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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) To investigate intra-thoracic pressure (ITP) and intra-abdominal pressure (IAP) during lifting and jumping, 11 males were monitored as they performed the dead lift (DL), slide row (SR), leg press (LP), bench press (BP) and box lift (BL), at 50, 75, and 100% of each subject's 4-repetition maximum, the vertical jump (VJ), drop-jump (DJ) from 0.5 and 1.0 meter heights, and Valsalva maneuver (VM). Measurements were made of peak pressure, time from pressure rise to switch-marked initiation of body movement (TRISE), and time from the movement to peak pressure (TPEAK). The highest ITP and IAP occurred during VM (22.2+6.0 and 26.6+6.7 kPa		

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In ascending order of peak ITP during the highest resistance sets, the activities were SR, BP, VJ, DJ, DL, BL, LP and VM, while the order for IAP was BP, VJ, DJ, BL, DL, LP, SR and VM. Pressures significantly ($P < .05$) increased with amount of weight lifted and rose before but peaked after the weight moved. IAP rose earlier and was of greater magnitude than ITP. For the jumps, pressure rose and diminished before the feet lost contact with the ground. Drop-jump height did not affect pressure. Correlation of pressure with weight lifted was fair to good for most activities.

DISCLAIMERS

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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SCIENTIFIC PAPER

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Intra-abdominal and intra-thoracic pressures during lifting and jumping

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Abdominal and thoracic pressures during lifting and jumping

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Intra-abdominal and intra-thoracic pressures during lifting and jumping

ABSTRACT

To investigate intra-thoracic pressure (ITP) and intra-abdominal pressure (IAP) during lifting and jumping, 11 males were monitored as they performed the dead lift (DL), slide row (SR), leg press (LP), bench press (BP) and box lift (BL), at 50, 75 and 100% of each subject's 4-repetition maximum, the vertical jump (VJ), drop-jump (DJ) from 0.5 and 1.0 meter heights, and Valsalva maneuver (VM). Measurements were made of peak pressure, time from pressure rise to switch-marked initiation of body movement (TRISE), and time from the movement to peak pressure (TPEAK). The highest ITP and IAP occurred during VM (22.2[±]6.0 and 26.6[±]6.7 kPa respectively) with one individual reaching 36.9 kPa (277 mmHg) IAP. In ascending order of peak ITP during the highest resistance sets, the activities were SR, BP, VJ, DJ, DL, BL, LP and VM, while the order for IAP was BP, VJ, DJ, BL, DL, LP, SR and VM. Pressures significantly ($P < .05$) increased with amount of weight lifted and rose before but peaked after the weight moved. IAP rose earlier and was of greater magnitude than ITP. For the jumps, pressure rose and diminished before the feet lost contact with the ground. Drop-jump height did not affect pressure. Correlation of pressure with weight lifted was fair to good for most activities.

ESOPHAGEAL, DIAPHRAGM, RESPIRATORY MECHANICS

INTRODUCTION

Mathematical models of lifting activities, based on simplifying assumptions about anatomical structure, have been developed for estimation of compressive and shear forces on spinal discs given weight, position, and acceleration of the load and body segments (2,3,10,19). Most of the disc compressive force during lifting has been attributed to tension in the erector spinae muscles which serves to oppose spinal flexion, overcome inertia and initiate acceleration of the trunk mass (4,19). Paradoxically, early models calculated forces on the spine during lifting greater than that required to fracture isolated vertebrae or rupture disks (4,7,9,14). To account for the discrepancy, it was theorized that the intra-abdominal pressure (IAP) observed during lifting creates a rigid body compartment which aids in resisting spinal flexion. Torque generated by IAP pushing against the diaphragm and rear abdominal wall acts together with torque generated by contraction of the erector spinae muscles to counteract torque due to the lifted weight.

Biomechanical analysis shows that most spinal disc compressive force is accounted for by force of the erector spinae muscles. Thus reduction through IAP supplementation, of the erector spinae muscle force necessary to effect a lift, reduces disc compressive force. IAP, which tends to increase with load weight (11,12,16,20) and results from tension in the abdominal wall and diaphragm muscles, has been estimated to reduce spinal disc compressive forces by up to 40% (12,15,16,20). The oblique and transverse abdominal muscles, but not the rectus abdominus, have been shown via electromyography (EMG) to be primary muscles along with the diaphragm

involved in the generation of IAP.

Contraction of the abdominal muscles and generation of IAP has been hypothesized to be the result of a reflex whose exact nature is unknown (4,11,14), possibly supplemented by subconscious voluntary muscle contraction (4). Kumar and Davis (14) suggest that the IAP reflex is initiated by stretch receptors in the erector spinae muscles, since they found no evidence, either histologically or physiologically, of neural structures on either the vertebral bodies or intervertebral discs.

In addition to lifting, activities such as walking, running, and jumping were found to cause fluctuation in IAP. The locomotion activities brought about cyclic pressure changes, the magnitudes of which increased with speed. Jumping down from a height produced larger IAP's than did jumping up from and landing on the same level. Pressure buildup occurred concurrently with EMG activity in the abdominal muscles just prior to impact (9,12).

High IAP can theoretically be generated either by closing the epiglottis and tensing the muscles surrounding both the abdominal and thoracic cavities or by tensing only the diaphragm and abdominal muscles, allowing IAP to increase without increasing intra-thoracic pressure (ITP). Simultaneous monitoring of ITP and IAP during intense physical activities could help to clarify the question of how internal pressure is normally generated and if there are large individual variations in pressure generation technique.

Studies performed to date on internal pressure fluctuations during physical exertion have left some important questions unanswered by either not recording intra-thoracic pressure and intra-abdominal pressure

simultaneously, not having event markers to associate pressure transients with key points in the exercise movements, not quantifying time patterns of pressure generation, or not comparing different types of exercise movements to determine whether IAP 1) is generated only to reduce spinal compressive forces or 2) results from muscle contraction used to effect the movement. The present study was designed to supplement the information provided in previous studies by:

1. Simultaneously recording data from intra-thoracic and intra-abdominal pressure transducers and photo-sensitive and contact switches triggered at key points in the exercise movements.
2. Quantifying and comparing the timing of pressure generation events.
3. Examining a number of different lifting and jumping activities, some of which involve high spinal disc compressive forces and others which don't, to determine whether the pressures are generated only when they are needed to protect spinal structures or if they result from muscle contraction needed to effect the exercise movement.

METHODOLOGY

Apparatus

Intra-abdominal and intra-thoracic pressures were measured using Millar model SPC 350 Mikro-Tip catheter pressure transducers (Millar Instruments, Houston, TX) inserted nasally. The transducers are optically isolated and incorporate strain gauge pressure sensors with frequency response flat to 10 kHz. A control unit (model TCB 500) produces, according to switch position, either calibration voltages corresponding to 2.667 and

13.333 kilopascals (kPa) or a .15 volt per 10 kPa (.2 volt per 100 mmHg) signal reflecting pressure at the catheter tip. Control unit output was fed into a strip-chart recorder (Western Graphtec, Irvine CA).

The weight lifting exercises were the dead lift, slide row, leg press, bench press, and box lift. For the dead lift and bench press, Olympic style barbells and weight plates were used. The leg press was done on a Universal Gym (Universal Gym Equipment, Cedar Rapids IA) which incorporated an adjustable weight stack. For the slide row, the rail and seat of a Concept II (Morrisville VT) rowing ergometer was situated facing the Universal Gym low pulley station so that the rowing movement could be effected while raising a weight stack. An aluminum lifting box with handles, loaded with weight plates, and a sturdy shelf 1.5 meters above the floor, were used for the box lift. Boxes 0.5 and 1.0 meter high served as platforms for the drop-jumps.

For those lifts where the starting position for the weight was on the floor (dead lift and box lift), contact pad switches (model PE-30, Tapeswitch Corporation, Farmingdale NY) were connected to the chart recorder, indicating when the weight began its upward movement. The contact pads also indicated when the feet lost contact with the floor for the jumps. Sets of light beam emitters and photo-sensitive switches (Radio Shack, Fort Worth TX) were set up for the lifts where the contact pads couldn't be used (bench press, slide row, leg press).

Pressure and time measurements from the strip chart recordings were made using a digitizing table (model ACT23, Altek Corporation, Silver Spring MD) with .01 mm resolution connected to a microcomputer (model 310, Hewlett Packard, Lexington MA). Data was transferred to a VAX 780 mainframe

computer for statistical analysis using BMDP (Los Angeles, CA) programs.

Physical activities examined

The lifts are illustrated in Figure 1. For the dead lift the subject grips a barbell resting on the floor and raises the weight, while keeping back and arms straight, till an upright body position is achieved. The movement is effected by the quadricep, gluteal and lower back muscles.

The slide row is not a standard weight lifting exercise. It was designed to simulate competitive rowing. The subject sits on a seat which rolls forward and backward along a rail, bends his knees while reaching past his feet to grip a T-bar handle attached to the weight stack cable, and pulls the bar to the upper chest area while straightening the body around the knees and hips and sliding away from the stack. The pull is effected by the lower back, quadriceps and gluteal muscles and in its latter stages by the muscles of the arm and upper back. The slide row pull covers a considerably longer distance than does the dead lift pull, and starts in much more of a "crunched" body position, in which the thighs contact the abdomen.

For the leg press, the seat on the Universal machine is adjusted so that when a lifter sits down, holds two handgrips to stabilize himself, and places his feet against the footpads connected to a lever system, his knee angle is 45 degrees. The exercise movement involves straightening the legs while raising a weight stack, and is effected mainly by the quadriceps and gluteal muscles, though the lower back muscles may contribute in the early stages of the lift.

In the bench press, the lifter lies face up on a bench, lifts a barbell

from an overhead rack, lowers the bar to his chest, then pushes the bar up till his arms are straight. The movement is effected mainly by the pectorals, deltoids and triceps.

The box lift was included because it is a common task in the manual work environment. The lifter bends down and grips the handles of a box resting on the floor, raises the box and places it on a shelf. While the recommended starting position is bent legs and straight back, the lifter is allowed some freedom of technique, as in an industrial setting. The lift is effected mainly by the quadriceps, gluteal, and lower back muscles, with some involvement of the upper body, particularly in the latter portion of the lift.

The heaviest weight lifted by each subject in each exercise was his four repetition maximum (RM) weight, defined as the maximum weight with which he could perform four repetitions. Maximal single lifts were not used due to risk of injury and the absence of such lifts in most weight training programs. The four RM was selected as a heavy but relatively safe lift.

In all of the weight lifting exercises except the bench press, the first repetition starts directly with a concentric contraction, while for subsequent repetitions, the muscle is stretched during the recovery phase of the previous repetition before the concentric contraction. Thus the first and second repetitions were compared to determine the effect of the stretch-shortening cycle on pressure generation. Lifting cadence was a metronome-cued 0.5 repetitions per second.

In the vertical jump the subject starts with feet parallel, bends the knees while swinging the arms back, and jumps as high as possible. For the

drop-jumps, the subject stands on a platform, drops down to the floor, and jumps as high as possible.

For the Valsalva maneuver subjects voluntarily generated the highest pressure they could while in a standing position.

Experimental procedure

The experiment was conducted in accordance with the policy statement of the American College of Sports Medicine (MEDICINE AND SCIENCE IN SPORTS 10:ix-x,1978) and U.S. Army regulation AR 70-25 on use of volunteers in research, which require that human subjects give free and informed voluntary consent before participation.

The subjects were 11 male volunteers who had varying degrees of non-competitive weight lifting experience, and were physically active but not engaged in organized sports. Prospective subjects were interviewed to screen out those with any gastro-intestinal, sinus or nasal disorders, history of back problems, or hernia. At the start of the first session, information was collected on the subject's age, height and weight. Instruction were given on catheter insertion and lifting procedures. Each subject's four RM lifting capacity in each exercise was determined. Descriptive statistics on the four RM lifts, age, height and body mass are shown in table 1.

On the second day of testing, after having abstained from food for at least five hours, the subject inserted two probes into his nose and down his esophagus. Lidocaine, a local anesthetic, was sprayed into the nose and applied to the catheter tip to relieve some of the discomfort associated with catheter insertion. One catheter was positioned 2-3 cm above, and the

other 2-3 cm below the diaphragm. By sniffing during the procedure, the subject created pulses of reduced pressure in the chest cavity and increased pressure in the abdomen. By noting the direction of pressure spikes on the strip-chart recorder, the experimenter was able to tell when the subject had inserted the transducer below the diaphragm. Once the catheters were in place and taped to the nose and cheek, the subject sat quietly and breathed normally while baseline data was collected. Next, the subject was led through ten minutes of calisthenics designed to warm-up the entire body.

After warming up, the subject performed in random order three repetitions each of the maximal Valsalva maneuver, maximal vertical jump, maximal drop-jump from two different heights, dead lift, slide row, leg press, bench press, and box lift. The lifts were performed at 50%, 75%, and 100% of four RM.

A light beam emitter and photo-sensitive switch were aligned across the direction of weight travel for the bench press, leg press, and slide row in such a way that the light beam was unblocked as the weight moved up from its low point. For the box lift and dead lift, a mat switch opened when the weight left the ground. For the jumps, the contact switches indicated when the subject left the floor. All event marking signals were recorded on the chart recorder concurrently with signals from the pressure transducers.

Data Processing

The strip charts containing simultaneous recordings of ITP, IAP and event switch status were placed on the digitizer pad for measurement of peak pressures and time between events. A program used chart speed to

convert from horizontal screen units to time, and a scaling factor established from the coordinates of digitized pressure calibration signals from the transducer control box to convert from vertical screen units to pressure.

Time measurements were made relative to an event for each activity. For the weight lifting exercises, the event was the start of weight movement in the concentric phase. For the jumps, the event was takeoff. The dependent time variables (Figure 2) were time from the event to start of pressure rise (TRISE) and time from the event to pressure peak (TPEAK), with negative times indicating the pressure event occurred before the weight or body movement event. The third dependent variable was peak pressure (PP) for the exercise movement.

Independent variables included activity, intensity, repetition and body compartment. Activity specified the Valsalva maneuver or particular lift or jump. The intensities were 50%, 75% and 100% of the 4 RM weight for the lifting exercises and the one-half and one meter box heights for the drop-jumping. The repetitions were the first and second of each set, and body compartment referred to the thoracic and abdominal cavities. A one-way analysis of variance was used to compare pressure generated during the highest intensity sets of all the activities, while a four-factor multivariate analysis of variance (MANOVA) was used to compare the effects of activity, intensity, repetition and body compartment among the five weight lifting exercises. The jumps and Valsalva could not be included in the MANOVA since they did not have intensities comparable to those of the weight lifting exercises. Neuman-Kuels post hoc tests were used to identify significant differences. Pearson product-moment correlations were used to

examine the relationship of subject age, height, body mass and weight lifted to magnitude of pressure generated in the highest intensity trial of each activity. The selected criterion for significance was $p < .05$ for all statistical tests.

RESULTS

Figure 3 shows typical chart recordings of ITP, IAP and the event marker for lifting and jumping. Table 2 shows means in ascending order and standard deviations for peak ITP and IAP during the highest intensity set of each activity, which was 100% of the 4 RM weight for the lifts, and the 1.0 m height for the drop-jumps. All vertical jumps and Valsalva maneuvers were included, since they were performed at maximal intensity. It can be seen that the rank order of activities according to pressure magnitude is essentially the same for both body compartments except that the slide row exercise evinced the lowest ITP but the second highest IAP. One-way ANOVA and post hoc tests showed that for both ITP and IAP the Valsalva maneuver produced the highest pressure of all the exercises. ITP was significantly higher for the leg press than for any other activity except the Valsalva. IAP was significantly lower for the bench press than for any other activity and significantly lower for the vertical jump than for any other activity except the bench press and box lift.

The MANOVA on peak pressure during the five weight lifting exercises, which included data from all the exercise intensities, showed significant ($p < .05$) main effects of exercise, intensity and body compartment, but not repetition. Table 3 shows means and standard deviations of pressure peaks

for each exercise, compartment, and intensity. Post hoc examination of the exercise effect showed pooled ITP and IAP for the bench press lower than those for all the other exercises, and pressures for the leg press lower than those for the dead lift and box lift. Pressures differed significantly among the three intensities with progressively higher pressures from 50 to 75 to 100% of the 4 RM weight. Overall, IAP was significantly higher than ITP.

Significant interactions included one for exercise by repetition which can be explained by the tendency towards lower pressure for the second than the first repetition for the dead lift, slide row, and leg press with the opposite repetition effect for the bench press. An exercise-compartment interaction is explained by the significantly higher abdominal than thoracic pressures for all exercises but the bench press, which showed higher thoracic pressures. A compartment-intensity interaction is explained by the increasing difference between mean thoracic and abdominal pressures with increasing exercise intensity.

When the lifts were examined for pressure effects individually, higher intensity was consistently associated with significantly higher pressures, except for the box lift where the two higher intensities didn't differ significantly in pressure, and the bench press where the two lower intensities didn't differ significantly. Pressures during the drop-jumps from the 0.5 meter platform weren't significantly different from those during jumps from the 1.0 meter platform. The only individual exercise to show a significant repetition effect was the bench press, in which repetition two showed a higher mean pressure than repetition one. For all the individual lifts and jumps, IAP was significantly higher than ITP,

except for the leg press where there was no significant difference and the bench press where ITP was significantly higher than IAP. The only interactions found in the pressure analysis of individual exercises were those of intensity-compartment for the slide row and leg press, both of which are explained by the more precipitous increase in IAP than ITP with increased exercise intensity.

The MANOVA's on TPEAK and TRISE showed significant activity effects. However, the differences were judged to be mainly due to differences in the timing switch setup since time variables for activities with the same switch setup weren't significantly different from each other. For the jumps, dead lift and box lift, the event marker chart recorder channel was connected to a mat switch that changed state just as the body or weight cleared the floor. With the leg press, slide row and bench press exercises, the weights unblocked a light beam as they began to move. There was a small degree of weight travel that had to be allowed before the light beam was unblocked since the weight didn't return to the same exact same position on each repetition. While it had been expected the effect would be insignificant, the leeway caused a slight but significant delay between the beginning of weight movement and marking of the event on the strip chart. Therefore, the time variables could not be considered accurate in an absolute sense for the three light-beam timed activities. However, differences among values of the time variables for different intensities, repetitions and compartments could still be considered accurate.

For the box lift and dead lift, where the precise switch pad system was used, timing data was accurate in absolute terms. The box lift showed pressure start to rise a mean of $.417 \pm .20$ sec before and peak a mean of

.277±.30 sec after the weight left the floor. For the dead lift, pressure began to rise a mean of .332±.18 sec before and peaked a mean of .189±.16 sec after the weight left the floor.

The MANOVA on TRISE for the five lifts examined together showed a significant intensity effect. For the highest intensity there was a mean of .14 sec more time at the start of the lift between pressure rise and movement of the weight than for the two lower intensities. There was no repetition main effect, but in a significant compartment effect, mean time of pressure rise was .07 sec earlier in the abdominal than in the thoracic cavity.

Significant TRISE interactions included one for repetition by compartment which is explained by the tendency for TRISE to be shorter in repetition two than in repetition one for the abdominal cavity, with little difference between repetitions for the thoracic cavity. An activity-repetition interaction is explained by significantly longer TRISE for the second repetition than the first during the leg press, while the dead lift showed significantly longer TRISE for the first repetition than the second. An activity-compartment interaction is explained by TRISE tending to be longer in the thoracic than the abdominal cavity for the bench press, but significantly shorter in the thoracic than the abdominal cavity for other lifts.

For the activities examined individually, the only significant intensity effects on TRISE were in the leg press and drop-jump. For the leg press, mean TRISE was .19 s longer for the 75% of four RM weight than for 50%, and .27 s longer for 100% than for 75%. For the drop-jump from 1.0 m there was a mean .06 s more time between pressure rise and takeoff from the

ground than for the drop-jump from 0.5 m.

Some individual activities showed repetition effects for TRISE. For the leg press, mean TRISE was .18 s longer during the second than the first repetition, while for the dead lift mean TRISE was .11 seconds longer during the first lift than the second. For the drop-jumps mean TRISE was .05 seconds longer for the first repetition than for repetitions two or three.

There were significant compartment effects for most of the individual activities. For the slide row, leg press, dead lift, vertical jump and drop-jump mean TRISE was .06 to .11 s longer in the abdominal than in the thoracic cavity.

The only significant TRISE interactions for individual activities occurred for the dead lift and slide row. Both were repetition-compartment interactions explained by the greater TRISE difference between the abdominal and thoracic cavities for repetition one than repetition two.

TPEAK showed neither an intensity nor a repetition main effect for any of the lifts or jumps examined together or individually. Significant compartment effects on TPEAK were for the leg press where the mean time of pressure peak was .05 seconds earlier in the abdominal than in the thoracic cavity and for the bench press where mean time of pressure peak was .03 seconds earlier in the thoracic than in the abdominal cavity. There was a significant exercise-compartment interaction for the five lifts examined together which can be explained by the tendency for abdominal pressure to peak sooner than thoracic pressure in all lifting exercises except the bench press where thoracic pressure peaked sooner.

Correlations were made of the internal pressures with age, height, body

mass and weight lifted. Age and height showed consistently poor correlation with the pressures. Table 4 shows correlation of ITP and IAP with body mass and weight lifted, first for the pooled trials of all intensities, and then for the highest intensity trials only.

For ITP, correlations with body mass tended to be low for all intensities examined together, but were fair to good for some activities in the high intensity trials. The bench press, which was the only activity evincing higher thoracic than abdominal pressure showed the highest correlation (.723) of body mass with ITP for any activity during the high intensity trials. Correlations of weight lifted with ITP was fair to good during most activities, both for all intensities pooled and the high intensity trials only.

For IAP, correlation of body mass with pressure during trials of all intensities pooled was generally poor, though somewhat better than for ITP. Yet many of the correlations of body mass with IAP were considerably higher when only the high intensity trials were examined. The dead lift was the only weight exercise to show poor correlation of body mass to IAP. It is interesting that correlations of body mass and pressure for the drop-jump are considerably higher for the thoracic than the abdominal cavity. For the lifting exercises, correlation of the amount of weight lifted with IAP was generally good except for the dead lift.

DISCUSSION

Findings in agreement with previous research include higher IAP for the drop-jumps than for vertical jumping (9,12) and increasing pressures with

increasing load (11,12,16,20). The IAP magnitudes observed in this study are very similar to those found by Lander et al. (15) whose subjects lifted weights similar to those in the present study. Other studies in which lower pressures were reported (1,4,5,6,8,11,13,16,18,21) involved lighter lifts.

The association of IAP with activities that require back extension against high resistive force is supported by the fact that the bench press and jumps evinced lower IAP's than did the remaining weight lifting exercises. However, the fact that the dead lift, in which extremely heavy weights were supported in large part by the lower back muscles, did not evince higher IAP's than the slide row, suggests an effect of body position in addition to that of back strain in IAP generation.

The difference between ITP and IAP at a given point in time, called transdiaphragmatic pressure, must be reflected in tension in the diaphragm which serves as a common wall to the thoracic and abdominal cavities. Assuming tension in the diaphragm, one factor that might explain the greater pressures in the abdominal than the thoracic cavity in most of the activities studied is that the abdominal cavity consists almost exclusively of liquids and solids while the thoracic cavity contains a considerable amount of gas, even after full exhalation. Since liquids are not compressible and solids are minimally compressible, extremely high pressures can be generated in a liquid and solid filled compartment by exerting force on its surface, without appreciably changing the compartment's volume. However, the pressure of a closed compartment containing gas is inversely proportional to its volume. Thus the volume of the thoracic cavity must be reduced by a considerably greater percentage than that of the abdominal cavity if high pressures are to be generated.

Because the shortness of the intercostal muscles and the structure of the rib cage limit the degree to which the volume of the thoracic cavity can be reduced, a relatively full inspiration is a prerequisite for high ITP generation.

From a teleological point of view, ITP may be generally lower than IAP during physically strenuous activities because of the greater functional value of IAP. Spinal disc compressive force is widely considered highest between the lower vertebrae (L4, L5 and S1), and is the most likely cause of back pain in workers engaged in lifting (17). The lesser compressive force on thoracic than lumbar and sacral spinal discs may call for less supportive intra-thoracic pressure.

ITP may serve the purpose of helping to generate IAP. The diaphragm is both the roof of the abdominal cavity and the floor of the thoracic cavity. When the diaphragm contracts, its central portion moves downward. Thus contraction of the diaphragm readily contributes IAP but not to ITP. High IAP can be generated without appreciable ITP but not vice versa. The slide row exercise is an example of how high IAP and low ITP can be concurrent. However, generation of ITP may not be required for but may facilitate buildup of IAP by helping to push the diaphragm down. It is not surprising then that rank order of the activities by pressure magnitude was very similar for ITP and IAP. The slide row was the only exception, possibly because high ITP would have interfered with achieving the concentric phase starting position in which the thighs are pressed close to the abdomen and shoulders and arms are extended forward, reducing chest volume.

The bench press was the only activity where peak ITP was higher than

peak IAP. From a static point of view ITP cannot be higher than IAP since when contracting, the diaphragm moves downward, and upward force on the thoracic cavity must come from IAP pressing the diaphragm from below. However, from a dynamic point of view, the force of the barbell weight transmitted to the chest by the arms during the bench press, as well as contraction of chest wall muscles can drive gas molecules in the chest towards the diaphragm. The force thus transmitted to the diaphragm tends to accelerate it downward. However, the mass of the diaphragm and tissue below it provides inertial resistance to acceleration which translates into upward force on the thoracic cavity, accounting for transiently higher ITP than IAP.

The fact that the leg press, considered an exercise for the quadriceps and gluteals rather than for the back, produced some of the highest pressures, suggests that body position may be as important a factor in internal pressure generation as load on the back. As in the slide row, the "crunched" lower body position at the beginning of the movement apparently contributes to IAP generation. If back extension force alone accounted for IAP it would seem that the dead lift and box lift would be associated with higher pressures than the leg press.

There may be more back involvement in the leg press movement than is apparent. As the lifter begins to push against the foot pads, the powerful gluteal muscles act to extend the thigh. Yet when thigh extension is resisted, the gluteal contraction tends to rotate the pelvis clockwise when seen from the left side, an action counteracted by contraction of the deep lower back muscles. In addition, of all the exercises, the heaviest weights were lifted in the leg press. Even if the back was only secondarily

involved in the exercise, it still could have been under considerable strain.

The longer time between pressure rise and the start of vertical weight movement for the heavier than the lighter two lifting intensities may reflect a longer push time needed to get the heavier weights moving. The overall lift cadence was regulated by metronome, but time lost in the push phase could have been made up by the lifter letting the weight drop faster to the starting position during the recovery phase.

IAP may rise earlier than ITP for almost all of the activities because the muscles around the minimally compressible abdominal cavity have only to contract a short distance to generate IAP. For high ITP generation, air must be inspired and the chest muscles must contract through a greater range, taking more time. Also contraction of the diaphragm has the initial effect of reducing, not increasing ITP.

The longer TRISE for the first than for the second or third drop-jump repetitions may be the result of a short term practice effect. Anticipation may cause sooner than optimal pressure buildup on the first repetition, after which more appropriate timing is used.

The fair to good correlations in most cases between weight lifted and pressure generated for all trials together and for the high intensity trials alone suggest that the more weight an individual lifts the higher the concurrent internal pressure, and that individuals capable of lifting more weight than others generate higher pressures when they do so. That the correlations weren't excellent points up individual differences in pressure response to exercise.

If internal pressure generation is indeed desirable for reduction of

disc compressive force and corresponding back injury, then it may be possible to train individuals to increase the magnitude of pressure generated during lifting.

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TEXT TO FIGURES

Figure 1. Starting (top row) and ending (bottom row) positions for the five weight lifting movements.

Figure 2. The pressure and time variables. Time progresses leftward. TRISE was always negative since pressure began to rise before the body or weight movement event occurred.

Figure 3. Chart recordings of ITP (upper trace), IAP (lower trace) and the event marker (vertical line) for a) the vertical jump and b) the dead lift. Time progresses leftward.

Table 1. Subject age, height, body mass and 4 RM weights.

	<u>mean</u>	<u>SD</u>	<u>minimum</u>	<u>maximum</u>
age (yrs)	25.2	6.6	19.0	42.0
height (cm)	183.3	4.7	175.3	189.0
body mass (kg)	83.2	9.3	72.6	97.5
slide row 4 RM (N)	870	115	715	1036
leg press 4 RM (N)	1520	282	1067	2044
box lift 4 RM (N)	439	114	280	614
bench press 4 RM (N)	760	233	441	1127
dead lift 4 RM (N)	1171	225	882	1519

Table 2. ITP and IAP (kPa) for the highest intensity set of each activity

a. ITP			b. IAP		
<u>Activity</u>	<u>mean</u>	<u>SD</u>	<u>Activity</u>	<u>mean</u>	<u>SD</u>
slide row	11.7	4.3	bench press	10.6	5.9
bench press	12.7	5.0	vertical jump	17.4	5.8
vertical jump	12.8	3.3	drop-jump	20.5	5.9
drop-jump	13.0	3.1	box lift	21.2	7.2
dead lift	13.5	4.4	dead lift	21.5	5.5
box lift	14.0	2.7	leg press	21.6	7.4
leg press	17.3	3.8	slide row	21.9	5.3
Valsalva	22.2	6.0	Valsalva	26.6	6.7

1.00 kPa = 7.50 mmHg

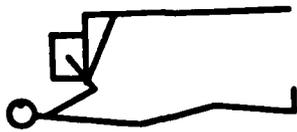
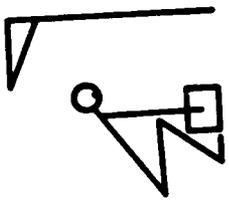
Table 3. Peak ITP and IAP (mean±SD kPa) during 5 lifts at 3 relative intensities

Exercise	Weight as percent of 4 RM					
	50%		75%		100%	
	ITP	IAP	ITP	IAP	ITP	IAP
Box lift	9.46±3.1	16.15±5.8	11.56±2.8	20.17±7.8	14.09±2.6	21.25±7.0
Dead lift	8.64±2.4	16.66±6.1	11.88±3.5	18.50±5.7	13.54±4.4	21.50±5.5
Slide row	7.58±4.4	12.89±4.1	9.74±5.2	17.73±5.4	11.76±4.3	21.92±5.3
Leg press	5.95±2.1	5.62±3.3	9.98±3.6	12.58±6.2	17.35±3.8	21.54±7.4
Bench press	7.09±2.0	4.77±2.2	8.89±2.8	6.15±3.0	12.77±5.0	10.65±5.9

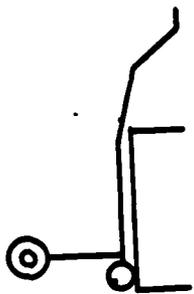
Table 4. Correlation of body mass and weight lifted with pressure using trials of a) all intensities, and b) highest intensity only

<u>a. ITP</u>	All trials		Highest intensity trials	
	<u>Body mass</u>	<u>Weight lifted</u>	<u>Body mass</u>	<u>Weight lifted</u>
<u>Activity</u>				
Valsalva maneuver	.308	-	-	-
vertical jump	.341*	-	-	-
drop-jump	.500*	-	.529*	-
slide row	.178	.441*	.228	.341
leg press	.107	.789*	.548*	.485*
box lift	.053	.568*	.597*	.717*
bench press	.481*	.745*	.723*	.691*
dead lift	.040	.618*	.151	.453*
all five lifts	.176*	.511*	.383*	.505*
<u>b. IAP</u>				
Valsalva maneuver	.197	-	-	-
vertical jump	.232*	-	-	-
drop-jump	.233*	-	.281*	-
slide row	.445*	.685*	.506*	.347
leg press	.210*	.852*	.653*	.812*
box lift	.451*	.579*	.620*	.688*
bench press	.395*	.667*	.601*	.604*
dead lift	.216*	.286*	.222	.099
all five lifts	.257*	.385*	.414*	.416*

* = significant ($p < .05$) correlation



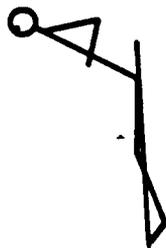
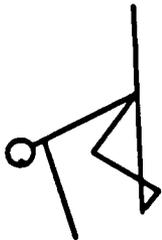
**BOX
LIFT**



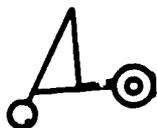
**BENCH
PRESS**



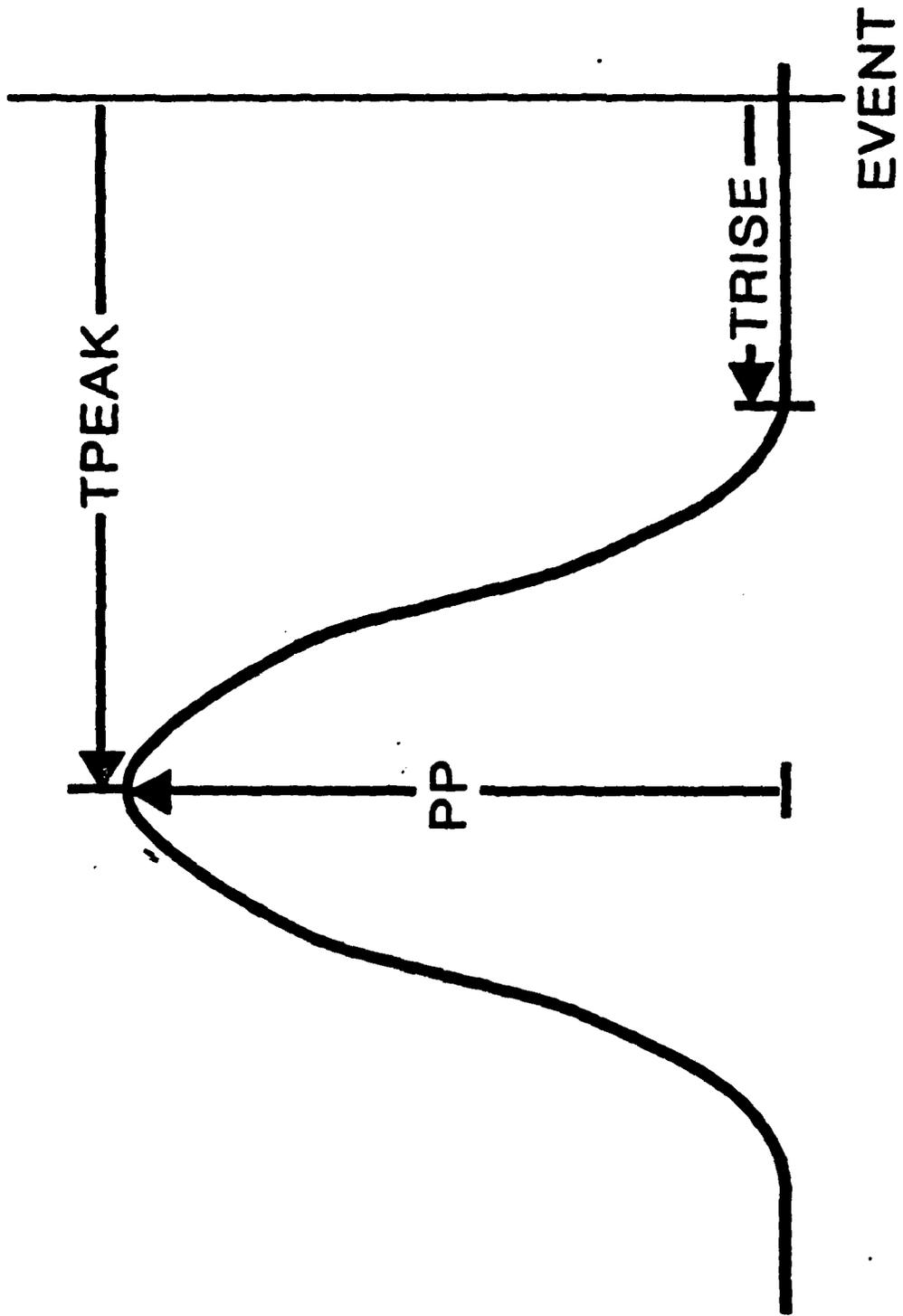
**LEG
PRESS**

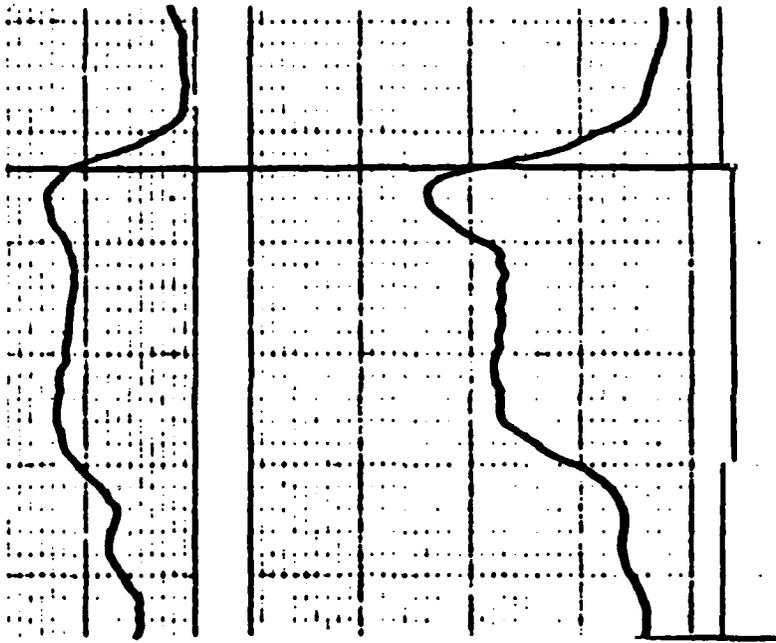


**SLIDE
ROW**



**DEAD
LIFT**





b)



a)

END

6-87

DITIC