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

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INTRA-ABDOMINAL PRESSURE AND TRUNK MUSCLE ACTIVITY DURING LIFTING

IV. The Cause Factors of the Intra-abdominal Pressure Rise
Bertil Henborg, Ulric Moritz and Harold Löwing

From the Construction Industry’s Organization for Working Environment, Safety and Health (Bygghållens), Malmö, and the Dept. Phys. Therapy, Lund University, Lund Sweden

ABSTRACT. The intra-abdominal pressure (IAP) has been regarded as important for stabilization and relief of the lumbar spine when exposed to heavy loads, such as when lifting. Previous trials, however, have failed to increase the IAP by abdominal muscle training. Twenty healthy subjects, 20 low-back patients and 10 weight-lifters, were tested with various breathing techniques in order to elucidate the causal factors of the IAP rise during lifting and the effects respiration. Those with high IAP and low IAP as well as those with great variations in IAP underwent an extended program. The intra-abdominal and intra-thoracic pressures and the EMG of the oblique abdominal, the erector spine and—in some cases—the psoas muscles, were recorded. The transdiaphragmatic pressure was calculated both during lifting and during the Mueller manoeuvre. The IAP rise during lifting seems to be correlated to a good coordination between the muscles surrounding the abdominal cavity. Of these, the diaphragm seems to be the most important for the IAP rise. Closure of the glottis seems to help the diaphragm to maintain the IAP rise, otherwise the respiration type seems to be less important for the IAP during lifting.

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

The intra-abdominal pressure (IAP) has been regarded as important for function of the lumbar spine. It is believed to stabilize the trunk and relieve the lumbar spine when carrying out heavy tasks, such as lifting (2, 4, 6, 7, 9, 10, 15, 16, 25, 26, 31, 36). As regards the building up of the IAP, interest has been focused on the anterior abdominal muscles which are thought to initiate the pressure rise, except for the rectus abdominis which remains inactive during lifting of small or moderate weights. Recent investigations (18, 20, 29) showed, however, that strengthening of the abdominal muscles did not generally affect the IAP during lifting. Moreover, the oblique abdominal muscles seemed to be of minor importance for the IAP in those situations (18, 20). Thus it seemed desirable to elucidate the factors responsible for the IAP during lifting, in order to find possible ways of preventing low-back pain.

The abdominal cavity, containing mainly liquid and solid material, is surrounded by muscles, anteriorly by the rectus abdominis, laterally by the external and internal oblique abdominal muscles and the transversus abdominis, above by the diaphragm and below by the muscles of the pelvic floor. The dome-shaped diaphragm divides the abdomen from the air-containing thorax. The transdiaphragmatic pressure difference (Pdi) reflects the tension and the position of the diaphragm and may be used to estimate the part played by the diaphragm in the lifting of the IAP.

When lifting heavy burdens, most people, even weightlifters, breathe in and hold their breath. However, there is no systematic studies on the effects of different breathing techniques on the intra-thoracic (ITP) and intra-abdominal (IAP) pressures and hence on the stability of the trunk during lifting.

The aim of this study was to analyse first the effects of respiration on the IAP during lifting, and secondly, the activation pattern of muscles possibly involved in the initiation and maintenance of the increased IAP during lifting.

MATERIAL
Fifty male volunteers took part in different sections of this study. Twenty subjects had no history of low-back pain, as previously described (18). Twenty subjects with chronic low-back pain were described in part II. The last 10 subjects were very skilled weightlifters, who had been training for 2–12 years (median value 6.5 years). Three of them were national champions in their own weight classes. Three weightlifters reported previous minor low-back complaints of short duration and 2 had intermittent low-back pain for 1–3 years, but not during the year before the examination. All the weightlifters generally

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used a leather belt for the heaviest training and at competi-
tions.

Table 1: The respiration recording system. The ultrasound
unit is located on the middle of the tube and the thermistor
in the distal opening. Note the spring-hanger on the nose
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Respiratory recording (Fig. 1)

A new flow-meter was constructed for recording the res-
spiratory flow without motion artefacts (Heng M, Minson, BN
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principle and consists of a tube, a mouthpiece, an ultra-
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Lifts were done with 'leg lifting' as well as 'back lifting'.
'Leg lifting' means symmetrical lifts with flexed knees and
the back as straight as possible. 'Back lifting' is used
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METHODS

Electrogoniographic recordings

For the oblique abdominal muscles and the erector spinae
muscle the myoelectrical activity was recorded by sur-
face electrodes for details, see part II.

In addition, 3 healthy subjects were supplied with wire
processors for the psoas muscle, that is insulated bipolar
fine-wire electrodes (Nikrota LK, 0.05 mm in
diameter) from which about 3 mm of the insulation was
burnt off in a flame. They were prepared according to
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needles, dorsolaterally from the anus, were pushed through
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<td>Weight (kg)</td>
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Fig. 1. The respiration recording system. The ultrasound unit is located on the middle of the thigh and the thermistor in the distal opening. Note the spring holder on the nose and the catheters for the pressure recordings.

Intra-abdominal and intrathoracic pressure recordings

The intra-abdominal (i.e. intra-gastric) pressure was recorded in all cases, and the intrathoracic (i.e. intra-oesophageal) pressure in the patients, the weightlifters and the 3 healthy subjects, mentioned above.

The pressures were recorded via an open polyethylene catheter fitted with saline and without a balloon, as previously described (18, 19). The three fine polyethylene catheters (Portex 100, internal diameter of 0.86 mm), fused distally, were passed through the nose to the upper part of the stomach. The pressure changes during respiration indicated when the opening at the lower end rested in the stomach, and the second opening 35 cm proximally rested in the oesophagus. The third catheter contained air and served only as a guide. The pressure curves were recorded simultaneously with the myoelectrical signals on the monitor and the tape, and the catheter was flushed with saline when necessary.

The pressure recording system was tested according to Ammosen, Linscheid & Ullsten (1). The rise time was found to be 0.005 s, the settling time 0.1 s and the over-shoot 26 % in repeated recordings, which was considered adequate for analysis of the frequencies occurring.

From X-ray pictures taken during pressure recordings we calculated the source of error due to the external location of the thermocouple and corrected the pressure values accordingly.

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Electro-myographic recordings

For the oblique abdominal muscles and the erecter spinae muscle the myo-electrical activity was recorded by surface electrodes for details, see part II.

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9. The patients and the weightlifters performed the Mueller manoeuvre (12, 34), before and after the
dominal muscle training mentioned above. On each occasion, three consecutive tests were performed. Af- ter an ordinary expiration, when the subject was sup- posed to be roughly at the position of functional resid- ual capacity (FRC), he was asked to perform a maxi- mum diaphragmatic inspiratory effort with the mouth and nose closed. Before this, the subjects had, during attempted inspiration, practiced pushing the abdominal wall outwards and avoiding rib cage expansion. The maximum transdiaphragmatic pressure (\(P_{Dmax}\)) during the Mueller manoeuvre was then compared with the peak IAP during lifting.

Fig. 2 summarizes the methodology used in this study. With the healthy subjects during moments 1, 2, and 4 and 5 the computer was omitted. Table II shows when the respiration system and the EMG of the pubococcygeus muscle were used.

Evaluation procedure, including statistical methods

Throughout the study all lifts were performed twice and the calculations were made from the mean values of these two lifts.

For the healthy subjects during moments 1, 2, 4, and 5 the signals were recorded with the Minograph. From these curves we calculated manually the peak IAP and the values of the integrated EMG during 0.3 s coincidently with the peak.

For the rest of the lifts, the analogue signals from the EMG of the oblique abdominal and the erector spine muscles, from the IAP and ITP, from the electromyometer and from the accelerometer were simultaneously recorded on magnetic tapes. The same applied to the EMG of the pubococcygeus muscle and the respiration recording, whenever applicable. All information was then fed into a computer where the myoelectrical signals were full-wave rectified and integrated over preset periods of 0.1 s, each containing 400 readings. The other signals were also aver- aged over the same periods of 0.1 s and converted digital. The registrations comprise the periods from 0.5 s before the lift-off to the end of the lifting and from the start of the lowering to 0.5 s after the touch-down.

During the Mueller manoeuvre we recorded the maxi- mum transdiaphragmatic pressure (\(P_{Dmax}\) = IAP – ITM).

Concerning moments 1, 2, 4, and 5, the design of the study was chosen to get a matching situation where each subject could be compared with himself while performing a certain lift with and without modification. Here the analysis of significance was performed with the IAP and EMG values according to Student's t-test, and the strength of covariance was determined by Pearson's correlation coefficient, r. This also applies to moments 1 and 5 as regards the calculations.

Concerning moments 1, 2, 4, and 5, the analysis of significance was extended and carried out throughout the whole lifting procedure by calculating the 95% confidence limits of the mean difference between values with and without modification of the lift. As the time varied between lifts, the time was then normalized and expressed as a percent- age of the whole time, and for lifting and lowering sepa- rately, it runs from 0 to 100%.

RESULTS

Effects of breath holding after maximal inspiration

Maximal inspiration before, followed by breath holding during lifting, did not affect any of the three parameters, either the peak IAP or the myoelectric- al activities of the oblique abdominal muscles and the erector spine muscle during 0.3 s coincidently with the peak (Fig. 3).

The average lifting times varied very little, 0.06 s out of the average lifting times of 1.76-1.94 s. The same applied to the times when the IAP and the myoelectrical activities of the oblique abdominal, and the erector spine reached their highest values during the lifts.

Effects of breath holding after maximal expiration

Fig. 3 shows that this type of breath holding did not affect any of the three parameters significantly. Neither the total lifting times, nor the times of peak values were influenced materially.

Effects of breathing out during lifting

The intra-abdominal pressure decreased significant- ly during 30% of the lift time with leg lifting of 25 kg. In all other instances with 10, 25, and 40 kg, lifting as well as lowering, there were no significant changes with-in lift.

The intrathoracic pressure decreased significant- ly during lifting and lowering with 40 kg, both leg lifting and back lifting. The average differences were 3.4 kPa. For the lifts of 10 and 25 kg there were no significant changes, but a tendency to- wards lower values in some instances.

The myoelectric activity of the oblique abduminal muscles increased significantly during the last phase of lifting with 25 kg (leg lifts and back lifts), but otherwise there was no change in any instance. The myoelectrical activity of the erector spinous muscle was quite unaffected in all instances, lifting or lowering, leg lifting or back lifting, irrespective of the weight of the burden. The patterns of activation, as reflected by the average curves, were quite unaffected by expiration.

Effects of facilitation

The next question is whether the proposed facilita- tion manoeuvre adds anything to the above. These lifts were examined by the same methods as moments 1 and 2.

Fig. 3 shows that the peak IAP was quite unaffect- ed in all instances. The average activity of the oblique abdominal muscles was significantly in- creased with back lifting 25 kg, but in all other instances the muscular activity around the peak IAP was not significantly affected.

The average lifting times were not significantly changed by the facilitation technique, which was easy to learn and use. Nor did the times for the maximum IAP and myoelectrical activity after markedly.

Natural breathing during lifting

In 160 lifts by both patients and weightlifters we recorded the subjects' natural breathing. After fa- miliarizing themselves with the apparatus, that forced them to breathe through the mouth but of- fered no noticeable resistance, they were asked to lift in their usual manner.

Table III shows how the two groups breathed natu- rally. For 20-45% of the cycles they held their breath. For the rest of the cycles they seemed most common to exhale when lifting and inhale when lowering. Some started by holding their breath and then changed to breathing in or out during move- ments; others began to inhale or exhale before lift- ing or lowering. The weightlifters often seemed to take deeper breaths than patients.

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dominal muscle training mentioned above. On each occasion, three consecutive tests were performed. After an ordinary expiration, when the subject was sup- posed to be roughly at the position of functional residual capacity (FRC), he was asked to perform a maximum diaphragmatic inspiratory effort with the mouth and nose closed. Before this, the subjects had, during attainment inspiration, practiced pushing the abdominal wall outwards and avoiding rib cage expansion. The maximum transdiaphragmatic pressure ($P_{Dmax}$) during the Mueller manoeuvre was then compared with the peak IAP during lifting.

Fig. 2 summarizes the methodology used in this study. With the healthy subjects in moments 1, 2, 4, and 5 the computer was omitted. Table II shows when the respiration system and the system for the subject were used.

Fig. 3: Schematic view of the methods used in this study. For details, see text. A. Pressure recording system; B. EMG recording system; C. respiration recording unit; D. electrogoniometer; E. video camera.

Concerning moments 7 and 8, each separate lift was plotted to determine the mutual relationship between the parameters in case. The time was normalized here too, as described above.

**RESULTS**

**Effects of breath holding after maximal inspiration**

Maximal inspiration before, followed by breath holding during lifting, did not affect any of the three parameters, either the peak IAP or the myoelectrical activities of the oblique abdominal muscles and the rectus spinae muscle during 0.3 s coincidental- ly with the peak (Fig. 3).

The average lifting times varied very little, 0.06 s out of the average lifting times of 1.78-1.94 s. The same applied to the times when the IAP and the myoelectrical activities of the oblique abdominal muscles, and the rectus spinae reached their highest values during the lifts.

**Effects of breath holding after maximal expiration**

Fig. 3 shows that this type of breath holding did not affect any of the three parameters significantly. Neither the total lifting times, nor the times of peak values were influenced materially.

**Effects of breathing out during lifting**

The intra-abdominal pressure decreased significantly during 30% of the lift time with leg lifting of 25 kg. When lifting and back lifting. The average differences were 3.4 kPa. For the lifts of 10 and 25 kg there were no significant changes, but a tendency towards lower values in some instances.

The myoelectrical activity of the oblique abdominal muscles increased significantly during the last phase of lifting with 25 kg (leg lifts and back lifts), but otherwise there was no change in any instance. The myoelectrical activity of the erector spinae muscle was quite unaffected in all instances, lifting or lowering, leg lifting or back lifting, irrespective of the weight of the burden. The patterns of activation, as reflected by the average curves, were quite unaffected by expiration.

**Effects of facilitation**

The next question is whether the proposed facilitation manoeuvre adds anything to the above. These lifts were examined by the same methods as moments 1 and 2.

Fig. 3 shows that the peak IAP was quite unaffected in all instances. The average activity of the oblique abdominal muscles was significantly in- creased with back lifting 25 kg, but in all other instances the muscular activity around the peak IAP was not significantly affected.

The average lifting times were not significantly changed by the facilitation technique, which was easy to learn and use. Nor did the times for the maximum IAP and myoelectrical activity after markedly.

**Natural breathing during lifting**

In 160 lifts by both patients and weightlifters we recorded the subjects’ natural breathing. After familiarizing themselves with the apparatus, that forced them to breathe through the mouth but offered no noticeable resistance, they were asked to lift in their usual manner.

Table III shows how the two groups breathed naturally. For 20-45% of the cycles they held their breath. For the rest of the cycles they seemed most commonly to exhale when lifting and inhale when lowering. Sometimes by holding their breath and then changed to breathing in or out during moving; others began to inhale or exhale before lifting or lowering. The weightlifters often seemed to take deeper breaths than patients. The myoelectrical activity of the oblique abdominal muscles during lifting is inconsistent with a positive intraabdominal pressure.
Table III. Natural breathing during lifting and lowering, expressed as volume of air passed through the respiratory tube from the lift-off to the end of lifting and from the start of lowering to the touch-down; number of lifts within parentheses

<table>
<thead>
<tr>
<th>Lifting (%)</th>
<th>Lowering (%)</th>
<th>Lifting (%)</th>
<th>Lowering (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 kg</td>
<td></td>
<td>40 kg</td>
<td></td>
</tr>
<tr>
<td>Volume of air:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.001 litres</td>
<td>45</td>
<td>36</td>
<td>27</td>
</tr>
<tr>
<td>inhalation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1–0.81</td>
<td>17</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>&gt;=0.81</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Exhalation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1–0.81</td>
<td>38</td>
<td>14</td>
<td>62</td>
</tr>
<tr>
<td>&gt;=0.81</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Total 100 (99) 100 (50) 100 (56) 100 (40)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* In a few isolated cases the subjects breathed in and out a little during the lifting or lowering. The table then shows the net volume of air passing the tube.

The Mueller manoeuvre

The patients could produce an average maximal transdiaphragmatic pressure of 10.4 kPa (SD = 4.23) and the weightlifters 8.3 kPa (SD = 4.09). The test showed fairly good reproducibility in repeated trials with the same subject (SD = 1.88 and 2.27 kPa respectively for the patients and the weightlifters). The Mueller manoeuvre is regarded as a test of the strength of the diaphragm (12, 34), and it was therefore interesting to try to correlate the value of the P_dia, and the peak IAP during different lifts. Table IV shows that for the patients there was a positive correlation, significant in nine out of twelve instances. For the weightlifters we could find no correlation in any of the lifts with 25 and 40 kg.

Building up of intra-abdominal pressure during lifting

The lifts noted under moments 7 and 8 in Table II we tried to analyse the possible effects on the IAP of the different muscles surrounding the abdominal cavity. This is complicated by the possibility that the muscles may well contract so as to increase the pressure but may also contract due to an increased pressure from within. We then have to consider the timing of the different activities during lifting.

The activity of the diaphragm can be judged by following the transdiaphragmatic pressure difference.

From about 40 graphs illustrating lifts with 25, 40, and 55 kg by the three groups, we tried to analyse the interplay between the diaphragm, the oblique abdominal muscles, and the puborectalis muscle during lifting, and the relationship between them and the IAP.

Fig. 4 shows three different subjects doing the same lift with different patterns. Figs. 5 and 6 each show a pair of graphs from one subject lifting the same load before and after abdominal muscle training with the same technique but with different muscular responses and pressures. The results of the analysis may be summarized as follows.

(a) The important function of the diaphragm is reflected by the close correlation between the transdiaphragmatic pressure difference (P_dia) and the peak IAP during lifting (Table V). This correlation could also be shown throughout the lift in many instances, as can be seen in Figs. 4 (subject A), 5a, and 6b.

(b) The oblique abdominal muscles. The myoelectrical activity showed that they were regularly activated during lifting. The activity rose somewhat simultaneously with the pressure rise (Figs. 5b, 6b), sometimes without any pressure response (Fig. 5a).

(c) The puborectalis muscle. The myoelectrical activity showed that it was regularly activated during lifting (Fig. 4), but the rise in activity varied among the three subjects. In subject B the rise in activi-
Table III. Natural breathing during lifting and lowering, expressed as volume of air passed through the respiratory tube from the lift-off to the end of lifting and from the start of lowering to the touch-down: number of lifts within parentheses

<table>
<thead>
<tr>
<th>Volume of air</th>
<th>Lifting (%)</th>
<th>Lowering (%)</th>
<th>Lifting (%)</th>
<th>Lowering (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.1 litres</td>
<td>45</td>
<td>36</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>0.1-0.8 P</td>
<td>17</td>
<td>30</td>
<td>0</td>
<td>47</td>
</tr>
<tr>
<td>0.8-1.0 P</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>&gt;1.0 P</td>
<td>38</td>
<td>14</td>
<td>62</td>
<td>20</td>
</tr>
</tbody>
</table>

* In a few isolated cases the subjects breathed in and out a little during the lifting or lowering. The table then shows the net volume of air passing the tube.

For both patients and weightlifters who breathed during lifting, there was no definite correlation between the breathing volumes and the intrathoracic pressure. Nor was there any significant correlation between the breathing volumes and the peak intra-abdominal pressures, either for the patients or for the weightlifters.

The Mueller manoeuvre

The patients could produce an average maximal transdiaphragmatic pressure of 10.4 kPa (SD=4.23) and the weightlifters 8.3 kPa (SD=4.09). The test showed fairly good reproducibility in repeated trials with the same subject (SD=1.88 and 2.27 kPa respectively for the patients and the weightlifters). The Mueller manoeuvre is regarded as a test of the strength of the diaphragm (12, 34), and it was therefore interesting to try to correlate the strength of the diaphragm (Pmax) with the peak IAP during different lifts. Table IV shows that for the patients there was a positive correlation, significant in nine out of twelve instances. For the weightlifters we could find no correlation in any of the lifts with 25 and 40 kg.

Building up of intra-abdominal pressure during lifting

From the lifts noted under moments 7 and 8 in Table II we tried to analyse the possible effects on

![Graph showing intrathoracic and abdominal pressures during lifting and lowering.](image)

**Table IV.** Correlation between the maximum transdiaphragmatic pressure (P_dia) during Mueller manoeuvre and the maximum intra-abdominal pressure (peak IAP) during lifting

<table>
<thead>
<tr>
<th>Lifting technique</th>
<th>Weight (kg)</th>
<th>Patients Lifting</th>
<th>Lowering</th>
<th>Weightlifters Lifting</th>
<th>Lowering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td>Leg lifting</td>
<td>10</td>
<td>0.45&lt;0.05</td>
<td>0.49&lt;0.05</td>
<td>-0.28 NS</td>
<td>-0.31 NS</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.52&lt;0.05</td>
<td>0.52&lt;0.05</td>
<td>-0.36 NS</td>
<td>-0.54 NS</td>
</tr>
<tr>
<td>Back lifting</td>
<td>10</td>
<td>0.35 NS</td>
<td>0.38 NS</td>
<td>-0.07 NS</td>
<td>-0.09 NS</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.36&lt;0.01</td>
<td>0.30&lt;0.05</td>
<td>-0.07 NS</td>
<td>-0.09 NS</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>0.41&lt;0.01</td>
<td>0.60&lt;0.01</td>
<td>-0.07 NS</td>
<td>-0.09 NS</td>
</tr>
</tbody>
</table>

The IAP of the different muscles surrounding the abdominal cavity. This is complicated by the possibility that the muscles may well contract so as to increase the pressure but may also contract due to an increased pressure from within. We then have to consider the timing of the different activities during lifting.

The activity of the diaphragm can be judged by the transdiaphragmatic pressure difference.

From about 40 graphs illustrating lifts with 25, 40, and 55 kg by the three groups, we tried to analyse the interplay between the diaphragm, the oblique abdominal muscles, and the pubococcygeus muscle during lifting, and the relationship between them and the IAP.

Fig. 4 shows three different subjects doing the same lift with different patterns. Figs. 5 and 6 each show a pair of graphs from one subject lifting the same load before and after abdominal muscle training.

**Table V.** Relation between peak IAP during lifting and the co-incident transdiaphragmatic pressure difference (P_dia)

<table>
<thead>
<tr>
<th>Lifting technique</th>
<th>Weight (kg)</th>
<th>Patients Lifting</th>
<th>Lowering</th>
<th>Weightlifters Lifting</th>
<th>Lowering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td>Leg lifting</td>
<td>25</td>
<td>0.90&lt;0.0001</td>
<td>0.82&lt;0.0001</td>
<td>0.97&lt;0.001</td>
<td>0.92&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>0.90&lt;0.0001</td>
<td>0.84&lt;0.0001</td>
<td>0.91&lt;0.001</td>
<td>0.95&lt;0.001</td>
</tr>
<tr>
<td>Back lifting</td>
<td>25</td>
<td>0.85&lt;0.0001</td>
<td>0.85&lt;0.0001</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>0.91&lt;0.0001</td>
<td>0.88&lt;0.0001</td>
<td>0.97&lt;0.001</td>
<td>0.86&lt;0.001</td>
</tr>
</tbody>
</table>
Fig. 5. Patient D lifting 40 kg with leg lift before (a) and after (b) 5 weeks of isometric abdominal muscle training. T denotes the lift-off. Prior to that point is 0.5 s in absolute values, while the lifting time is normalized and expressed in percentages of the whole time (from 0 to 100%). IAP, ITP and Pab are expressed in absolute values (left scale). EMG activity is expressed in percentages (right scale) of the highest value registered at any of the four lifts performed by the same subject with the same technique and with the same weight. The activity level is thus comparable between Fig. 3a and b. IAP: ⬤ •, EMG abd. m.: ⬤ — ⬤, ITP: ▲ • ▲, EMG rectus spine m.:  ● — ●, Pab: ○ — ○. Acceleration of the box ⬤ — ⬤ (second right scale).

Fig. 6. Weightlifter F lifting 55 kg with leg lift before (a) and after (b) 5 weeks of isometric abdominal muscle training. For explanation, see Fig. 5.

During lifts of 25 kg, despite the facts that the lift was otherwise unchanged and the acceleration of the box was reduced. When subject A was asked to lift while contracting the pelvic floor muscles deliberately, he increased the activity of the oblique abdominal muscles instead and the peak IAP rose from 8.5 to 11.7 kPa. Subject C, on the other hand, activated both the puborectalis and the oblique abdominal muscles, but there was no increase in the IAP.

It should also be mentioned that there was no detectable activity at rest, whether standing or sitting (sensitivity 125–250 μV/cm). This was also usually true for the instances when the subjects were standing upright with the load in front of the body. On the other hand, the muscle was always activated during trunk muscle strength tests and during the Valsalva and the Mueller manoeuvres.

(d) The intrathoracic pressure showed great individual variations (Fig. 7). The pressure was negative throughout the lift, gradually rising from negative to positive values during the lift, or positive throughout the lifting procedure.

The graphs in Fig. 4 show that subjects A and C produced about the same negative ITP throughout the lifts, while subject B had an elevated and posi-
ty coincided with the lift-off, and the pressure rose early in the lifting. In subject A the rise of activity came after 10% of the lifting time, and the pressure rose gradually during the first 50% of the lifting time. In subject C there was a rather weak activity and only a small pressure rise. During lowering, the activity was generally lower than during lifting.

When asked to contract the pelvic floor muscles deliberately during lifting, the 3 subjects differed in activity. Subject B increased his previously high activity and his peak IAP rose from 7.4 to 18.6 kPa during lifts of 25 kg, despite the facts that the lift was otherwise unchanged and the acceleration of the box was reduced. When subject A was asked to lift while contracting the pelvic floor muscles deliberately, he increased the activity of the oblique abdominal muscles instead and the peak IAP rose from 8.5 to 11.7 kPa. Subject C, on the other hand, activated both the puborectalis and the oblique abdominal muscles, but there was no increase in the IAP.

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The graphs in Fig. 4 show that subjects A and C produced about the same negative ITP throughout the lifts, while subject B had an elevated and posi-
Intra-abdominal pressure and trunk muscle activity during lifting. IV

The following physiological formulas should be considered:

1. \( ITP = P_{ac}-P_{ba} \)
2. \( ITP = P_{ac} \) is pressure within the oesophagus
3. \( P_{ac} \) is the pressure within the aortic and tracheal segment
4. \( P_{ac} + P_{ba} \) is lung recoil pressure
5. \( P_{ac} \) is equal to the pressure in the open air when the glottis are open, except for the small variations of \( \pm 0.1-0.2 \) kPa during natural breathing
6. \( P_{ac} \) is dependent on the air volume within the lungs, varying between about 4 kPa after maximal inhalation to about 0.5 kPa after maximal expiration
7. \( P_{ac} \) is the pressure in the oesophagus (ITP) and is equal to the pleural pressure on the same level.
8. There is a small vertical pressure gradient with increasing values downwards.
9. The gradient amounts to about 0.4 kPa between the upper and lower parts of the oesophagus.
10. \( P_{ac} \) = IAP-ITP (2/3R (Laplace Law))
11. \( P_{ac} \) = transdiaphragmatic pressure difference
12. \( T = \) tension (active or passive) in the diaphragm
13. \( R = \) radius of curvature of the diaphragm
14. In this context IAP should actually be measured just below the diaphragm instead of the stomach and the ITP close above the diaphragm.
15. The error of \( P_{ac} \) due to the methods of measurement, maximally about 1 kPa, varied in all the subjects in the same way according to the trunk position and was disregarded.
16. \( P_{ac} \) is zero when the diaphragm is relaxed and rises with increased tension of the diaphragm, whether due to active contraction or passive stretching (8).
17. Grassino et al. (14) found a curvilinear relationship between \( P_{ac} \) and the EMG of the diaphragm during static contractions.
18. Sears et al. (33) found a nearly linear relationship between \( P_{ac} \) and the EMG of the diaphragm during Mueller manoeuvre.
19. The average variation of \( P_{ac} \) during quiet breathing in the standing position was 0.85 kPa for men, according to Gilbert (33).
20. The Laplace Law, these variations may, of course, be attributed both to varying tension and to varying radius. It should also be considered that the diaphragmatic muscle obeys the force-length relationship and produces a higher tension when elongated than when flattened.

The different respiratory steps in this study did not affect the IAP significantly in any instance, though the oblique abdominal muscles were more activated in some lifts during expiration, with or without facilitation. This might seem surprising, as everybody knows that one should inhale before lifting heavy burdens. The main point, however, is not the phase of respiration, but the closure of the airways, preferably by closing the glottis. This enables us to build up a positive ITP which will support the diaphragm from above and thus diminish the demands on that muscle, by reducing the \( P_{ac} \). In other words, if the glottis is closed, a higher IAP may be possible with less effort from the diaphragm. This was done spontaneously by many patients (those with positive ITP in Fig. 7) and was even more common among the weightlifters, especially when they did real lifts with a barbell (22).

Compton et al. (5) recorded intrathoracic pressures up to 34.6 kPa among two weightlifters performing the "clean and jerk" and investigated the circulatory effects.

When lifting during expiration the abdominal muscle activity increased, which may be due to these muscles' respiratory function especially towards the end of expiration. The activity did not affect the IAP, however, either with or without facilitation.

\( P_{ac} \) during maximal diaphragmatic effort, i.e. the Mueller manoeuvre, was found to be fairly well correlated to the peak IAP during lifting in the patients but not in the weightlifters. In both groups, there was, however, a very good correlation between...
Intra-abdominal pressure and trunk muscle activity during lifting. IV

The following physiological formulas should be considered:

1. $\text{ITP} = P_{aw} - P_a$
   
   $P_{aw}$ is pressure within the osseous
   
   $P_a$ = pressure within the alveolar
   
   $P_a$ = lung recoil pressure

   $P_{aw}$, is equal to the pressure in the open air
   
   when the glottis are open, except for the small variations of $\pm 0.1$ to $0.2$ kPa
   
   during natural breathing $P_a$ is dependent on the
   
   air volume within the lungs, varying between about 4 kPa after maximal inhalation to about
   
   0.5 kPa after maximal expiration.

   The pressure within the osseous (ITP) is equal to the pleural pressure on the same level.

   There is a small vertical pressure gradient with increasing values downwards. The gradient
   
   amounts to about 0.4 kPa between the upper and
   
   lower parts of the osseous (55).

2. $P_a = 1/P - \text{ITP} = (2/T)R$ (Laplace Law)

   $R = \pi$ in the curvature of the diaphragm

   In this context IAP should actually be measured just below the diaphragm instead of
   
   under the stomach and ITP close above the diaphragm.

   The error of $P_a$ due to the methods of measurement,
   
   maximally about 1 kPa, varied in all the
   
   subjects in the same way according to the
   
   trunk position and was disregarded.

   $P_a$ = zero when the diaphragm is relaxed and
   
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   whether due to active contraction or passive
   
   stretching (8). Grassino et al. (14) found a curvilinear relationship between $P_a$ and
   
   the EMG of the diaphragm during static contractions. Sears

   et al. (33) found a nearly linear relationship
   
   between $P_a$ and the EMG of the diaphragm during
   
   Mueller manoeuvre. The average variation of $P_a$

   during quiet breathing in the standing position
   
   was $0.85$ kPa for men, according to Gilbert
   
   (33). By the Laplace Law, these variations may,
   
   of course, be attributed both to varying tension
   
   and to varying radius. It should also be consid-

   ered that the diaphragmatic muscle obeys the
   
   force-length relationship and produces a higher tension
   
   when elongated than when flattened.

3. The abdominal cavity contains mainly fluid and
   
   semifluid material and is thus practically incom-
   
   pressible, except for the small amounts of gas
   
   that may occur in the stomach and the colon.

   The walls are flexible, and a muscular

   contraction somewhere will result in a protrusion some-

   where else, if possible; otherwise the pressure

   will rise quickly.

4. There is always a ‘force balance’ (4) between the
   
   intra-abdominal pressure and the tensile forces
   
   in the abdominal wall, equal to the Laplace law
   
   for the diaphragm. This means that a rise of IAP

   will necessarily be resisted by an increased ten-

   sion, active or passive, in the wall and/or a

   a reduced radius of the curvature of the abdominal

   wall and the pelvic floor.

Respiration

The different respiration steps in this study did not affect the IAP significantly in any instance, though the oblique abdominal muscles were more activat-

ed in some lifts during expiration, with or without facilitation. This might seem surprising, as everybody knows that one should inhale before lifting heavy burdens. The main point, however, is not the phase of inspiration, but the closure of the airways, preferentially by closing the glottis. This enables us to build up a positive ITP which will support the diaphragm from above and thus diminish the demands

on that muscle, by reducing the $P_a$. In other

words, if the glottis is closed, a higher IAP may be

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When lifting during expiration the abdominal

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facilitation.

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correlated to the peak IAP during lifting in the

patients but not in the weightlifters. In both groups,

there was, however, a very good correlation be-
The building up of the IAP

As for the interplay between the muscles lining the abdominal 'ball', it should first be mentioned that there are obviously several ways of doing the same thing. For example, A was a 'high pressure' subject with a pretty good co-ordination between the dia-
 phragm, the oblique abdominal, and the psoas ma-
 lus muscles, and an ability of the diaphragm to
create a high Pdi. Subject B was 'expert' at activat-
ing the psoas muscle, which seemed to be the
prime mover, while the diaphragm could not res-
tend to the IAP but gave way. As he had obvi-
ously closed his glottis, the ITP increased and
thus the whole trunk was pressurized. Subject C
started with a fairly active abdominal muscle but there was only a small peak IAP. Something is lacking, pro-
ably the co-ordination, perhaps the capacity of the
diaphragm.

Secondly, we may conclude from Figs. 5-6, that it is possible to influence the mechanism of the IAP
rise, although previous studies (18, 20, 29) have
demonstrated that it cannot generally be accomplished by
abdominal muscle training. We cannot say, why this
was the case in Subject B. Successful training
was probably because the co-ordination was
improved (Figs. 5, 6, 5a). Perhaps a pre-programmed
exercise is needed to improve the IAP, but
probably not. The co-ordination before the lift-off
seems to have improved (Figs. 5, 6a).

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tween the peak IAP and the P_{muc} during lifting. Thus it seemed as though the weightlifters did not use the capacity of their diaphragms wholly.

The building up of the IAP

For the interplay between the muscles lining the abdominal "ball", it should first be mentioned that there are obviously several ways of doing the same lift (Fig. 4). In addition, A was a "high pressure" with a pretty good co-ordination between the diaphragm, the oblique abdominal, and the pectoral muscles, and an ability of the diaphragm to create a high P_{muc}. Subject B was "expert" at activating the pectoral muscles, which seemed to be the prime mover, while the diaphragm could not respond to the IAP but gave way. As he had obviously closed his glottis, the ITP increased and thus the whole trunk was pressurized. Subject C started with a fairly active abdominal muscle but there was only a small peak IAP. Something is lacking, probably the co-ordination, perhaps the capacity of the diaphragm.

Secondly, we may conclude from Figs. 5-6, that it is possible to influence the mechanism of the IAP rise, although previous studies (18, 20, 29) have shown, that it cannot generally be accomplished by abdominal muscle training. We cannot say, why the two subjects in Figs. 5-6 managed to increase the IAP, but probably how. The co-ordination before the lift-off seemed to have improved (Figs. 5-6, 6b). Perhaps a re-programming after having performed a great many lifts in our laboratory? Fig. 6a shows that a high activity of the oblique abdominal muscles alone does not suffice.

As regards the transverse abdominal muscle, we do not know anything about its activity during lifting. Due to the direction of its muscle fibres, it should be useful for pressurization without giving any bending moment or spinal compression.

It should be pointed out that the activity of the erector spine muscle is reduced in Fig. 6b compared with Fig. 6a during the phase when the IAP is elevated. This was seen in a fairly large number of comparable lifts, and might indicate that the load on the erector spine muscle was reduced when the IAP increased.

Lastly, the two pairs of graphs in Figs. 5 and 6, gave about the same shape of the acceleration curve for each couple. Nor could we find any differences, when, for each couple, we made comparisons of the curves from the electromyogram or of the one-sided activation of that muscle is not sufficient for an IAP-rise during lifting. The few recordings of the pelvic floor muscle suggest that this muscle may be fairly important for the rise of IAP. The transversus abdominis muscle is probably of some importance, but we lack information about it. If the diaphragm is too weak to withstand the pressure from below, activation of the erector spinae seems to help to maintain the IAP rise. Otherwise the type of respiration seems to be less important.

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EARLY REHABILITATION FOLLOWING OSTEOSYNTHESIS WITH THE SLIDING HIP SCREW FOR TROCHANTERIC FRACTURES

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ABSTRACT. A prospective study of 104 patients with trochanteric hip fractures was undertaken with particular regard to postoperative complications and rehabilitation at the follow-up 3 months later. The mortality was 29%. The injuries were divided into stable and unstable fractures. The patients were classified into four groups according to their dependence on the social welfare system.

Among the devices available for internal fixation of trochanteric hip fractures, the sliding screw-plate has gained considerable acceptance in the treatment of both stable and unstable fractures (6, 9, 11).

The literature concerning the treatment of extra-capsular hip fractures is comprehensive. However, few studies have dealt with the early postoperative complications and social rehabilitation, and when the present study was designed, no prospective study had been published concerning the sliding screw method.

The purpose of this paper was to elucidate the technical failures and the clinical complications as well as the social rehabilitation within the first 3 months postoperatively in patients treated with the Richards sliding screw-plate system for trochanteric hip fractures.

MATERIAL AND METHODS

The series included 104 consecutive patients with trochanteric hip fractures admitted to the hospital during the period January 1, 1981, to December 31, 1982. Seventy-four were women with a mean age of 78 years, and 30-96) and 29 men with a mean age of 73 years (range 36-96). The fractures were divided into stable and unstable according to Jansen (14).

Postoperatively, early weight bearing within 5 days was emphasized unless the fracture was severely comminuted. The patients were followed radiographically and clinically for 3 months. All X-rays were evaluated by the authors.

Technical failure was defined as any complicating fracture, bending, breakage of the implant or dislocation of the implant in relation to the bone. Telescoping of the screw was recorded.

On admission to the hospital and after 3 months the patients were assessed and classified into four social function groups according to their dependence on the social welfare system (21). The ability to walk prior to the fracture and at the follow-up at 3 months was recorded as well as the pain and postoperative movement of the hip.

The results were classified into four groups using the Stinchfield hip fracture classification (20).

RESULTS

Associated diseases at the admission were common (Table 1) and associated fractures occurred in 10% (10/104) of the patients.

Twenty-one of the patients died within 3 months after the operation; causes of death are listed in Table 1. Thus 83 patients (83 fractures) were followed for 3 months. Of these, 26 fractures were classified as stable and 57 as unstable.

The clinical postoperative complications are listed in Table III, the most frequent being a cardiovascular or pulmonary nature. Deep infection occurred in 2 patients (2%). However, the implant was not removed and the fractures healed.

Technical failures were encountered in 8 cases (10%), all among unstable fractures. Varus dislocation, being the most frequent (5 cases), was always combined with cutting of the screw in an osteoporotic femoral head. In 3 cases the telescoping action of the sliding screw failed, and was followed by a slight penetration of the femoral head, but without