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**THE RELATION BETWEEN TRUNK STRENGTH MEASURES AND LUMBAR DISC
DEFORMATION DURING STOOP TYPE LIFTING**

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ABSTRACT

THE RELATION BETWEEN TRUNK STRENGTH MEASURES AND LUMBAR DISC DEFORMATION DURING STOOP TYPE LIFTING. **M. DeBeliso, J. P. O'Shea, C. Harris, K. J. Adams, M. Climstein.** **JEPonline.** 2004;7(6):16-26. Low-back pain and injury are responsible for a major portion of lost workdays and injury compensation claims. Strong well-conditioned trunk musculature has been forwarded as a counter measure towards reducing low-back injuries. The purpose of this study was to determine if strong well-conditioned trunk muscles relieve stresses encountered by the lumbar spine during stoop type lifting. Twelve male subjects (49.7±3.7 yr) performed a session of stoop type lifting with a loaded milk crate (11.5 kg), at 4 reps/min, for 15 min in accordance with the NIOSH lifting equation. Lateral fluoroscopic images were collected prior to and following the lifting session with the subjects positioned at the initiation (flexed trunk), mid-range, and completion of the lift (erect standing). The initial series of images were collected under a no-load condition, while the second series were collected with the subjects lifting the 11.5 kg milk crate. Images were imported into AutoCAD where lumbar disc deformation and joint angles were measured by calculating changes in position of adjacent vertebra (L3-4 and L4-5). A reduction of deformation was deemed indicative of reduced stress. Trunk extension and flexion strength were measured with a Kin Com isokinetic dynamometer. Trunk flexion endurance was measured via a 60 s curl-up test. Trunk strength and endurance were compared to disc deformation and joint angles to determine if any meaningful relationships existed. Significant inverse relationships were detected ($p < 0.05$) between: abdominal strength and shear deformation (flexed trunk: positions: $r = -0.63$ thru -0.96), abdominal endurance and shear deformation (erect trunk: $r = -0.74$ thru -0.75), and spinal erector strength and L3-L4 joint angle (erect trunk: $r = -0.60$). Strong, well-conditioned trunk musculature is associated with reduced lumbar disc deformation and presumably, less stress on the lumbar spine.

Key Words: Trunk strength, Trunk endurance, Lumbar disc deformation

INTRODUCTION

Occupational back disorders have plagued man for centuries (1) and recent years have shown little departure from this trend. It is estimated that 60-70% of the work force will experience at least one serious incidence of sciatica or back strain during their lifetime (2,3). Mitchell et al. (4) correlated these injury occurrences to average 28.6 lost workdays/100 workers/year. According to the American Academy of Orthopedic Surgeons (5), low back pain is second only to the common cold as the cause of missed workdays in those younger than 45 years. The financial burden associated with work place back disorders has been estimated to cost U.S. industry in excess of \$50 billion dollars/year (6).

Strong well-conditioned trunk musculature may prevent low-back injuries. The muscles of the anterior wall of the abdominal cavity consist of the rectus abdominis, external obliques, and the internal obliques. These muscle groups are major trunk flexors and are thought to provide support to the lumbar spine and pelvic girdle (7,8). The posterior aspect of the abdominal cavity consists of the lumbar spine and an intricate complex of muscles, ligament, and fascia. The primary extensor muscles of the lumbar spine are longissimus, iliocostalis, and multifidus (9). These muscles are also thought to provide support to the lumbar spine.

In light of the personal and financial burden associated with low back pain, further research investigating the relation between trunk strength/endurance, external loads, and stress encountered by the lumbar spine during lifting tasks is warranted. The purpose of this study was to determine if strong, well-conditioned trunk muscles relieve stresses encountered by the lumbar spine during stoop type lifting and thus reduce the risk of injury.

METHODS

Subjects

Fifteen subjects 40 to 55 years of age participated in this study. The subjects were recruited from a heavy industrial facility and were free of back injury or pain at the time of data collection. The subjects averaged approximately 20 years of employment and were primarily assigned to physically demanding labor positions associated with a heavy industrial site. Prior to participation, all subjects were verbally informed of the details of the study and required to read and sign an informed consent document approved by a University Institutional Review Board for the use of Human Subjects.

Protocol for Measuring Lumbar Disc Deformation

The dependent variables measured were: compressive and anterior shear disc deformation (L3-L4, and L4-L5), and the associated sagittal plane joint angles. The methodology utilized to measure these variables was fluoroscopic imaging. Fluoroscopy is a procedure where x-rays are projected through the subject in an anatomical area of interest and are collected on a fluorescent screen, which in turn emits photons of light. An image intensifier is generally used to boost the energy levels of these photons to a level consistent with the visible light spectrum. An image of the subject can be seen real time providing the capability to monitor dynamic movement or static postures. Typically, fluoroscopic images are recorded via videotape or digital imagery of the image intensifier output. Although fluoroscopic imaging does not measure soft tissue characteristics, it does allow measurement of changes in position between adjacent vertebrae (10). Changes in position of adjacent vertebrae are directly related to disc deformation and the associated stresses encountered. Lateral fluoroscopic images of subjects under two different conditions were used to determine their effects on the aforementioned dependent variables. These two conditions were: from a stooped position with spine flexed to standing erect under no load, and from a stooped position with spine flexed to standing erect under load.

The load lifted (11.5 kg) was based on the Revised NIOSH lifting equation (11) and was so selected to address NIOSH's criticism of previous research efforts where loads were inconsistent with NIOSH lifting recommendations (12). The load was placed in a milk crate such that when lifted from the floor, the load was suspended just below waist level (Figure 1). In this position the arms did not interfere with the lateral fluoroscopic images. Additionally, this lifting procedure is commonly undertaken during manual handling tasks.

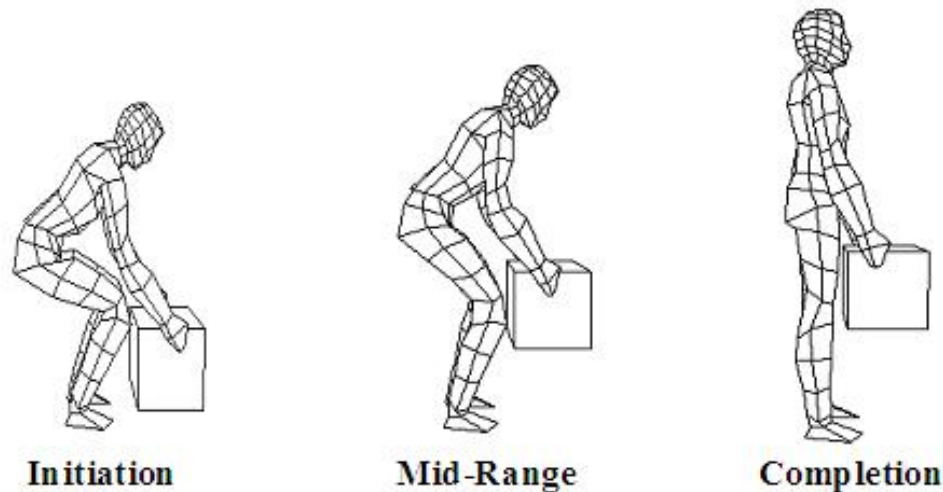


Figure 1. Stoop-type lifting and the positions where fluoroscopic images were collected.

In order to achieve the minimum volume of mass lifted to induce spinal shrinkage (consistent with the previous research efforts), a lifting frequency of 4 lifts/min was selected along with a 15 min stimulus period. The mass lifted was 690 kg for the stimulus period (11.5 kg load, 15 min stimulus period, and 4 lifts/min). This loading duration is consistent with the methodology and findings of Tyrrell, Reilly, and Troup (13) and was intended to assure that the lumbar discs reached hydrostatic equilibrium due to the load and loading pattern. The subjects were monitored to assure a controlled repeatable movement that was based on the body mechanics unique to each subject.

The dependent variables were measured during the no load condition; erect standing position served as the baseline values. To assure that loads experienced during the course of the day (prior to testing) did not confound baseline measures, each subject was instructed to assume the Fowler's position for six min. The Fowler's position is typically recommended for the relief of back pain, the subject is supine with knees and hips flexed (both at 90 °) and the legs supported. This position has been demonstrated to return stature lost during loading (spinal shrinkage) to preloading conditions (13). Further standardization prior to the baseline fluoroscopic images included the subjects standing for 20 min with their body weight evenly distributed on both feet (14,15). This additional period of standing assured that the discs returned to a hydrostatic equilibrium that was due to body weight alone.

Following the standardization period, lateral fluoroscopic images were taken of the subjects going from a stooped position with spine flexed to erect standing (under no load). The fluoroscopic image collected in the erect standing position provided the baseline from which changes in the dependent variables were compared.

The stimulus period consisted of the subjects lifting the 11.5 kg load for 15 min at a frequency of 4 reps/min. The subjects performed the stoop lift, lifting the load from the floor to knuckle height.

Following the stimulus period the subjects were positioned for a series of fluoroscopic images. The subjects were positioned uniformly with the position assumed for the initial series of fluoroscopic images. Once the subjects were properly aligned, they again lifted the 11.5 kg load to knuckle height (going from a stooped position with spine flexed to erect standing) while the lateral fluoroscopic images were collected.

The fluoroscopic images were collected by a certified technician. The images were captured with an Infimed 2000 fluoroscopic imaging system. Three fluoroscopic images were collected for each of the two conditions. For each condition, the first image was collected at the initiation of the movement (stooped position with spine

flexed), the second image was collected at mid-range of the movement, and third image was collected at the completion of the movement in the erect standing position (Figure 1). The total radiation exposure was less than 60% of a standard lumbar examination.

Careful attention was given to the subject's sagittal positioning and distance relative to the collection plate and beam emitter between conditions. This minimized artificial changes in the dependent measures due to out-of-plane body movement and image distortion due to beam dispersion (16). Additionally, the same technician was used throughout the data collection to minimize error. The maximum distance between the beam emitter and the fluoroscreen was 80 cm. Therefore subjects were positioned in a manner such that the lumbar spine was centered at the mid-point between the emitter and the fluoroscreen (i.e. approximately 40 cm). The beam was centered at the forth-lumbar vertebrae, this minimized beam distortion at the L3-L4 and L4-L5 junctures.

A calibration grid (1/8x1/8"; 3.175x3.175 mm) was placed at the same field depth as the subject's lumbar spine. The true size of the grid allowed for the calculation of actual kinematic measures collected from the fluoroscopic images. This is equivalent to the multiplier method utilized with cinematography. The fluoroscopic images were imported into the software package AutoCAD release 12 (AutoDesk, Inc.) for data analysis.

The 1/8" x 1/8" calibration grid provided the means for characterizing the distortion within the fluoroscopic field. Comparison of the grid size in the fluoroscopic field where measurements were recorded varied by less than 0.10 mm. However, the measured variance could not be explicitly attributed to either field distortion or variability of the true size of the calibration grid. Since distortion of the fluoroscopic image was comparable to that observed in previous studies (17), it was deemed negligible in this study as well.

Disc deformation was characterized in a manner consistent with Kanayama et al. (17). A local coordinate system (Figure 2) was established to define disc deformation for both discs L3-L4 and L4-L5. In the local coordinate system for L4-L5, the posterosuperior corner of L5 served as the origin. The X-axis extends out along the superior border of the fifth lumbar vertebrae and the Y-axis is perpendicular to it. The displacement (X and Y) of the inferior corners (anterior B and posterior C) of L4 served as the measure of L4-L5 disc deformation. X and Y displacements defined shear and compressive disc deformation, respectively. A similar local coordinate system was established for the L3-L4 juncture. The displacement of the inferior corners (anterior B and posterior C) of L3 served as the measure of L3-L4 disc deformation. X and Y displacements defined shear and compressive disc deformation, respectively.

The local coordinate systems from which displacements and angular measures were recorded were established through the use of AutoCAD release 12 (AutoDesk, Inc.). Silhouettes of the vertebrae L3, L4, and L5 were sketched. The local coordinate system for L3-L4 was affixed to the superior border of the L4 silhouette. The local coordinate system for L4-L5 was affixed to the superior border of the L5 silhouette. These silhouettes were maintained in layers, where they could be retrieved and superimposed onto other images. This procedure

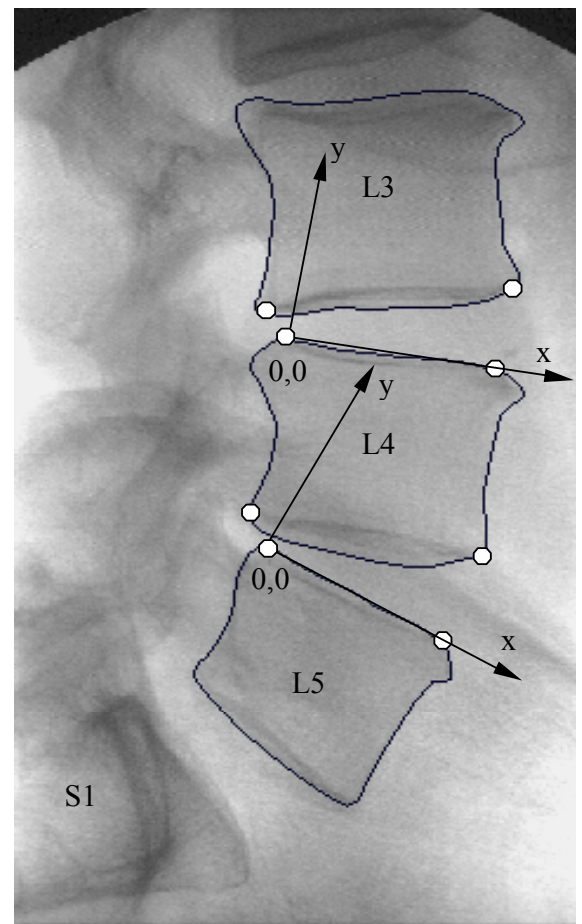


Figure 2. Local coordinate systems for lumbar disc junctures L3-4 and L4-5.

is essentially the same as that described by Dvorak et al. (18), except that the silhouettes were generated and superimposed with AutoCAD instead of by hand (see Figure 2).

All images were analyzed by the same author. Twenty images were randomly selected for re-analysis in order to quantify intra-observer variance or repeatability. The correlation between the repeated measures was 0.99, and the mean and SD of the intra-observer difference were 0.00 ± 0.12 mm (19). All of the intra-observer differences were within ± 2 SD of the mean difference.

Protocol for Trunk Strength Measures

Muscle strength of the trunk extensors and flexors was measured with an isokinetic dynamometer (Kin Com, model H5000, Chattecx Corporation, Chattanooga, TN.). Isokinetic testing measures the muscle force exerted throughout the range of motion for a particular exercise while the movement speed is held constant. The reliability of the Kin Com is reported to range from $r=0.97$ to 0.99 (20,21).

Prior to collecting the trunk strength measures, the subjects were led through a warm-up. The subjects performed five minutes of stationary cycling followed by light stretching exercises. The stretches were: double knee to chest, lateral trunk stretch, hamstring stretch, and the squat. Following the warm-up, the subjects performed five light warm-up trials for both the trunk extension and trunk flexion exercises to allow the subjects to accommodate to the specificity of the Kin Com's speed of movement and range of motion. Range of motion was -15 to $+15^\circ$ for extension and 0 to $+15^\circ$ for flexion. Speed of movement was held constant at $15^\circ/s$ for extension and flexion trials. After performing the five warm-up trials, the subjects performed four maximum trials. The trial with the greatest force output was considered indicative of peak muscle strength. A 2 to 3 min rest period between each trial was allowed to ensure adequate recovery.

The trunk flexion endurance

The protocol was administered to measure the flexion endurance of the abdominal musculature. In order to achieve this, the subjects performed a 60 second curl-up test in a manner consistent with that described by Donatelle, Snow-Harter, and Wilcox (22).

Statistics

Pearson product correlations were conducted in order to determine if any meaningful relationship existed between trunk strength measures (flexion and extension), trunk flexion endurance, and L3-L4, L4-L5 disc deformation or joint angles. A correlation matrix was utilized to identify r -values greater than or equal to 0.57 . A relationship was deemed significant if $r \geq 0.57$. This significance level is based on a one tail $\alpha = 0.05$ and 10 degrees of freedom (23). Assuming an effect size of $r \geq 0.60$ to be noteworthy, 71% power can be approached with $n=12$ (24). There were 12 participants at the completion of this study.

Table 1. Subject characteristics.

Subjects	Height (cm)	Mass (kg)	Age (yrs)
Mean \pm SD	177.4 \pm 6.4	87.0 \pm 10.7	49.7 \pm 3.7

RESULTS

Subject Characteristics

Fifteen subjects recruited from Teledyne Wah-Chang (Albany, Oregon) participated in this study. The subjects averaged approximately 20 years of employment with Teledyne and were primarily assigned to physically demanding labor positions associated with a heavy industrial site. Subject mean height, mass, and age are presented in Table 1.

Attrition of the subject pool is as follows: one subject's images were distorted with out-of-plane movement and were thus not included in subsequent analysis, another subject's back became uncomfortable during the stoop lifting and did not complete the imaging portion of the study, and one subjects was unable to participate during the collection of the trunk strength measures. Therefore, a total of 12 subject's data were used for correlation calculations between trunk strength/endurance, disc deformation, and lumbar segment joint angles.

Disc Deformation

Data for disc deformation are presented in Tables 2 and 3. Disc deformation data was used in correlation analyses with the data for trunk flexion and extension strength.

Table 2. L3-4 disc deformation (mm) and joint angles (degrees) following 15 minutes of stoop type lifting.

Body Position	L3-4				
	B		C		Angle
	ΔX	ΔY	ΔX	ΔY	
<i>Erect Standing</i>	0.34 ± 0.21	-0.66 ± 0.47	0.37 ± 0.22	-0.80 ± 0.33	12.8 ± 3.7
<i>Mid-range</i>	2.18 ± 0.83	-3.31 ± 1.33	1.44 ± 0.67	1.91 ± 1.07	4.5 ± 4.4
<i>Flexed Trunk</i>	2.83 ± 1.08	-4.19 ± 1.21	2.01 ± 0.75	2.84 ± 1.46	1.7 ± 4.7

Table 3. L4-5 disc deformation (mm) and joint angles (degrees) following 15 minutes of stoop type lifting.

Body Position	L4-5				
	B		C		Angle
	ΔX	ΔY	ΔX	ΔY	
<i>Erect Standing</i>	0.43 ± 0.28	-0.77 ± 0.40	0.42 ± 0.23	-0.75 ± 0.54	15.9 ± 5.1
<i>Mid-range</i>	2.54 ± 1.46	-3.78 ± 1.80	1.43 ± 0.94	2.15 ± 1.31	6.2 ± 5.7
<i>Flexed Trunk</i>	3.20 ± 1.85	-4.32 ± 1.92	1.96 ± 1.25	2.75 ± 1.43	4.3 ± 5.2

Trunk isokinetic flexion strength

Trunk flexion strength as measured by the Kin Com isokinetic dynamometer is reported in Table 4. Trunk isokinetic flexion strength was compared with compressive and shear-force disc deformation. At the initiation of the movement (stooped position with spine flexed), significant correlations between flexion strength and shear disc deformation were observed at the L3-L4 and L4-L5 junctures ($r=-0.63$ thru -0.96). At mid-range of the movement, significant correlations between flexion strength and shear disc deformation were observed at the L4-L5 juncture ($r=-0.83$ thru -0.96). No relationship was detected between flexion strength and compressive disc deformation at either the L3-L4 or L4-L5 juncture in either flexed trunk position.

In the erect standing position, no meaningful relationship was detected between trunk flexion strength and compressive or shear-force disc deformation. Additionally, no meaningful relationship was detected between isokinetic trunk flexion strength and the L3-L4 or L4-L5 joint angles.

Trunk isokinetic extension strength

Trunk extension strength as measured by the Kin Com isokinetic dynamometer is reported in Table 4. Trunk extension strength was compared with compressive and shear-force disc deformation. No meaningful relationships were detected between extension strength and compressive or shear disc deformation, for any of the body positions during the lift. However, a significant relationship was detected between isokinetic extension strength and the L3-L4 joint angle in the erect standing position ($r=-0.60$).

Trunk flexion endurance

Mean trunk flexion endurance scores as measured by a 60 s curl-up test is reported in Table 4. Trunk flexion endurance was compared with compressive and shears disc deformation. At the initiation of the movement (stooped position with spine flexed) and at mid-range of the movement, no relationships were detected between flexion endurance and shear or compressive disc deformation at either L3-L4 or L4-L5.

Table 4. Trunk strength and endurance measures.

Measure	Mean ± SD		
<i>Trunk Extension Strength (Newtons)</i>	993 ± 320	993 ± 320	993 ± 320
<i>Trunk Flexion Strength (Newtons)</i>	660 ± 128	660 ± 128	660 ± 128
<i>Curl-up Score (rep/min)</i>	44 ± 9	44 ± 9	44 ± 9

At the completion of the movement (erect standing position), significant correlations between flexion endurance and shear disc deformation were observed at the L3-L4 juncture ($r=-0.74$ thru -0.75). No meaningful

relationship was detected between flexion endurance and compressive disc deformation. Additionally, no meaningful relationship was detected between trunk flexion endurance and the L3-L4 or L4-L5 joint angles.

DISCUSSION

The goal of this study was to determine if isokinetic trunk strength and abdominal endurance have a favorable impact on the reduction of disc deformation and the maintenance of normal lumbar lordosis. Trunk strength and endurance measures were compared to lumbar disc deformation and joint angles following 15 min of stoop type lifting in a manner consistent with NIOSH approved lifting guidelines (11).

Trunk isokinetic flexion strength was compared with compressive and shear-force disc deformation. At the initiation of the movement (stooped position with spine flexed), significant correlations between flexion strength and shear disc deformation were observed at the L3-L4 and L4-L5 junctures. The correlations ranged from -0.63 thru -0.96. The negative sign indicates that greater isokinetic trunk flexion strength is associated with smaller amounts of shear disc deformation. No meaningful relationship was detected between flexion strength and compressive disc deformation in this position. It appears that in this position, abdominal flexion strength is associated with a significantly reduced the amount of shear stress on the lumbar spine, with little or no effect on compressive stress.

At mid range of the movement, significant correlations between isokinetic flexion strength and shear disc deformation were observed at the L4-L5 juncture. The correlations ranged from -0.83 thru -0.96. The negative sign indicates that greater isokinetic trunk flexion strength is associated with smaller amounts of shear disc deformation. It appears that in this position abdominal strength is associated with significantly reduced amounts of shear stress on the lumbar spine.

In the erect standing position, no meaningful relationships were detected between isokinetic trunk flexion strength and compressive or shear disc deformation. Additionally, no meaningful relationship was detected between trunk flexion strength and L3-L4 or L4-L5 joint angles. The data suggest that trunk flexion strength has no measurable impact on the amount of compressive or shear stress encountered by the lumbar spine or the amount of lumbar lordosis in this position.

In flexed trunk positions (initiation and mid range of the lift), the loads on the spine due to body segments and the weight lifted are supported more so by an axial load due to a restorative moment generated by the spinal erectors, as opposed to a direct axial load of the lumbar spine. Further, because of the increased trunk angle in flexed positions, trunk shear forces are large. Abdominal muscular strength is accompanied by increased IAP due to increased active muscular tension. Since the loads on the spine are greatest during flexed trunk positions (9), muscular abdominal strength is likely responsible for generating IAP. It is likely that in flexed trunk positions abdominal muscular strength is responsible for stabilizing the trunk via increased IAP (the mechanism of IAP and trunk stabilization is elucidated below). If this is the case, it might explain why a significant correlation exists between abdominal strength and reduced shear stress on the lumbar spine while in flexed trunk positions.

Trunk isokinetic extension strength was compared with compressive and shear-force disc deformation. No meaningful relationships were detected between these variables for any of the body positions during the lift for either L3-L4 or L4-L5. The lack of relationship between any of these variables suggests that spinal erector strength has no measurable impact on the amount of compressive or shear stress encountered by the lumbar spine during lifting tasks of this nature. A significant relationship was detected between isokinetic extension strength and the L3-L4 joint angle in the erect trunk position. The magnitude of the relationship was -0.60. The negative sign indicates that greater isokinetic trunk extension strength is associated with smaller increases in

lumbar lordosis. The data suggest that trunk extension strength is associated with the amount of lumbar lordosis in this position during lifts of this nature.

Cailliet (7) discussed the relationship between accentuated lumbar lordosis and low back pain. During extreme lordotic conditions, posterior elements of the functional unit approximate. The various tissues innervated by nerves become potential sites of nociception. If spinal erector strength is functional in minimizing lordotic changes during lifting tasks, then it is possible that strengthening this muscle group may serve to reduce the potential of encountering low back pain.

Wilby, Linge, Reilly, and Troup (8) compared isometric back strength with stature loss. Back strength was significantly correlated with the inverse of stature loss. The implications of their finding suggested that a stronger back reduces the load on the lumbar spine. In this study, isokinetic trunk extensor strength exhibited no relationship with compressive disc deformation. Thus, results of this study do not support Wilby, Linge, Reilly, and Troup's (8) findings. The incongruence between the results of these two studies could be due to comparison of total stature loss of the spine to a localized stature loss (compressive disc deformation). Recall, the sum of compressive disc deformation over the length of the spine should equate to stature loss. Further, it is possible that the method of measuring strength, isometric versus isokinetic might in some manner explain lack of similarity of findings between the two studies.

Trunk flexion endurance was compared with compressive and shear-force disc deformation. At the initiation of the movement (stooped position with spine flexed), no significant relationships were detected between flexion endurance and shear or compressive disc deformation at either the L3-L4 or L4-L5 juncture. Abdominal endurance appears to have no measurable impact on reducing the compressive or shear stress encountered by the lumbar spine while in this position. At mid range of the movement, no significant relationships were detected between flexion endurance and shear or compressive disc deformation, at either the L3-L4 or L4-L5 juncture. Abdominal endurance appears to have no measurable impact on reducing the compressive or shear stress encountered by the lumbar spine while in this position.

At the completion of the movement (erect standing position), significant correlations between flexion endurance and shear disc deformation were observed at the L3-L4 juncture. The correlations ranged from -0.74 to -0.75. The negative sign indicates that greater trunk flexion endurance is associated with smaller amounts of shear disc deformation. No meaningful relationship was detected between flexion endurance and compressive disc deformation in this position. Additionally, no meaningful relationship was detected between flexion endurance and the L3-L4 or L4-L5 joint angles. It appears that in this position abdominal endurance significantly reduces the amount of shear stress on the lumbar spine with no measurable effect on compressive stress or the amount of lumbar lordosis.

In the erect position, the loads on the spine due to body segments and the weight lifted are supported more so by a direct axial load of the lumbar spine as opposed to an axial load due to a restorative moment generated by the spinal erectors. Further, because of the decreased trunk angle in the erect position, trunk shear forces are reduced dramatically. Increased IAP likely accompanies muscular contractions associated abdominal muscular endurance. IAP due to muscular contractions associated with abdominal muscular endurance in erect standing positions is likely much smaller than IAP due to muscular contractions associated abdominal muscular strength in flexed trunk positions. Since the loads on the spine are reduced during erect standing, it is possible that muscular endurance takes over the responsibilities for generating IAP. It is likely that in the erect standing position muscular endurance, rather than muscular strength, is responsible for stabilizing the trunk (the mechanism of IAP and trunk stabilization is forwarded below). If this is the case, it would explain why a significant correlation exists between abdominal endurance and reduced shear stress on the lumbar spine.

McGill and Norman (25) hypothesized that IAP was likely related to a mechanism by which the lumbar spine is stabilized with little or no effect on reducing compressive loads. McGill (9) suggested that "the spine can be likened to a flexible rod-under compressive loading, it will buckle". Expanding on this theory, assume the spine and trunk behave as a column. Acute failures of the lumbar spine (tissue injuries) can be equated to a column buckling. Column buckling theory suggests that the buckling limit of a column can be elevated by increasing the area moment of inertia (I) or by providing lateral support to the column (26). Abdominal strength and endurance might increase the buckling limit of the spine. The addition of abdominal strength and endurance should be accompanied by an increase in muscle mass. The added muscle mass should increase the area moment of inertia (I) of the trunk and spine, hence improving the buckling limit. Abdominal strength and endurance has a direct impact on active and passive muscular tension development. Greater abdominal muscular tension is associated with increased levels of IAP. The increase in IAP as a result of active and passive muscular tension acts directly against the posterior wall of the abdominal cavity. Essentially, the abdominal cavity acts a pressure vessel (27). A normal directed force is applied equally to the entire internal surface area of the abdominal cavity. The posterior wall of the abdominal cavity is coincident with the anterior perspective of the lumbar functional units. The increase in IAP is directly applied to the functional units and thus supports the spinal column and improves stability. Additionally, the surface area of the posterior wall of the abdominal cavity acts as a "sail" connected to the lumbar spine, which acts as a mast. The sail effect collects the force exerted by IAP and lends itself to stabilizing the lumbar spine. This notion could best be visualized in the following manner: whatever pressure is exerted against the anterior abdominal cavity wall is equivalent to the pressure exerted against the posterior wall of the abdominal cavity, hence stabilizing the lumbar spine.

It is likely that IAP has a number of indirect effects on stabilizing the lumbar spine. Gracovetsky, Farfan, and Lamy (28) postulated two theories as to how IAP could facilitate reduced compressive loading on the lumbar spine. First, increases in IAP facilitated through abdominal muscular contraction could create a hydraulic force causing a posterior tension on extensor tissue, thus generating a restorative moment. Second, internal oblique and transverse abdominis muscular contractions exert a lateral tension on the lumbodorsal fascia, shortening the fascia. Shortening of the fascia pulls the posterior spinous processes together via the Poisson's effect. Thus, a restorative moment is generated, reducing compressive loading of the lumbar spine. The restorative moment theory forwarded by these authors was re-examined in latter works and deemed negligible (29). More likely, the impact of increased in IAP on these structures is one of increasing the area moment of inertia and reducing the slenderness ratio of the lumbar spinal column. When these passive tissues are pre stressed via IAP, they become active load bearing members of the column. As active load bearing members of the spinal column, they enlarge the mass distribution, which in turn increases the area moment of inertia and the critical buckling limit. Increasing the mass distribution increases the radius of gyration. An increase in the radius of gyration reduces the slenderness ratio (a ratio of column length to radius of gyration); the square slenderness ratio is inversely proportional to the critical stress at buckling (26). Spinal erector muscle action is essentially zero at the initiation of lifting activities when the trunk is in a flexed position (7). Any support to the lumbar spine via increased IAP pre stressing passive tissue would be of great importance in terms of minimizing the potential of the spine buckling.

McGill (9) discussed a similar effect; " the co-contracting musculature of the lumbar spine can perform the role of stabilizing guy wires to each lumbar vertebrae bracing against buckling". If McGill and Norman's hypothesis is valid then the contention related to IAP and lumbar stabilization presented in the previous paragraphs should hold some validity.

The results presented suggest that abdominal strength is associated with reduced shear stress on the lumbar spine during flexed trunk conditions. Abdominal endurance is associated with reduced shear stress on the lumbar spine during erect conditions. Spinal erector strength was not related to the unloading of the lumbar spine in any position. However, it was found to be effective in maintaining normal lordosis during lifting tasks, once returned to the erect trunk position.

The results support the contention that abdominal strength and endurance support the lumbar spine. Of great interest is the fashion in which the spine is supported, reduction of shear stress. Cailliet (7) suggested that cumulative micro trauma to the disc endplates as a result of compressive loading leads to subsequent nutrient deprivation of the disc via disruption of the inhibition process. Disc degeneration results, with an ever-increasing probability of injury. Mechanical properties exhibited by the lumbar disc suggest that discs fail in shear before failing in compression. That being the case, failures at the disc endplate-annular fiber interface could then be hypothesized to be to a greater extent related to shear stress as opposed to compressive stress. While it was proposed earlier that acute failures of the spine can be likened to a column buckling, this eventual acute failure is no doubt impacted by the chronic degradation of the disc endplate due to compressive and shear-force loading. If abdominal strength and endurance are responsible for reducing shear stress on the lumbar spine, as the data suggest, then maintenance and/or development of such strength and endurance is imperative to disc health. Additionally, if spinal erector strength is associated with normal lumbar lordosis during lifting in the erect trunk position, then the development of such strength may reduce the risk of low back pain associated with accentuated lumbar lordosis.

CONCLUSIONS

Within the limits of this study, it is concluded that:

1. Subjects with greater abdominal strength had less shear stress in the lumbar spine while stoop lifting in flexed trunk positions.
2. Subjects who had greater abdominal endurance had less shear stress in the lumbar spine while lifting in the erect trunk position.
3. Subjects who had greater spinal erector strength were better able to maintain normal lumbar lordosis while lifting in the erect trunk position.

To determine if there is a causal relationship between these variables, a longitudinal training study should be undertaken. The premise being that if trunk strength and endurance levels are increased via a strength and conditioning program, an accompanying reduction in lumbar stress should take place during lifting tasks. Assuming that a causal relationship manifests, health care professionals would then have precedent for prescribing an exercise-training program targeted at improving abdominal strength and endurance as well as spinal erector strength. In lieu of a longitudinal study of this sort, the data from the current study support the notion that strong, well-conditioned trunk muscles relieve stresses encountered by the lumbar spine.

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