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Squat, stoop, or something in between?

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Abstract

This article reviews the empirical and theoretical bases for recommendations regarding lifting technique. Lifting from postures involving extreme lumbar vertebral flexion, (approximately 60° of lumbar flexion, characterised by absence of electromyographical activity in erector spinae) has the potential to contribute to damage to ligaments and intervertebral discs, especially if combined with lateral flexion or rotation. The only appropriate recommendation regarding posture of the lumbar spine during lifting is to avoid postures involving extreme lumbar vertebral flexion (and rotation and lateral flexion). There is no empirical basis for avoiding postures involving moderate lumbar vertebral flexion, and no justification for advocating lifting from a full squat posture. Further, lifting from semi-squat postures, involving a moderate range of flexion at both knees and trunk, allows a pattern of interjoint coordination which appears to be functional in reducing muscular effort. Lifting training is generally ineffective, and there is unlikely to be a single "best" technique which is appropriate in all situations. Consequently, it may be preferable to provide education in general lifting guidelines and assist lifters to discover individually appropriate postures and patterns of movement. The article concludes by presenting recommendations for lifting technique which are justified by current knowledge.

Relevance to industry

Lifting from a full squat posture is frequently recommended as a means of reducing the likelihood of back injury. This recommendation is not justified, and training of this type should not be provided. Education in the general lifting guidelines provided here may be beneficial.

Keywords: Lifting technique; Lumbar spine; Injury mechanics

1. Preface

For centuries lumbago has been regarded as a rheumatic manifestation. … It is evident that abnormalities have been sought in the lumbar muscles without critical enquiry into whether or not lumbago is primarily a muscular lesion. In my view it is not; it is the result of an attack of internal derangement of a low lumbar joint. …

Prophylaxis. Patients liable to lumbago must avoid heavy work involving trunk-flexion. They must learn to kneel and squat instead of bending forwards. … it is full flexion that encourages the onset of lumbago. … Should a patient liable to lumbago feel discomfort in (their) back lasting more than an hour, (they)

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> should go and lie down at once… Recurrence of attacks at short intervals … points to the danger of the development of sciatica from disc protrusion. Hence, patients in this state should adopt lighter work, and wear a belt stiff and tight enough to limit movement at the lower lumbar spine.
>
> If the views set out in this paper gain acceptance, it will become reasonable for medical officers attached to factories to warn employers of the danger of allowing anyone with a defective low lumbar intervertebral disk to do heavy work…

So wrote James Cyriax (then Assistant Medical Officer, Physiotherapy Department, St. Thomas's Hospital) in a letter published in *The Lancet*, October 6, 1945 (Vol. 2, pp. 427–429). The passage quoted is one of the earlier occurrences of a recommendation regarding altering lifting technique to avoid back injury (although the idea can be traced back to the 1920s).

There are a number of observations to make about the article. One is that Cyriax believed "lumbago" was caused by "a momentary posterior displacement of a movable piece of intra-articular fibrocartilage", and that the "defect" was genetic, rather than a consequence of loading. He wrote:

> Posterior defect of the annulus fibrosis may be regarded as a failure in embryonic fusion… I regard the accident mentioned by some patients not as fracturing the cartilage but as making manifest a defect already in existence. A history of lumbago or sciatica in parents and siblings is often met with…

Interestingly, Cyriax's comments regarding the benefits of avoiding heavy work involving trunk-flexion were restricted to such genetically predisposed persons. Somewhere along the line it became an article of faith that lifting should be carried out from a full squat posture, despite many researchers noting that the recommendation was unjustified (e.g., Whitney, 1958; Brown, 1973; NIOSH, 1981). The aim of this article is to examine current knowledge about the mechanisms of back injury, the biomechanical consequences of different lifting techniques, and the implications of these for avoiding injury due to lifting.

2. Injuries caused by lifting

Large extensor moments about the joints of the lumbar vertebral column are produced during lifting by the paravertebral musculature to overcome the flexor moment caused by the weight of the upper body and load. Injury to musculoligamentous structures occur as a direct consequence of the high forces involved.

These high forces also result in large compressive and shear forces acting between each pair of vertebra. Unless the cadaveric lumbar spine is in a posture of extreme flexion, the mechanism of failure due to a single compressive load is failure of the endplates of the vertebral bodies and the underlying trabeculae as the nucleus pulposus bulges upward and downward (Adams and Dolan, 1995). In life, the magnitude of compressive forces experienced during a single lift is unlikely to cause endplate failure, and injury is more likely to be cumulative.

Cumulative damage to the vertebral endplates may occur in a number of ways. Microdamage to vertebral endplates is likely during heavy lifting, and injury may arise if the microdamage accumulates more rapidly than can be repaired. Repeated compressive loading will also reduce the failure tolerance of the tissues, resulting in injury if repeated loading continues (McGill, 1997). Damage may also be additive in that prolonged exposure to other sources of loading, and especially whole body vibration, may render the vertebral bodies vulnerable to injury during lifting.

Lifting from postures involving extreme lumbar vertebral flexion has the potential to contribute to injury. Extreme lumbar vertebral flexion is characterised by absence of electromyographical activity in erector spinae (e.g., McGill and Kippers, 1994). In this situation the anterior moment caused by the weight of the upper body and load is balanced by an extensor moment created by tension in the paravertebral ligaments, interspinous ligaments, posterior fibres of annulus fibrosus, and passive elements of the musculotendinous tissues. The first tissues to be injured in this situation are the interspinous ligaments (Adams and Dolan, 1995). Disruption of the posterior fibres of annulus may follow if extreme lumbar flexion is combined with compression and lateral bending or torsion.

If damage to the posterior annulus progresses, seepage of the nucleus pulposus through the annulus may result (an intervertebral disc prolapse). While intervertebral disc prolapse only accounts for small proportion of claims for back injuries (5–10%), the injury frequently results in chronic back pain and accounts for a considerably larger proportion of claims costs.

Compressive load alone will not cause intervertebral disc prolapse, and damage to the intervertebral disc is unlikely to occur as a consequence of one-time loading (although this is possible if high compressive load is placed on the spine while hyperflexed and laterally bent) (Adams and Dolan, 1995). Injury to the intervertebral disc is more likely to be the consequence of an accumulation of microdamage due to repeated compressive and torsional loading applied while the lumbar spine is extremely flexed.

Anterior shear forces are also very high when loads are lifted from a posture of extreme lumbar flexion and this represents a risk of injury. However, the orientation of the fibres of the erector spinae muscles (in particular, the pars lumborum fibres of longissimus thoracis and iliocostalis lumborum) is such that when tension develops in these muscles a posterior shear force is created on the superior vertebrae which counteracts the anterior shear created by the weight of the upper body and load (McGill, 1997). The erector spinae are active unless lumbar flexion is extreme, and consequently the anterior shear forces are reduced in postures which do not involve extreme lumbar flexion.

Prolonged exposure to static postures involving extreme lumbar vertebral flexion will also cause the tissues to creep (the ligaments do not return to their resting length immediately upon unloading). The consequence may be a temporary loss of stability after the period of sustained extreme lumbar flexion which may lead to a higher likelihood of injury in subsequent loading in any posture (McGill, 1997). The abdominal muscles normally contribute to stability of the spine, and failure to contact these muscles appropriately may also increase the risk of injury.

3. Biomechanical consequences of different techniques

Lifting technique has typically been defined in terms of the posture adopted just before the load is lifted. It has commonly been proposed that the postures adopted to lift loads from a low level may be characterised in terms of two extremes. One extreme, described as a stooped posture, is one in which the knee joints are almost fully extended and the hip joints and vertebral column are flexed to reach the load (see Fig. 1A). The second extreme, described as a full squat, is one in which the knee joints are fully flexed and the trunk is held as vertical as possible (Fig. 1C). It has become a matter of dogma that the latter posture is the "correct" manner of lifting.

The authors of the otherwise influential 1981 NIOSH "Work Practices Guide for Manual Lifting" observed that the full squat posture reduced stability (the heels are inevitably lifted from the ground and the knees are in an unstable "loose packed" posture when maximally flexed) leading to the possibility of injury due to unexpected perturbations; and that the technique increased the distance of wide loads from the spine (increasing the load moment and consequently the resulting extensor moment and compressive forces). It was concluded that the squat lift recommendation was based on simplistic mechanical logic which failed to take dynamic loading on the back and the knees into account. More recently, van Dieen et al. (1999) conducted a comprehensive review of 27 biomechanical studies comparing stoop and squat technqiues, and similarly concluded that no justification existed for advocating a squat technique.

The proponents of the full squat technique suggested that the stresses on the vertebrae are better distributed with the lumbar spine in a lordotic posture. However, Jager and Luttman (1989) utilised a three-dimensional dynamic model

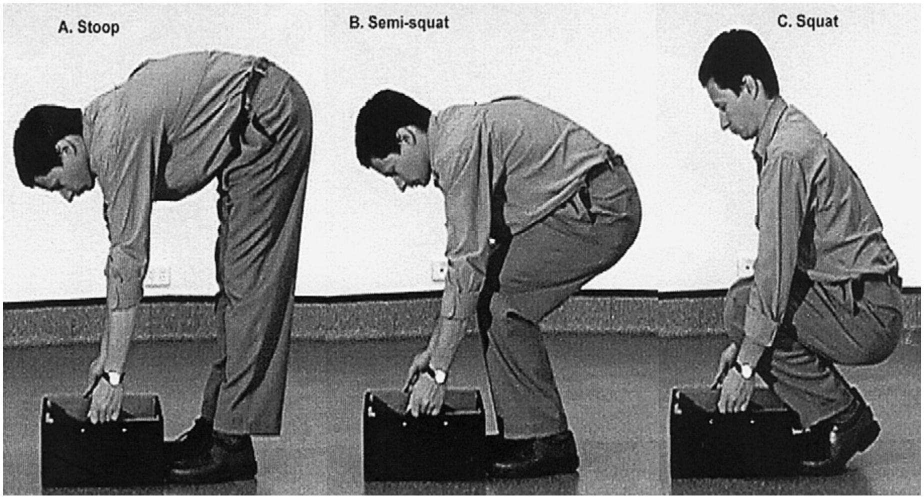

Fig. 1. Demonstration of a stooped posture (A), a semi-squat posture (B), and a full squat posture (C).

to estimate lumbar compression and found that while compression was highly influenced by load moment, lifting speed, and acceleration; lumbar curvature had little influence. In fact, lordosis poses several disadvantages relative to postures of partial flexion (Adams and Dolan, 1995), including increased loading of apophyseal joints and increased compression of the posterior annulus. Lordosis has been advocated to reduce hydrostatic pressure in the nucleus, but this only indicates that the load has been shifted to the annulus and apophyseal joints.

An additional pragmatic problem with the "full squat" recommendation is that it cannot be utilised in many situations. Maximal knee flexion has the consequence of lengthening the quadriceps beyond their optimal length leading to decreased knee extensor strength. The result is that lifting capacity is reduced: sub-maximal loads require greater muscular effort leading to more rapid onset of muscular fatigue; maximal loads cannot be lifted at all.

From the discussion of injury mechanisms above it is evident that the only appropriate recommendation regarding posture of the lumbar spine is to avoid extreme lumbar vertebral flexion, and trunk rotation and lateral flexion. There is no basis for avoiding postures involving moderate lumbar vertebral flexion.

The traditionally recommended full squat posture is seldom, if ever, spontaneously adopted in the absence of specific instruction. Investigations of self-selected lifting technique have revealed that the postures typically adopted to lift low lying loads are intermediate between full squat and stoop extremes (see Fig. 1B), and might be termed semi-squat (e.g., Burgess-Limerick et al., 1995; Burgess-Limerick and Abernethy, 1997). Lifting a low lying load from a semi-squat posture typically involves about 45° of lumbar vertebral flexion, that is, about 75% of the normal range of movement. In conjunction with the absence of an electromyographical silent period in erector spinae, this suggests that the passive structures of the back are not substantially stretched during lifting from this posture. Stooped postures involving greater lumbar flexion are adopted by some people in some circumstances, although typically this occurs when the load is relatively light.

An adequate description of lifting technique requires consideration of the pattern of interjoint coordination as well as the posture adopted at the start of the lift. The posture adopted at the start of extension influences the pattern of subsequent interjoint coordination by determining the range of movement available at each joint. The semi-squat posture most commonly adopted at the start of extension allows a pattern of interjoint coordination which appears to be functional.

The coordination of self-selected lifting involves contemporaneous movement of the lower limb and trunk joints, that is, the joints flex and extend at the same time rather than sequentially (as is sometimes modelled). However, the joints are not perfectly synchronised: a consistent pattern of deviation from synchronous coordination is commonly observed. Knee extension typically occurs more rapidly earlier in the lifting movement relative to extension of the hip, and the onset of rapid lumbar vertebral extension is delayed substantially after the start of the lift. The moderate lumbar flexion observed lengthens the erector spinae relative to its length in normal standing, and the delay before rapid lumbar vertebral extension delays rapid shortening of the erector spinae. Estimation of the length changes of the biarticular hamstring muscles has revealed that these muscles are also relatively lengthened at the start of the extension phase, and that the pattern of coordination between knee and hip joints also has the consequence of delaying rapid shortening of the hamstrings.

Muscles are stronger when lengthened, and when not shortening rapidly, and thus this pattern of coordination increases the strength of the hamstrings and erector spinae early in the extension phase when the acceleration of the load is greatest by both lengthening the muscles, and delaying their rapid shortening. Delaying shortening of the hamstrings has the additional functional consequence of allowing the monoarticular knee extensors to, paradoxically, contribute to hip extension through a tendinous action of the hamstrings. The pattern of coordination observed thus reduces the muscular effort required to perform the task, and the pattern of interjoint coordination is exaggerated with increased load mass.

A different pattern of coordination between hip and knee occurs when a stooped posture is adopted at the start of extension. The large range of hip flexion and small range of knee flexion involved results in the hamstrings being lengthened further than if a semi-squat posture were adopted. A stooped posture has the advantage of lowering the centre of gravity of the upper body less than a semi-squat posture and thus less work is done in lifting the upper body during each lift. However, during lifting from a stooped posture the hamstrings must immediately shorten rapidly because the knee is unable to extend rapidly. This counteracts to some extent any strength advantage which might accrue as a consequence of the increased hamstring length and prevents the monoarticular quadriceps from contributing to hip extension.

4. Implications for avoiding injury due to lifting

Training people to perform lifting in safer ways has been consistently proposed as a means of reducing the risk of injury, however research evaluating the effectiveness of lifting training programs involving uninjured workers has generally failed to find any evidence of persistent modification in lifting technique (Pheasant, 1986). If it can be assumed that muscular fatigue contributes to injuries suffered as a consequence of lifting, then a technique which reduces muscular effort may be preferred. Rather than prescribing a single "best" technique which is not likely to be appropriate in all situations, it may be preferable to provide education in general lifting guidelines and use exploratory learning techniques (Newell, 1991) to assist lifters to discover individually appropriate postures and patterns of movement.

General lifting guidelines which can be justified on the basis of current knowledge include:

- Wherever possible, remove exposure to manual lifting by providing mechanical aids (hoists, etc),
- If manual lifting must be undertaken, reduce the load mass (weight),
- Raise the initial height of low loads,
- Keep the load close,
- Adopt a posture at the start of the lift which involves a moderate range of motion at the knee, hip and vertebral column (a semi-squat posture),
- Avoid lifting from a posture of extreme lumbar vertebral flexion (a stooped posture),
- Avoid trunk rotation while lifting,
- Avoid lateral trunk flexion (bending sideways) while lifting,

- Avoid lifting after prolonged periods of extreme lumbar vertebral flexion (stooping),
- Avoid high acceleration of the load (lift smoothly).

The risk of injury to the back caused by lifting can also be reduced by:

- Reducing exposure to whole body vibration (driving)
- Strengthening the bones, ligaments, and muscles by appropriate exercise.

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