Knee-Extension Exercise’s Lack of Immediate Effect on Maximal Voluntary Quadriceps Torque and Activation in Individuals With Anterior Knee Pain

Jihong Park, Terry L. Grindstaff, Joe M. Hart, Jay N. Hertel, and Christopher D. Ingersoll

Context: Weight-bearing (WB) and non-weight-bearing (NWB) exercises are commonly used in rehabilitation programs for patients with anterior knee pain (AKP). Objective: To determine the immediate effects of isolated WB or NWB knee-extension exercises on quadriceps torque output and activation in individuals with AKP. Design: A single-blind randomized controlled trial. Setting: Laboratory. Participants: 30 subjects with self-reported AKP. Interventions: Subjects performed a maximal voluntary isometric contraction (MVIC) of the quadriceps (knee at 90°). Maximal voluntary quadriceps activation was quantified using the central activation ratio (CAR): CAR = MVIC/(MVIC + superimposed burst torque). After baseline testing, subjects were randomized to 1 of 3 intervention groups: WB knee extension, NWB knee extension, or control. WB knee-extension exercise was performed as a sling-based exercise, and NWB knee-extension exercise was performed on the Biodex dynamometer. Exercises were performed in 3 sets of 5 repetitions at approximately 55% MVIC. Measurements were obtained at 4 times: baseline and immediately and 15 and 30 min postexercise. Main Outcome Measures: Quadriceps torque output (MVIC: N·m/Kg) and quadriceps activation (CAR). Results: No significant differences in the maximal voluntary quadriceps torque output ($F_{2,27} = 0.592$, $P = .56$) or activation ($F_{2,27} = 0.069$, $P = .93$) were observed among the 3 treatment groups. Conclusions: WB and NWB knee-extension exercises did not acutely change quadriceps torque output or activation. It may be necessary to perform exercises over a number of sessions and incorporate other disinhibitory interventions (eg, cryotherapy) to observe acute changes in quadriceps torque and activation.

Keywords: central activation ratio, strengthening exercise, sling-based exercise unit

Anterior knee pain (AKP) is a common musculoskeletal problem in both general and athletic populations, with prevalence rates as high as 25%. Symptoms typically include pain with prolonged sitting, patellofemoral compressive force, and ascending or descending stairs. Individuals with AKP may present with weakness and inhibition of the quadriceps.

Common interventions for AKP include patellar taping, therapeutic exercise, activity modification, ultrasound, electrotherapy, bracing, foot orthotics, and surgery. Although interventions may be multifaceted, most include voluntary muscle-strengthening exercises for the lower extremity, specifically, the quadriceps. Programs have used both weight-bearing (WB) and non-weight-bearing (NWB) strengthening exercises, and both have been shown to be effective to decrease pain and regain function.

Despite conservative interventions, some individuals with AKP may continue to have pain and quadriceps inhibition. Persistent quadriceps inhibition is thought to accelerate AKP and may lead to an earlier onset of knee osteoarthritis. However, voluntary muscle-strengthening exercise in isolation may not be beneficial in increasing quadriceps activation. This may partly explain why some individuals do not respond to programs that focus on improving quadriceps strength. Strength gains from voluntary exercise for the first 3 to 5 weeks are thought to result from increased neural activity and adaptation of the neural system via increased recruitment-pattern efficiency. Neural adaptation followed by muscle hypertrophy is known for long-term effects of strengthening exercise.

A single session of voluntary exercise may cause short-term alterations in neural activity. The sling-based suspension exercise, a type of WB exercise, has been shown to be effective in decreasing pain and improving function. In addition, NWB
knee-extension exercise has been shown to produce daily quadriceps strength gains. Although it has been suggested, the short-term effect of WB or NWB voluntary exercise in a pathological population has not been objectively examined. WB exercise may be more effective than NWB exercise in increasing neural activity because it stimulates greater joint-receptor and proprioceptive activity due to joint compressive forces from body weight, it recruits a more balanced activation pattern in the vastus medialis and lateralis, and it maintains an optimal length–tension relationship of the quads due to the concurrent shift mechanism.

The purpose of this study was to determine the immediate effects of WB and NWB knee-extension exercises compared with a no-exercise group on quadriceps torque output and activation in individuals with AKP. We hypothesized that WB and NWB knee-extension exercises would immediately increase maximal voluntary quadriceps torque and activation more than the no-exercise condition. We further hypothesized that WB knee-extension exercise would increase maximal voluntary quadriceps torque and activation more than NWB knee-extension exercise. The results of this study could potentially provide greater insight on the effectiveness of voluntary exercise in reversing arthrogenous muscle inhibition and facilitating rehabilitation. In addition, the results could indicate which type of exercise is superior in terms of quadriceps activation in patients with AKP.

Methods

A single-blind randomized controlled trial with repeated measures was used to evaluate the effects of 3 different interventions on increasing maximal voluntary quadriceps torque output and activation. Independent variables were treatment (WB knee-extension exercise, NWB knee-extension exercise, and control group) and time (baseline and 0, 15, and 30 min postintervention). The dependent measurements were maximal voluntary quadriceps torque and activation, calculated using the central activation ratio (CAR).

Subjects

Thirty subjects with AKP (16 women, 14 men; Table 1) volunteered and qualified for study participation. All participants read and signed the informed-consent form approved by the institutional review board at the university. All subjects completed a health-history form and the Lower Extremity Functional Scale. AKP was defined as a self-reported insidious onset of unilateral or bilateral pain, at least 2 weeks in duration, reproduced with at least 2 of the following special tests: patella compression, squatting, prolonged sitting, going up or down stairs, or isometric quadriceps contraction. In addition, subjects had to demonstrate quadriceps inhibition, which was defined as a CAR less than .85. This allowed a .15 possible change in CAR value after the intervention, with values greater than .95 considered normal.

A total of 76 subjects volunteered for the study (Figure 1). Thirty-six were excluded before intervention allocation. During baseline measurements, 3 subjects refused to participate because of the discomfort from the electrical stimulation. Other exclusion criteria included current pregnancy, lower extremity osteoarthritis, rheumatoid arthritis, history of lumbar-spine or lower extremity surgery, and lower extremity injury within the past 6 months (other than AKP). All measurements and interventions were performed on the symptomatic limb. If bilateral knee pain was present, the subject was asked to determine the most symptomatic knee, and that limb was tested. No subject reported an increase of AKP during data collection.

Maximal Voluntary Quadriceps Torque Output and Activation

Maximal voluntary quadriceps torque output was measured using a Biodex dynamometer (System 3 No. 900-550; Biodex Medical Systems, Inc, Shirley, NY) interfaced with a data-acquisition system (MP 150 Biopac System, Inc, Goleta, CA). Data were sampled at 2000 Hz. Maximal voluntary quadriceps activation was measured using the superimposed-burst technique. The S88 Grass Stimulator with the SU8T transformer stimulus-isolation unit (Grass-Telefactor, West Warwick, RI) was used to deliver a 100-millisecond train of 10 square-wave pulses to the quadriceps muscle. Individual pulse duration was 600 microseconds delivered at a carrier frequency of 100 pulses/s. Self-adhesive electrodes (Dura-Stick II, Chattanooga, Hixson, TN; 7 cm × 12.7 cm) were placed on the skin overlying the quadriceps muscle.

The following table summarizes the demographics of the subjects:

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Subjects Demographics, Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight-bearing, n = 12</td>
<td>Non-weight-bearing, n = 10</td>
</tr>
<tr>
<td>Age, y</td>
<td>26.1 (10.9)</td>
</tr>
<tr>
<td>Height, cm</td>
<td>168.9 (9.7)</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>69.0 (14.1)</td>
</tr>
<tr>
<td>Pain duration, mo</td>
<td>52.9 (31.1)</td>
</tr>
<tr>
<td>LEFS</td>
<td>67.3 (9.4)</td>
</tr>
</tbody>
</table>

Abbreviations: LEFS, Lower Extremity Functional Scale.
Subjects performed a maximal voluntary isometric contraction (MVIC) of the quadriceps with the knee at 90° flexion and the hip at 85° flexion. Once the MVIC reached a plateau, a supramaximal electrical stimulus was manually triggered and transmitted directly to the quadriceps through the stimulating electrodes. This stimulation caused a transient increase of torque by recruiting the remaining motor units or optimizing the firing rate of the quadriceps muscle. CAR was calculated by dividing torque measurements of the MVIC (FMVIC) by the sum of the torque produced by the superimposed-burst technique (FMVIC+SIB):

Quadriceps CAR = \( \frac{FMVIC}{FMVIC+SIB} \)

The mean MVIC torque value for a 100-millisecond period immediately before the stimulation was used for FMVIC, and the peak superimposed-burst torque was used for FMVIC+SIB. A CAR of 1.0 indicates complete voluntary activation. CAR values of .95 have been suggested as normal in healthy people.

**Assessment Procedures**

On completion of consent and health-history forms, baseline maximal voluntary quadriceps torque output and activation were measured. The anterior thigh was prepared for electrode placement while the subject was seated on the Biodex. Overlying hair was removed with a razor, and the skin was cleaned with an alcohol swab. After the alcohol dried on the skin, 2 self-adhesive electrodes were applied to the distal vastus medialis (~5–7.5 cm above the medial femoral condyle) and proximal lateral quadriceps (~5–7.5 cm below the inguinal crease). The chest and pelvis were secured with Velcro straps, and the subject was asked to cross his or her arms on the chest. This position was used to secure the body and minimize contribution of other muscles during the isometric contraction.

Subjects performed a warm-up consisting of 3 isometric contractions (2 submaximal with 50% and 75% and a maximal with 100%) coupled with submaximal electrical stimulus to familiarize them with testing procedures. The MVIC served as a target to ensure...
that they were providing a consistent MVIC. Continual verbal encouragement\(^42\) and visual feedback via computer monitor were provided during contraction. Once subjects understood the testing procedure, the measurements of quadriceps activation began. Subjects were instructed to slowly build up and hold an MVIC for 2 to 3 seconds. Once a plateau in torque occurred, the examiner manually triggered the superimposed burst, and a supramaximal electrical stimulus was applied to the quadriceps to recruit any remaining muscle fibers that had not been stimulated. If torque did not plateau, an electrical stimulus was not given, and the same procedure was repeated. A 90-second rest period was given between measurements. Three measurements were obtained and averaged to quantify torque output and percentage quadriceps activation. After we obtained baseline measurements, subjects who had quadriceps activation greater than .85 CAR were excluded from the study. On completion of the baseline session, the assessor (N.N.) left the testing area and a separate clinician (J.P.) performed the randomly assigned intervention (WB knee-extension exercise, NWB knee-extension exercise, or control group). After the intervention, the assessor (N.N.), who was blinded to intervention allocation, returned to perform postintervention measurements at 3 times (0, 15, and 30 min postintervention). Subjects had 15 minutes between postintervention intervals and were asked to remain seated on the Biodex during rest periods.

**Voluntary Muscle-Strengthening Exercises**

**WB Knee Extension.** WB knee-extension exercise\(^47\) was performed using a sling-based exercise unit (Redcord AS, Staubo, Norway) with the subject positioned prone on a treatment table (Figure 2). The testing limb was fixed to the device with a sling attached to the ipsilateral ankle, while the uninvolved limb was not supported. An additional sling attached to 2 elastic cords was placed under the subject’s abdomen and provided assistance with the exercise by unloading body weight, if necessary. Subjects were instructed to fully extend their fixed knee and maintain the prone position by putting their elbows on the table (Figure 2), similar to a prone plank exercise. Knee-extension exercise on this device is thought to isolate the quadriceps muscle,\(^47\) while other WB exercises (squats, lunges) usually involve cocontraction with the hamstrings. In addition, this setup of WB suspension exercise provided an increase in exercise complication due to the labile surface. Muscle contraction performed on an unstable surface, compared with a stable surface, is known to cause more challenging exercise conditions, resulting in an increase in muscle activity.\(^48\) Volume (1 set for familiarization, 3 sets consisting of 5 repetitions each) and rest intervals (1 min) were consistent between exercise conditions. This volume was determined by the clinical protocol suggested by the manufacturer of the sling-based unit.\(^49\)

A familiarization set was performed to allow the subject to practice the exercise and to determine the amount of sling-support assistance under the abdomen necessary to perform the exercise. The amount of sling support was determined by the subject’s ability to complete the task pain free with correct technique. The initial amount of sling support was set so the abdomen was approximately 10 cm off the treatment table when the subject was in a relaxed prone plank position. A knee-extension trial was performed for sling-support adjustment. If subjects reported pain or difficulty, the support was increased until the pain or difficulty resolved. If the subject reported that the task was easy, the amount of support was decreased (less elastic-cord tension). The correct resistance was found within 5 repetitions of the familiarization set.

**NWB Knee Extension.** NWB knee-extension isotonic exercise was performed with the subject seated on the Biodex system. Setup was similar to methods for obtaining MVIC and CAR values. Resistance level for isotonic knee extension was based on 55% of the MVIC torque obtained during baseline measurement.\(^50\) A warm-up set of 5 repetitions was performed to familiarize subjects with the isotonic knee-extension exercise. Subjects were given

---

**Figure 2** — A subject performing weight-bearing knee-extension exercise with the sling-based exercise therapy unit: (a) starting position and (b) completed knee-extension ending position. The elastic sling was attached to the abdomen pad to reduce resistance (body weight).
a 1-minute rest and then performed 3 sets of 5 repetitions with a 1-minute rest between sets. After completing 3 sets of this exercise, the subjects stood up from the Biodex system and walked (30 m) to the apparatus used for WB knee extension and returned to the dynamometer for postintervention testing. Walking was performed to standardize the same amount of movement and time that the WB knee-extension exercise group preformed. The use of 3 sets of 5 repetitions (15 total repetitions) was selected to mimic WB exercise volume.

**Control.** The control group did not receive any treatment. Subjects remained seated on the Biodex system for 9 minutes, which was approximately the amount of time required for the other interventions. Subjects in the control group also performed a walking session similar to the NWB knee-extension exercise group.

### Statistical Analysis

Two separate 2-way repeated-measures (3 × 4) ANOVAs were performed to compare maximal quadriceps torque output and activation values between groups across each period. Independent variables were treatment (NWB knee-extension exercise, WB knee-extension exercise, and control group) and time (baseline and immediately and 15 and 30 min postintervention). All statistical analyses were performed with SPSS (version 15.0; SPSS Inc, Chicago, IL). The significance level was chosen as .05.

An a priori sample-size calculation was performed using an expected change in quadriceps activation of 0.10 and a standard deviation of 0.10. Based on these values we calculated that 10 subjects per group were necessary to have an 80% chance of detecting a significant difference in quadriceps activation with \( P = .05 \).

### Results

There were no significant differences \((P > .05)\) in any of the subject-group demographics (Table 1). For maximal quadriceps torque output there was not a significant time × group interaction \((F_{6,81} = 0.39, P = .89, 1 – \beta = .16)\), between-groups main effect \((F_{2,27} = 0.59, P = .56, 1 – \beta = .14)\), or time main effect \((F_{3,81} = 1.857, P = .14, 1 – \beta = .47)\). For maximal quadriceps activation there was not a significant time × group interaction \((F_{6,81} = 0.14, P = .99, 1 – \beta = .83)\), between-groups main effect \((F_{2,27} = 0.07, P = .93, 1 – \beta = .59)\), or time main effect \((F_{3,81} = 0.89, P = .45, 1 – \beta = .24)\). Maximal quadriceps torque output and activation with the means and standard deviations are presented in Tables 2 and 3, respectively.

### Discussion

Our study examined the immediate effects of a single session of knee-extension exercises. Neither WB nor NWB knee-extension exercises changed maximal voluntary quadriceps torque output (MVIC) or activation (CAR) in individuals with AKP. This is in agreement with previous reports that traditional strengthening exercise programs may not influence muscle activation.51,52 A single session of voluntary knee-extension exercises in individuals with AKP may not be an effective intervention to disinhibit the quadriceps. Our findings also indicate that a single session of WB or NWB voluntary exercise did not alter quadriceps muscle activation. According to these results, quadriceps inhibition should be reversed using accepted disinhibitory interventions (eg, cryotherapy, electrotherapy, or manual therapy) early in rehabilitation of AKP patients before voluntary exercises are applied.

Low exercise volume in our intervention may have affected the results. We used 3 sets of 5 repetitions (excluding a set for familiarization) in both WB and NWB knee-extension exercises. Based on the training principles of the sling-based exercise therapy unit, recommendations included low volume such as low sets (2 or 3) with low repetitions (4 or 5) with higher resistance. An assumption was made that the sling-based therapy unit causes cocontraction with abdominal stabilization.
Therefore, we used 15 repetitions total for volume of both WB and NWB exercise. Fifty-five percent of MVIC was set for low-load exercise. The exercises were not intended to fatigue the quadriceps but potentially to increase and stimulate afferent neural activity between the muscle and central nervous system in the knee joint. However, the volume that we used may have not been sufficient to produce these effects. Most subjects in this study had chronic AKP, for 47.6 months on average. This chronic AKP may have been an important condition that a single treatment does not typically resolve. Therefore, a single exercise treatment may not be appropriate for chronic AKP patients.

The study inclusion criteria were based on subject self-reported pain. Perhaps this included broad pathology from acute traumatic or chronic overuse mechanisms. Any patellofemoral joint structure such as patella, cartilage, synovium, capsule, tendon, infrapatellar fat pad, subchondral bone, or retinacula can be a potential pain generator associated with AKP. We did not differentiate these pathological structures as exclusion criteria. The subjects with AKP in this study may be too diverse to be evaluated on the effects of a volitional contraction compared with a single damaged entity such as the anterior cruciate ligament or meniscus.

AKP has been reported as a factor contributing to quadriceps inhibition in patients with clinical AKP. However, the relationship between AKP and quadriceps inhibition remains inconclusive. Quadriceps inhibition has been reported in the absence of AKP. In addition, both nonsteroidal anti-inflammatory drugs and knee arthroscopy have shown a reduction in AKP without a change in quadriceps activation. We examined 76 subjects with AKP, and 32 of them (42.1%) did not have significant quadriceps inhibition (<.85 CAR). AKP may have an association with quadriceps inhibition, but other factors such as structural damage, inflammation, atrophy, or joint effusion, alone or combined with pain, may have a larger role in causing quadriceps inhibition.

We assumed that each subject consistently provided their MVICs during repeated measurements. Decreased quadriceps torque output has been described with repeated testing with the superimposed-burst technique. Subjective discomfort from the superimposed-burst technique in healthy subjects has been reported as moderate (mean 3.5 cm out of 10 cm on a visual analog scale). Subjects in our study performed 15 MVICs augmented with the 125-V electrical stimulus. Throughout the entire data-collection process, it may have been difficult for subjects to continue to produce maximal effort due to local muscle fatigue or electrical stimulation. Because of inconsistencies in baseline MVICs with and without electrical stimulation, we decided to exclude 8 subjects who had completed the data-collection process (Figure 1)—those whose MVIC with the electrical stimulation did not reach 90% of the MVIC without electrical stimulation in the baseline measurement. To minimize fluctuation in MVICs, we suggest using a visual target for MVIC on the computer screen that subjects can aim for during muscle contraction.

Future studies should attempt to identify characteristics of individuals with AKP who would benefit from voluntary exercises. Although performing a single exercise intervention did not immediately increase quadriceps strength and activation, increased quadriceps torque output and activation may be observed over multiple sessions of training. It is necessary to determine the number of sessions or the optimal exercise volume to demonstrate changes in torque output and activation. It may also be beneficial to examine the effects of strengthening exercises combined with other interventions that have shown to increase quadriceps muscle activation, such as cryotherapy, electrical stimulation, or lumbopelvic joint mobilization. Determining immediate effects of the WB and NWB exercises with different volumes and intensity (eg, high repetitions with low resistance vs low repetition with high resistance) to see if these exercises increase quadriceps activation may be clinically beneficial. It may be beneficial to examine muscle activity, using EMG, to compare WB (with the sling-based unit) knee-extension exercise and other WB knee-extension exercises such as squats, lunges, or suspended chain squat exercise. Finally, we suggest examining how isolated knee pain, knee effusion, or a combination of the 2 contributes to quadriceps activation.

Conclusion

Neither WB nor NWB knee-extension exercises acutely increased maximal voluntary quadriceps torque output or activation in patients with AKP. It may be necessary to perform exercises over a number of sessions and incorporate other disinhibitory interventions such as cryotherapy, electrical stimulation, or joint mobilization.

Acknowledgments

This study was funded by a gift from Redcord AS, Staubo, Norway. We also thank Naoki Negishi for his assistance in the data-collection process.

References

Knee-Extension Exercise and Quadriceps Activation


