Effects of eccentric exercise on trunk extensor torque and lumbar paraspinal EMG

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ABSTRACT

HERMANN, K. M., and W. S. BARNES. Effects of eccentric exercise on trunk extensor torque and lumbar paraspinal electromyographic (EMG) parameters. Med. Sci. Sports Exerc., Vol. 33, No. 6, 2001, pp. 971–977. Purpose: Little is known about the effects of eccentric contractions on the function of the lumbar paraspinal muscles. The purpose of this study was to determine the effects of a single bout of eccentric contractions using the trunk extensor muscles on torque and lumbar paraspinal electromyographic (EMG) parameters. Methods: Twenty healthy men between the ages of 18 and 49 yr participated in the study. Subjects performed a single bout of 50 maximal voluntary concentric \((N = 10)\) or eccentric \((N = 10)\) trunk extension movements while surface EMG signals were recorded from the multifidus and iliocostalis lumborum muscles. A series of isometric contractions were performed both before the exercise protocol and at five additional time points over the following 7 d. Results: During the exercise protocol, peak torque decreased 30% and 24% in the eccentric and concentric groups, respectively, whereas no change occurred in EMG root-mean-square (RMS). There were no group differences in peak torque generation at any of the postexercise protocol time points. Compared with the preexercise protocol values, multifidus EMG was elevated 27% immediately post and 15 min post in the eccentric group. Similarly, compared with the concentric group, multifidus EMG in the eccentric group was increased 34%, 40%, and 25% immediately post, 15 min post, and 1 d after the exercise protocol, respectively. Conclusion: Eccentric contractions using the trunk extensor muscles result in higher levels of multifidus EMG activity to produce a given level of torque. This reduction in neuromuscular efficiency persisted for one day with recovery to baseline levels by the third day. Contrary to studies using other muscle groups, no sustained alteration in muscle function was observed. Key Words: EXERCISE, LUMBAR SPINE, MUSCLE ACTIVATION, MUSCLE FATIGUE

A great deal of research has focused on the potential differences that exist between concentric (shortening) and eccentric (lengthening) skeletal muscle contractions. Many of these studies have assessed force/torque and electromyographic (EMG) variables and their relationship. For example, torque output has been shown to be up to 146% greater during eccentric compared with concentric contractions when maximal efforts using the knee extensor muscles are performed (35). Despite the ability to generate greater levels of torque during eccentric contractions, muscle activation is not increased proportionately, suggesting an alteration in the torque:EMG ratio compared with concentric contractions (30,35). Likewise, at submaximal intensities, muscle activation during eccentric contractions is less than that observed during concentric contractions at the same level of torque production (3). When repeated, maximal effort contractions are performed, torque has been shown to decrease for both concentric (12,13,30) and eccentric actions (34), whereas EMG remained constant (34).

Studies have also documented the long-term effects of repeated, maximal concentric and eccentric contractions. Compared with isometric and concentric contractions, it is generally accepted that eccentric contractions can produce long-lasting changes in torque and EMG variables. For instance, in one study involving the performance of repeated, maximal eccentric contractions using the elbow flexors, torque generating ability was reduced 50% immediately after the exercise protocol and had only recovered to 80% by 2 wk after the exercise bout (20). Presumably, the prolonged decrement in torque generation was the result of muscle injury induced by the high-intensity lengthening contractions. In another study using the elbow flexors, increased EMG activity for a given level of torque was observed up to 96 h after performance of eccentric contractions (14). Similarly, Felici et al. (8) reported a decrease in EMG initial median frequency at a given level of torque that was still present 96 h after a bout of eccentric contractions. Because median frequency values are related to muscle fiber type (15), these authors interpreted their data to indicate that selective injury occurred in fast-twitch fibers during the eccentric contraction protocol.
Although these studies provide important information concerning muscle function during and after concentric and eccentric contractions, the vast majority have studied limb muscles. Less is known about the effects of eccentric contractions on trunk muscles such as the lumbar paraspinal muscles. To our knowledge, there are no reports documenting the sustained effects of maximal, dynamic contractions on lumbar paraspinal muscle performance. Most reports assessing lumbar muscle function have used static contractions for which torque and EMG parameters including both amplitude and spectral variables have been well characterized (6,17,26). However, because many daily activities require dynamic contractions, it would be instructive to study the effects of these kinds of contractions on lumbar muscle performance. Similar to findings in limb muscles, decrements in torque output have been observed during a bout of maximal contractions (29). Another finding common to both limb muscles and the paraspinal muscles is that eccentric contractions produce lower levels of EMG activity for a given force output compared with concentric contractions (25). However, when EMG parameters are recorded during a bout of eccentric exercise, findings have been inconsistent. Smidt et al. (29) recorded surface EMG amplitude measures from the lumbar paraspinal muscles during repeated maximal concentric and eccentric contractions. They found that integrated EMG decreased during 10 successive maximal concentric/eccentric contractions, which they attributed to fatigue. Similarly, Robinson and coworkers (25) recorded surface EMG from the lumbar paraspinal muscles during submaximal, isotonic eccentric contractions at a load equivalent to 60% maximal voluntary isometric contraction (MVC) and found a decline in integrated EMG during the exercise bout. However, another study found EMG amplitude measures to increase during a bout of repetitive trunk flexion/extension movements at a similar workload (19).

Although these studies provide data during or immediately after an exercise bout, no data were collected in the days after a bout. This information would be useful in light of data from limb muscles documenting sustained impairments in muscle function (8,14,20). If such an impairment were to exist in the lumbar paraspinal muscles after performance of eccentric contractions, spinal tissues may be more vulnerable to injury during subsequent tasks.

The main objective of this study was to determine the acute and chronic effects of eccentric exercise on the performance of the lumbar paraspinal muscles. Torque and EMG variables were recorded before, during, and for an extended period after a single bout of maximal concentric or eccentric contractions. It was hypothesized that: 1) an acute bout of maximal voluntary eccentric contractions using the trunk extensor muscles would result in progressive changes in torque output and lumbar paraspinal muscle activation recorded during the exercise bout, 2) an acute bout of maximal voluntary eccentric contractions using the trunk extensor muscles would cause long-term changes in muscle function consistent with muscle injury, and 3) that both the acute and chronic effects of maximal voluntary eccentric contractions using the trunk extensor muscles would differ when compared with a similar bout of maximal voluntary concentric contractions.

METHODS

Subjects. Twenty male subjects without lumbar pathology volunteered to participate in the study. Subjects were between 18 and 49 yr of age and reported no contraindication to exercise testing as determined by questionnaire. They were randomly assigned to a group performing a bout of maximal voluntary eccentric contractions (N = 10) or a group performing a bout of maximal voluntary concentric contractions (N = 10). Physical characteristics of the subjects in the eccentric and concentric groups, respectively, were (mean ± SD): age 25.5 ± 10.6, 22.2 ± 6.9 yr; height 177.8 ± 7.2, 178.3 ± 6.1 cm; and body mass 74.8 ± 9.1, 78.0 ± 12.6 kg. All subjects gave written informed consent before initiation of the study. The experimental protocol was approved by the Institutional Review Board for the Use of Human Subjects in Research at Texas A&M University.

Experimental procedures. An isokinetic dynamometer (KinCom® 500–11; Chattanooga Group, Hixson, TN) was used to measure trunk extensor torque during the exercise protocol and pre- and post-exercise protocol isometric contractions. Subjects were positioned sitting in a specially designed chair attached to the dynamometer. This chair stabilizes the pelvis and lower extremities so that the center of rotation of trunk movement is supposed to be isolated to the L5–S1 motion segment. The L5–S1 interspace was palpated to align the axis of the actuator arm. Force output was sensed by a load cell attached to a hard rubber pad that was aligned with the inferior angle of the scapula. Angular position was monitored by a digital shaft encoder contained within the dynamometer itself. Voltage signals were recorded from a circuit board contained within the dynamometer and digitized at 3000 Hz by a 12-bit A/D board (DAS-1802 ST-DA; Keithley Instruments, Inc., Cleveland, OH) located in an off-board computer. These signals yielded information related to trunk extensor torque output and angular position.

Before performing the exercise protocol, each subject completed a series of isometric contractions. To become familiarized with the dynamometer, and to serve as a warm-up, subjects performed three 10-s submaximal (~50% MVC) isometric contractions of the trunk extensor muscles followed by two maximal contractions (100% MVC) each lasting 5 s. After the warm-up contractions, maximal and submaximal test contractions were performed, each preceded by 2 min of rest and lasting 5 s. The peak torque observed during one maximal contraction was recorded as 100% MVC. Next, subjects performed isometric contractions at each of the submaximal loads (20, 40, 60, and 80% MVC) presented in a random order. The L5–S1 interspace was used to measure trunk extensor torque during the exercise protocol and pre- and post-exercise protocol isometric contractions. Subjects were positioned sitting in a specially designed chair attached to the dynamometer. This chair stabilizes the pelvis and lower extremities so that the center of rotation of trunk movement is supposed to be isolated to the L5–S1 motion segment. The L5–S1 interspace was palpated to align the axis of the actuator arm. Force output was sensed by a load cell attached to a hard rubber pad that was aligned with the inferior angle of the scapula. Angular position was monitored by a digital shaft encoder contained within the dynamometer itself. Voltage signals were recorded from a circuit board contained within the dynamometer and digitized at 3000 Hz by a 12-bit A/D board (DAS-1802 ST-DA; Keithley Instruments, Inc., Cleveland, OH) located in an off-board computer. These signals yielded information related to trunk extensor torque output and angular position.
Subjects then performed the exercise protocol, which consisted of a single bout of 50 maximal voluntary eccentric or concentric contractions using the trunk extensor muscles, dependent on the group they were assigned to. Eccentric contractions began with the trunk in 10° extension and ended at 40° flexion. Concentric contractions began with the trunk in 40° flexion and ended at 10° extension. Subjects actively returned (without resistance) to the starting position between contractions. The movements were performed at an angular velocity of 20°·s⁻¹. This angular velocity has been used previously and found to be well tolerated by subjects for performance of maximal eccentric contractions using the trunk extensor muscles (29). One contraction was performed every 15 s (4).

The series of isometric contractions (i.e., 20, 40, 60, 80, and 100% MVC) performed before the exercise protocol was then repeated at five time points after the exercise protocol: immediately post, 15 min post, and 1, 3, and 7 d postprotocol. The procedures during these testing sessions was the same as before the exercise protocol except that the warm-up was not performed as at least one submaximal contraction preceded performance of the 100% MVC, and it was thought that this provided sufficient warm-up for the subjects. Lumbar paraspinal muscle soreness was assessed through use of a visual analog scale (28) at each of these same time points.

**EMG.** During all contractions, EMG data were recorded from the lumbar paraspinal muscles using bipolar surface electrodes (Ag-AgCl, 10-mm recording diameter, 25-mm interelectrode distance). Similar to the methods of Ng and Richardson (23), the electrodes were placed on the skin overlying the more superficial iliocostalis lumborum muscle at L2 and the deep multifidus muscle at L5 on the right, with a reference electrode placed on the ulnar styloid process. These electrode locations are based on the results of a previous study that related muscle fiber orientation to surface anatomical landmarks and should encompass the majority of electrical activity from the two muscles (7). Nevertheless, because of the overlapping anatomical arrangement of the lumbar musculature (16), the possibility of cross talk must be entertained. At the L2 level, the longissimus thoracis muscle lies just medial to the iliocostalis lumborum muscle (16) and therefore may contribute to the EMG signal at this location. For this reason, the EMG signal recorded from the iliocostalis lumborum muscle could be considered representative of the lumbar erector spinae.

Before electrode application, the skin was prepared by shaving, abrating, and cleansing with alcohol. Interelectrode impedance was checked to ensure that it was below 5 kOhm. To ensure the same electrode placement between days, indelible ink was used to mark the skin outlining the electrode placement sites. The EMG signals were amplified 1000 times, band-pass filtered at 10 and 1000 Hz (Grass Instruments P511K; Astro-Med, Inc., West Warwick, RI), and sampled at 3000 Hz using the same computer and interface board used for acquisition of the torque and angle data. A custom software program was used to display and write the data to disk, as well as calculate torque and EMG root-mean-square (RMS).

**Reiability.** Although high test/retest reliability of EMG parameters obtained from the lumbar paraspinal muscles has been shown previously (2,23,27,31), data were analyzed from six subjects who performed a series of isometric contractions at loads equivalent to 20, 40, 60, 80, and 100% MVC on two occasions separated by 1 d. The torque generated during the 100% MVC performed on the first day was used to determine the submaximal isometric contraction levels. Intraclass correlation coefficients (ICC [3,1]) for torque and EMG RMS ranged from 0.91 to 0.92.

**Statistical analyses.** Dependent variables included torque and EMG RMS. To assess the effects of contraction type (i.e., eccentric vs concentric) on the dependent variables during the exercise protocol, a two-way analysis of variance (group × contraction) with repeated measures (contraction) was performed. To determine the influence of the exercise protocol on the dependent variables recorded during the submaximal isometric contractions over time, the effects of group (concentric vs eccentric), time (preprotocol, immediately post, 15 min post, and 1, 3, and 7 d postprotocol), and contraction level (20, 40, 60, and 80% MVC) were evaluated using a three-way analysis of variance with repeated measures on time and contraction level. The 100% MVC data were evaluated using a two-way analysis of variance (group × time) with repeated measures on time. When significant interactions were found, contrast statements were used to determine significant differences between means. An α level of 0.05 was used for all analyses. The statistical analyses were performed using SAS version 6.12 software (SAS Institute Inc., Cary, NC). Values reported in the Results are means ± standard errors.

**RESULTS**

**Exercise protocol.** During the exercise protocol, eccentric peak torque exceeded concentric peak torque for all contractions (Fig. 1; P < 0.01). Peak torque progressively decreased over the 50 contractions for both groups (P < 0.05). By the 50th contraction, torque was 30% and 24% lower than the initial contraction for the eccentric and concentric groups, respectively (Table 1). There was no difference between groups for multifidus or iliocostalis lumborum muscle activity (Fig. 2). Similarly, there was no change in muscle activity during the exercise protocol for either muscle (Fig. 2).

**Isometric contractions.** At baseline (i.e., preexercise protocol), the eccentric and concentric groups were similar with respect to torque and muscle activation patterns during maximal (Fig. 3) and submaximal (Fig. 4) isometric contractions. Likewise, after the exercise protocol, there were no group differences in peak torque generating ability at any time point (Fig. 3). For the submaximal contraction data, muscle activation levels increased with increasing contraction intensity in a linear manner. The highest order interaction for the submaximal contraction data was group × time; therefore, the data are presented collapsed across contraction intensity. Compared with the preexercise protocol values, multifidus muscle activity was elevated 27%
immediately after and 15 min after the exercise protocol in the eccentric group (Fig. 4; *P* < 0.05). Contrary to the similarities in the group data at baseline (i.e., preexercise protocol), multifidus muscle activity in the eccentric group was increased 34%, 40%, and 25% immediately after, 15 min after, and 1 d after the exercise protocol, respectively, compared with the concentric group (Fig. 4; *P* < 0.05). The eccentric group also had higher levels of muscle soreness on days 1 and 3 compared with the concentric group (Fig. 5; *P* < 0.001).

**DISCUSSION**

The results of this study show that a single bout of maximal eccentric contractions using the trunk extensor muscles resulted in an increase in the amount of neural drive required to achieve the same amount of torque. No such change in neuromuscular function was observed for the concentric group. This increase, observed only in the multifidus muscle, persisted for 1 d with recovery to baseline levels by day 3. The mechanisms underlying this change in neuromuscular function could be fatigue or exercise-induced injury. In support of the latter, subjects in the eccentric group experienced delayed-onset muscle soreness on days 1 and 3.

The effects of eccentric contractions on muscle function over time has been reported by others, but the majority of these studies have used limb muscles. A reduction in isometric force generation after performance of a single bout of eccentric contractions lasting for several days has been observed for the human knee extensor muscles (9,10) and the elbow flexor muscles (5,14). This decrease in force generating ability has been shown to persist in some cases more than 2 wk after the exercise bout (20). Sustained increases in muscle activity to produce a given submaximal force have also been noted after a bout of eccentric contractions (13,14,22). In contrast, the present findings did not reveal any sustained changes in isometric torque production or muscle activity. One explanation for this may be related to the fiber type composition of the lumbar paraspinal muscles. It is generally accepted that type II fibers are preferentially damaged as a result of eccentric contractions (11). The lumbar paraspinal muscles have a high percentage (~60%) of type I fibers (32), which may render them less susceptible to eccentric contraction-induced injury.

Another possible explanation may relate to lumbar paraspinal muscle function. Owing to their importance in maintaining an upright posture, the lumbar paraspinal muscles are more chronically active and may be “trained” to the extent that a bout of maximal eccentric contractions will not produce the sustained changes in torque production or muscle activity that have been reported by others studying limb muscles. In support of this, it has been shown that recent contractile history is a better determinant of susceptibility to eccentric contraction-induced injury than fiber type composition (33).

A third possibility relates to muscle excursion. Subjects in the present study performed each contraction over a 50° arc of motion while avoiding the extremes of trunk movement. Newham et al. (21) have shown that exercise performed at long muscle lengths produces more pronounced and longer-lasting changes in muscle function compared with exercise performed at short muscle lengths. The range of trunk movement used in this study may not have been sufficiently large to produce sustained decrements in muscle function. Muscle architectural differences between limb muscles and trunk muscles could also be a contributing factor. Rather than a homogeneous, common muscle mass, the lumbar paraspinal muscles are characterized by a series of overlapping fascicles (16), which may render them more resistant to exercise-induced injury.

**TABLE 1. Torque and EMG root-mean-square (RMS) for the iliocostalis lumborum (IL) and multifidus (M) muscles during the exercise protocol (mean ± SE).**

<table>
<thead>
<tr>
<th></th>
<th>Concentric (<em>N</em> = 10)</th>
<th>Eccentric (<em>N</em> = 10)</th>
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<tbody>
<tr>
<td></td>
<td>1st Contraction</td>
<td>50th Contraction</td>
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<tr>
<td>Peak torque (Nm)</td>
<td>257.6 ± 11.0</td>
<td>194.8 ± 17.6*</td>
</tr>
<tr>
<td>IL EMG RMS (mV)</td>
<td>0.21 ± 0.04</td>
<td>0.19 ± 0.03</td>
</tr>
<tr>
<td>M EMG RMS (mV)</td>
<td>0.21 ± 0.03</td>
<td>0.18 ± 0.02</td>
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* Less than 1st contraction (*P* < 0.05).
+ Greater than concentric group (*P* < 0.01).
During the exercise protocol, decrements in maximal dynamic torque were noted for both the eccentric and concentric groups while no changes in EMG activity were noted for either muscle studied. The percent decrements in peak torque observed in this study (30% and 24% for the eccentric and concentric groups, respectively) were greater than what has been reported in another study using the lumbar paraspinal muscles (10% and 8% for eccentric and concentric protocols, respectively). However, the protocol in that study consisted of only 10 (rather than 50) maximal contractions (29). Another report using the anterior crural muscles and a similar exercise protocol (50 maximal contractions) have reported decrements in eccentric torque similar to that observed in this study (34). During the exercise protocol, the decreases in peak torque despite constant EMG amplitude in either muscle suggested that the lumbar paraspinal muscles became less efficient with repetitive loading. Here, decreased efficiency is used to describe less torque production for a given amount of neural drive.

A reduction in neuromuscular efficiency for the subjects in the eccentric group was observed immediately after, 15 min after, and at 1 d after the exercise protocol where a greater amount of multifidus muscle activity was required to achieve the same level of isometric torque. The iliocostalis lumbarum muscle was unaffected. Similar findings have been reported by others studying patients with low back pain where EMG activity of the lumbar paraspinal muscles is increased compared with pain-free control subjects during sustained, voluntary contractions at similar submaximal force levels (6). This indicates that subjects with low back pain produce force less efficiently than subjects without low back pain. Interestingly, the multifidus muscle has been implicated in lumbar spine pathology. For example, structural changes (core-targetoid and moth-eaten fibers), evidence of denervation and selective atrophy of the type II fibers in the multifidus muscle have been reported in patients with intervertebral disk disorders (18). However, it must be noted that other muscles contribute to trunk extension (e.g., hip extensors) that were not measured in this study. To conclude that the multifidus muscle was the only trunk extensor affected by the eccentric contraction protocol used in this study would be premature.

The reason for the differential effects of the eccentric contraction protocol on the multifidus and iliocostalis lumbarum muscles is probably not due to differences in
fiber type composition (32). However, it may be due to the specific roles these two muscles play. Although both muscles contribute to trunk extension, the multifidus muscle is considered to be a primary stabilizer of individual spinal motion segments (24), whereas the iliocostalis lumborum muscle provides general trunk stabilization (1). It may be that during maximal effort eccentric contractions, the multifidus muscle is working at a relatively higher level to stabilize the lumbar motion segments compared with the iliocostalis lumborum muscle and is therefore more susceptible to exercise-induced injury. Another possibility relates to the excursion each muscle underwent during the contractions. The range of trunk movement used in this study may have required a greater relative excursion of the multifidus muscle, making exercise-induced changes in function more likely in this muscle.

In summary, a single bout of maximal voluntary eccentric contractions using the trunk extensor muscles resulted in a change in neuromuscular function such that an increase in neural drive was required to achieve a given level of submaximal isometric torque production. This effect was limited to the multifidus muscle and persisted for 1 d with recovery to baseline levels by the third day after the exercise bout. Contrary to studies using other muscle groups, no sustained decrement in torque production or alteration in muscle activity was observed.

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