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Different Knee and Ankle Positions Affect Force and Muscle Activation During Prone Leg Curl in Trained Subjects

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Abstract

Marchetti, PH, Magalhaes, RA, Gomes, WA, da Silva, JJ, Stecyk, SD, and Whiting, WC. Different knee and ankle positions affect force and muscle activation during prone leg curl in trained subjects. *J Strength Cond Res* XX(X): 000–000, 2019—Different joint positions for biarticular muscles may affect force and muscular activity during single-joint exercises. The aim of this study was to compare the maximal isometric contractions and muscle activation in 2 different knee and ankle positions during prone leg curl exercise in trained subjects. Fifteen resistance-trained men (27 ± 4 years, 178.80 ± 5.72 cm, 86.87 ± 12.51 kg) were recruited. The peak force (PF) and muscle activation of biceps femoris, gastrocnemius lateralis (GL), and soleus lateralis (SL) were measured during knee flexion at 0 and 90° and maximal dorsiflexion (D) or plantarflexion (P). Three maximal voluntary isometric contractions of 5 seconds were performed for each combination of knee and ankle positions. Two-way repeated-measures analysis of variances were used for all dependent variables. For PF, there was a significant difference between ankle positions (D × P) at 90° ($p = 0.009$) and knee positions (0 × 90°) for D ($p < 0.001$) and P ($p < 0.001$). Peak force was greater with the knee at 0° and the ankle maximally dorsiflexed. For GL, there was a significant difference between ankle (D × P) at 0° ($p = 0.002$) and knee positions (0 × 90°) for D ($p = 0.005$). Gastrocnemius lateralis activation was greater with the knee at 90° of flexion and the ankle maximally dorsiflexed. For SL, there was a significant difference between ankle positions (D × P): at 90° ($p = 0.001$) and at 0° ($p = 0.002$). Soleus lateralis is more active in plantarflexion irrespective of the knee joint position. Isometric contractions with full knee extension produce more strength regardless of the ankle position; neither the knee position nor the ankle position may influence the activity of the hamstrings.

Key Words: strength, performance, hamstrings

Introduction

The hamstrings (long head of the biceps femoris, semitendinosus, and semimembranosus) are classified as biarticular muscles, acting as both primary hip extensors and knee flexors (9,19,22). The specific development of these muscles can be performed by both single-joint and multijoint exercises (17). However, during multijoint exercises, the hamstrings are considered synergists and present moderate to low muscle activity during squats (3,4,13,24), leg press (6), and lunges (14). Thus, the incorporation of single-joint exercises such as the prone leg curl is recommended as part of a complete training program for lower limbs (20), producing approximately twice as much hamstring activation compared with the squat exercise (24). In addition, the gastrocnemius (lateral and medial head) present biarticular characteristics and act as both primary knee flexors and ankle plantarflexors (10,21); it is plausible that these muscles may affect the knee flexion in different ankle positions. Ballantyne et al. (1) demonstrated that the threshold required to activate the hamstrings is reduced when the gastrocnemius performs isometric action in plantarflexion.

Scientific evidence is provided indicating that the alteration in force and muscle activation may be related to changes in muscle length and mechanical advantage, which may affect the level of strength and muscle activation patterns (1). Knee and ankle joint angles have a large influence on overall contractile capacity with different muscle length changes (8). Therefore, possibly the combination of gastrocnemius and hamstring muscle action could influence force during prone leg curl exercise. Thus, the aim of this study was to compare the maximal isometric contractions and muscle activation in 2 different knee and ankle positions during prone leg curl exercise in well-trained subjects. The main hypothesis considers that the maximal isometric force and muscle activation of biceps femoris and gastrocnemius lateralis occur with knee in extension and maximal dorsiflexion positions, with no effect on soleus activation. The rationale of this study was to verify whether specific changes in the knee or ankle joint position may affect the force production or muscle activity during leg curl exercise. The understanding of specific joint changes might help in the adequate use of this exercise in rehabilitation programs and prescription of strength training.

Methods

Experimental Approach to the Problem

This article was a randomized crossover study design. All subjects performed isometric prone leg curls in 4 experimental conditions: 0 and 90° of knee flexion with maximal dorsiflexion (D0 and D90, respectively) and 0 and 90° of knee flexion with maximal

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plantarflexion (P0 and P90, respectively). Three maximal voluntary isometric contractions (MVICs) of 5 seconds were performed for each combination of knee and ankle position. The peak force (PF) and surface electromyography (sEMG) (gastrocnemius lateralis [GL], Biceps Femoris [BF], and soleus lateralis [SL]) were recorded during each condition for the analyses.

Subjects

Based on a statistical power analysis derived from the maximal isometric contraction data from a pilot study, a sample size of 5 subjects was deemed necessary to achieve an alpha level of 0.05 and a power $(1 - \beta)$ of 0.80 (5). Therefore, 15 young, healthy, resistance-trained men (mean ± *SD*: age: 27 ± 4 years, height: 178.8 ± 5.7 cm, and body mass: 86.9 ± 12.5 kg) were recruited to participate in the current study. They had 6 ± 3 years of resistance training experience (at least 3 times a week), with no previous surgery or history of injury with residual symptoms (pain) in the lower limbs or spine within the past year. The institutional review board of Nove de Julho University approved this study (#3.050.388/2018); the subjects were informed of the risks and benefits of the study before any data collection and then read and signed an institutionally approved informed consent document.

Procedures

This project used a randomized crossover design. Subjects attended 1 laboratory session and refrained from performing lower-body exercise other than activities of daily living for at least 48 hours before testing. Before data collection, subjects were asked to identify their preferred leg for kicking a ball, which was then considered their dominant leg (15). All subjects were right-leg dominant. In addition, anthropometric data were evaluated (total body mass and height). Subjects performed a general warm-up of lower-body cycling for 5 minutes at a cadence of 70 rpm at 1 kp and a familiarization session with 5 bilateral prone leg curl subMVICs at 0 and 90° of knee flexion and maximal ankle dorsiflexion and plantarflexion with 30-second rest between trials.

Then, all subjects lay prone on a leg curl machine (Leg Extension Machine, Riguetto, Brazil), and the dominant lower limb was positioned with the lateral femoral condyle in alignment with the mechanical axis of the equipment, maximal dorsiflexion, and hip was kept in 15° of flexion. A strap was placed across their pelvis and bench to minimize hip movement. The machine lever arm was connected perpendicularly to a load cell, which was interfaced with a computer for recording, sampling at 2 kHz. All subjects performed 3 MVIC in unilateral knee flexion against a locked prone leg curl machine for 5 seconds with a rest period of 15 seconds between trials. All subjects performed isometric prone leg curls in 4 experimental conditions: 0 and 90° of knee flexion with maximal dorsiflexion (D0 and D90, respectively) and 0 and 90° of knee flexion with maximal plantarflexion (P0 and P90, respectively). All experimental conditions were randomized for each subject, and 30 minutes was allowed between conditions. All subjects received verbal encouragement during all trials and conditions, and all measurements were performed between 6 and 8 PM, by the same researcher.

Measurements: Surface Electromyography. The subjects' skin was prepared before placement of the EMG electrodes. Hair at the site of electrode placement was shaved, and the skin was cleaned with alcohol. Bipolar passive disposable dual Ag/AgCl snap electrodes were used which were 1 cm in diameter for each circular conductive area with 2-cm center-to-center spacing. These were placed on the dominant limb of muscle BF at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia; GL at 1/3 of the line between the fibular head and the heel and SL at 2/3 of the line between the medial femoral condyle and medial malleolus, according to the SENIAM/ISEKI protocol (7). The sEMG signals of the BF, GL, and SL were recorded by an electromyographic acquisition system (EMG832C, EMG system Brasil, São José dos Campos, Brazil) with a sampling rate of 2 kHz using a commercially designed software program (EMG system Brasil). EMG activity was amplified (bipolar differential amplifier, input impedance = 2 MΩ, common mode rejection ratio >100 dB min (60 Hz), gain × 20, noise > 5 μV) and analog-to-digitally converted (12 bit). The ground electrode was placed on the bony prominence of the lateral malleolus. All sEMG data were analyzed with a customized Matlab routine (MathWorks, Inc., Natick, MA, USA). The digitized sEMG data were band-pass filtered at 20–400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation time domain analysis, RMS (150 ms moving window) was calculated for all trials. Then, the first second was removed from sEMG RMS to avoid body adjustments, and the following 3 seconds of each trial were integrated EMG (IEMG).

Peak Force (Maximal Voluntary Isometric Contraction). The MVIC was measured by a load cell acquisition system (EMG832C, EMG system Brasil) with a sampling rate of 2 kHz using a commercially designed software program (EMG system Brasil). All MVIC data were synchronized with the sEMG signals and analyzed with a customized Matlab routine (MathWorks Inc.). The digitized MVIC data were low-pass filtered at 10 Hz using a fourth-order Butterworth filter with a zero lag. The lower limb weight was measured by the same dynamometer in both knee angle positions and removed from the MVIC. Then, the first and the last second was removed from force to avoid body adjustments, and then the maximal value of 3 seconds of each trial was used for further analysis.

Statistical Analyses

The normality and homogeneity of variances within the data were confirmed with the Shapiro-Wilk and Levene's tests, respectively. Two-way repeated-measures analysis of variance was used with 2 knee positions (0 and 90°) and 2 maximal ankle positions (dorsiflexion and plantarflexion) for all dependent variables (PF and IEMG). Post hoc comparisons were performed with the *Bonferroni* test. Cohen's formula for effect size (d) was calculated, and the results were based on the following criteria: trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (>2.0) effects (2). Test-retest reliability (intraclass correlation coefficient) was operationalized using the following criteria: <0.40 poor; 0.40 to <0.75 satisfactory; and ≥0.75 excellent (18). An alpha of 5% was used to determine statistical significance.

Results

For PF (Figure 1A), there were significant main effects for ankle position ($p = 0.001$) and knee position ($p < 0.001$). There was no interaction between ankle and knee positions ($p = 0.518$). There was significantly greater value in PF for dorsiflexion when compared with plantarflexion only for knee position at 90° ($p = 0.009$, $d = 1.01$ [large], $\Delta\% = 22\%$). There were significantly greater values in PF for knee position at 0° when compared with knee position at 90° for both ankle positions {dorsiflexion ($p < 0.001$, $d = 3.24$ [very large], $\Delta\% = 48\%$) and plantarflexion ($p < 0.001$, $d = 2.66$ [very large], $\Delta\% = 51\%$)}.

For BF muscle activation (Figure 1B), there were no significant main effects for ankle position ($p = 0.940$) and knee position ($p = 0.435$). There was no interaction between ankle and knee positions ($p = 0.518$).

For GL muscle activation (Figure 1C), there were significant main effects for ankle position ($p = 0.005$) and knee position ($p = 0.007$). There was no interaction between ankle and knee positions ($p = 0.081$). There was significantly greater value in GL activation for plantarflexion when compared with dorsiflexion only for knee position at 0° ($p = 0.002$, $d = 1.49$ [large], $\Delta\% = 44.1\%$). There was significantly greater value in GL activation for knee position at 90° when compared with knee position at 0°, only for dorsiflexion ($p = 0.005$, $d = 0.38$ [small], $\Delta\% = 12.3\%$).

For SL muscle activation (Figure 1D), there were a significant main effects for ankle position ($p < 0.001$) and knee position ($p = 0.001$). There was an interaction between ankle and knee positions ($p = 0.025$). There were significantly greater values in SL activation for plantarflexion when compared with dorsiflexion in both knee positions {at 90° ($p = 0.001$, $d = 1.59$ [large], $\Delta\% = 47.5\%$) and at 0° ($p = 0.002$, $d = 0.99$ [moderate], $\Delta\% = 33.6\%$)}.

Table 1 shows the confidence intervals and test-retest reliability (ICC) for all experimental conditions.

Discussion

The aim of this study was to compare the maximal isometric contractions and muscle activation in 2 different knee and ankle positions during prone leg curl exercise in trained subjects. The main findings were as follows: (a) PF was higher in knee extension at 0° when compared with 90°; (b) PF was higher in dorsiflexion compared with plantarflexion; (c) BF did not present differences between knee or ankle positions; (d) GL presented lower activation during knee extension and dorsiflexion when compared with other knee and ankle positions; and (e) SL was only affected by the ankle position. The present results partially corroborated the main hypothesis considered that the maximal isometric force and muscle activation of BF and GL occurred during knee extension and maximal dorsiflexion positions, and higher values of SL activation were observed in plantarflexion with no effect of knee joint position.

Joint angles have a large influence on overall force capacity with muscle length changes. In this study, the PF was higher in knee extension at 0° when compared with knee flexion at 90°. This main difference between knee angle positions may be related to the isometric length-tension relationship when the muscle is shortened and the contractile capacity is decreased (10,17). This effect can be observed in the results of this study and corroborate with Kirk and Rice (10), Onishi et al. (17), and Worrel et al. (23) Kirk and Rice (10) measured a brief MVICs during knee flexion at 2 joint angles (90 and 160° extension), and their results showed that knee flexion MVICs were 60–70% greater in the extended position (160°). This difference in force was similar to that in this study, which verified an increase of 48–51% (very large effect size) in knee extension. In addition, Onishi et al. (17) observed that during maximal isometric

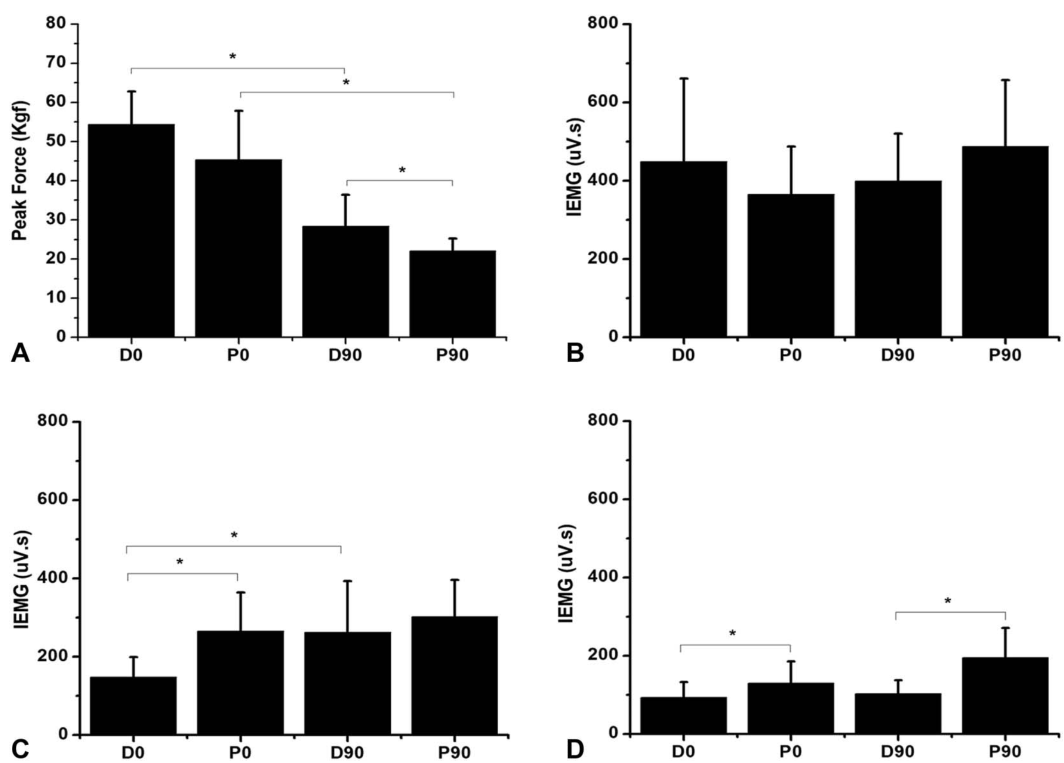

Figure 1. Mean ± *SD* for (A) PF and muscle activation of (B) biceps femoris (BF), (C) gastrocnemius lateralis (GL), and (D) soleus lateralis (SL) for all experimental conditions. *Significant difference, $p < 0.05$. D = dorsiflexion; P = plantarflexion; 0 = knee position at 0°; 90 = knee position at 90°.

Table 1
Confidence intervals (testretest reliability, ICC) for all experimental conditions.*

	D0	P0	D90	P90
Peak force (kgf)	49.62–59.49 (0.89)	38.39–52.25 (0.86)	23.79–32.77 (0.96)	19.95–26.77 (0.86)
BF (IEMG, μV)	324.65–626.06 (0.77)	297.55–432.84 (0.65)	392.33–581.29 (0.66)	329.63–481.77 (0.64)
GL (IEMG, μV)	120.24–176.38 (0.84)	210.54–320.16 (0.89)	188.99–334.70 (0.77)	241.13–430.60 (0.93)
SL (IEMG, μV)	66.58–132.89 (0.92)	98.55–173.95 (0.91)	78.91–139.32 (0.76)	153.46–237.02 (0.94)

*D = dorsiflexion; P = plantarflexion; 0 = knee position at 0°; 90 = knee position at 90°; BF = biceps femoris; IEMG = integrated electromyography; GL = gastrocnemius lateralis; SL = soleus lateralis.

testing, the knee flexion torque at 60° knee flexion was greater than that at 90°. The mean peak isokinetic torque occurred between 15 and 30° knee flexion angle, and then, the torque decreased as the knee angle increased. Worrel et al. (23) revealed that mean knee flexor torque was significantly high at 30° and low at 90° than all other knee angles.

In addition, a higher PF was verified in D position when compared with PF in knee flexion at 90° (22%, large effect size). Curiously, even with no significant statistical effect in knee flexion at 0°, a difference of 16.7% (moderate effect size) was verified (D > PF). The dorsiflexion position may create a better mechanical advantage (reducing the pennation angle (16)) for the gastrocnemius and, consequently, adding force during knee flexion. This effect was more evident during knee flexion position at 90° than at 0°.

Studies report that the activation of the hamstrings is influenced by muscle length when altered by hip and/or knee joint positions (10,12,17,20). However, in this study, the hip joint remained constant, and only the knee joint position was altered. Thus, the length-tension relationship of the hamstrings was altered, but curiously, no difference in BF activation was observed in both knee positions (0 and 90°). One plausible explanation for this result may be the intercoordination among muscles of the hamstring complex acting differently on different knee joint positions as observed in the Onishi et al. (17) study. Onishi et al. (17) reported that peak activity of BF was observed at a knee angle position between 15 and 30°, whereas the other hamstrings (semitendinosus and semimembranosus) showed the largest activity at a knee angle between 90 and 105°. This result indicates that BF participates strongly in knee flexion torque at the early stages of knee flexion.

Although GL and SL are considered synergists (based on reciprocal activation (11)), they present specific functions and characteristics in that the SL crosses only the ankle joint, whereas GL crosses both the knee and ankle joints (11). Owing to the force-length properties of both active and passive structures, the activation of these muscles must be constantly regulated to produce force/torque. Their muscle-tendon unit lengths and consequently force are affected by both joint positions (11). The present results showed lower GL activation only during both knee extension and maximal dorsiflexion position; the reduction in muscle activation may be related to some level of reciprocal inhibition caused by the activation of the anterior leg muscles (i.e., tibialis anterior) to maintain the ankle joint in maximal dorsiflexion. In addition, this effect was observed only in knee extension as a function of both the longer length of the gastrocnemius and higher passive force expected at long muscle length as a function of the length-tension relationship.

Finally, higher values of SL activation were observed in plantarflexion with no effect of knee joint positions. The SL is a monoarticular muscle that does not influence knee joint movements; thus, the SL does not participate in the force production of the knee flexors. The consequent reduction of SL activity during maximal dorsiflexion may be explained by a certain level of reciprocal inhibition caused by the activation of the anterior leg muscles (i.e., tibialis anterior).

We recognize that this study has some limitations. We did not measure all muscles of the hamstrings complex that could help to understand some effects on PF. We did not control for skinfold thickness of the sEMG detection area, which is considered to be a low-pass filter, and there may have been some inherent differences in the musculotendinous tightness between subjects. We also used a healthy, resistance-trained population, and our results, therefore, are not generalizable to other conditions, populations, or athletes.

Our results showed that specific changes in the knee or ankle joint position may affect the force production or muscle activity during leg curl exercise. The present findings suggest that force is higher in knee extension combined with dorsiflexion. The muscle activation of biceps femoris presents no difference between knee or ankle positions. The activation of GL is higher during knee position at 90° compared with 0° only in dorsiflexion. The soleus is more active in plantarflexion than dorsiflexion irrespective of the knee position.

Practical Applications

This research may be of benefit to recreational athletes, bodybuilders, and rehabilitation programs. Isometric contractions are of great importance in increasing the strength at specific joint angles, which may aid in rehabilitation programs/testing or at certain phases of training of recreational athletes/bodybuilders when the aim is to increase strength in joint angles with lower mechanical advantage (sticking point) or even increase metabolic stress aiming at greater neuromuscular fatigue. The results of this research support the notion that isometric contractions with full knee extension produce more strength, regardless of ankle position. However, when the training goal is to specifically use the 90° knee flexion position (e.g., some isometric testing), the ankle positioning in dorsiflexion assists in increased force production. On the other hand, when the main objective is the greater participation of the hamstrings, neither the knee position nor the ankle position may influence their level of muscular activity.

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