The Load on the Lumbar Spine During Isometric Strength Testing

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Reports of back discomfort and even back injuries during isometric strength testing in specific lifting positions indicated an analysis of the loads on the lumbar spine during this type of testing. A biomechanical analysis, which has been validated against EMG and intravital disc pressure measurements, was used for the calculations of the loads in four test persons. The calculations indicated compressive loads on L3 ranging from 5000–11,000 N during squat and torso lifting. Such loads *in vitro* have been found to cause structural failures of the vertebral endplates. Similar loads also may result in damage to the spine *in vivo*. [Key words: low-back pain, spinal loading, strength testing]

Isometric strength testing in specific lifting positions has been reported as a method that can be used to reduce occupational back injuries occuring from a mismatch between the strength of the worker and the tasks he/she is attempting to perform.[6,10] The strength testing device and the appropriate technique have been developed and well described by Chaffin.[4] We currently are using the Chaffin device in a longitudinal prospective study of industrial back injuries.

Reports of mild back discomfort by several employees during strength testing, coupled with an objective analysis of apparent back injuries to two employees during the strength testing procedure, stimulated us to analyze the loads on the lumbar spine during this type of strength testing. In addition, we analyzed the loads on the lumbar spine induced by testing trunk flexors and extensors.

METHODS

Analysis of the loads on the lumbar spine during isometric strength testing were performed on four volunteers, two men and two women (Table 1). Strength was tested in five different positions (Figures 1–5). The arm-, leg-, and torso-lifting strength positions are the positions described and used by Chaffin.[5] The positions for testing the strength of the trunk flexors and extensors were modified from Nachemson et al and McNeill et al.[11,12] The University of Michigan strength test system, manufactured by Prototype Design and Fabrication Company (Ann Arbor, MI) was used for the testing. During the trunk strength testing, a frame for stabilization of the pelvis and thighs was added to this device (Figures 4,5). The five different strength tests all were performed as a sustained voluntary isometric exertion during 5 seconds. The average exertion by the four subjects during the final three seconds was registered, as well as the peak value during this time interval. Strength was tested three successive times in each position for each subject. A rest period of a minimum of 30 seconds was enforced between every exertion. To minimize variations due to motivation factors in the test subjects, the procedures and instructions recommended by Chaffin were followed.[5]

The procedures included: (1) giving objective instructions to the volunteer, with no emotional appeal; (2) asking volunteers to increase exertion during the first 2 seconds and then to hold steady for 3 seconds more; and (3) minimizing other influences on the performance (eg, noise, spectators).

Lateral view photographs were taken of the subjects during the exertions in all of the five different positions. The pictures then were used for computation of the load on the lumbar spine according to the method presented by Schultz et al.[16] Since all of the exertions were executed with sagittal symmetry preserved (Figure 1–5), only two-dimensional analysis was required. An example of the calculation of the load on the L3 during a torso lift is presented. The position of the subject during testing and the figures used are detailed below and in Figure 6.

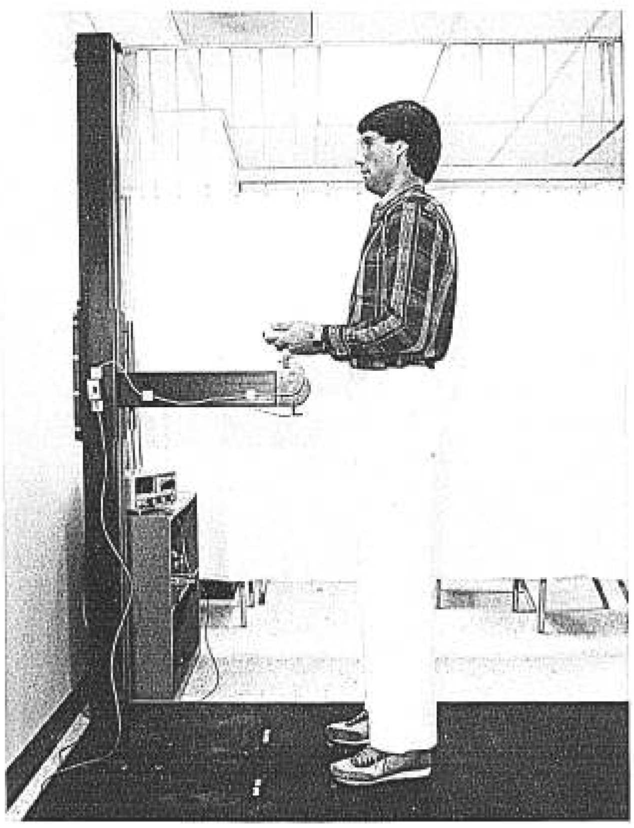

Fig 1. The position of one of the test subjects during the arm lift showing the strength testing device.

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Table 1. Sex, Age, Height and Weight of Four Test Subjects and the Mean and Peak Values of Their Three Exertions in Each of the Five Strength Test Positions

Subject	Sex	Age (years)	Height (cm)	Weight (kg)		Torso lift (N*) exertion			Squat lift (N) exertion			Arm lift (N) exertion			Trunk ext. (N) exertion			Trunk flex. (N)		
						I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1	M	38	171	67	M†	641	623	601	1019	1114	1045	418	441	423	521	530	557	472	485	499
					P‡	749	708	734	1184	1324	1232	449	468	458	574	565	593	507	526	526
2	M	27	192	80	M	498	525	557	963	912	912	441	468	418	553	561	525	507	489	508
					P	565	561	589	1150	1067	1067	489	517	467	580	587	547	552	516	553
3	F	25	166	53	M	400	446	405	636	669	636	271	276	276	427	432	437	409	418	419
					P	445	495	432	788	816	743	303	317	307	481	463	482	458	445	459
4	F	26	175	59	M	462	485	468	791	777	768	312	322	321	429	448	455	436	421	425
					P	490	518	499	874	851	869	326	348	341	484	490	493	470	449	456

*N = newton; †M = mean value during three seconds of exertion; and ‡P = peak value during exertion.

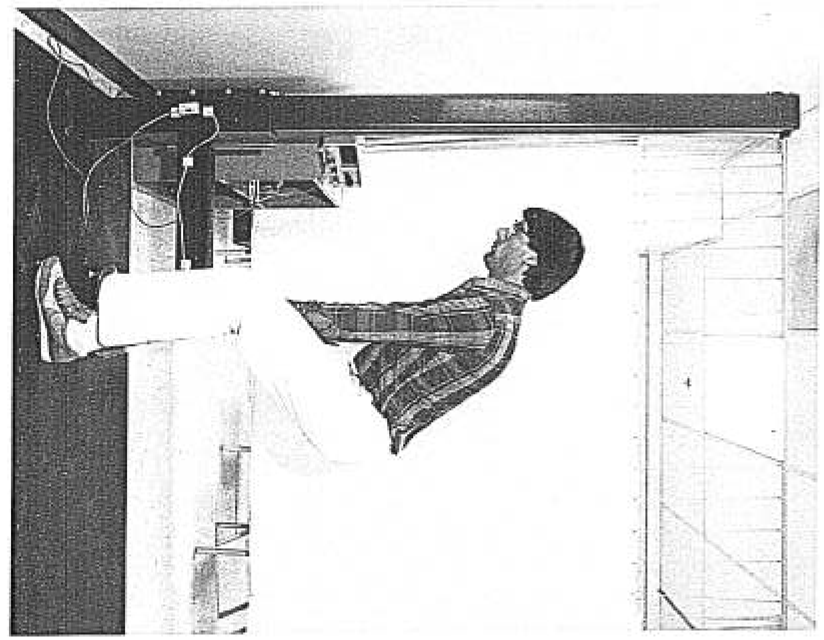

Fig 2. The position during the squat lift.

Fig 3. The position during the torso lift.

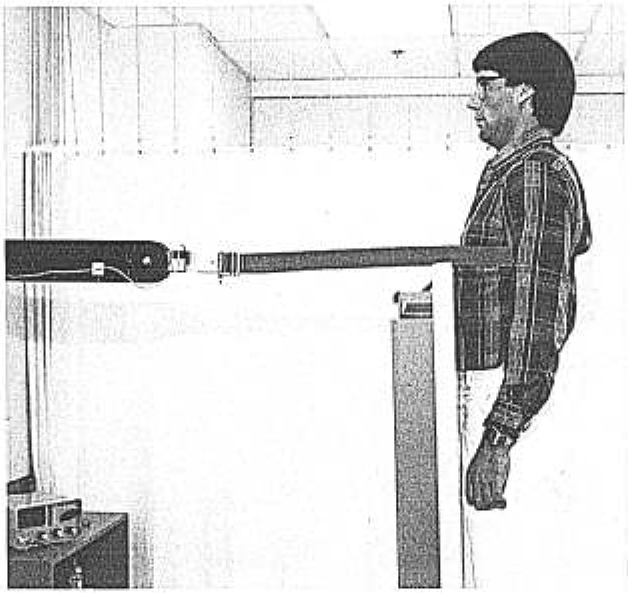

Fig 4. The position during the test of trunk extensor strength. The pelvis and thighs were stabilized against a special frame.

Anthropometric Measurements. The anthropometric measurements were as follows—body weight: 80.0 kg; body height: 192.0 cm; sagittal plane pelvis width: 20.0 cm; standing, shoulder to trochanter major: 53.0 cm; arm length, shoulder to fingertip: 80.0 cm; arm length, shoulder to elbow: 38.0 cm; arm length, elbow to fingertip: 42.0 cm; arm length, elbow to MCP joints: 35.0 cm; head to L3: 74.5 cm; head to C7: 30.5 cm; and load lifted—mean load: 557.3 N; peak load: 588.6 N.

Estimation of Moment Arms. The center of L3 lies at 66% of the trunk sagittal diameter: 66% of 20 cm = 13.2 cm.

Moment Arms to L3 Center. The moment arms to L3 center measurements were as follows—head to L3: 57.8 cm; trunk to L3: 28.9 cm; arm to L3: 34.2 cm; and load to L3: 36.8 cm.

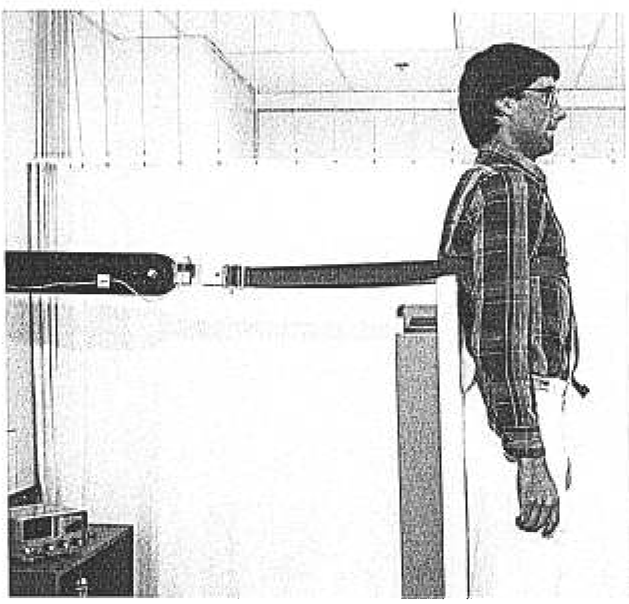

Fig 5. The position during trunk flexor strength testing.

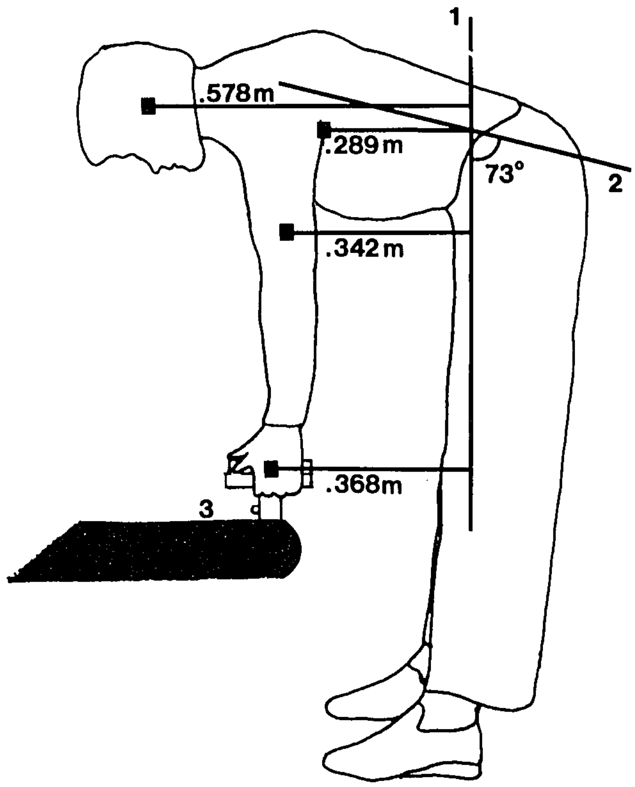

Fig 6. A schematic drawing of the person in Figure 3. The mass centers of head, trunk, and arms are indicated, as well as the lever arms for the external loads, including the load lifted. (1) The vertical plane through L3; (2) the inclination of the lumbar spine; and (3) part of the strength testing device. The angle between the vertical plane and the lumbar spine in this example is 73°.

Estimation of Weight Forces. The authors estimated weight forces for the following—body weight (BW): 80.0 kg = 784.8 N; weight of trunk above L3: 36.1% BW = 283.3 N; weight of head and neck: 5.0% BW = 39.2 N; weight of two arms: 8.9% BW = 69.8 N; and load held— mean load: 557.3 N; peak load: 588.6 N.

Calculation of Net Reaction. Since all loads act vertically, the net reaction consists of only two components, an upward vertical force, V, and a flexion moment, M. V equilibrates the sum of the body segment weights and the load held:

V_m (mean load held) = 283.3 + 39.2 + 69.8 + 557.3 = 949.6 N

V_p (peak load held) = 283.3 + 39.2 + 69.8 + 588.6 = 980.9 N.

M has contributions from the weights and moment arms—head: 39.2 N × 0.578 m = 22.7 Nm; trunk: 283.3 N × 0.289 m = 81.9 Nm; arms: 69.8 N × 0.342 m = 23.9 Nm; mean load: 557.3 N × 0.368 m = 205.1 Nm; and peak load: 588.6 N × 0.368 m = 216.6 Nm. Total flexion moment at mean load = 333.6 Nm, and total flexion moment at peak load = 345.2 Nm.

Estimation of Internal Forces. Single equivalent erector spinae muscle contraction force, E, required to produce the net reaction moment, M:

$$\text{Equilibrium requires that } Ea = M$$

$$\text{or } E = \frac{M}{a}$$

where "a" is taken as 22% of measured trunk depth = 20 cm, and 22% × 20 cm = 4.4 cm. Erector muscle force for mean load = 7,582 N, and erector muscle force for peak load = 7,845 N. These are the estimated muscle contraction forces required to perform the two torso lift exertions.

The corresponding compression and shear forces that need to be resisted by the L3 motion segment now can be calculated. During this torso lift, the trunk is inclined at 73° to the vertical. This angle is called (α).

The requirements for equilibrium of vertical and horizontal forces are:

$$s = V \sin \alpha \text{ where } s = \text{shear forces}$$

$$(C - E) = V \cos \alpha \text{ where } C = \text{compressive forces.}$$

The second equation can be written: $C = V \cos \alpha + E$. Since V and E already have been calculated, S and C can derived. The shear forces and the compression forces on L-3 during this lift were for the mean load value, 908 N and 7,860 N, respectively, and for the peak load value, 938 N and 8,132 N, respectively.

RESULTS

The forces applied by the volunteers and the load these forces created on L3 during the five different exertions are presented in Tables 1 and 2. The figures presented in Table 2 are the highest of the three exertions made in each of the five test positions.

DISCUSSION

To our knowledge, the method used for calculation of the load on L3 is the only one that has been validated against both electromyography and intravital disc pressure measurements.[16] Since determination of the moment arms, the center of the body segments, and the inclination of the spine are determined from the photographs, the tabulations cannot be considered precisely accurate. Although the photographs provide only estimates, moderate variations, for example, in the inclination of the spine, have only marginal influences on the final result of the compressive load on L3. Changes of the external moments had, on the other hand, a more profound effect on the compressive load C. The greatest reduction, for example, of the external moments and thus the load on the lumbar spine would be achieved by keeping the weight lifted as close as possible to the body.

In all the test persons, the trunk was flexed more than 65° during the torso lift. EMG studies have demonstrated that during deep trunk flexion, activity of the erector spinae muscles almost ceases, causing a "flexion silence or relaxation" phenomenon.[1,7] A considerable portion of the longitudinal forces required during large flexion is probably provided by passive tissue responses, for example, the ligaments of the spine and the connective tissue of the muscles.[8] It is also reasonable to assume that intraabdominal pressure will help in reducing the compressive force on the lumbar spine in large flexion.

Both the torso and the squat lifts produced astonishingly high estimates of compressive loads in all of the four subjects. The loads calculated in these volunteers, ranging from 5000–11,500 N, were definitely within the range of compressive force at which microfractures of vertebral end-plates have been observed *in vitro*.[2,3,15] A hypothetic reduction of 25% or even 50% of the actual loads lifted by the volunteers in the present study still would create compressive forces on the lumbar spine that are close to or within the range of values that have produced end-plate fractures *in vitro*.[9,13,14]

The squat lift, performed with the back as erect as possible, caused more load on the lumbar spine than did the torso lift in both the male subjects. With the load lifted between the knees, the moment arms were considerably shorter than during the torso lift. It was, however, possible to lift a much heavier load in the squat position than in the torso lift position. Thus, the increase in lifting capability in the squat position overshadowed the decrease in moment arms, and resulted in more load on the lumbar spine than did the torso lift. The compressive loads created during the isometric trunk flexion and extension were definitely lower than the ones found during the three isometric lifting maneuvers. However, the isometric trunk muscle strength testing technique has not been evaluated as a technique nor as a screening method to predict or identify individuals who may be prone to back problems.[11,12]

The torso and squat lifts also created the highest shear forces of the different lifting procedures (range: 363–1,012 N). The effect of shear forces of this magnitude during a single or repeated exertion is unknown.

CONCLUSIONS

The findings emphasize that the estimated compressive loads on the lumbar spine, especially during the torso and squat lifts, are surprisingly high and probably close to a level at which structural failure of the spine could be expected. This appeared to remain consistent even during submaximal efforts of the subjects. The calculations also showed that during the squat lifting some persons, irrespective of more favorable moment arms, demonstrated an increase in strength, which in turn resulted in more load on L3 than the torso lifting technique. Isometric tests of trunk flexors and extensors caused considerably less load on the lumbar spine. The value of this testing method in predicting back injuries, however, has yet to be determined.

Table 2. The Calculated Compressive and Shear Forces on L3 in the Four Tested Subjects During Mean and Peak Exertions in the Five Different Strength Test Positions

		Torso lift			Squat lift			Arm lift			Trunk extension			Trunk flexion		
Subject		E* (N†)	C (N)	S§ (N)	E (N)	C (N)	S (N)	E (N)	C (N)	S (N)	E (N)	C (N)	S (N)	E (N)	C (N)	S (N)
1	M¶	641	7637	911	1114	8797	764	441	3572	0	557	1748	0	499	2313	0
	P‖	749	8898	1012	1324	10084	875	468	3759	0	593	1839	0	526	2438	0
2	M	557	7860	908	963	10051	796	468	4928	0	553	1800	0	508	2425	0
	P	589	8132	938	1150	11497	906	517	5136	0	580	1868	0	553	2604	0
3	M	446	6289	682	669	5326	363	276	2786	0	437	1367	0	419	1932	0
	P	495	6785	729	816	6248	420	317	3139	0	482	1481	0	459	2101	0
4	M	485	6564	731	791	6488	492	322	3203	0	455	1495	0	436	2097	0
	P	518	7212	790	874	6841	558	348	3482	0	493	1593	0	470	2288	0

*E = exertion registered; †N = newton; ‡C = compressive force; §S = shear force; ¶M = mean value during three seconds of exertion; and ‖P = peak value during exertion.

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