Trunk Strengths in Attempted Flexion, Extension, and Lateral Bending in Healthy Subjects and Patients with Low-Back Disorders

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Trunk strengths were measured in 27 healthy males and 30 healthy females, and in 25 male and 15 female patients with low-back pain and/or sciatica. Maximum voluntary isometric strengths were measured during attempted flexion, extension, and lateral bending from an upright standing position. Both male and female patients had approximately 60% of the absolute trunk strengths of the corresponding healthy subjects. Intra-individual trunk strength ratios were used to interpret the results. Use of these ratios tends to avoid interpretational problems created by the general weakness of the patients and any lack of motivation of either patients or healthy subjects. The ratios showed that the patients had attempted extension strengths that were significantly less than their strengths in the other types of movements tested. The strength ratios for attempted extension were particularly low for patients with sciatica. [Key Words: low-back pain, trunk muscle strength, voluntary isometric contraction]

THE CAUSES of most low-back disorders are unknown. The involvement of mechanical factors is suspected by many, but only indirect evidence is available to support this argument. It may be possible to learn more about the influence of mechanical factors in the development of low-back disorders by studying the behavior of patients who already have such disorders. It is accepted that some physical activities are limited in these patients. But exactly which activities are limited, to what extent, and for what underlying reasons, are largely unknown. Quantification and biomechanical analyses of limitation of patients' physical activity may provide insights into the etiologic role of mechanical factors in low-back disorders. Specifically, comparisons of maximum voluntary isometric trunk strengths of patients with low-back disorders with those of healthy subjects provide useful data.

Maximum voluntary trunk strengths during lifting, pushing, and similar activities were recently measured in our laboratories.[3] In that report, strengths of male adults with acute low-back pain were compared with those of healthy male adults. While the data are useful for many purposes, they have two shortcomings with re-

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gard to analyses of activity limitation of patients with low-back disorders. First, forces were applied to the hands, so that measured strengths were not always limited by trunk strength capacities. Second, body configurations were not completely controlled, so that computations of internal trunk forces necessary for an analysis of possible mechanisms of activity limitation were tedious to make and subject to errors of description of configuration. The design of the present study was based on experience gained in the earlier study.

Alston[1] measured the trunk flexion strengths of 32 male patients with chronic low-back pain and 32 male control subjects when they were in a supine position and their trunk extension strengths when they were in a prone position. Nachemson and Lindh[7] measured trunk strengths in 80 low-back-disorder patients and 80 healthy controls. They measured extension strengths of subjects in prone and standing positions, and flexion strengths of subjects in a supine position.

The results of tests of trunk strength of patients in supine and prone positions are more difficult to analyze than are those obtained for patients in erect positions. In horizontal-position tests, a major proportion of the load is due to the weight of the upper body segments, and the effect of this can only be estimated. For this reason, we thought it would be worthwhile to collect additional data on strengths during attempted trunk flexion and extension in the standing position. We sought data on trunk strengths during attempted lateral bending as well, since none seemed to be available.

This paper reports maximum voluntary isometric trunk strengths during attempted flexion, extension, and lateral bending from a controlled upright standing position. Measurements were made for healthy subjects and patients with low-back disorders, including males and females in both groups.

Table 1. Characteristics of Healthy Subjects and Patients*

	Males		Females	
	Healthy subjects	Patients	Healthy subjects	Patients
Number	27	25	30	13
Mean age (years)	33.5	39.8	31.6	37.0
≤ 30 years (number of patients)	24.6 (14)		26.0 (17)	
> 30 years (number of patients)	43.0 (13)		38.9 (13)	
Range	21–61	22–61	21–59	20–60
Mean height (cm)	177	179	165	163
Range	152–191	168–190	152–185	157–175
Mean weight (newtons)	766	828	602	713
Range	623–979	578–1188	445–881	498–957
Mean period of clinical history (months)		30.8		28.8
Range		2–192		1–120
Mean pain grade				
In general		2.4		2.6
At time of test		1.9		2.2

* Some data were not available for all subjects.

MATERIALS

The subjects consisted of 57 healthy persons, 27 males and 30 females, and 40 low-back-disorder patients, 25 males and 15 females. Table 1 provides subjects' ages, heights, and weights. Healthy subjects were university students or hospital staff members. They were free of back symptoms at the time of the test, and no abnormalities were found by physical examination of their trunks and extremities. Several healthy subjects had experienced occasional back pain in the past, but not severe enough to substantially interfere with normal activities. For some data analyses, the healthy subject group was divided into subgroups of those older and those younger than 30 years old.

The patients were all receiving treatment in a private orthopedic practice for low-back pain, sciatica, or both. They were otherwise unselected. All but four were seen as outpatients. A patient was said to have sciatica if he had any pain referred inferiorly from the low-back region.

The patients were asked seven questions about their disability: two about their needs for medication, three about the extent to which pain limited their tolerances to sitting, standing, and other physical activities, and two about estimates of their ability to lift loads or participate in sports. Based on the answers, their disabilities were graded mild (Grade 1), moderate (Grade 2), somewhat severe (Grade 3), or very severe (Grade 4). Two disability grades were assigned: one for their symptoms over the few weeks preceding the test, and one for their symptoms immediately preceding the time of the test (Table 1). The patients were further grouped according to the duration of symptoms, whether they had had previous back operations, and the distribution and nature of any referred (sciatic) pain (Table 2).

METHODS

The subjects stood upright in the test apparatus (Figure 1), with their buttocks against a backboard whose superior edge was set at the level of the iliac crest. They were strapped to the backboard by a canvas belt. The pelvis was also supported bilaterally by two adjustable padded arms. After a comfortable standing position has been assumed, the subjects' legs were strapped by a similar belt.

A harness was placed snugly around the chest, just under the arms. Cables secured to this harness ran hori-

Table 2. **Findings for Some Subcategories of the Patient Group**

	Number of patients	Forces (newtons)				Intra-individual relative strength ratios				
		Flexion	*Extension*	*Left bending*	*Right bending*	*Extension/ flexion*	*E/A*	*Left/ Right bending*	E/V_L	A/V_L
Male patients										
≤ 6 months duration	7	348	279	254	240	0.57	2.19	1.07	2.93	1.42
≥ 6 months duration	18	325	310	262	248	1.02	2.55	1.20	3.47	1.40
No surgery	18	342	319	277	271	1.04	2.59	1.13	3.43	1.38
Surgery	7	307	256	216	181	0.84	2.09	1.23	3.03	1.48
No sciatica	14	309	314	244	224	1.11	2.79	1.19	3.76	1.43
Any sciatica	11	360	286	279	271	0.81	2.02	1.12	2.76	1.38
Right sciatica	5	259	212	197	179	0.84	2.09	1.10	2.82	1.36
Left sciatica	6	445	347	348	348	0.78	1.95	1.13	2.71	1.40
Bilateral sciatica	0	—	—	—	—	—	—	—	—	—
Female patients										
≤ 6 months duration	3	198	199	165	165	0.95	2.37	0.96	2.90	1.25
> 6 months duration	12	156	134	115	115	0.97	2.42	1.02	3.59	1.50
No surgery	11	172	162	133	130	0.98	2.45	1.03	3.49	1.46
Surgery	4	124	107	102	110	0.92	2.31	0.94	3.34	1.40
No sciatica	5	147	152	112	115	1.06	2.64	0.98	3.84	1.48
Any sciatica	10	174	152	130	131	0.92	2.30	1.02	3.26	1.43
Right sciatica	7	169	143	120	111	0.93	2.33	1.09	3.25	1.45
Left sciatica	1	—	—	—	—	—	—	—	—	—
Bilateral sciatica	2	190	189	158	188	0.95	2.37	0.84	3.53	1.37

zontally to force-measuring strain-gauge load cells secured to the frame of the apparatus. For measurements of strength of attempted trunk flexion, two parallel cables were run posteriorly (Figure 2). Similar cables were run anteriorly for measurement of strength of attempted trunk extension, and laterally for measurement of strength of lateral bending. Cable lengths were adjusted so that the subjects were not bent in any direction during exertion. The subjects were instructed not to use their arms for support, so that the forces exerted would be developed purely by the trunk muscles.

Before testing, the width and depth of the trunk at the L5 level and the vertical distance from the L5–S1 level to mid-harness level were measured in a relaxed standing position. At the conclusion of each task, all subjects were asked about the nature and intensity of any pain they experienced during performance of the task. Pain was graded on a scale of 0 (none) to 4 (very severe).

In each task, the subjects were asked to increase their effort steadily over the first few seconds and then maintain their maximal effort until a total of 5 seconds had elapsed. They were asked to pull against the cables as forcefully as they could without injuring themselves. Each exercise was carried out twice. The different exercises were carried out in random order. Approximately 30 minutes were needed to test each subject. The subjects were encouraged to take rest periods during the experiments, but they seldom chose to do so.

Forces were recorded using a light-beam oscillograph. The steady-state force magnitudes were later read from the oscillographic records and entered into a computer for processing. For each subject and each exercise, the mean steady force over the two trials was calculated, as well as the moment of that mean force about the L5–S1 intervertebral disc level. Estimates were made of the single net resultant muscle force required to produce that moment (see Appendix)—in the anterior abdominal wall muscles (denoted A) for flexion, in the erector muscles (E) for extension, and in the vertical component of the lateral abdominal wall muscles (V_L or V_R) for left or right lateral bending, respectively.

Intra-individual strength comparisons were made by calculating seven relative strength ratios for each subject. These were the ratio of extension force to flexion force (the moment ratios would be identical for both), the corresponding estimated muscle-force resultant ratio (E to A), the ratio of left-lateral to right-lateral force (the moment ratio and the ratio V_L to V_R would be identical), and the ratios of both E and A, respectively, to both V_L and V_R.

Means and standard deviations were calculated for comparisons between a number of subject subpopulations. Statistical significance was analyzed by Student's *t* test.

Reproducibility of subject performances was examined only for healthy subjects. Two females and four males were tested twice, with the second test several weeks after the first. Two additional males were tested three times, on three different days.

RESULTS

Absolute Strengths of Healthy Subjects

The mean absolute trunk strengths of the healthy males were approximately 550 newtons for attempted extension and 400 newtons for attempted flexion and attempted lateral bending (Table 3). The corresponding

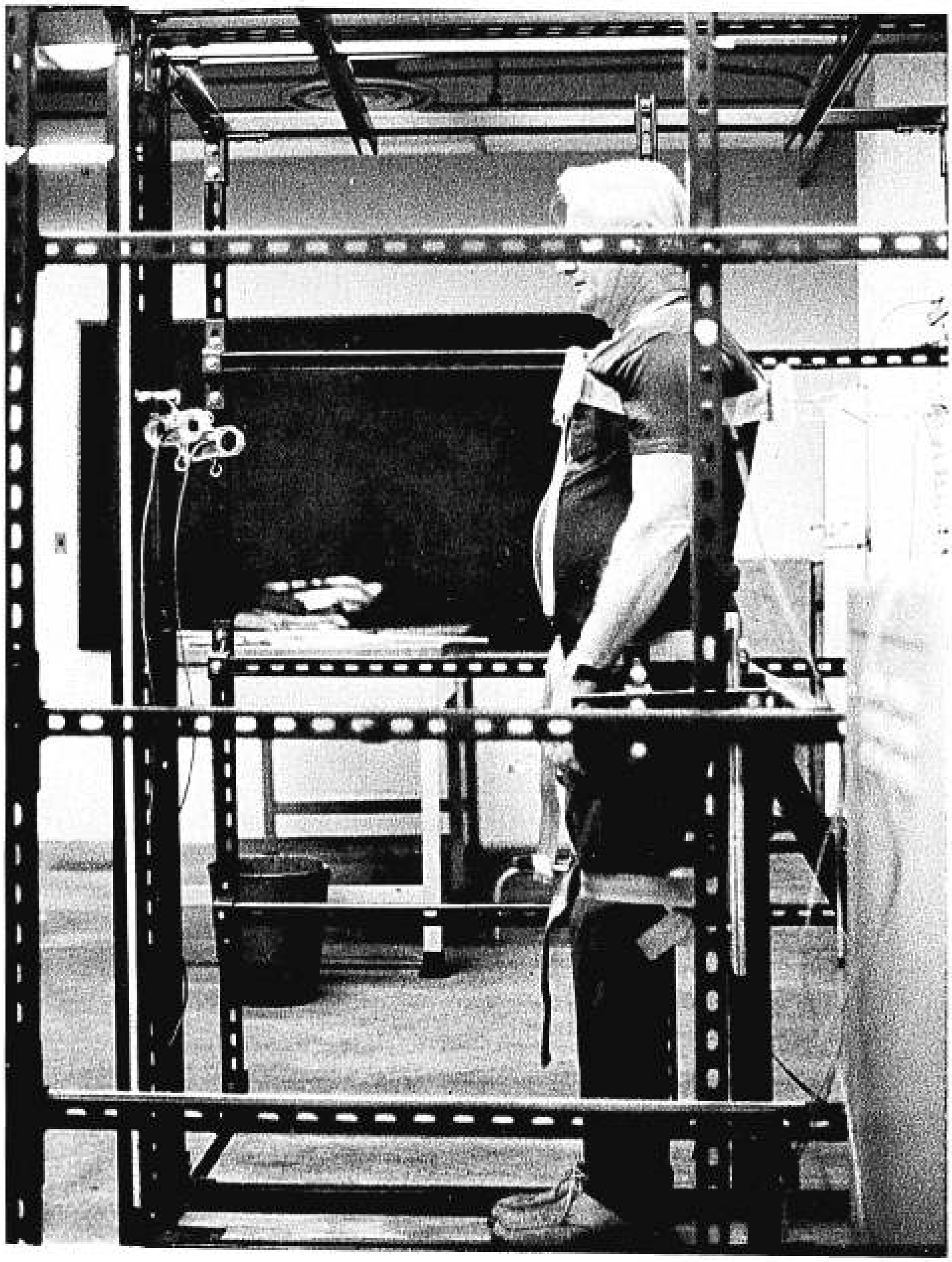

Fig. 1. A subject positioned and secured in the test apparatus.

moments at the L5–S1 level were about 200 and 150 newton-meters, respectively. The corresponding estimated muscle force resultants were approximately 4000 newtons in the erector muscles (E) during extension and 1000 newtons in the anterior abdominal muscles (A) during flexion and in the vertical component of the lateral abdominal muscles (V_L or V_R) during lateral bending (Table 4).

On the average, healthy females developed about 60% of the above values, respectively, for each of the four exercises. This percentage value is approximately applicable for any external forces, external moments, or estimated muscle force resultants.

For both sexes, the mean strengths for the younger group (age 30 or less) of healthy subjects tended to be 10–30% greater than the mean strengths for the older group (Table 3).

Absolute Strengths of Patients

In terms of any of the external forces, external moments, and estimated muscle-force resultants, male patients developed approximately 80% of the strengths developed by the healthy males during flexion, 65% during lateral bending, and 55% during extension. For the female patients, the corresponding figures were 65, 55, and 45%, respectively (Table 3). Relative to the male patients, the female patients developed approximately 50% of the three measures of absolute strength.

Fig. 2. Placement of the chest harness. Cables and load cells are in place for the measurement of trunk flexion strength.

Intra-Individual Relative Strength Ratios

The performances of patients and healthy subjects of the same sex were compared on the basis of the seven intra-individual relative strength ratios. These ratios showed that, on the average, patients limited their performance during extension attempts more than during flexion or lateral bending attempts (Table 5). The differences between the means of the ratios of extension force to flexion force and of E to A for healthy subjects compared with those for patients were statistically significant, both for the males ($P < 0.001$) and for the females ($P < 0.01$). The differences between the ratios of E to V_L for healthy subjects and patients were also statistically significant for both the males ($P < 0.01$) and the females ($P < 0.05$).

There were no significant differences between right- and left-sided mean lateral bending strengths of healthy subjects or female patients (Table 4). Male patients had somewhat greater strength during left than during right lateral bending ($P < 0.05$).

There were no significant differences in these ratios between healthy males and healthy females, between male patients and female patients, or between older and younger healthy males. The younger group of healthy females had significantly greater ($P < 0.01$) extension strengths relative to their other strengths. More complete tabulations of data, including standard deviations of the results, are available from the authors.

Subcategories of Patients

Some trends became apparent when the patients were grouped as to whether their symptoms were of more than six months' duration, whether they had had back operations, or whether they had sciatica (Table 2).

There were few notable differences between left and right lateral bending strengths for any of the subcategories, even when cases of right and left sciatica were compared. There were also few notable differences between the ratios of anterior abdominal to lateral abdominal muscle strengths for any of the subcategories. Notable differences were observed almost exclusively among measures involving attempted extension strength, that is, for the mean intra-individual ratios of extension-to-flexion strength, erector-to-anterior abdominal muscle resultants, and erector-to-lateral abdominal muscle resultants.

As to the durations of symptoms, the results suggest that with symptoms of short duration, the loss of erector strength relative to other strengths is pronounced for the males, but some of this strength is recovered if the symptoms last. In other words, the males with persistent syndromes did not seem to have any loss of erector strength, either relative to their measured strengths, or absolutely. There were only three female patients whose symptoms were of short duration.

Absolute strengths of the patients who had received surgical treatment were less than those of the other pa-

Table 3. Mean Trunk Strength Forces and Moments About the L5 Level: Intergroup Comparisons

	Number of subjects	Forces (newtons)				Moments (newton-meters)			
		Flexion	Extension	Left bending	Right bending	Flexion	Extension	Left bending	Right bending
Males									
Healthy subjects	27	403	567	386	406	149	210	143	151
≤30 years	14	436	645	426	421	155	230	153	151
> 30 years	13	367	489	341	388	143	189	132	150
Patients	25	331	302	260	245	119	108	93	88
Females									
Healthy subjects	30	257	347	229	237	87	117	78	80
≤ 30 years	17	249	383	237	246	84	130	81	83
> 30 years	13	264	304	218	225	89	102	74	76
Patients	15	165	149	125	125	56	51	42	42
Ratio comparisons									
Patients/healthy									
Male		0.82	0.53	0.67	0.60	0.80	0.51	0.65	0.58
Female		0.64	0.43	0.55	0.53	0.64	0.44	0.54	0.53
Females/males									
Healthy		0.64	0.61	0.53	0.58	0.58	0.56	0.55	0.53
Patients		0.50	0.49	0.48	0.51	0.47	0.47	0.45	0.48

tients. Erector strengths relative to other strengths of males who had received surgical treatment were also low, but the differences were not statistically significant. There were no consistent differences of the duration of symptoms between surgically-treated and non-surgically-treated groups.

Whether or not sciatica was present had a strong influence on patient behavior. This finding seemed to be unaffected by the nature of the sciatica. Patients with sciatica had less erector strength than other strengths, by comparison both with strengths of patients without sciatica and with those of healthy subjects. With minor exceptions, the former differences were not statistically significant for the females and were significant at a $P < 0.01$ level for the males; the latter were significant for the females at a $P < 0.01$ level and for the males at a $P < 0.001$ level.

Patients with only low-back pain had relative erector muscle strengths that were greater than those of the patients with sciatica. Nevertheless, the patients in this category still had relative erector muscle strengths that were low compared to those of the healthy subjects. Statistically, this trend was not significant for the females and was significant at a $P < 0.05$ level for the males.

Severity of Pain Before and During Testing

Two male and three female patients stated that they were in somewhat severe or severe (Grades 3 or 4) pain at the beginning of the test sequences. This did not affect the mean performance of the males, either as to their absolute strengths compared with those of the total male patient group, or as to their intra-individual relative strength ratios. In contrast, the three females had substantially less extension strength, both absolutely and as shown by their corresponding intra-individual strength ratios.

Healthy subjects rarely reported that any pain occurred during the tests. When it did, it was at most moderate (Grade 2). Patients reported pain during approximately 20% of the tests for flexion, 40% of the tests for extension or left-lateral bending, and 50% of the tests for right-lateral bending. Occasionally, the pain was reported as Grade 3, but it was usually Grade 1 or 2. There seemed to be no pattern of association between the higher grades of pain during testing and particular

Table 4. Mean Estimated Single Equivalent Muscle Resultant Forces Required to Produce Measured Strengths

	Estimated muscle resultants (newtons)			
	E in extension	A in flexion	V_L in left lateral bending	V_R in right lateral bending
Healthy males	4057	1153	953	1002
Male patients	1863	813	579	548
Healthy females	2243	635	498	516
Female patients	881	374	270	271
Ratio values for patient/healthy subject comparison				
Males	0.46	0.71	0.61	0.55
Females	0.39	0.59	0.54	0.53

Table 5. Mean Intra-Individual Strength Ratios

	Healthy males	Male patients	Healthy females	Female patients	Significance of patient–healthy subject difference: Males	Significance of patient–healthy subject difference: Females
Extension/flexion*	1.37	0.98	1.41	0.95	$P<0.001$	$P<0.01$
E/A	3.42	2.45	3.53	2.36	$P<0.001$	$P<0.01$
Left/right†	0.96	1.16	0.99	1.01	$P<0.05$	
E/V_L	4.25	3.32	4.46	3.25	$P<0.01$	$P<0.05$
A/V_L	1.22	1.41	1.30	1.40	$P<0.05$	

* Applies equally to force or moment
† Applies equally to force, moment, or muscle resultant

exercises. Moreover, there were no definite tendencies for patients who reported pain during a test to perform that test weakly.

Reproducibility

For the eight healthy subjects tested more than once, the maximum forces exerted on different occasions differed by a mean of 22% for extension, 13% for flexion, and 17% for lateral bending. The intra-individual performance ratios differed by a mean of 20% for extension-to-flexion and 17% for left-to-right lateral bending. These percentages seem reasonable for a voluntary strength-testing program.

DISCUSSION

One purpose of this investigation was to compare voluntary isometric trunk strengths of healthy subjects in the standing position with those of patients seeking routine treatment of low-back pain, sciatica, or both. The only data of this kind available seemed to be those of Nachemson and Lindh[7] on extension strength. As expected, the patients were generally weaker than the healthy subjects. In quantitative terms, the patients developed 45–80% of the trunk strengths of the healthy subjects. Our findings that healthy females developed 50–60% of the strengths of healthy males is consistent with other reports on strengths of healthy subjects, as cited in a literature survey by Laubach.[6] We found similar male–female differences among our patients. To the extent to which we investigated age-related trends of strengths, our findings are consistent with those of Asmussen and Heeboll-Nielsen.[2]

A second purpose was to determine whether certain trunk muscle strengths are limited more than others by preexisting low-back disorders. For this purpose, we analyzed our data in terms of the intra-individual relative strength ratios. Two problems arise in studies like this one—the first because patients are weaker in general than healthy subjects, and the second because physical exertion is limited not only by physical capacity but also by motivation. Patients may be weaker than healthy subjects because their performance is limited by pain, either actually experienced or merely anticipated. Lack of motivation can limit performance by either patients or healthy subjects. However, it is not likely, for example, that a patient would anticipate, a priori, more pain for attempted extension than for attempted flexion; nor is it likely that either type of subject would be less motivated to attempt extension than flexion. We believe the use of the intra-individual relative strength ratios substantially overcomes these problems by allowing the specific activities limited by low-back disorders to be identified.

Our main finding is that, as a whole, low-back-pain patients are more limited in their attempts to extend the trunk than in their attempts to flex or laterally bend it. The differences between the relative extension strengths of healthy subjects and patients were statistically significant for both males and females.

We also found that the loss of extension strength relative to other strengths is marked for male patients with sciatica of any kind, and this tendency holds for female patients with sciatica, any patient who had received surgical treatment, and male patients with syndrome durations of six months or less.

Our findings apply only to isometric exertions in the standing position, and not to motions of the trunk. They seem to point to an organic source for trunk-extension limitation, since the influence of motivation or general weakness on our findings has probably been substantially removed by the use of intra-individual relative strength ratios. Moreover, no clear-cut associations between performance and reported pain were evident.

Comparison with Results of Other Investigations

Alston et al also found, on the basis of trunk strength tests in the supine and prone positions, that male patients with chronic low-back pain generally had weak trunk muscles compared with those of healthy males. The ratio of mean extension strength of patients to that of healthy subjects was smaller than that for flexion, but the difference was not statistically significant. Since Alston et al excluded cases with any indications of herniated intervertebral discs, their results should be compared with ours only for male patients without sciatica. Despite the differences of test positions, the findings of the two studies are generally in agreement. The statistical significance of the difference found in our study may be due to differences in data treatment; Alston et al examined the ratio of the mean strengths; we examined the mean of the individual strength ratios.

Nachemson and Lindh[7] also excluded patients with sciatica from their study. The strengths they reported for extension are in general of the same magnitudes as ours. The flexion strengths they reported are substantially different. Their flexion tests were conducted with subjects' hips and knees flexed, significantly altering the state from which the psoas and the anterior abdominal muscles had to contract. Most of the disagreements between results are probably due to this difference in testing technique.

Biomechanical Analysis of Findings

Why are low-back pain patients more limited during attempted trunk extension than during other efforts? Answers to this question may provide insights into the pathogenesis of low-back disorders. There are no answers yet, but a biomechanical analysis of the present findings can provide some clues to guide further research.

A tentative analysis of the mechanics involved points to three sources that may limit exertion during attempted trunk extension by patients: patients may avoid great tensions in the soft tissues posterior to the spine; they may avoid large direct compressions of the lumbar motion segments; and they may be unable to develop significant intraabdominal pressure.

The moment arm over which the erector muscles act on the spine is small. This means that development of an external moment during trunk extension requires erector-muscle longitudinal forces to be much larger than the anterior-abdominal- or lateral-abdominal-muscle longitudinal forces necessary to develop the same magnitude of external moment during flexion or lateral bending.

Simple equilibrium considerations show that in trunk extension tests, the direct compressive force on the lumbar motion segments (C) should approximately equal the posterior soft-tissue tension (E) plus the superimposed body weight, in the absence of significant intra-abdominal pressure. So, trunk extension tests result in not only a large E force, but a large C force as well. The present tests cannot distinguish between these two possible sources of activity limitation. Tests in which direct compression is applied to the shoulders may produce a large C force without producing any substantial E force. Tests of this kind are needed to provide further insight into the implications of the present findings.

Development of a significant intra-abdominal pressure will alter trunk mechanics in exertions during attempted flexion, extension, or lateral bending. It will alter both the muscle forces and the compression forces on the vertebrae. For a given magnitude of external moment, it will increase the muscle force required to produce that moment during flexion; it will leave the muscle force required for lateral bending substantially unchanged; and it will significantly lessen the muscle force required to produce the moment during extension. The effect of increased intra-abdominal pressure on the compression forces on the lumbar vertebrae will always be to reduce those forces, but the effect will be several times larger for attempted extension than for attempted flexion or lateral bending. So, an intra-abdominal pressure increase is of much greater importance for extension than for flexion or lateral bending.

Nevertheless, the patients' inability to develop intra-abdominal pressure can explain at best only part of the healthy subject–patient performance differences during attempted trunk extension. We will quantify this for the males, but our arguments apply equally for the females. First, calculations show that healthy male subjects should be capable of developing their estimated mean E force of 4000 newtons without any assistance from increased intra-abdominal pressure. The erector musculature has a cross-sectional area of approximately 50 cm^2.[4] To develop a contraction force of 4000 newtons requires a contraction intensity of 80 newtons/cm^2, which is within the estimated voluntary contraction capacity of human muscle, 40–100 newtons/cm^2.[5]

Second, the estimated maximum reduction of the E force resulting from raised intra-abdominal pressure seems insufficient to fully explain the patients' performance inability. Many investigators have observed intragastric pressures associated with heavy exertions and report that they seldom exceed 150 mm Hg. The abdominal cavity has a cross-sectional area of approximately 300 cm^2, corresponding to a peak pressure resultant of 600 newtons that acts approximately 10 cm anterior to the spine. Equilibrium considerations show that this pressure resultant would reduce the E force by 30% (from 4000 to 2800 newtons) and the C force by 45% (from 4000 to 2200 newtons) for the same exertion during trunk extension. However, male patients develop only 50% of the extension strength that normal males develop. To explain the relative inability of male patients to develop trunk extension moments purely on the basis of intra-abdominal pressure differences seems to require the assumption that healthy males develop maximum intra-abdominal pressure during attempted extension, while male patients do not develop any at all. This seems unreasonable.

In summary, the biomechanical analysis suggests that differences of ability to raise intra-abdominal pressure are not likely to be a major factor in explaining patient–healthy subject performance differences. The patients' avoidance of large tensions in the posterior soft tissues or large compressions on lumbar motion segments are more likely factors. Further research is needed to deter-

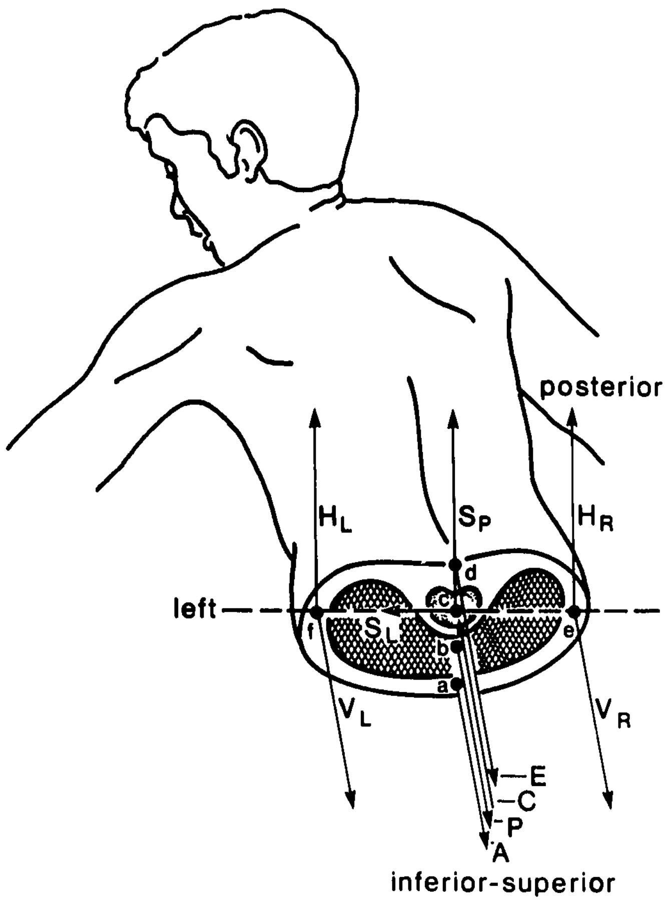

Fig 3. Geometry used in calculation of muscle equivalent forces. The meanings of the symbols are described in the Appendix.

mine whether one or the other factor predominates. The finding that one of these factors does predominate would represent a significant advance in our understanding of low-back disorders.

CONCLUSIONS

1. In general, the patients were found to have approximately 60% of the trunk strengths of the healthy subjects.

2. On an absolute basis, the patients had less abdominal muscle strength than did the healthy subjects during attempted flexion. But, in comparison with the other types of trunk strengths, the patients' abdominal muscle strength was not weak during attempted flexion. In fact, on a relative basis, the patients had stronger abdominal muscles than did the healthy subjects.

3. Compared with the patients' other types of trunk muscles, the muscles involved in attempted extension were weak.

4. The relative weakness of extension was particularly pronounced for patients with sciatica.

In other words, isometric exertions during attempted trunk extension are more limited by existing low-back conditions than are exertions during attempted flexion or lateral bending.

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APPENDIX

Estimation of Lumbar Region Muscle Contraction Forces

To help interpret our results, we estimated the contraction forces that would be required of the muscles at the lumbar levels of the trunk to produce the trunk strengths demonstrated by our subjects. To do this, we first computed the moment about the L5 level of the external force developed by each subject in each strength test. The magnitude of this moment (Table 3) is the external force times the vertical distance from the harness to the L5 level of the trunk. In direction, this moment would occur in flexion, extension, or lateral bending, in correspondence to whatever strength was being measured.

Next, we assumed that the moment was developed by contraction of a single muscle equivalent (Figure 3): the equivalent of the erector muscles (E) in attempted extension, of the anterior abdominal muscles (A) in attempted flexion, and of the right or left lateral abdominal muscles (V_R or V_L) in attempted right or left lateral bending, respectively. In the latter instance, we assumed that the horizontal components of the contraction forces of the internal and external oblique elements cancelled one another, leaving only the vertical components to act. All of these instances involve the assumption of negligible activity in muscle antagonists, and that the center of mass of the upper body segments lies nearly directly over the lumbar vertebrae, so that only relatively insignificant muscular activity is required for maintenance of upper body posture. It was assumed that the centroids of the cross sections of the abdominal and the erector muscles lay in the midsagittal plane of the body. The centroids of the cross sections of the lateral abdominal muscles were assumed to lie in a purely lateral position relative to the center of the body of L5. Under these conditions, contractions of the muscle equivalents, E, A, V_R, and V_L develop moments about the L5 center only in flexion, extension, and right and left lateral bending, respectively. For equilibrium, the contraction force in the muscle equivalent times its distance from the L5 center must equal the magnitude of the external moment. In other words, the contraction force was calculated simply by consideration of the effects of the involved lever arms.

Lever arm lengths were assigned on the basis of the data presented in the scaled cross-sectional anatomic drawings of Eycleshymer and Schoemeker.[4] The A centroid was placed at 12%, the L5 center at 66%, and the E centroid at 88% of the distance from the anterior to the posterior edge of the L5 level cross section. The V_L centroid was placed at 5%, the L5 center at 50%, and the V_R centroid at 95% of the distance from the left lateral to the right lateral edge of the cross section. These anteroposterior and lateral diameters were measured for each subject at the start of the test sequence.

NATO ADVANCED STUDY INSTITUTE IN SPINAL CORD INJURY REHABILITATION ENGINEERING

The NATO Advanced Study Institute in Spinal Cord Injury Rehabilitation Engineering will be held at Stoke Mandeville Hospital, Aylesbury, Buckinghamshire, England, May 11–13, 1981. The Institute offers instruction by lecturers from both clinical and engineering-science backgrounds, instructional films, clinical demonstrations, study groups on research and development, and coordination of international research in the field.

Discussion topics will include:

- Introduction to Spinal Cord Injury Pathophysiology, Rehabilitation Methods and Needs
- Spinal Cord Properties and Response to Injury
- Fixation–Stabilization of the Fractured Spine
- Bladder Dysfunction, Assessment and Rehabilitation
- Plastic Surgical Repair
- Vascular Disturbances and Their Management
- Electrical Stimulation Techniques and Applications

NATO-country residents who have medical or engineering-science backgrounds are eligible for travel and boarding–lodging grants.

Persons interested in participating in the Institute should send resumes listing their professional, academic, and educational experience to Professor D. N. Ghista, Michigan Technological University, Houghton, Michigan 49931, or to Dr. H. L. Frankel, Stoke Mandeville Hospital, Aylesbury, Buckinghamshire, England.