Weight lifting using a "squat bar" is a commonly performed activity in athletes of all ages, disciplines, and levels of expertise. The potential injuries in both skeletally immature and fully developed athletes resulting from this exercise include muscle and ligamentous strains, ruptured intervertebral discs, spondylosis, and spondylolisthesis (secondary to severe loading in hyperextension).1,9,28 The most common cause of injury in this group appears to be poor technique and loss of form, particularly when heavy weights are lifted.24

The lumbar vertebral bodies and intervertebral discs resist approximately 80% of the compressive force acting on the spine in the upright standing posture, with about 40% of the vertebral body's resistance being supplied by the cortical shell.1 The vertebral body is the first spinal structure to fail during compression, and its ability to resist this force depends on the age, sex, and body mass of the individual, along with the subject's bone mineral density.1 Failure of the vertebral body has been found to occur with much lower forces during repetitive (fatigue) loading, and the compressive strength of a vertebral body is reduced by 30% if 10 loading cycles are applied.1,5 Spinal compression increases linearly with the weight being lifted and with its distance from in front of the feet, with the peak compressive force on the spine being doubled if weights are lifted rapidly.7 In addition to this, the extent to which the athlete extends his or her lumbar spine during this exercise becomes significant when it is considered that

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**Background:** Heavy weight lifting using a squat bar is a commonly used athletic training exercise. Previous in vivo motion studies have concentrated on lifting of everyday objects and not on the vastly increased loads that athletes subject themselves to when performing this exercise.

**Hypothesis:** Athletes significantly alter their lumbar spinal motion when performing squat lifting at heavy weights.

**Study Design:** Controlled laboratory study.

**Methods:** Forty-eight athletes (28 men, 20 women) performed 6 lifts at 40% maximum, 4 lifts at 60% maximum, and 2 lifts at 80% maximum. The Zebris 3D motion analysis system was used to measure lumbar spine motion. Exercise was performed as a “free” squat and repeated with a weight lifting support belt. Data obtained were analyzed using SAS.

**Results:** A significant decrease ($P < .05$) was seen in flexion in all groups studied when lifting at 40% maximum compared with lifting at 60% and 80% of maximum lift. Flexion from calibrated 0 point ranged from $24.7^\circ$ (40% group) to $6.8^\circ$ (80% group). A significant increase ($P < .05$) was seen in extension when lifting at 40% maximum was compared with lifting at 60% and 80% maximum lift. Extension from calibrated 0 point ranged from $-1.5^\circ$ (40% group) to $-20.3^\circ$ (80% group). No statistically significant difference was found between motion seen when exercise was performed as a free squat or when lifting using a support belt in any of the groups studied.

**Conclusion:** Weight lifting using a squat bar causes athletes to significantly hyperextend their lumbar spines at heavier weights. The use of a weight lifting support belt does not significantly alter spinal motion during lifting.

**Keywords:** lumbar spine; disc; weight training; 3D motion
2° of extension increases the compressive stress within the posterior annulus by a mean of 16% compared with neutral loading.2

Vigorous sporting activities are associated with degenerative changes in the lumbar spine and lower back pain.11,26,27 Low back injuries in athletes and their long-term sequelae may be owing to repetitive (fatigue) weight training causing damage to vertebral bodies, growth plates, and intervertebral discs. The loss of form seen when lifting heavy weights and after fatigue due to resistance training attenuates the forces being exerted on the spinal segments and is likely to contribute to the short- and long-term injuries seen in this group.1,24

Previous studies have shown that intradiscal pressure is significantly influenced by body position and maneuver while lifting light weights.2,18-21,23,25 However, no studies have been undertaken examining the motion of the lumbar spine while performing squat lifting. The aim of our study was to analyze the lumbar spinal motion that occurs during squat lifting using light, intermediate, and heavy weights and to assess the potential implications that this motion might have for the athletes undertaking this exercise as part of their training regimens. As an adjunct to the study, the athletes’ spinal motion was also analyzed while performing the same set of exercises using a commercially available weight lifting belt, to view whether this altered their spinal motion during the performance of squat lifting.

MATERIALS AND METHODS

A total of 48 athletes were recruited from senior varsity rowing and rugby union teams. This consisted of 28 male and 20 female athletes. These athletes were selected because they regularly perform in-line squat lifting exercises as a part of their training regimens for these sports.

The recruited athletes performed a total of 24 lifts each during the course of the study. The subjects initially performed 6 lifts at 40% of their maximum weight lifting capability. This was then followed by 4 lifts at 60% maximum and 2 lifts at 80% maximum (an assessment of maximum lifting capability was determined within 1 week before the study, and all subjects were supervised by a qualified coach). This initial group of exercises was then repeated using a weight lifting support belt (York Fitness, Northants, England) to see if this altered the range of motion seen in the athletes by providing support to the lumbar spine during lifting. One subject in the male group was noted to have a number of unusual movement values and was omitted from the analysis.

The male athletes were 23.9 years (range, 20-30 years) on average, with a mean height of 185.8 cm (range, 170-204 cm) and a mean weight of 84.6 kg (range, 70-105 kg). The weights lifted by the male group in each of the 3 lifting exercises averaged 41.75 kg (40% group), 63.75 kg (60% group), and 85.41 kg (80% group).

The female athletes were 22.4 years (range, 19-26 years) on average, with a mean height of 171 cm (range, 166-177 cm) and a mean weight of 61.3 kg (range, 54-79.3 kg). The weights lifted by the female group in each of the exercises averaged 28.75 kg (40% group), 43.13 kg (60% group), and 58.7 kg (80% group).

Motion analysis of the athletes was performed using the Zebris 3D real-time motion analysis system CMS 50 (D-88316, Zebris Medizintechnik GmbH, Isny, Germany). This system has been previously validated in a number of spinal motion studies6,8,17,22 and performs a 3D motion analysis by measuring the propagation time of ultrasound pulses. It achieves this using an ultrasonic triple emitter and an ultrasonic triple sensor array (Figures 1 and 2). The system then calculates and images the ultrasound pulses in real time, allowing the absolute spatial coordinates of the ultrasound markers to be determined with the aid of triangulation. The basic unit is connected to the parallel printer port of a personal computer, allowing the kinematic data to be transmitted. These data are then analyzed by dedicated software and displayed graphically. By having each plane of movement represented graphically, it is possible to examine pure movements in single planes. For the purpose of this study, 1 triple emitter and 1 triple sensor array, working with a frequency of 35 kHz, were used for measuring the lumbar spine.

The lifts were performed using a free-squat Olympic bar, and the motion assessment was achieved using 1 emitter and 1 sensor array connected to the Zebris system. The triple emitter array was positioned at the thoracolumbar junction, with the triple sensor array positioned at the sacrum. Both the emitter and the sensor array were attached to the body by elasticized straps to minimize artifact motion during lifting (Figures 1 and 2).
Motion was then analyzed to view changes in lifting form (flexion, extension, lateral flexion, axial motion) occurring during heavy weight lifting and after repetitive lifts, at the varying weights previously described, to analyze lumbar spinal motion occurring during this activity.

The Zebris system was calibrated to the 0 position with the athletes standing with the weight supported on their shoulders at the top position of the lift (Figures 2 and 3). Any flexion from this position was recorded as a positive value, with any extension being recorded as a negative value by the motion analysis software.

During the performance of the lift, the athletes commenced the test in the 0 position and then descended in a steady fashion to the lowest point of the lift at which their knees were bent at a 90° angle (Figure 4). The athletes were then instructed to rise and return to the 0 position, in preparation for the next lift. All lifts were supervised by a qualified instructor.

STATISTICAL ANALYSIS

For the purpose of analysis, the athletes were divided into male and female groups and further divided by movement (flexion/extension). The data were analyzed for each gender and extension-flexion combination using a fixed-effects approach with repeated measures and treating subject as a block effect. The statistical package SAS (SAS Institute, Cary, NC) was used for the analysis. The statistics software Minitab was used to obtain histograms for each gender, lift, and belt usage combination for both flexion and extension. Statistical significance was noted for values of $P < .05$. In the case of multiple comparisons, the Bonferroni adjustment was made.
When reviewing the data obtained from the 3D motion study, a low level (<5°) of axial rotation and lateral flexion was found in all groups and on viewing each incremental weight exercise. Further analysis, therefore, concentrated on the varying ranges of flexion and extension in the different groups with and without the weight lifting support belt.

A table of means for each gender, lift, and flexion-extension combination, along with SDs of the means (SDs of the means for each gender, lift, and movement combination are equivalent for belt and no belt), is given in Table 1. To illustrate the range and variation in the data, histograms for each gender, movement, lift, and belt (“free” or belt) combination are presented in Figures 5 through 8. From these figures, we can see that the range in flexion for the 60% lifts and the range in extension for the 60% lifts were slightly larger in the male group than in the female group. The ranges in the remaining movement lift and belt combinations were similar for the male and female groups.

In the male group, there was a significant decrease in flexion between the 40% lift and the 60% lift (P < .001) and between the 40% lift and the 80% lift (P < .001). However, there was no significant difference in flexion between the 60% lift and the 80% lift (P = .149). In the female group, there was a significant decrease in flexion between the 40% lift and the 60% lift (P < .001), between the 40% and the 80% lift (P < .001), and between the 60% and the 80% lift (P = .008).

In the male group, there was a significant increase in extension between the 40% lift and the 60% lift (P < .001), between the 40% and the 80% lift (P < .001), and between the 60% and the 80% lift (P = .005). There was a significant increase in extension in the female group between the 40%
lift and the 60% lift, between the 40% and the 80% lift, and between the 60% and 80% lift (each with \(P < .001\)).

For men, use of a support belt did not reduce flexion in comparison with the free squat for the 40% lift (\(P = 2.94\)), 60% lift (\(P = .995\)), or 80% lift (\(P = .673\)). This is evident from Table 1 in that the differences between the means for each lift are small relative to the SDs of these means. Similarly, for women, using a support belt did not reduce flexion in comparison to the free squat for the 40% lift (\(P = .437\)), 60% lift (\(P = .464\)), or 80% lift (\(P = .328\)). This can be seen from the differences between the means for each lift and the SDs of these means in Table 1.

Wearing a belt did not reduce extension in the male group for the 40% lift (\(P = .652\)), the 60% lift (\(P = .701\)), or the 80% lift (\(P = .857\)). Similar results were seen in the female extension group with means displayed in Table 1 (40% lift, \(P = .868\); 60% lift, \(P = .912\); 80% lift, \(P = .602\)).

**DISCUSSION**

It can be seen from our results that although athletes exhibit a low level of extension when lifting at a relatively light weight (40% maximum), they hyperextend to a significant degree when lifting at heavier (60%, 80% maximum) weights.

The increased hyperextension seen when lifting the heavier weights in this study may be related to decreased stability in the athletes during the performance of the lift at increased loads. During the study, we observed that (regardless of the weight being lifted) as the athletes descended from the 0 position (Figures 2 and 3), their spines flexed, bringing the weight in front of the spinal column and exerting a flexion force acting on the lumbar spine. At the heavier weight (60%, 80%), this moment of force is increased. The overall effect of this is that the athletes are forced to raise their heels from the ground as the moment acting on the lumbar spine pulls them forward. This is a relatively unstable position, and to avoid falling forward, the lifter must find a way to bring the weight closer to its original (0) position directly above the spine. This can only be achieved by hyperextending the lumbar spine to move closer to the original loading axis. As the spine hyperextends, the athletes’ heels return to the floor, providing a more stable platform and allowing them to complete the lift.

A potential method of decreasing (or preventing) the hyperextension seen at heavier weights from occurring would be to instruct the athletes to maintain their heels on the ground throughout the lift or to provide a heel support to allow a greater degree of stability to be maintained during the course of the lift (Figure 3). This simple alteration in technique or easily added device would result in the athletes maintaining a more upright posture during the lift and would obviate the need to hyperextend the spine to regain stability.

The cause for our concern regarding the degree of hyperextension seen in these groups stems from studies that have subjected the spine to compression during extension, which have shown that the posterior annulus can experience significantly increased pressures when this occurs.\(^3,10,25\) In addition to this, whereas numerous studies have examined the pressure effects of lifting and posture on the spine in both live and cadaveric models,\(^7,10,23,25\) these studies have concentrated on the lifting of everyday objects placed in the hands (<20 kg) and not on the vastly increased loads that athletes subject themselves to when weight training during squat lifting. To the authors’ knowledge, this is the first study examining lumbar spinal motion during light and heavy squat lifting as a training exercise using a 3D motion analysis system.

Although this exercise has in the past often been performed using a Smith machine (consisting of a barbell linked to a vertical track by cylinder bearings, permitting only vertical displacement of the attached weight), the use of this particular piece of equipment was associated in some isolated cases with severe injury.\(^11\) Its use has largely fallen out of favor with modern coaching methods, leaving the free squat lifting (with or without a weight lifting support belt) to form the most commonly used method of performing this type of exercise.

The use of the belt weight lifting support device seen in this study appears to be of little more than psychological benefit from the perspective of spinal motion. Although many of the athletes studied felt that the belt provided an additional support to their lower backs during lifting, the results show that there was no significant difference in the motion seen in male and female athletes when a comparison of the groups while lifting with and without a belt was made.

Although the significant degree of lumbar hyperextension seen in this study at the heavier (60% and 80%) weights is a cause for concern among the adult athletic population, particular attention should be paid to skeletally immature athletes performing this exercise. The pattern of injury that occurs in the lumbar spine in adolescents differs from that occurring in the spines of fully mature individuals, with growth plate fractures forming a prominent feature in the spines of individuals younger than 20 years of age, whereas in adult lumbar spinal segments, vertebral body fractures are more common when the spine is subjected to compression.\(^16\)
Furthermore, numerous studies have displayed the vulnerability of the lumbar spine in adolescent and young athletes engaging in high-impact sports by showing they have a number of radiographic abnormalities in their lumbar spines.\(^4\,5\,12\,16\,17\)

When the increased pressure that occurs in the posterior annulus of lumbar discs subjected to compression during extension is considered,\(^6\) it can be seen that athletes performing heavy and repetitive squat lifting exercises are subjecting themselves to a significantly increased hyperextension load and a potentially elevated injury risk at a very early stage of their careers. Further research is required to assess the interrelationship between the level of weight lifting and the incidence of injury in this group at such a vulnerable stage in their development. In addition, although the weight lifting support belt was not found to influence the motion of the spine during squat lifting, it remains to be seen whether it has effects on the intrathecal pressure in the lumbar spine when used during this exercise. The ultimate goal of research in this area should be to answer the question as to whether skeletally immature individuals should be prohibited from performing heavy squat lifting as part of training for any athletic discipline.

REFERENCES