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INTRA-ABDOMINAL PRESSURE AND TRUNK MUSCLE ACTIVITY DURING LIFTING.

II. *Chronic Low-back Patients*

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ABSTRACT. The aim of this study was to compare trunk muscle strength and intra-abdominal pressure during lifting in low-back patients and in healthy controls.Twenty male workers with 2–18 year history (median 5.5 years) of low-back pain went through strenght tests of trunk flexion and extension and a series of standardized lifts. The intra-abdominal pressure (IAP) and the EMG activity of the oblique abdominal muscles and of the erector spinae muscles were recorded. The results were compared with those in 20 healthy men exposed to similar loads at work and at leisure.

1. **The low-back patients had reduced abdominal muscle strength (−25 %) compared with the healthy controls.**
2. **The IAP during lifting was the same in the two groups despite the difference in abdominal muscle strength.**
3. **The trunk extension strength was the same in the two groups.**
4. **The oblique abdominal muscles were only moderately activated during lifting (5–15 % of maximum activity with 25 kg) both in low-back patients and in healthy controls.**
5. **The erector spinae muscle was strongly activated during lifting (40–60 % of maximum activity with 25 kg) both in low-back patients and in healthy controls.**
6. **During backlifting the duration of erector spinae activity varied. Back patients had extended activity compared with the healthy controls. Stiffness seemed to affect the duration of activity in both groups.**
7. **The oblique abdominal muscles seem to be of no decisive importance to the IAP.**

Key words: Low-back pain, intra-abdominal pressure, trunk muscle strength, electromyography

Strengthening of the abdominal muscles is generally considered essential in the prevention of low-back pain. This idea is based on the assumption that low-back patients have a reduced intra-abdominal pressure (IAP) during the performance of heavy tasks, such as lifting in bent forward positions, due to weak abdominal muscles. The IAP is suggested to reduce the load on the lumbar spine during lifting (4, 8, 10, 11, 22).

Several investigators (for references see 25) have studied the strength of trunk flexors and trunk extensors in healthy subjects and low-back patients. There are also several studies on healthy subjects concerning the intra-abdominal pressure during lifting (for references, see 18) but only one (13) deals with IAP in low-back patients. There is so far no study of trunk muscle strength and IAP during lifting in the same individuals, whether healthy or sick.

Therefore we compared trunk muscle strength and IAP during lifting in low-back patients and in healthy subjects. We also compared the two groups with regard to the myoelectrical activity in the oblique abdominal and erector spinae muscles during lifting.

MATERIAL

Twenty male chronic low-back patients from the construction industry were selected. Using the unions' lists of members and our previous case records from the medical health service for all construction workers in the city of Malmö, we picked out all cases of low-back pain and appropriate ages, heights and weights among electricians, carpenters, painters and supervisors. From these 222 subjects we selected those 32 men who had most low-back pain without sciatica, least physical activity in leisure and no other complicating diseases. Everything else being equal, we preferred an electrician before the others, as our previous healthy subjects were all electricians. Twenty-six men consented to take part in the investigation. Twenty of these were finally selected after medical examination: (13 electricians, 4 carpenters, 2 supervisors and 1 painter). Those excluded had signs of thoracic spine disorders or sacro-iliac joint diseases and were treated.

Through this procedure—and knowledge about their work—we obtained a group of patients with a fairly uniform case history and as similar exposure to loads as possible, both at work and leisure. They all seemed to have chronic lumbar complaints with more or less continuous pain, which was aggravated by heavy work or by protracted static posture. On examination we found local tenderness and suspected instability in the lumbosacral and/or the adjacent lumbar segments. Hips and other

Table I. *Characteristics of the low-back patients and the healthy controls*

	Low-back patients	Controls
Number	20	20
Age (years)		
mean	32	28
range	22–37	23–33
Height (m)		
mean	1.80	1.80
range	1.74–1.88	1.71–1.87
Weight (kg)		
mean	76	75
range	57–89	68–86
Occupation		
Electrician	13	20
Carpenter	4	–
Supervisor	2	–
Painter	1	–
Physical activities in leisure time (during last 3 months):		
None	18	12
Physical activity 1–3 h/week	2	6
Soccer (amateur)	–	2

joints and routine tests were quite normal in all cases. None had a suspected inguinal hernia. They had had their complaints for 2–18 years (average 5 ½ years), but apparently they had learnt to live with their pain. Twelve out of 20 stated that they tried to be cautious and avoid heavy lifts. Five men had been sicklisted during the last year, one had changed his job due to back pain. One of the patients had used a corset during his leisure hours for 6 years, and another a weightlifter's bealt for 6 months. Their ages ranged between 22 and 37 yars (mean 32), heights 174–188 cm (mean 180) and all had a normal body weight (mean 76 kg).

Eight subjects had previously been treated by a physiotherapist, either invidividually or in a group (so-called Back school), including instructions in lifting techniques and abdominal muscle training, but only one of them was still doing abdominal muscle exercises 2–3 times a week. Before our tests they were instructed in lifting technique as regards leg lifting. Thus they had all received roughly the same information.

Twenty healthy subjects with no history of back pain served as controls (Table I) and were examined in the same way as those with pain. One of the controls had done some abdominal muscle exercise during the last year before the examination.

METHODS

Assessment of spinal flexion and straight leg raising test

Measuring of spinal flexion was performed according to recommendations from the American Academy of Orthopaedic Surgeons (2). Table II shows the increase in distance C7–S1 from standing erect to bending forward and the distance between fingertips and floor during maximum forward flexion. In the straight leg raising test the angle between the table and the straight leg was measured with a goniometer.

Assessment of trunk flexion strength

Measurement of the strength of the trunk flexors was carried out in the upright position (Fig. 1). A special frame was made with a support behind the pelvis. The strap of the recording instrument was placed across the chest and upper arms at the level of the attachment of the deltoid muscles. The tension in the strap was recorded by means of a strain-gauge. Each subject had to do three maximum isometric ventral flexions with a duration of at least 3 sec. The estimates were then made from the median values.

The measuring was carefully standardized to permit comparisons. The subjects were told to do a trunk flexion and not a hip flexion and their minute movements during the test were supervised. The position of the feet in relation to the frame was also standardized. The healthy controls, who had taken part in a previous investigation (18), were re-examined in the same manner as the low-back patients to get comparable values. (Three failed to appear.)

Assessment of trunk extension strength

The strength of the trunk extensors was measured with the same method, except that the subject faced the frame with the strap placed across the dorsal part of the chest and the upper arms at the same level as before.

Intra-abdominal pressure recordings

The intra-abdominal (i.e. intragastric) pressure was recorded via an open polyethylene tube as previously described (18). In the case of the patients the tube was connected to a pressure transducer (Bentley Trantec) and

Table II. *Spinal flexion and straight leg raising test*

	Low-back patients (n=20)	Controls (*n*=20)
Increase of distance C 7–S 1		
6–8 cm	7	4
9–11 cm	13	14
12–14 cm	0	2
Distance between fingertips and floor		
≤5 cm	11	7
6–14 cm	5	8
≥15 cm	4	5
Straight leg raising test		
Symmetrical		
70–75°	7	7
80°	8	11
85–90°	3	2
Asymmetrical		
>10° diff	2	0

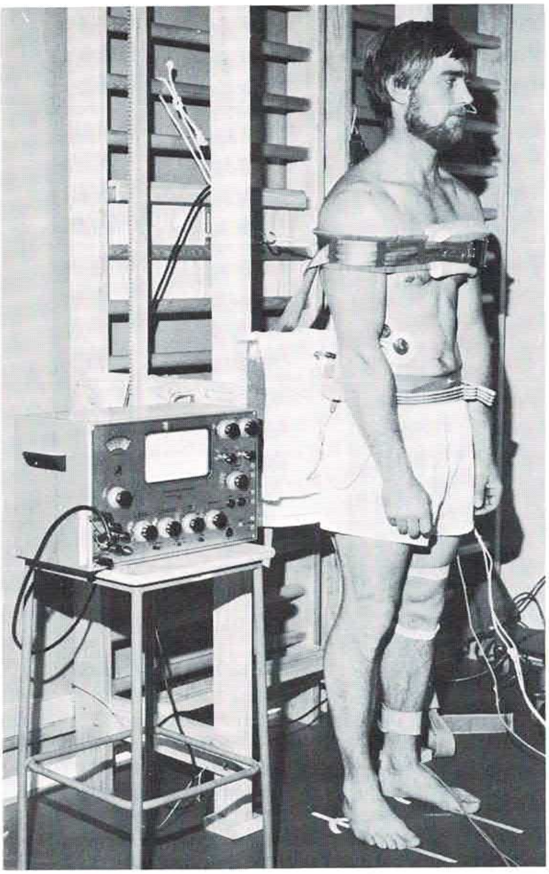

Fig. 1. Subject preparing to measure trunk flexion strength. The strain gauge is situated behind the frame. The figure also shows the electrodes over the oblique abdominal muscles.

the variations in pressure were transmitted via a pressure amplifier (BM Elektronik, Åhus, Sweden) to a tape recorder (Racal Store 14 FM) for subsequent analysis in a computer. The pressure curves were continuously checked on a mingograph (Siemens 82), and the tube flushed with saline when necessary.

Electromyographic recordings

The low-back patients were supplied with disposable electrodes (3M Red Dot 2247 Ag–AgCl) over the right erector spinae muscle at the L2–L3 level (3 cm lateral to the spinous processes) and over the right oblique abdominal muscles at umbilical level and above the ventral iliac spine. The skin was prepared in the prescribed manner with the enclosed piece of sandpaper and alcohol. The interelectrode distance was 5 cm and the direction of the electrodes parallel to the direction of the muscle fibres. The myoelectric signals were fed to preamplifiers fastened to the patient's waist. The signals were further amplified and recorded on magnetic tape. During recording the signal quality was continually checked on a mingograph. For analysis, the myoelectric signals were full-wave rectified and integrated over a preset period, throughout this study 0.1 s. The upper and lower cut-off frequencies were 1 000 and 50 Hz respectively. An active T-filter was used with a slope of 12 dB/octave. The myoelectric recordings in the healthy controls have been described previously (18).

The examination procedure

Each subject was asked to carry out three trunk flexion strength tests, three trunk extension strength tests and a series of symmetric lifts from floor to upright position with the load on extended vertical arms in front of the body (Fig. 2). Each lift was done twice and all calculations were made from the mean value of the two lifts. The subjects were allowed to rest between lifts.

Lifts were performed with 10, 25, and 40 kg, in all cases with 'leg lifting' as well as 'back lifting'. Leg lifting is defined as lifts with bent knees and the back as straight as possible. Back lifting means lifting with straight knees and flexed back.

Each subject could choose his own lifting speed and breathing technique, but otherwise the lifts were carefully standardized to facilitate comparisons between the low-back patients and the healthy controls. The subject stood in a fixed position relative to the load and a physiotherapist gave instructions about the lifting technique to be used.

The subjects were asked to report any pain during or after a strength test or a lift. If there was any fear that the pain would prove too severe, that particular test or lift was excluded.

In all lifts, a box (40×25×16 cm) was used, that could be symmetrically loaded with 5 kg weights. Attached to the box were an accelerometer for recording vertical acceleration and a switch for recording the start of the lifting and the end of the lowering. Another switch was placed behind the subject at the Th 3–4 level when standing erect, recording the end of the lifting and the start of the lowering.

With the low-back patients the lifts were also controlled by an electrogoniometer on the left knee.

Statistical methods

The strength of the covariance was determined by Pearson's correlation coefficient, r. The analysis of significance was carried out according to Student's t-test.

RESULTS

Trunk flexion strength

The low-back patients exhibited reduced trunk flexion strength as compared with the healthy controls (Table III). The difference was highly significant ($p<0.001$). When attempting to test flexion and/or extension strength, 3 patients reported pain and were excluded.

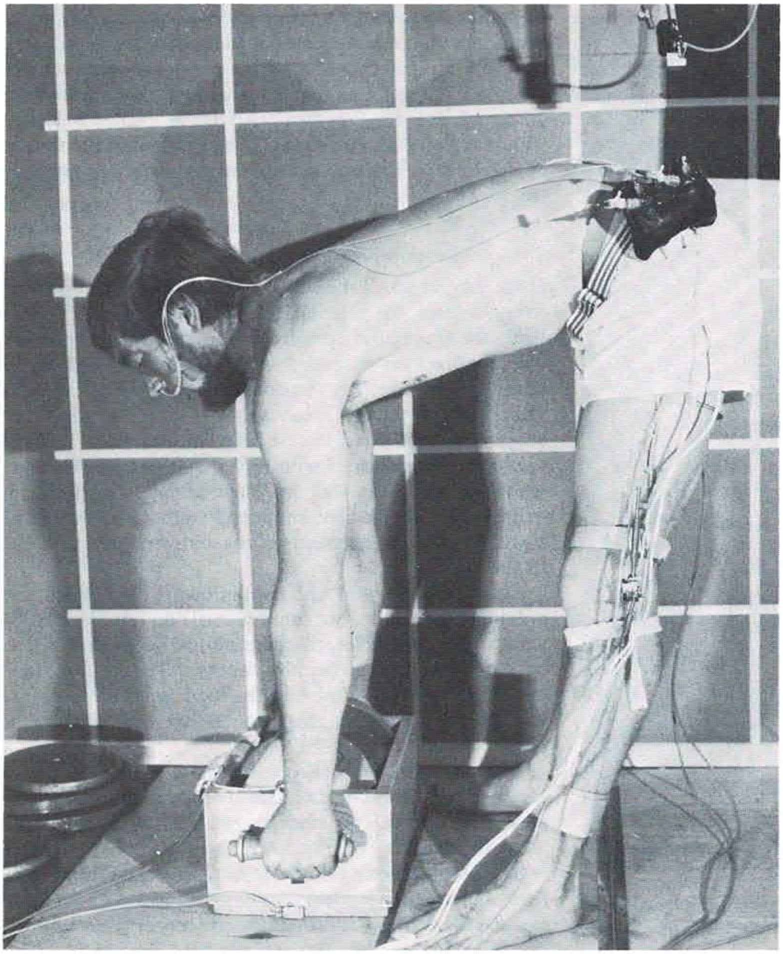

Fig. 2. Example of back lift of 40 kg. Note the switch at the bottom of the box, the electrogoniometer on the left knee and the pressure recording system. The EMG electrodes are situated on the subject's right side. Part of the upper switch is seen on the top of the picture.

Trunk extension strength

The two groups showed no differences either in trunk extension strength (Table III) or in reported pain.

Extension/Flexion ratio

The ratio was determined for each subject by dividing the extension strength by the flexion strength. The mean ratio of the low-back patients was 1.54 and of the healthy controls 1.29 (Table III). The difference was significant ($p=0.015$).

Intra-abdominal pressure during lifting

There was no difference in IAP during lifting, regardless of weight or lifting technique (Fig. 3 *a*, *b*).

As it was a main concern to avoid any injury to the patients, only five lifts by 3 patients were reported to be painful, out of about 200 lifts. No pain was reported in the control group.

Trunk muscle activity during lifting

As the two groups were examined with different electrodes, they could not be compared quantitatively. Within the groups the different tests may be roughly compared, however, if it is taken into con-

Table III. *Maximum trunk flexion strength and trunk extension strength (mean values and range within parentheses)*

n	Low-back patients ($n=17$)	Controls ($n=17$)	p
Trunk flexion strength (N)	549 (350–830)	721 (460–1 010)	<0.001
Trunk extension strength (N)	821 (660–1 200)	859 (660–1 070)	N.S
Extension/flexion ratio	1.54 (1.08–2.17)	1.29 (0.88–2.15)	0.015

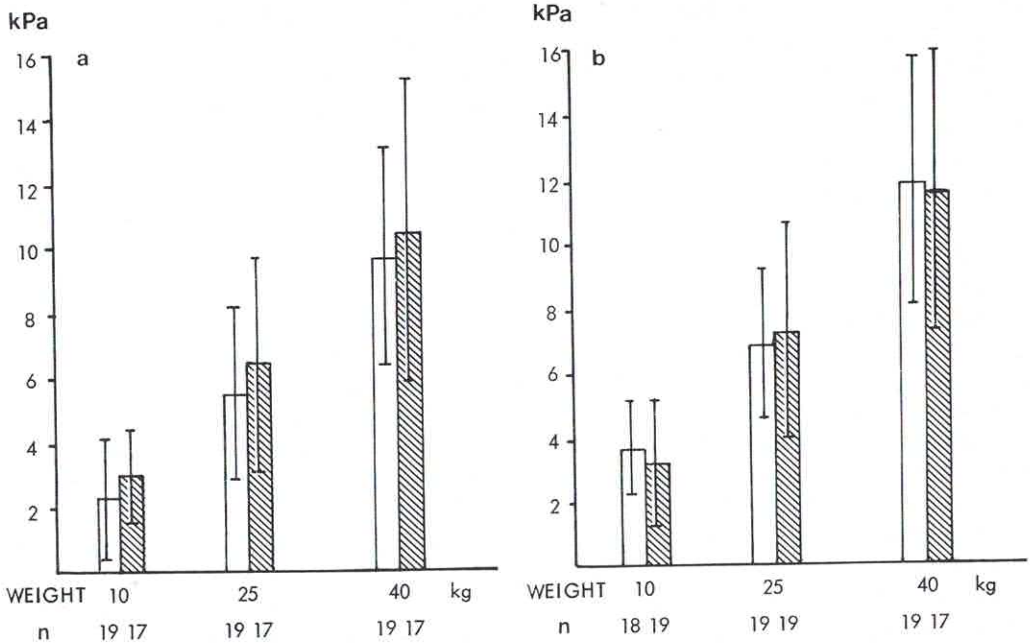

Fig. 3. Peak values of IAP at lifting 10, 25, and 40 kg (mean ± SD). (*a*) Back lifting, (*b*) leg lifting. □, Healthy controls; ▩ low-back patients.

sideration that the strength test is isometric while lifting contains concentric and eccentric contractions.

During the lifts of 25 kg, leg lifts or back lifts, the activity of the oblique abdominal muscles was only 5–15% of the maximum activity during the trunk flexion strength test. During the lifts of 40 kg the corresponding figure was 15–25%.

The erector spinae was relatively more active during the lifts. With 25 kg, the activity was 40–60% of the maximum recorded during the trunk extension strength test. For 40 kg the corresponding figure was 50–75%.

In these respects, there were no significant differences between the two groups.

There was, however, a clear difference in the duration of activity during the back lifts. Fig. 4 shows the duration of detectable erector spinae activity (sensitivity 600–1 000 μV/cm) as a percentage of the total time of lifting and lowering respec-

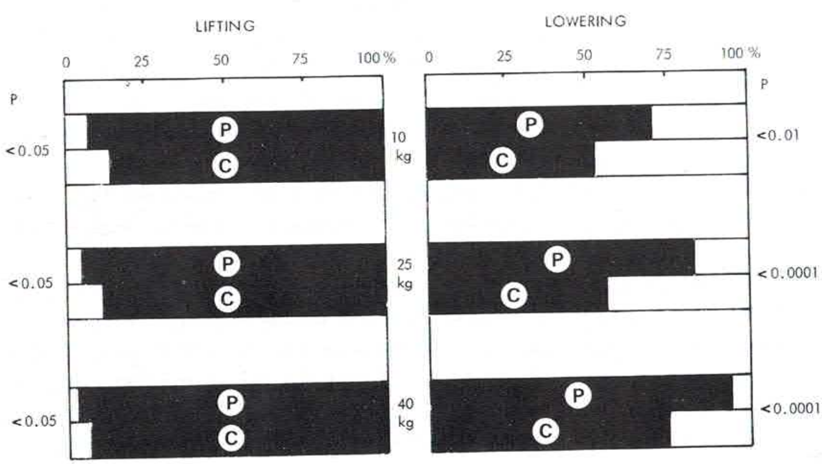

Fig. 4. The duration of myoelectric activity of the erector spinae at back lifting with 10, 25, and 40 kg in percentage of the time for lifting and lowering. Scattered area = detectable myoelectrical activity (means and *p*-values for the difference between the patients (*P*) and the controls (*C*).

tively. There was a significant difference, as the low-back patients started activating their erector spinae muscles earlier and, moreover, the activity lasted longer during the lowering.

The ability to reach the floor in forward bending (distance fingertips to floor in Table II) was compared in back lifting to the relative duration of erector spinae muscle activity during lifting and lowering (Fig. 4). We found a weak positive correlation between stiffness and duration of activity. For the patients, r varied between +0.37 and +0.56 for lifting or lowering of different weights ($p<0.05$ for lifting 10 kg and 25 kg) and for the healthy subjects between +0.12 and +0.42 (NS). This seems to suggest that the stiffer subjects started activating their erector spinae later during lifting than the more mobile ones. They also ceased activating their muscles earlier during lowering.

The low-back patients and the healthy controls are comparable as regards the ability to reach the floor in forward bending. Therefore the correlation between mobility and muscle activity could not explain the difference between the groups seen in Fig. 4.

The other mobility test (C7–S1 distance) and straight leg raising test gave too small ranges to allow any calculations.

DISCUSSION

The main purpose of this investigation was to study the relationship between trunk muscle strength and intra-abdominal pressure during lifting in low-back patients compared with healthy controls. Furthermore we wanted to illustrate some features in the trunk muscle activity during lifting that might have clinical implications.

Trunk flexion strength test

Concerning trunk muscle strength we first have to discuss what forces we really measure during these tests. The test situation was exactly the same for the two groups, which is essential. They were all standing upright, to exclude the effect of gravity (26) and to minimize the effect of variations in maximum torque produced during trunk flexion and trunk extension (26). Their heights and weights were quite equal, they were all bare-foot with approximately the same leg–floor angle to minimize variations in friction against the floor. The same personnel instructed and supervised the subjects during the tests.

When this technique is used, the bilateral axis of motion is located about the intervertebral disc L 3–4 during trunk flexion test (18) and ventrally to L 1–2 during trunk extension test. This means that only the anterior abdominal muscles and to a minor degree perhaps the psoas can exert a forward bending movement against the strap. The other hip flexors and all the hip extensors balance each other in stabilizing the pelvis, provided that it does not move, which may be detected during the test. The psoas muscles account for 5–9% of the trunk flexion strength, according to Alston et al. (1), but Farfan (14) calls attention to the fact that no digitation of the psoas can exert a bending moment between 15° of extension and 65° of flexion.

Among the abdominal muscles the rectus abdominis, the ventral portion of the external oblique and most of the internal oblique may be responsible for a forward bending movement (14). The transverse abdominal muscles cannot contribute due to their anatomical position.

As the test is isometric we always have to take into consideration that the antagonists—the erector spinae muscles—may be more or less activated simultaneously. In fact our back patients exhibited an average erector spinae activity during the flexion test amounting to 14% of their maximum activity during the extension test, and the healthy controls about the same relative activity. This antagonist activity has not been considered before, to our knowledge.

Furthermore, the intra-abdominal pressure was increased during the trunk flexion test (mean 11.7 kPa, SD=4.3 among the patients and 10.5 kPa, SD=6.1 among the controls). This pressure rise has been reported in corresponding situations, such as push and pull 20–40 kg (9) and upright horizontal loading (17), but not in connection with maximum trunk strength test, though discussed by some authors (21, 25).

In summary we may conclude that the rectus abdominis, the external and internal oblique abdominal muscles have to overcome the extending moments from the erector spinae and the intra-abdominal pressure during the trunk flexion test, and that we measure the net effect on the strain gauge, provided that the pelvis and the lower extremities can be kept immobile by the hip flexors and extensors and, of course, the other leg muscles.

Morris et al. (22) calculated that 14.1 cm^2 of the oblique abdominal muscles (=50% of the whole muscles) and 8.4 cm^2 (=100%) of the rectus abdominis act in a longitudinal direction. We cannot measure the strength of the separate muscles, but we may estimate that the oblique muscles account for a considerable part of the flexion strength, and consequently also for a great share of the loss of strength among the low-back patients.

Trunk extension strength test

Concerning the trunk extension test, we must consider the effects of the antagonists and the IAP. The average oblique abdominal muscle activity was for the patients 37% and for the controls 39% out of their respective maximum activity during the flexion tests. This seems to agree with Carlsöö (7) who reported "strong" activity of the external oblique muscles in the same test. We did not record the rectus abdominis muscle, but Carlsöö (7) stated that—in healthy subjects—the rectus abdominis was activated only occasionally and then only slightly during the trunk extension strength test. As the axis of motion was located ventrally to the L1–L2 segment we may assume that a certain amount of the oblique muscles works antagonistically to the trunk extensors during the test.

The maximum IAP during the trunk extension test was rather high (mean 16.0 kPa, SD=4.1 among the patients and 11.3 kPa, SD=5.0 among the controls). As for the axis of motion the lever of the IAP will probably be rather small.

Thus, the erector spinae muscles as prime movers have to overcome the flexing moment of the oblique abdominal muscles, perhaps with some help from an extending moment of the IAP.

Trunk muscle strength in low-back patients and controls

Our two groups appeared to be quite comparable in age, height and weight, and fairly comparable regarding loads at work or leisure, as far as could be assessed from interviews and knowledge about their work.

The difference in average age—32 years for the patients, 28 for the controls—cannot, according to Asmussen et al. (3), explain any difference observed in strength.

Pain may be a confounding factor in any strength test, or even fear of pain. Our low-back patients were not acutely ill at the moment except for 3 of them who felt pain during either the flexion or extension test or both. These painful recordings were excluded. The remaining 17, like the healthy group, reported no pain during the tests. In fact, in their experience the risk of pain was greater at extension test than at flexion test. It thus seems less probable that the difference in strength should be due to pain during the tests.

From biomechanical considerations we may conclude that our low-back patients had a reduced trunk flexion strength due to weaker abdominal muscles than the healthy controls, as the extending moments from the IAP and from the erector spinae muscles were about the same for the two groups. Unfortunately we could not compare the myoelectrical activity between the two groups, so we cannot decide whether the reduced strength was caused by muscular or neurophysiological disturbances (e.g. inhibition). This considerable decrease in strength (25%) should also affect the oblique abdominal muscles, which have been believed to be important for the IAP during lifting.

We used the same strength test technique as did Asmussen et al. (3) and Tornvall (27) and, with modifications, Nordgren et al. (24), Nachemson & Lindh (23) and McNeill et al. (21).

Our results for the healthy group agree with those of Asmussen et al. and Nordgren et al. Tornvall examined young conscripts (19–20 years old) who were apparently weaker than our construction workers. The values reported by Nachemson & Lindh and McNeill et al. are lower.

The extension/flexion ratio is for corresponding groups of healthy subjects: Asmussen et al., 1.36; Tornvall, 1.09; Nordgren et al., 1.23; Nachemson & Lindh, 1.11; and McNeill et al., 1.37. Our figure of 1.29 is thus consistent with previous studies using the same technique. By contrast, the ratio for our patients (mean 1.54) seems to deviate.

Earlier investigators on trunk muscle strength in low-back patients have found a selective decrease in trunk flexor strength or trunk extension strength, or both (e.g. 21, 23). The differences may originate from different selections of patients, different methods, and varying influence of pain.

Our low-back patients were a selected group. The duration of their back complaints averaged more than 5 years, but they were all working full time, and only 5 out of 20 had been sicklisted during the past year. Yet, they had a considerable reduction in abdominal muscle strength, which we can neither explain, nor determine if it preceded or followed the back complaints.

Intra-abdominal pressure during lifting

The next question concerns the IAP during lifting. The lifts were standardized so that conditions should be as uniform as possible for patients and controls. Our equipment was tested in a model and under X-ray control (18) and our peak levels are fairly consistent with previous studies with similar lifts but other devices such as balloon-catheter (22), radio pill (20), and intragastric transducer (13).

We could find no difference between the groups regarding the peak IAP (Fig. 3*a, b*), in spite of the clear difference in abdominal muscle strength. Fairbank et al. (13) did not assess the trunk muscle strength but measured IAP during 13 different lifts of 5 or 10 kg in different postures. Their findings from those loads and ours from lifting up to 40 kg are quite consistent for painless lifts. They found higher pressures during painful lifts. In our series, however, only five lifts were painful with very inconsistent values, which is why no comments can be made on the effect of pain on IAP.

We may conclude that there appears to be no relationship between abdominal muscle strength and intra-abdominal pressure during lifting.

Trunk muscle activity during lifting

Floyd & Silver (15) often found asymmetric trunk muscle activity. We always recorded from one side only and any asymmetry should be equalized among the series of lifts.

Caution must be taken in comparing maximum activity during isometric contractions and myoelectrical activity during eccentric and concentric contractions during lifting. Nevertheless, the figures give a rough idea of the part played by the oblique abdominals in lifting and lowering. It is obvious that the oblique abdominal muscles were only slightly activated during these activities compared with the strength tests. This agrees with previous studies (12, 22). Morris et al. (22) stated that the degree of activity in the oblique abdominal muscles during lifting of 90 kg was approximately one-sixth (about 17%) of that obtained with maximum voluntary contraction in the same position as that in lifting the weights.

The same conclusion applies even more to the rectus abdominis, which is usually fairly silent during lifts up to about 40–50 kg (12, 22).

In contrast to the slight activation of the anterior abdominal muscles we found that the erector spinae muscles, when engaged at all, were very active during lifting, that is 50–70% of maximum activity already at 40 kg. It seems that the capacity of the extensors may be a limiting factor.

It is well known since Floyd & Silver (16) that the erector spinae is often silent on EMG during maximum ventral flexion (the so-called flexion–relaxation). Jonsson states this to be due to the interspinous and supraspinous ligaments being tautened and taking over the load from the erector spinae muscle (19). The activity ceases during flexion between 40 and 130° and starts again when rising (6). Carlsöö supposes the variation between individuals to be related to elasticity and mobility (6). Both in healthy subjects and low back patients we found a connection between the duration of the 'flexion–relaxation' and the distance between fingertips and floor during maximum forward flexion, i.e. flexibility of the trunk and hips. This is in conformity with the statements of Jonsson and Carlsöö, but needs further studies on a larger material.

Another interesting finding as regards the erector spinae activity, was the clear distinction between the back patients and the controls. The patients kept the activity of their erector spinae longer than the healthy men, especially during lowering.

We can only speculate about the clinical importance of these observations. Have they been forced to train their muscular coordination to save joints and ligaments from further wear and tear, or is it a protective mechanism against pain?

It also remains to be investigated if these back patients with the same IAP as the healthy subjects derive any advantage from their demonstrated ability to produce IAP rises during lifting in spite of weak abdominal muscles.

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