

Biomechanics of Lifting

(An implication Review)

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□ Abstract:

Lifting has been the subject of research for many years. The reasons that triggered this interest in lifting are its believed association to low back pain on one hand and to its usefulness in muscle training, rehabilitation and technique enhancement on the other hand. Even though the area of lifting biomechanics is saturated with studies, there still is no agreement on most aspects of lifting and in particular, the safest lifting technique, contribution of intra-abdominal pressure (IAP), use of lifting belts. Previously, there was some effort by some researchers to give some conservative recommendations. With the publication of many recent studies, it was important to review them in light of the previous ones in the hope of reaching some solid implications. After the review, it was clear that definite recommendations are not at hand yet specifically in terms of lifting technique, lifting belt, or the contribution of IAP in lowering loads on the lumbar region. The only obvious factor that was in agreement by almost all researchers is the superiority of the use of dynamic biomechanical models in estimating lumbar loads compared to static ones. Based on this review, more research is still needed before definite recommendations are reached. In the end, some implications are suggested in both the ergonomic and sports areas.

Key words: Lifting, Intra abdominal pressure, Lifting belt, Lifting technique

□ ملخص :

ميكانيكية رفع الأحمال هو أحد مجالات البحث العملي منذ سنوات عديدة و من أهم دواعي الاهتمام به هو العلاقة المفترضة بينه وبين آلام و مشاكل أسفل الظهر و خاصة المنطقة القطنية إضافة إلى فائدته في تقوية العضلات و إعادة تأهيلها و تحسين الأداء في مسابقات رفع الأثقال. و على الرغم من تشبع المجال بالدراسات العلمية حول هذا الموضوع، إلا انه لا يوجد اتفاق بين الباحثين حول عدد من العوامل المؤثرة أثناء الرفع و على وجه الخصوص : طريقة الرفع الأكثر أمانا، مساهمة الضغط داخل التجويف البطني، استخدام حزام الظهر. في السابق حاول البعض من الباحثين تقديم بعض التوصيات المتحفظة و لكن مع ظهور الكثير من الدراسات الحديثة كان من المفيد مراجعة هذه الدراسات مع الأخذ في الاعتبار ما نشر سابقا لغرض الوصول إلى توصيات مؤكدة عوضا عن المتحفظة. و بعد مراجعة الدراسات تبين أن الوصول إلى توصيات مؤكدة ليس في المنال حتى الآن و خاصة حول انساب طريقة رفع و مدى مساهمة ضغط التجويف البطني في تخفيف العبء على المنطقة القطنية و استخدام حزام الظهر. الأمر الوحيد الذي كان حوله اتفاق هو ضرورة استخدام النموذج الميكانيكي الديناميكي في تقدير الأحمال نظرا لقربة من المستوى الحقيقي مقارنة بالنموذج الميكانيكي الاستاتيكي. و اعتمادا على هذه المراجعة فقد تبين الحاجة إلى المزيد من البحث العملي حول هذا الموضوع كما اقترح في النهاية بعض التوصيات في مجالي بيئة العمل و الرياضة.

العنوان: ميكانيكية رفع الأحمال

مفاتيح الكلمات: الرفع، حزام الظهر، ضغط التجويف البطني

□ Introduction:

Lifting has been the subject of study for many years. It is expensively studied because of the believed association between lifting and low back disorders¹⁻⁴ on one hand and on the other hand because of its use in sports training for muscle strength improvement, rehabilitation and technique enhancement⁵. So, it is no wonder that lifting is researched by many scientists from different disciplines in order to explore its positive or

negative effect under the environments of these different disciplines. Because low back pain is one of the most common musculoskeletal complaint encountered by individuals¹⁻³, it dominates the area of lifting biomechanics. It has been reported that it is the leading cause of disability in those under the age of 45 and the third major cause of disability in general^{6,7}. The national Center for Health Statistics in the United States approximates six million Americans suffer from low back impairment⁸. That accounts to almost 3 in every 100 people. In

addition, Lamode in his analysis of the accidents profiles in workers of a freight company found that 1/3 of the accidents were due to muscular efforts. Sixty nine of these accidents were for the back, especially in the lumbar region⁹. Furthermore, low back pain is becoming more common in adolescents because of the nowadays life style¹⁰.

The mechanics of lifting is not fully understood, as a result the proper lifting technique that minimizes the risk of low back pain is not at hand yet¹¹. It is generally believed that this is because of the complexity of the mechanical effect on the spine and so the estimation of spinal load during lifting is very important in addressing problems of lifting induced back pain⁹.

A great deal of effort has been devoted to the development of means of assessing the risk of injury under a variety of lifting conditions. Biomechanical mathematical modeling is one way of estimating these loads¹². Others have focused on determining the capacity of an individual to perform a specific task based on muscle strength or physiological endurance^{13,14}. On the other hand, the psychophysical approach was suggested and presented as the only method available to researchers for determining the acceptable level at which individuals perform frequent and infrequent manual handling tasks¹⁵. However, before assessing the relationship between the workload and low back pain, low back pain has to be distinguished from low back impairment, low back disability, and low back compensation. Low back pain is defined as lumbosacral pain as well as buttock pain and leg pain. Low-back disability is defined as time lost from the job whereas low back impairment represent a decrease or loss of ability to perform various musculoskeletal activities¹⁶.

Lifting can be accomplished using a variety of techniques. Each technique produces a particular amount of stress on the spine vertebrae. The intervertebral discs in the adult do not possess any blood vessels. They are classified as a group called "bradytrophic" tissue which receive their nutrient substances merely by diffusion. Fluid shifts due to load and pressure promotes the exchange of substances in the vertebral disc. It has been experimentally shown that the reversal of the flow in loading and unloading occurs at about 70-80 kp. There is an outflow of fluid when standing, sitting, and carrying a load and influx of fluid when lying down¹⁷. Prolonged loading or prolonged unloading effects the exchange of these substances in which it depletes the fluid from the discs reducing its volume and its ability to absorb energy and raising the danger of injury.

Injury and proper technique of lifting are both important aspects that have to be addressed in addition to low back impairment. Even though the area of lifting biomechanics is full of studies, there is still no conclusive recommendations about most aspects of lifting and because there are many studies that have been done recently, it is useful to review the previous recommendations with the recent findings in the hope of reaching solid implications. Further more, there is no review that combined the subjects of lifting in sports with ergonomics. So, the coming sections are to address the most aspects that relate to lifting biomechanics from an implication point of view with the aim of integrating previous findings with the recent ones. This review begins with a brief description of the biomechanics of the spine and ends with possible implications.

Biomechanics of The spine

The spinal column consists of mainly twenty-four vertebrae, seven of which are in the cervical region, twelve in the thorax region, and five in the lumbar region. The main functions of the spine are: to protect the spinal cord, provides sites for muscle attachment and to transfer loads from the head and trunk to the pelvis^{18,19}. Each vertebra articulates with the adjacent one to provide motion in three planes: transverse, frontal, and sagittal (six degrees of freedom). This motion is small and involves the motion of other motion segments in the form of rotation and translation. Stability of the spine comes from the intervertebral discs and the surrounding ligaments and muscles, the discs and ligaments provide intrinsic stability and muscles provide extrinsic support¹⁸.

The functional unit of the spine consists of two vertebrae and their intervening soft tissues, particularly discs^{18,20}. The vertebral bodies could mainly bear compressive loads and they get progressively larger as weight of the upper body increases. The bodies of the lumbar vertebrae are thicker and wider which allow them to sustain larger loads. Trew²⁰ added that the vertebral body consists of a cylinder of cancellous bone with trabeculae surrounded by a thin layer of cortical bone. The trabeculae acts like a strut strengthening the vertebral body: the vertebral trabeculae resist compressive forces and horizontal trabeculae resist bowing of the trusts and thus increase its strength. The orientation of the facets of the intervertebral joints to the frontal and transverse planes determines motion of the functional unit of the spine. This orientation changes throughout the spine. For the lumbar region, the vertebrae are aligned in a 90 degree angle to the transverse plane

and at 45 degree to the frontal plane. This alignment allows flexion, extension, and lateral flexion but not rotation^{18,19}.

The other essential part of the functional unit is the intervertebral discs. The intervertebral disc is of great importance because it serves to distribute loads and restrain excessive motion. During daily activities, the disc is loaded in a combination of compression, bending and torsion. During loading of the spine, the nucleus pulposus acts hydrostatically allowing a uniform distribution of pressure throughout the disc, hence the entire disc acts as a cushion between the vertebral bodies to store energy and distribute loads²¹. During this process, the disc deforms elastically in response to high rate of loading and short duration and viscoelastically in response to loads applied slowly and for long time. Fluid content of the disc is squeezed out and the disc becomes thinner. This resembles water squeezed out of a sponge. The water content of the sponge gets absorbed after unloading it²². In addition to its mechanical importance, viscoelasticity of discs is essential in nutrient supplementation. The alternate expulsion and absorption of water enables the discs to receive nutrients and get rid of wastes²³. Furthermore, these discs are thinnest in the cervical region and thickest in the lumbar region. In proportion to the height of the vertebral body, the discs are thickest in the cervical region which enable the cervical spine to have a greater physiological range of movement²⁰.

Biomechanical Lifting Models

Moments and forces on the lumbar spine come from body-segments, movement of the trunk, and external loading. These moments and forces have to be equilibrated by internal forces which come from muscle contraction, resistance of soft tissue, and pressures within the trunk cavities²⁴. The most common biomechanical means of assessment for moments and forces on the lumbar spine during lifting are static and dynamic models. It has been shown that the static models usually used do not account for some of the factors involved in the lifting and hence loading of the lumbar spine²⁵⁻²⁷. The adequacy of the static models are important because they are being used to establish lifting guidelines (e.g. NIOSH. 1981) and the development of pre-employment selection standards for workers may be based upon them in the future²⁷. Static models have been shown to underestimate the loading on the lumbar spine. One study reported 5218N of compressive force on the L4/L5 in the case of using the static model²⁷. That is well below the NIOSH maximum

permissible limit which is 6377N. When using the dynamic model, 6391 N of compression force was found marginally above the permissible limit. Another study found the compressive force on the lower back was approximately two to three times greater when dynamic analysis was used than those based on static analysis²⁶. Furthermore, 33 to 60% increase in predicted moment was found when using the dynamic model compared to a static one²⁴. McGill and Norman²⁷ compared static and dynamic models and found similar results. They reported 19% increase in L4/L5 moments with the dynamic model. Also, Static and dynamic model were compared in relation to speed and varying loads. A 45 to 54% increase was found when the dynamic model was used. It was concluded that static models ignore the speed factor and hence underestimate the load on the L5/S1 vertebrae¹¹. Finally, Freivalds et al.²⁸ reported that static models underestimate the actual load by 40%. That may lead to an assessment that a particular load is safe when in fact it is not. At the same time, there is an ongoing effort to improve the accuracy of the biomechanical models by understanding spinal motion²⁹.

Lifting techniques

Even though the research is not completely conclusive about the safest style of lifting³⁰, the one technique that has been advocated by many sources is the squat lift, in which the back is relatively straight and the hips and knees are flexed¹⁰. This technique is supported by the National Safety Council (National) and the International Labor Office³¹. Many reasons have been cited for the advocating of this method: the center of gravity of the load may be held close to the body minimizing the torque, the strong leg muscles are active to assist in lifting the load, movement of the weight of the body is used to initiate horizontal motion during lifting, and the early onset of erector spinae muscles activities during the squat lifting is thought to be important in reducing the stress on the lumbar spine¹¹. Lower center of gravity of the body which improves balance, and finally the hamstring muscles operate at the closely their resting length which may improve their efficiency in stabilizing the pelvis³².

Squat lifting could be performed with differing styles. The optimal position for lifting load is the squat style with anterior tilt as opposed to posterior tilt. In this position, the lumbar spine is aligned in its normal lordosis and the pelvis is aligned in an anterior tilt³³. However, in this posture, there has

to be an accompanying strengthening and endurance training for the extensor muscles of the back³⁴. Furthermore, squat lifting with an angle from vertical decreases the compressive forces on the lumbar spine by 11%³⁵. Also, squat lifting results in the lowest compressive force on the lumbar L5/L4 (5866N) compared to other lifting techniques²⁵, however, as the weight lifted increases, there is a tendency to extend the knees early implying that the strength of the quadriceps muscles may be a determinant in lifting with the knees flexed³⁶. Furthermore, squat lifting may be recommended only when the weight is held in between the feet³⁰. Moreover, when the physiological load factor is taken into consideration, the stoop technique rather than the more suggested safe technique-squat- is preferred by subjects because of lower heart rate in the stoop and hence less physiological load^{12,37}. In a similar study, even though all types of lifts recorded high in all variables measured, squat lift with highest weight lifting produce the greatest physiological stress³⁸. Kirmir³⁹ in the conclusion of his most recent study said that cautioned needs to be exercised when applying the results of stoop or squat lifts to real life lifting.

Load knowledge can influence the technique used. Experienced lifter benefited from load knowledge and used different techniques that reduced the stress on the L4/L5. Non experienced lifters used the same technique regardless of the load weight. The result also showed that non lifters relied on the low back musculature in lifting the weight⁴⁰. In a similar study, with unexpected heavier weight, there was an increase in lumbar joint reaction moments which could lead to an increase in the risk of low back injury⁴¹.

Asymmetrical techniques have also been investigated. It is more dangerous to the musculoskeletal system when the weight is lifted at the side or in planes other than the sagittal. Maximum acceptable weight was found to be lower in asymmetrical lifting compared to symmetrical⁴². Also, trunk loading with unexpected loads is shown to be associated with increased risk of injury⁴⁰. Straddling- one foot placed at the side of the load and the other behind it- as a mean of lowering low back load has been also shown to be in no difference to the symmetric style of lifting⁴³. In addition, lifting an unstable load produced higher abdominal muscle activities compared to stable one which indicates the role of these muscles in spinal stability⁴⁴.

Dead lift is widely used as an effective exercise in sport training and muscle rehabilitation¹⁷. Dead lift could be performed with different styles depending on the preference of the athletes. There are two known styles of dead lift: sumo and conventional. Both use a squat style with feet positioned further apart and turned out more in the sumo style. In the conventional style, the arms are positioned to the outside whereas to the inside in the sumo style. Both the sumo and conventional style dead lifts could be used equally effective in muscle training¹⁷. However, the sumo dead lift is found to be more effective in working ankle dorsiflexors and knee extensors whereas conventional style is more effective in working ankle plantar flexors and knee flexors⁴⁵. In regards to sport competition, the ground reaction forces in power clean lifting were analyzed. It was found that the vertical force was higher in the second pull and the unweighted phase compared to the first pull. However, with increased weight lifted from 60 to 70% of maximum, the peak was higher in the first pull than the first one. The researchers emphasized understanding the proper lifting technique in order to be competitive in weightlifting or sporting events⁴⁶. Schilling et al⁴⁷ studied the effect of foot displacement on performance in snatch lifting. The horizontal displacement of the feet during the snatch lifting did not effect lifting ability or snatch success. Moreover, the snatch technique was compared between males and females and the results showed that there are significant differences between the two sexes. The differences were attributed to the lower skill level as a result to recent participation of women in weightlifting^{48,49}. In a similar study, it was also concluded that men and women should be considered separately in the evaluation of manual handling of tasks⁵⁰. That emphasizes the complexity of determining the acceptable weight for an individual or the proper technique of lifting because. In addition to what has been mentioned, other factors like: object weight, load acceleration, age, to name a few- play a role²⁴.

Intra Abdominal Pressure (IAP)

Even though there are dissenting opinions about the role of IAP in relieving the stress on the low back^{51,52} and restricting its role to helping stiffening the trunk and preventing tissue strain⁵³, IAP has been recognized as a normal accompaniment and an important factor in supporting the lumbar spine during lifting⁵⁴⁻⁵⁶. Bartilink⁵⁴ in 1957 proposed the idea and was expanded by other researchers⁵⁷⁻⁵⁹. It is believed that as a result of the inflated abdominal cavity

because of muscle contraction, the moment arm of the erector spinae muscle group is lengthened as the axis of rotation for the sagittal movement is shifted anteriorly into the abdomen from the intervertebral space. This allows the erector spinae muscles to stabilize the trunk with less force and hence reduce spinal compression. In addition to that, IAP makes a rigid compartment that resists lumbar flexion and as a result relieves stress off the erector spinae muscles⁵⁴⁻⁵⁶. One researcher reported that IAP may contribute from 11 to 20% in relieving compressive forces in the lumbar spine⁵⁵ While others suggested 40%^{55,60,61,62}.

In order to examine IAP with other aspects of lifting, oblique abdominal muscles (OA) activities were compared with intra abdominal pressure. The results showed that the intra abdominal pressure was higher in the squat lift (5.7kpa) than back lift (3.4kpa) and the activity of the OA and IAP tended to coincide but OA activity proceeded the IAP by about 100 ms. This may have happened because of the need to stabilize the trunk in the start of the lift⁶³. That is in agreement with another study that stressed the importance of this result to the pathogenesis of inguinal hernia¹³. Further more, less intra abdominal pressure(IAP) was observed when the trunk was flexed than when the trunk was erect⁶⁴ but when IAP was assessed in relation to lifting while sitting, It was found that the IAP increased when lifting with the trunk rotated to either side and also when bending forward. There was further increase as bending of the trunk increased⁶⁵.

Lifting Belt

Lifting belt is commonly used in industrial work and in sports. In one recent study, about 30% of health club members used lifting belts and most of them utilized belts in situations that do not typically stress the trunk musculature⁶⁶ (Dan Abraham, 2003) The working mechanics of the belt is thought be in forcing the abdominal muscles to move inward as they bulge while contracting which leads to a rise in abdominal muscle activity and hence increased IAP which help in decreasing the high lumbar compression and shear forces when lifting^{64,74-76}. The increased abdominal muscle activates is though to be a result of the belt resistance to the contraction of the abdominal muscles allowing a more intense voluntary contraction^{17,77}. The decrease in lumbar compression and shear forces is attributed to the increase in the abdominal cavity pressure (IAP) which in turn enables it to bear up to 50% of the load normally placed on the spinal column⁶⁸. An increase in IAP from 13-40% with the belt worn is

well documented^{7,75,65,78}. Others linked the use of the belt to improvement in performance when compared to without⁶⁸ and to trunk stabilization and avoidance of twisting when lifting^{17,34,59}.

Many studies have tried to evaluate the benefits of the lifting belt. Some of the studies have found positive effects of wearing a belt during lifting. One aspect that was researched is the effect of wearing a belt on IAP. In one study, it was found that wearing a belt increases IAP and suggested that using a belt reduces disc compression force and improve lifting safety^{34,76}. Another study found that wearing a belt aids in supporting the trunk by increasing IAP⁷. Furthermore, a positive correlation between the increase in IAP and weight lifted was found as a result of wearing a belt⁶⁸. Another aspect that was studied is the effect of the belt on muscle activities. The expected result is that with a belt, there would be an increase in abdominal muscle activities which leads to increased IAP which in turn help in unloading the lumbar spine by decreasing erector spinae stress and resistance to lumbar flexion. In fact, that was the case in one study. It was found that wearing a belt increases the activity of rectus abdominus and decreases the activity of external oblique¹⁷. The decrease in the activity of the external oblique with the belt was also found in an other study⁷⁹. The noticeable remark in this study is that the decrease was only in women subjects but not men which stress the differences between the two sexes in the analysis of lifting. Others found a positive effect on intra-muscular pressure of erector spinae muscle and concluded by saying that wearing a belt may contribute to stabilization during lifting exertions⁷⁸. Moreover, wearing a belt may improve the lifting explosive power by increasing the speed of the movement without altering muscle electrical activity or compromising joint range of motion and lifting technique⁸⁰.

Even though the previous studies may indicate positive effects of wearing a belt during lifting activities, there are also many studies that found either no positive effects or negative effects^{17,50,75-81}. In one study, Thomas found that the biomechanical effect of the belt during sudden loading is small and situationally dependent and there was no support to the use of the belt in order to minimize Para spinal muscle fatigue or a loss in isometric force production⁷⁷. Moreover, no difference was found between muscle activities of the spinae and abdominal when lifting with and without a belt^{17,78,82}. Furthermore, a possible preventive benefit in wearing a belt was found, but its effect on other joints needs to be studied before

a conclusive recommendation is given⁸². Marras⁸⁰ added that lifting with the belt adds a strain on the cardiovascular system and recommended that individuals with compromised cardiovascular system are advised not to exercise with back support.

The effect of wearing a belt was studied in relation to other factors involved in lifting like breath holding and asymmetric lifting. Breath holding when lifting is reported to unload the spine slightly when lifting. The belt has been shown to have no effect on IAP when lifting while holding breath^{72,78}. Asymmetric lifting is also studied. The effect of wearing a belt on erector spinea muscles during asymmetric sudden lifting and found small effect to provide effective protection of workers⁷⁷. Finally, an important issue that has not been addressed is the long term effect of wearing a belt⁵³.

Implications

By reviewing the previous recommendations and with this review that included the latest studies, it should be clear that it is still difficult to present solid recommendations about all aspects of lifting. The following recommendations should be considered in light of many involved factors that influence the amount of load placed on the lumbar region.

- 1- Low acceleration is recommended when lifting moderately heavy load.
- 2- Avoidance of the pausing in the process of lifting should be taken into consideration.,
- 3- it is recommended that the individual keeps the load as close to the body as possible in order to reduce torques resulting from load handling.
- 4- Leg lift (squat) where normal lumbar lordosis is preserved and knees and hips are flexed is recommended. Leg lift transfers the load from the small muscles of the back and arms to the strong ones in the legs⁸.
- 5- The belt should be worn for maximum or near maximum lifting. If training for an activity that a belt is not worn, athletes and workers are advised to do some of their training without a belt. That could help in strengthen the deep abdominal muscles and improve the pattern of muscle recruitment needed to generate high IAP when a belt is not worn⁷⁰.
- 6- People with a compromised cardiovascular system are advised not to lift with back support.
- 7- Gender Differences should be taken into consideration when giving advice about lifting.

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