INTRA-ABDOMINAL PRESSURE AND TRUNK MUSCLE ACTIVITY DURING LIFTING

III. *Effect of Abdominal Muscle Training in Chronic Low-back Patients*

Bertil Hemborg,[1] Ulrich Moritz,[2] Jern Hamberg,[3] Eva Holmström,[1]
Harold Löwing[1] and Ingrid Åkesson[2]

From the [1]The Construction Industry's Organization for Working Environment, Safety and Health (Bygghälsan), Malmö, [2]Dept. Phys. Therapy, Lund University, Lund, and [3]Alfta Rehab-Center, Alfta, Sweden

ABSTRACT. Isometric training of the abdominal muscles is often recommended in programs of primary or secondary prevention for low-back pain. In this study 20 male workers with 2–18 years' history (average 5 ½ years) of low-back pain without sciatica went through intense isometric abdominal muscle training for 5 weeks. Before and after training the subjects had trunk flexion and extension strength tests 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 muscle were recorded. It was found that:

1) **the strength of the abdominal muscles increased;**
2) **the increased strength was correlated to an improved recruitment of motor units in the oblique abdominal muscles;**
3) **the EMG activity of the oblique abdominal muscles when lifting decreased after training, i.e. the acquired ability to recruit more motor units was not made use of;**
4) **the IAP at lifting was generally not affected.**

A better knowledge of the mechanisms responsible for the IAP in different siutations is needed to support advice on training or other prevention.

Key words: low-back pain, intra-abdominal pressure, electromyography, prevention

Abdominal muscle training is often recommended in programs of primary or secondary prevention for low-back pain (18, 19). It is, in fact, the only 'home exercise' in the so-called 'Back school' (28). The aim of the training is to reduce the load on the vertebral column by increasing the intra-abdominal pressure (IAP) (18, 19) or by creating a 'muscle corset' (28).

In a previous study we investigated the effect of isometric abdominal muscle training in healthy subjects (12). Legg also studied the effect of dynamic abdominal muscle training in healthy subjects (17). In neither of these studies was there any effect of the training on the intra-abdominal pressure during lifting. Moreover, we found a reduced activity in the oblique abdominal muscles during lifting.

The aim of this investigation was to study the effect of abdominal muscle training in chronic low-back patients with regard to trunk muscle activity and IAP during lifting. In this study we were able to study the whole lifting procedure (from start to finish, of lifting and lowering) by computerizing the calculations. Otherwise the design of the study was similar to the previous one (12) to facilitate comparisons.

MATERIAL

The material was the same as in part II (13). It comprised 20 male chronic low-back patients.

METHODS

Assessments of trunk flexion and trunk extension strength, recordings of intra-abdominal pressure and electromyographic recordings were performed as described in part II.

The Examination Procedure

1. *Recordings before and after training of abdominal muscles*

Before and after abdominal muscle training the subjects were put through a standardized test program where the strength of the trunk flexors and extensors was recorded and a series of lifts was carried out.

Lifts were performed with 10, 25 and 40 kg, in all cases with three techniques, namely back lifting and two types of leg lifting. By back lifting is meant symmetric lifts with straight knees and flexed back. The first mode of leg lifting (leg lift A) is a symmetric lift with the feet placed behind the box, the knees flexed and the back as straight as possible. The second mode (leg lift B) was advocated by Davies (5) as "a new way to lift", the main point being that the feet have to be far enough apart to give a balanced

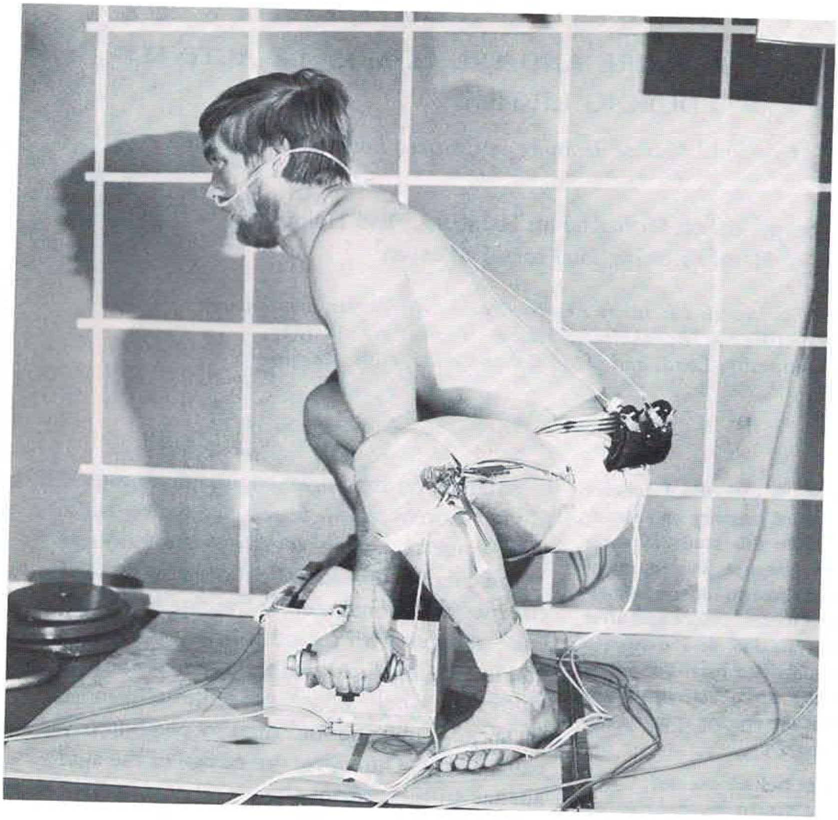


Fig. 1. Leg lift B. For explanation, see text.

distribution of the weight. The leading foot should point in the direction of the movement, the knees and hips should be flexed and the back kept as straight as possible (Fig. 1). The positioning of the feet makes it easier to keep the heels on the ground, while the leg lift A often forces one to balance on the soles. One can, moreover, come closer to the burden in leg lift B.

The lifts were performed from floor level to the upright position, with the load on extended hanging arms in front of the body.

In all lifts, a box was used (40×25×16 cm) (Fig. 1). On the box there was an accelerometer for registration of vertical acceleration and a switch for recording lift-off and touch-down. 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. The lifts were also controlled by an electrogoniometer on the left knee (Fig. 1) and by videocamera recording.

Each subject could choose his own lifting speed and breathing technique, but otherwise the lifts were carefully standardized to facilitate comparisons between the recordings before and after training. The subject stood in fixed positions 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 they were afraid that the pain would prove too severe, that particular test or lift was excluded. The subjects were allowed to rest between lifts.

Each lift was done twice and all calculations were made from the mean value of the two lifts. The order of lifts was changed between subjects. Each subject did, however, perform the lifts in the same order before and after training.

2. *Isometric training of abdominal muscles*

The training to be evaluated was exactly the same as was previously performed by healthy subjects (12), except that in back patients we had to consider their ability to endure the exercises and thus, in some cases, had to raise the load more slowly during training.

During the 5 weeks the program lasted, all subjects cooperated fully with one ambition to have the most intense and efficient training possible of the abdominal muscles. The subjects were not allowed to do any other physical training during that time.

Everyone received detailed personal instruction in the standardized technique and was checked twice a week throughout the period.

The initial position was supine, with hips and knees flexed, the heels supported, and with active plantar flexion of the feet. The back was pressed against the floor and the gluteal muscles were actively contracted. The training procedure was as follows. The subject breathed out and

Table I. *Trunk muscle strength (mean ± SD) before and after training (N)*

	Before	After	Diff.	*p*
Trunk flexion strength, $n=17$	549±114	671±118	+22%	<0.0001
Trunk extension strength, $n=16$	837±166	943±123	+12%	<0.001

held his breath, after which he curled up until he experienced a maximal effort, though without changing the position of the pelvis.

Each exercise was performed twice daily, with 10 curl-ups on each occasion. The subjects kept records of their daily training. The load and holding time were raised successively by the physiotherapists. This was done both by extending the holding time by 15 s and by increasing the external torque through the position of the arms, as the subjects grew stronger. Two subjects had to be excluded from the training, one due to severe low-back pain, and another due to intercurrent disease.

Evaluation Procedure

The myoelectrical signals and the pressure recordings were stored on magnetic tape, together with the signals from the electrogoniometer and from the accelerometer and the two switches indicating the start and end of all liftings and lowerings. The analogue myoelectrical signals on the tape were fullwave rectified, and integrated over pre-set 0.1 s periods, each containing 400 readings.

The pressure signals were averaged over the same periods from 0.5 s before the take-off to the end of the lifting and from the start of the lowering to 0.5 s after the touch-down. The accelerometer recordings were treated in the same way.

Statistical Methods

The design of the study was chosen to get a matching situation where each subject could serve as his own control. This approach was considered essential on account of the great interindividual variations in the variables studied.

In the strength tests, the calculations are based on the maximum activity during three consecutive 0.1 s periods in the tested muscle, the activity of the other recorded muscle, and the IAP read-off for the same 0.3 s.

For the lifts the calculations are made from the peak IAP in the different types of lifts and from the average pressures and myoelectrical activities during the lifting and lowering respectively. As the time varied between the lifts, the time has been normalized and expressed as percentages of the whole time, and for lifting and lowering separately, it runs from 0 to 100%. The mean activity and mean pressure during the whole lifting and lowering procedure may then be compared (see Figs. 3, 5, 8) before and after training. By calculating the 95% confidence limits of the mean difference between values before and after training, significance analysis is carried out throughout the whole lifting procedure. In other respects, the analysis of significance was performed according the Student's t-test and the strength of covariance was determined by Pearson's correlation coefficient, r.

RESULTS

Trunk flexion strength

The muscle strength before and after training was compared in two ways.

1. *Measurement of the trunk flexors* before and after training. Table I shows an average increase from 549 N to 671 N, i.e. by 22% ($p<0.0001$).

The maximum EMG activity of the oblique abdominal muscles was compared before vs. after training. One subject had to be excluded due to back pain, another owing to intercurrent disease and 2 more subjects because of technical interference. In the remaining 16 there was a correlation between increase in strength and increase in activity ($r=0.55$, $p=0.014$). The IAP during maximum effort increased from 11.7 kPa (SD=4.3) to 16.7 kPa (SD=6.2) after training.

2. *The load at training* may be regarded as an indirect measure of the increase in muscle strength as the external torque and the holding time were increased with the improved capacity of each subject. Fig. 2 shows that the subjects could perform heavier exercises after than before training.

Trunk extension strength

Measurement of the trunk extensors before and after training. Table I shows an average increase form 837 N to 943 N, i.e. by 12% ($p<0.001$).

The maximum EMG activity of the erector spinae was compared before vs. after training. Four subjects had to be excluded due to back pain and another 2 for technical interference. The remaining 14 showed no difference after training and no correlation between change in strength and change in activity.

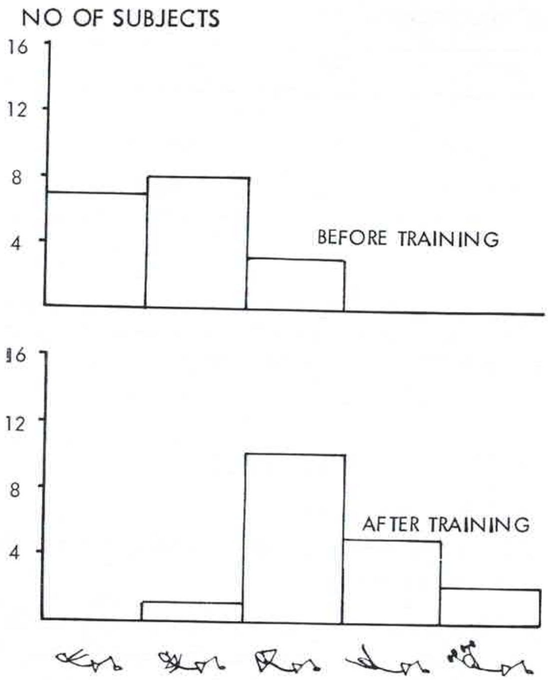


Fig. 2. The external torque depicted by the drawings along the horizontal axis could be successively increased during training ($n=18$, for explanation, see text).

Recordings during lifting

1. *The activity of the oblique abdominal muscles* when lifting was estimated during the whole working cycles, lifting as well as lowering. There was a constant decrease in activity after training, irrespective of lifting technique or load, which can be seen in practically all curves. The decrease is significant ($p<0.05$) during 30–80% of the lifting time in back lifting, during 40–100% in leg lift A and 50–100% in leg lift B. The decrease is less pronounced during lowering but significant ($p<0.05$) during 50–100% of the lowering time in leg lift B. Fig. 3 shows the oblique abdominal muscle activity in leg lift A with 10 kg (lifting).

2. *The intra-abdominal pressure (IAP).* The IAP curves are quite similar in shape in lifting as well as in lowering compared with those of the health subjects previously described (12). The curves vary between the patients, and in one patient between lifts with different weights, as regards the height of the peaks and their position in time, but the shape of the curves remains practically the same in all lifts of the same type.

The peak values of the IAP during lowering are, throughout, somewhat lower than the corresponding values during lifting, as for the healthy subjects (12).

Each subject performed all lifts twice. The average differences between these two lifts were 0.27 kPa with 10 kg, 0.47 kPa with 25 kg, and 0.66 kPa with 40 kg, or, for all lifts, 7.5%.

The IAP was compared before vs. after training (Figs. 4, 5, 6). It was then found that, in the whole material, there was no significant difference between lifts before and after training. This applies to all types of lift, irrespective of lifting technique and load, in any 0.1 s phase of the lift, whether lifting or lowering. The average difference of peak values in the whole material is 0.09 kPa in lifting and 0.05 kPa in lowering.

There were only small displacements of the IAP peaks after training. Thus, the peaks were displaced by 1–12% of the total time of lifting or lowering, i.e. up to 0.2 s.

In a few individual cases, there were remarkable differences after training. One subject raised his peak IAP at 25 kg and 40 kg leg lift A and back lift by up to 136% or 8.5 kPa, but not at leg lift B and

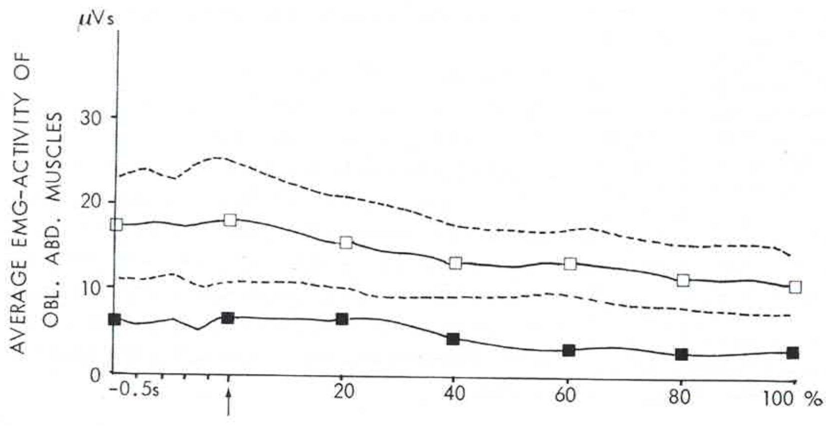


Fig. 3. EMG activity in the oblique abdominal muscles during lifting 10 kg; leg lift A. ↑ describes start of lifting. □===□ average activity before training with 95% confidence limits of the mean difference between values before and after training. ■—■, average activity after training. For further explanation, see text.

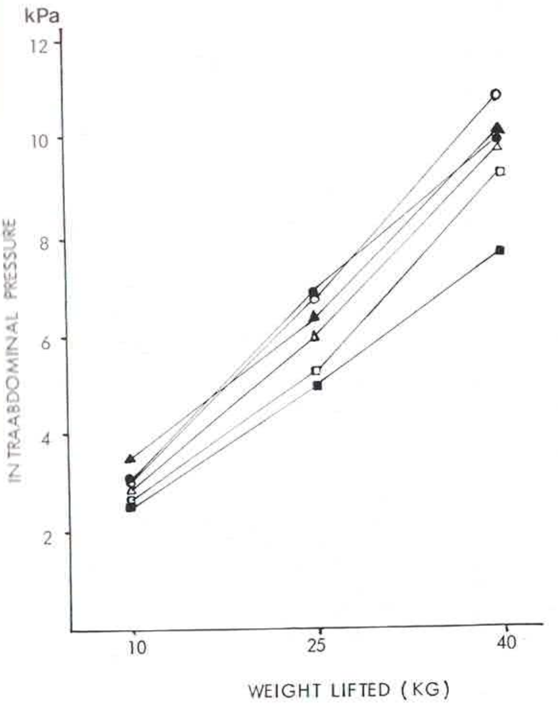


Fig. 4. Peak values of intra-abdominal pressure at lifting 10, 25, and 40 kg before and after training. ○—○, leg A before training, ●—●, leg lift A after training; □—□, leg lift B before training; ■—■, leg lift B after training; △—△, back lift before training; ▲—▲, back lift after training.

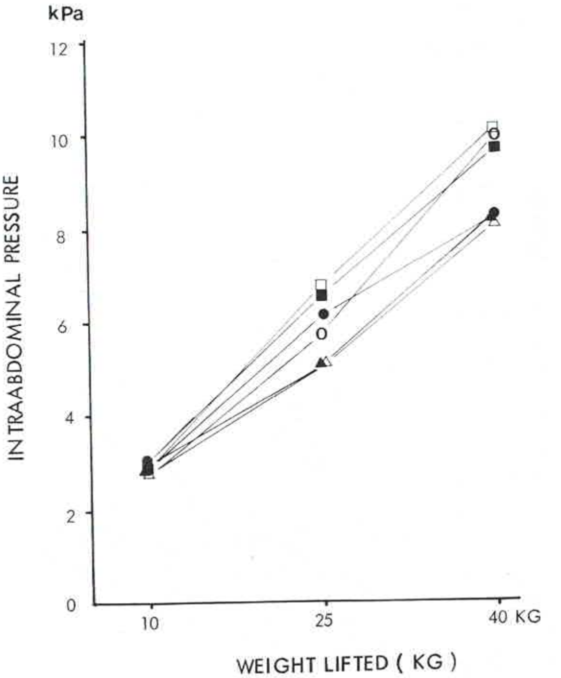


Fig 6. Peak values of intra-abdominal pressure at lowering 10, 25, and 40 kg before and after training. For explanation, see Fig. 4.

not at 10 kg lifts. Two subjects reported pain during lifts after training. One of those raised his peak IAP considerably (by 69% or 5.7 kPa), but the other one lowered his corresponding peak IAP by as much (81% or 5.9 kPa). Apart from these, only a few lifts by three other subjects were reported painful. These lifts gave very inconsistent figures, and do no affect the average values.

The IAP when lifting varied considerably between the individuals (Fig. 7 *a*, *b*). Back lifting of 25 kg could produce an increase to between 2.6 and 14.8 kPa and leg lift A of 40 kg an increase to between 4.0 and 18.6 kPa. Leg lift B showed a corresponding variation.

We found no significant differences between the

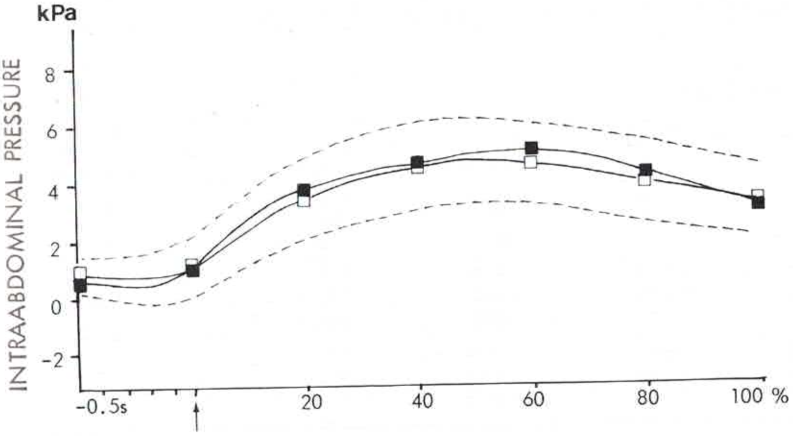
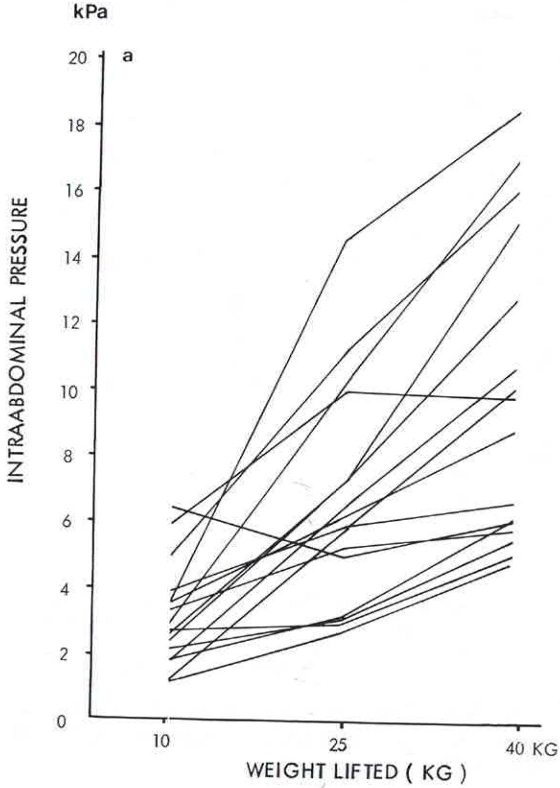


Fig 5. Intra-abdominal pressure during lifting 25 kg, back lift. ↑ denotes start of lifting. □---□, average IAP before training with 95% confidence limits of the mean difference between values before and after training. ■—■, average IAP after training. For further explanation, see text.



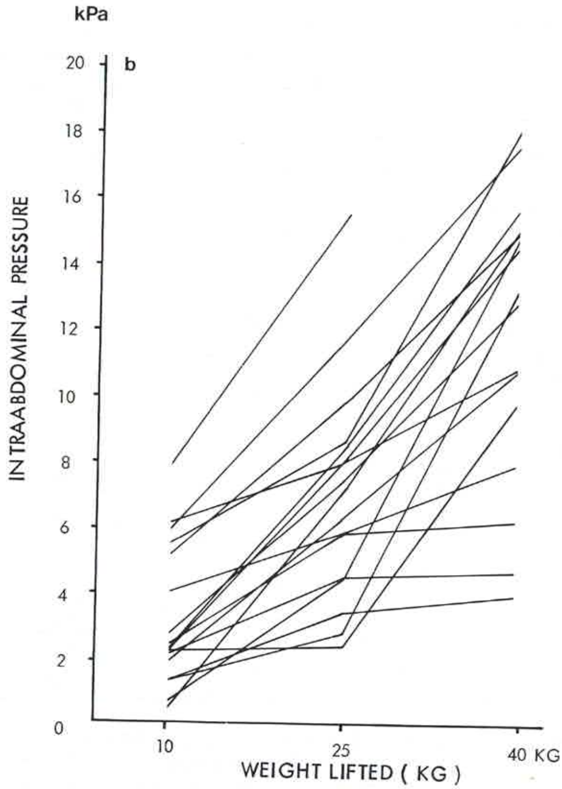


Fig. 7. Peak values of IAP at lifting 10, 25 and 40 kg, before training. (*a*) back lift, and (*b*) leg lift A. Each line represents one subject. The individual variations are considerable.

lifting techniques as regards peak IAP or the average pressure during the whole time of lifting and lowering, though there was a tendency towards lower values during leg lift B with the heaviest loads (Fig. 4).

3. *Relation between activity of oblique abdominal muscles and IAP*. If the activity of the oblique abdominal muscles is regarded as the cause of the increase in the IAP, there should be a relation between the two, in both time and quantity, when comparing the lifts before and after training.

The time intervals between the maximum activity of the oblique abdominal muscles and the maximum of the IAP varied between 0.0 and 0.6 s at leg lifts A and B and between 0.9 and 1.6 s at back lifts. The

Table II. *Relation between change of oblique abdominal muscle activity and change of intra-abdominal pressure after training*

Technique	Weight	Average change		r	p
		EMG (μVs)	IAP (kPa)		
Leg lift A	10	−5.5	+0.41	−0.45	0.036
	25	−5.6	+0.65	+0.17	NS
	40	−10.4	−0.49	+0.29	NS
Leg lift B	10	−9.9	+0.11	−0.11	NS
	25	−3.2	+0.21	+0.01	NS
	40	−6.1	−1.4	+0.57	0.010
Back lift	10	−5.3	+0.55	+0.24	NS
	25	−4.8	+0.36	+0.05	NS
	40	−5.2	+0.45	+0.27	NS

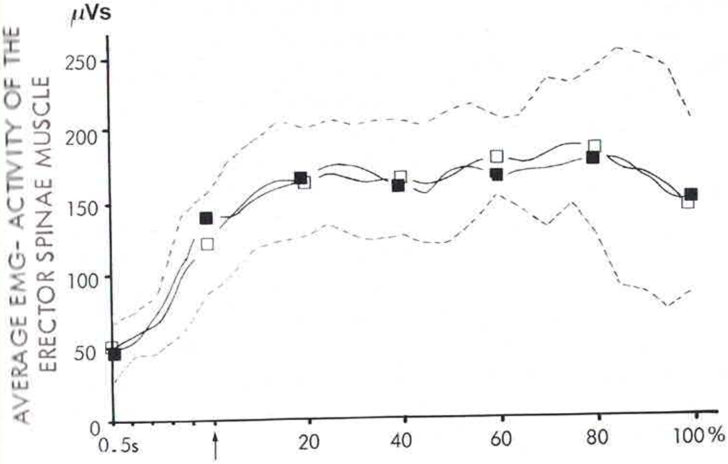


Fig. 8. EMG activity in the erector spinae muscle during leg lift A, 40 kg lifting. For explanation, see Fig. 3.

isometric training did not affect these relations in time.

The coefficient of correlation was calculated between the change of activity of the oblique abdominal muscles and the change in the IAP before and after training in each individual (Table II). We found no positive correlation between the two variables, except at one instance (leg lift B with 40 kg). Our conclusion was that an increase or decrease in the activity of the oblique abdominal muscles did not generally result in a rise or fall respectively of the IAP.

4. *Activity of erector spinae muscle*. The myoelectrical activity of the erector spinae muscle rose with increased weights during lifting. The same pattern was seen during lowering, though the differences were not significant between lifts with 10 and 25 kg.

There was no difference in the erector spinae activity after training. That applies to each type of lift, irrespective of technique and load and was seen in practically all 0.1 s phases of lifting and lowering (Fig. 8).

5. *Lifting time and patterns of movement*. The average lifting times for the different techniques and loads were 1.7–2.0 s before training and 1.4–1.7 s after training. The corresponding values of lowering were 1.9–2.2 s before, versus 1.5–1.9 s after training. This corresponded to an average reduction of 17% in lifting as well as lowering.

There were no systematic differences between the various lifting techniques or loads, but for the finding that the lifts with 40 kg lasted 0.1–0.2 s longer than the lifts with 10 and 25 kg.

By recording the knee angle during lifting before and after training, we found that the lifts in this respect were performed in the same way after training.

The general patterns of movement as judged from the average curves of activity and IAP showed very small differences after training, apart from the constant reduction in oblique abdominal muscle activity. The only change observed was somewhat smaller confidence limits of some variables in certain types of lifts, denoting a smaller inter-individual variation.

The tested techniques of lifting (back lift, leg lift A, leg lift B) presented, of course, different patterns of movement. This difference applies to back lifts versus leg lifts, while the two leg lifts were rather similar in our variables. The most important features of back lifts and leg lifts have been described previously for healthy subjects (12) and in relation to low-back patients (13), and it should only be mentioned here, that those findings were not affected by the training of the low-back patients.

DISCUSSION

Previous studies showed no effect of abdominal muscle training on IAP during lifting (12, 17) and no increase of oblique abdominal muscle activity after training, but a decrease (12). Subjects with low-back pain might, however, react differently on training, as they, according to some investigations (1, 20, 21), may have reduced abdominal muscle strength. They might also have another pattern of movement with another response to muscular training.

Our subjects were a selected group, not under medical care at the time, yet suffering from chronic low-back complaints for more than 5 years, on average. Their pain grew worse with increased lumbar load. They were all interested in taking part in the training program.

The training program

We used a common training method which has been shown to activate the external oblique muscles (6, 9, 10, 11, 22, 27) and the internal oblique muscles (27), beyond the rectus abdominis muscles. There are, so far, no studies on the activation of the transverse abdominal muscles.

According to Halpern & Bleck (11), our training procedure with curl-ups produces activity during 90% of the isotonic phases compared with 20–40% in the sit-ups. Ekholm et al. (6) compared the activity during the isometric phase of various curl-ups and two purely isometric exercises. They concluded that the supine hook-lying curl-up, as used in this study, elicited about the same activity (in percentage of maximum test) as the other methods except curl-ups with simultaneous trunk rotation which produced somewhat more activity.

Our subjects had to curl up until maximal effort and not to a specified angle between the trunk and the floor. This was supposed to increase the activity, according to our previous pilot study. The pelvis was not allowed to move. Simultaneous activation of the plantar–flexors of the ankle did not affect the activity of the abdominal muscles, either as increase or decrease (6). This element in our training program was introduced to inhibit the psoas major muscle, according to Janda (16), but needs further study (6).

The subjects were told to press the back against the floor and to contract the gluteal muscles, in order to stabilize the pelvis by a posterior pelvic tilt and perhaps to inhibit the iliopsoas muscle and the other hip flexors. From many records during training we found that the erector spinae muscles were mostly not or sometimes slightly activated in purely symmetric curl-ups. This agrees with Blackburn & Portney (2), who reported very slight activity in the paraspinal musculature on the Th6, L3 and S1 levels during curl-ups after posterior pelvic tilt (2–5% of maximum activity).

Ricci et al. (22) state that curl-ups and sit-ups, whether from a long-lying or a hook-lying position, start with an anterior pelvic tilt, hyperlordosis of the lumbar spine and hyperextension of the upper trunk. In response to pelvic rotation, the abdominal muscles should start the curl-up with an eccentric contraction, followed by a concentric and finally an isometric contraction. As for the gluteal activation when starting and the minimum of erector spinae activity when training, we may assume that our subjects mostly performed training with concentric and isometric contractions.

Our group thus trained their oblique abdominal muscles with one of the most efficient isometric training methods available (except for curl-ups with trunk rotation).

The training period was 5 weeks which should suffice for evaluating the gain of training (14).

Trunk flexion strength

The training gave a significant increase of the trunk flexion strength. The significant positive correlation between change of strength and change of EMG activity in the oblique abdominal muscles demonstrates that the latter muscles partly account for the increased flexor strength. It also indicates that the training has resulted in an improved recruitment of motor units during maximum effort.

The psoas major muscle should exert a rather small forward bending moment (1) or no such moment at all (8).

The increased strength measured may be due to augmented strength but also to an enhanced skill in the performance of the strength test, a 'motor learning' (15, 23, 26). Repeated tests of knee extension strength are reported to give significant increases between the first three weekly tests, after which the increases became less but yet considerable for the 5-week period as a whole (15, 23). Tornvall studied trunk flexion and trunk extension without other training during altogether 60 tests for 2½ months and found a great rise in test values (26). He noted that this rise was first manifest after 6–7 examinations. The question also arises if this frequent testing in reality meant training besides testing.

After being familiar with the equipment our subjects were asked to do three maximum strength tests and then, after 5 weeks, another three tests. Thus it appears that the tests after training reflect mainly the effect of training, which is supported by the fact that the load at training could be increased successively (Fig. 3).

Trunk extension strength

Our subjects activated their erector spinae muscles very little, if at all, during the training. Even if they omitted the posterior pelvic tilt, the erector spinae activity would not exceed 8–12% of maximum activity, according to Blackburn et al. (2). Thus it seems unlikely that the training might cause any notable increase in back muscle strength. This correlates with the lack of rise in EMG activity.

The observed increase in trunk extension strength (+12%) might be caused by technical faults due to variable positions of the trunk, earlier reported from isokinetic measuring of back muscle strength (25). In addition the rise in IAP might have influenced the test results.

Trunk flexion strength and trunk extension strength increased independently of each other. Those subjects who gained most in flexion might gain less in extension, and vice versa. The average extension/flexion ratio declined from 1.54 to 1.40, as expected.

Recordings during lifting

The most interesting approach when studying effects of training is not to look at the results of strength tests, but to find out how the subjects make use of their increased capacity in daily life activities. We chose to study lifts, as they are common in the construction industry, as they subject the low back to considerable loads and, finally, as they can be standardized fairly well.

We have previously reported (13) that these subjects with low-back pain had weaker abdominal muscles than another comparable group of healthy subjects. It would therefore be interesting to find out if they took advantage of their newly acquired ability of recruiting more motor units than before training.

The myoelectrical activity of the oblique abdominal muscles was, however, constantly reduced after training, irrespective of lifting techniques or weights of the burden. This implies that they utilized the metabolic effects of training on the muscle cells, so that a given muscular work could be performed with fewer motor units. The improved ability to recruit more motor units was, however, not used during lifting. This result agrees completely with our previous study on healthy subjets (12).

In the healthy subjects, we could find no correlation between the change in oblique abdominal muscle activity and the change in IAP after training. Furthermore, we could find no correlation between abdominal muscle strength and IAP at lifting (13). Subjects with and without low back complaints produced the same IAP when lifting, despite marked differences in abdominal muscle strength.

Against this background it is not surprising that our subjects with low-back complaints did not generally change their IAP when lifting even though they had trained isometric curl-ups intensely for 5 weeks. This agrees with our previous study in healthy subjects (12) and with Legg (17), who also trained healthy subjects but with another method (dynamic sit-ups).

Pain may influence muscle strength tests and IAP when lifting as well (7). In this study the painful strength tests were excluded and the few lifts with reported pain gave such inconsistent values that, on the whole, the influence of pain can be disregarded.

A great difference was found between the individuals as regards peak IAP during lifting, as also was the case for the healthy subjects (12). This cannot be explained by variations in levers of the load or body weight, but needs further study.

The activity of the erector spinae muscles was quite unaffected by the training. It was anticipated that the activity of the erector spinae muscles would be reduced in the case of increased IAP and vice versa, a phenomenon which was found in some instances in the two subjects who showed a marked increase in IAP after training. But, on the whole, the average activity is remarkably unchanged throughout the lifts (Fig. 8).

During lifting, a quite modest abdominal muscle activity is requried (13). Strengthening of these muscles seemed to have no effect during lifting and the pattern of activation was unaffected by the training. In contrast to this lack of effect on the IAP during lifting, there was a marked increase of IAP during the maximum strength tests. This implies that during maximal contractions an increase in muscle strength also causes an increase in IAP.

The IAP seems to be rather important in reducing the load on the lumbar spine. Schultz et al. (24) and Broberg (3) have from different measurements, calculated the relief of compression on the spine to lie between 4 and 30% and between 5 and 30% respectively (compared with zero pressure). The two determinations were made on static situations, but nevertheless tell us something about the magnitude of the relief. In addition, we need calculations on the effect of IAP in dynamic situations. It should, furthermore, be pointed out that there is a 'force balance' (3) between the abdominal muscles and the IAP, and that, accordingly, the IAP is necessary for the muscular stabilization of the trunk.

CONCLUSION

We have found that intense isometric abdominal muscle training did not generally affect the intra-abdominal pressure during lifting. During lifting, the oblique abdominal muscles are of minor importance for the IAP. Our findings might be explained by the fact that the pattern of movement in training is quite different from that during lifting.

REFERENCES

1. Alston, W., Carlson, K., Feldman, D., Grimm, Z. & Gerontinos, E.: A quantitative study of muscle factors in the chronic low back syndrome. J Am Ger Soc *14*: 1041–1047, 1966.
2. Blackburn, S. E. & Portney, L. G.: Electromyographic activity of back musculature during Williams' flexion exercises. Phys Therapy *61*: 878–885, 1981.
3. Broberg, K. B.: The mechanical behavior of the spinal system. Report from Division of Solid Mechanics, Lund Institute of Technology, Lund, Sweden, 1981.
4. Carlsöö, S.: A back and lift test. Applied Ergonomics *11*: 66–72, 1980.
5. Davies, B. T.: Moving loads manually. Applied Ergonomics *3*: 190–194, 1972.
6. Ekholm, J., Arborelius, U., Fahlcrantz, A., Larsson, A.-M. & Mattsson, G.: Activation of abdominal muscles during some physiotherapeutic exercises. Scand J Rehab Med *11*: 75–84, 1979.
7. Fairbank, J. C. T., O'Brien, J. P. & Davis, P. R.: Intra-abdominal pressure rise during weight lifting as an objective measure of low-back pain. Spine *5*: 179–184, 1980.
8. Farfan, H. F.: Mechanical Disorders of the Low Back. Lea & Febiger, Philadelphia, 1973.
9. Flint, M. M.: Abdominal muscle involvement during the performance of various forms of sit-up exercise. Am J Phys Med *44*: 224–234, 1965.
10. Flint, M. & Gudgell, J.: Electromyographic study of abdominal muscular activity during exercise. Am J Phys Med *36*: 29–37, 1965.
11. Halpern, A. A. & Bleck, E. E.: Sit-up exercises: An electromyographic study. Clin Orthop Relat Res *145*: 172–178, 1979.
12. Hemborg, B., Moritz, U., Hamberg, J., Löwing, H. & Åkesson, I.: Intra-abdominal pressure and trunk muscle activity during lifting—effect of abdominal muscle training in healthy subjects. Scand J Rehab Med *15*: 183–196, 1983.
13. Hemborg, B. & Moritz, U.: Intra-abdominal pressure and trunk muscle activity during lifting. II: Chronic low-back patients. Scand J Rehab Med *17*: 5–13, 1985.
14. Hislop, H. J.: Quantitative changes in human muscular strength during isometric exercises. J Am Phys Therap Assoc *43*: 21–38, 1963.
15. Hood, L. B. & Forward, E. M.: Strength variations in two determinations of maximal isometric contractions. J Am Phys Therap Assoc *45*: 1046–1053, 1965.
16. Janda, V.: Personal communication, 1975.
17. Legg, S. J.: The effect of abdominal muscle fatigue and training on the intra-abdominal pressure developed during lifting. Ergonomics *24*: 191–195, 1981.
18. Morris, J. M.: Biomechanics of the spine. Arch Surg *107*: 418–423, 1973.
19. Nachemson, A.: Towards a better understanding of low-back pain: A review of the mechanics of the lumbar disc. Rheumatol Rehabil *14*: 129–143, 1975.
20. Nachemson, A. & Lindh, M.: Measurement of abdominal and back muscle strength with and without low back pain. Scand J Rehab Med *1*: 60–65, 1969.
21. Nordgren, B., Schéle, R. & Linroth, K.: Evaluation and prediction of back pain during military field service. Scand J Rehab Med *12*: 1–8, 1980.
22. Ricci, B., Marchetti, M. & Figura, F.: Biomechanics of sit-up exercises. Med Sci Sports Exercise *13*: 54–59, 1981.
23. Schenck, J. M. & Forward, E. M.: Quantitative strength changes with test repetitions. J Am Phys Therap Assoc *45*: 562–569, 1965.
24. Schultz, A., Andersson, G., Örtengren, R., Haderspeck, K. & Nachemson, A.: Loads on the lumbar spine. J Bone Jt Surg *64-A*: 713–720, 1982.
25. Thorstensson, A. & Nilsson, J.: Trunk muscle strength during constant velocity movements. Scand J Rehab Med *14*: 61–68, 1982.
26. Tornvall, G.: Assessment of physical capabilities with special reference to the evaluation of maximal voluntary isometric muscle strength and maximal working capacity. Acta Physiol Scand *58*, suppl. *201*, 1963.
27. Walters, C. E. & Partridge, M. J.: Electromyographic study of the differential action of the abdominal muscles during exercise. Am J Phys Med *36*: 259–268, 1957.
28. Zachrisson-Forssell, M.: The back school. Spine *6*: 104–106, 1981.

Address for offprints:

Bertil Hemborg
Bygghälsan
Östra promenaden 7 B
S-211 28 Malmö
Sweden