.5 cos 40° = R cos β. R cos β = 1,697 pounds.

R sin β = 1,189 pounds. .574 R = 1,189 pounds. R = 2,071 pounds

Inclusion of Intracavitary Pressures (Fig. 11): M_1 is calculated, as just noted, to be 2,800 pound-inches. Let M_2 denote the moment resulting from the reaction of the pelvis to the downward force of the intra-abdominal pressure. Since the maximum pressure is 148 millimeters of mercury, or three pounds per square inch, and the cross-sectional area may be estimated at eighty square inches, the force exerted on the pelvis is 240 pounds. The net downward force is obtained by subtracting the tension of the vertical components of the abdominal muscles, fifty-eight pounds (Appendix 1), which gives 182 pounds. The equal and opposite reaction force of the pelvis (F_2) = 182 pounds. It may be considered to act 4.5 inches from the center of the disc, or approximately at the center of the abdominal cavity. Therefore, M_2 = 819 pound-inches (182 pounds × 4.5 inches). $M_3 = F_3$ (an unknown) × 2 inches (its lever arm). M_4 is calculated, as before, to be 897 pound-inches. It may be assumed that the connection between pelvis and spine can be approximated by a universal joint and that F_2 and F_3, acting in opposite directions, are parallel in a direction (angle α) 40 degrees to the vertical.

$\Sigma M = 0$

$F_3 \times 2 \text{ inches} = -(M_1 + M_2 + M_4)$

$$F_3 = \frac{-(-2{,}800 \text{ pound-inches} + 819 \text{ pound-inches} - 897 \text{ pound-inches})}{2 \text{ inches}}$$

F_3 = 1,439 pounds

In order to obtain the reaction (R) at point 0, the vertical and horizontal components of the forces acting on this point are considered:

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos \alpha - F_2 \cos \alpha - R \cos \beta = 0$

Horizontal components: $F_3 \sin \alpha - F_2 \sin \alpha - R \sin \beta = 0$

$$\tan \beta = \frac{R \sin \beta}{R \cos \beta}$$

Angle β, which the reaction (R) makes with the vertical direction, and the magnitude of R are not known, but with the values for F_1, F_2, F_3, W_1, W_2, and angle α (40 degrees) the equations just given can be used to obtain the two unknowns.

Solving for R and angle β, the force on the lumbosacral disc is found to be 1,483 pounds, which, in this specific example, acts in a direction 33 degrees to the vertical.

Force on Lower Thoracic Portion of Spine

The force on the lower thoracic part of the spine may be calculated by the same method. In the same specific example, the reaction (R), or the force at the disc between the tenth and eleventh thoracic vertebrae (point 0), will be determined. The spine at this level will be assumed to form an angle α of 60 degrees to the vertical.

F_1 is the weight of 200 pounds acting at a distance of seven inches from point 0. F_2 is the net upward force on the diaphragm—158 pounds acting five inches from 0. F_3 is the tension of the deep muscles of the back acting on the short posterior lever arm one and one-third inches from point 0. W_1 is thirty pounds (the weight of the head, neck, and arms) acting ten inches from the fulcrum, and W_2 is twenty-nine pounds (the weight of the trunk above the disc between the tenth and eleventh thoracic vertebrae) acting five inches from the fulcrum. The moments of these components are added to obtain M_4 (the moment of the body weight), which thus = 445 pound-inches.

Omission of Intracavitary Pressures: F_3 is calculated by use of the equation $\Sigma M = 0$, or

$$F_3 = \frac{M_1 + M_4}{1\frac{1}{3} \text{ inches}} = \frac{1{,}845 \text{ pound-inches}}{1\frac{1}{3} \text{ inches}} = 1{,}387 \text{ pounds}$$

In order to determine the reaction (R) at point 0, the vertical and horizontal components of the forces acting on this point are again considered.

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos\alpha - R\cos\beta = 0$

Horizontal components: $F_3 \sin\alpha - R\sin\beta = 0$

$$\tan\beta = \frac{R\sin\beta}{R\cos\beta}$$

Solving for R and angle β, it is found that the force on the disc between the tenth and eleventh thoracic vertebrae is 1,568 pounds acting at an angle of approximately 50 degrees to the vertical.

Inclusion of Intracavitary Pressures (Fig. 12): Solving for F_3, $\Sigma M = 0$

$M_1 + M_2 + M_3 + M_4 = 0$, or

$-$ (200 pounds $\times$ 7 inches) + (158 pounds $\times$ 5 inches) + ($F_3 \times 1\frac{1}{3}$ inches)

$-$ (30 pounds $\times$ 10 inches + 29 pounds $\times$ 5 inches) = 0

$$F_3 = \frac{1{,}400 \text{ pound-inches} - 790 \text{ pound-inches} + 445 \text{ pound-inches}}{1\frac{1}{3} \text{ inches}} = 793 \text{ pounds}$$

In determination of R, the vertical and horizontal components of the forces are again considered.

Vertical components: $F_1 + W_1 + W_2 + F_3 \cos\alpha - F_2 \cos\alpha - R\cos\beta = 0$

Horizontal components: $F_3 \sin\alpha - F_2 \sin\alpha - R\sin\beta = 0$

$$\tan\beta = \frac{R\sin\beta}{R\cos\beta}$$

Solving for R and sin β in these equations, it is found that the actual force on this disc is 791 pounds acting at approximately 44 degrees to the vertical.

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