INFLUENCE OF HIP EXTERNAL ROTATION ON HIP ADDUCTOR AND RECTUS FEMORIS MYOELECTRIC ACTIVITY DURING A DYNAMIC PARALLEL SQUAT

GLAUBER RIBEIRO PEREIRA,[1,2] GUSTAVO LEPORACE,[1,3] DANIEL DAS VIRGENS CHAGAS,[1,4]
LUIS F. L. FURTADO,[5] JOMILTO PRAXEDES,[1,6] AND LUIZ A. BATISTA[1,4,5,6]

[1]*Laboratory of Biomechanics and Motor Behavior, State University of Rio de Janeiro, Rio de Janeiro, Brazil;*
[2]*Program of Biomedical Engineering, COPPE, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil;*
[3]*Program of Post Graduation on Medical Sciences, State University of Rio de Janeiro, Rio de Janeiro, Brazil;*
[4]*Program of Post Graduation on Human Motricity, University Castelo Branco, Rio de Janeiro, Brazil;*
[5]*Graduate Program of Human Motricity, University Castelo Branco, Rio de Janeiro, Brazil; and*
[6]*Graduate Program of Mechanical Engineering, State University of São Paulo, São Paulo, Brazil*

ABSTRACT

Pereira, GR, Leporace, G, Chagas, DV, Furtado, LFL, Praxedes, J, and Batista, LA. Influence of hip external rotation on hip adductor and rectus femoris myoelectric activity during a dynamic parallel squat. *J Strength Cond Res* 24(10): 2749–2754, 2010—This study sought to compare the myoelectric activity of the hip adductors (HAs) and rectus femoris (RF) when the hip was in a neutral position or externally rotated by 30° or 50° (H0, H30, and H50, respectively) during a parallel squat. Ten healthy subjects performed 10 repetitions of squats in each of the 3 hip positions and the myoelectric activities of the HAs and RF were recorded. The signal was then divided into categories representing concentric (C) and eccentric (E) contractions in the following ranges of motion: 0–30° (C1 and E1), 30–60° (C2 and E2), and 60–90° (C3 and E3) of knee flexion. From those signals, an root mean square (RMS) value for each range of motion in each hip position was obtained. All values were normalized to those obtained during maximum voluntary isometric contraction . We found that HAs showed a significant increase in myoelectric activity during C3 and E3 in the H30 and H50 positions, as compared with H0. Meanwhile, RF activity did not significantly differ between hip positions. Both muscles showed higher activation during 60–90° (C3 and E3) of knee flexion, as compared with 0–30° (C1 and E1) and 30–60° (C2 and E2). The results suggest that if the aim is to increase HA activity despite the low percentage of muscle activation, squats should be performed with 30° of external rotation and at least 90° of knee flexion.

KEY WORDS squat, hip rotation, EMG, biomechanics, resistance training

---

Address correspondence to Glauber R. Pereira, glauberrp@oi.com.br.

24(10)/2749–2754

Journal of Strength and Conditioning Research

INTRODUCTION

Recently, strength training has been proposed as an important strategy for improving athletic performance, wellness, and injury rehabilitation (2). In sports, strength training has been used by a wide range of individuals, from novices to high-performance athletes. The parallel squat is one of the most common exercises included in these strength and conditioning programs (13,17), and its efficacy in increasing strength and inducing hypertrophy has been studied extensively (1,29,30).

An exercise's target and outcome can be characterized by monitoring the quantity and quality of muscle activity (6). Along these lines, several studies have examined the myoelectric activity of lower limb muscles during the execution of different squat variations. Muscle recruitment during squats has been found to depend on joint position, range of motion (ROM), and effort level (3,5,11,19,21,28).

The execution of squats with the hip in external rotation is one common variant of the exercise, despite a lack of scientific evidence supporting the benefits of the muscle activation pattern during this exercise. Previous studies examining the effect of hip rotation on muscle activity compared only knee extensors and flexors muscles (21,27). Ninos et al. (21) did not note changes in myoelectric activity when the hip joint rotation was varied. Signorile et al. (27), studying an isometric squat, did not find statistically significant differences in the activity of the rectus femoris (RF) when the hip was in a neutral position, externally rotated or internally rotated. However, the vastus medialis and vastus lateralis showed increased activity during squat execution with hip internal rotation. Meanwhile, both studies found that the myoelectric activity of all muscles was amplified as ROM increased.

Although past studies investigated the myoelectric activities of quadriceps and hamstrings in a rehabilitation setting, during strength training, squats with an externally rotated hip are usually prescribed to increase the recruitment of hip adductors (HAs). However, it is not known how muscle activity and its synergism with other muscles are changed as a function of hip external rotation. Therefore, the aim of this study was to compare the myoelectric activity of the RF and HAs during the execution of the squat with the hip at different degrees of external rotation, and to compare the ratio of activation of these muscles (RF/HA) in each position. We hypothesized that both the magnitude of hip rotation and the ROM influence the myoelectric activity of the HAs and RF because of their biarticular function during squats.

METHODS

Experimental Approach to the Problem

Strength training books (13,22,23,26) often explain that hip external rotation during squats increases the activity of HAs and thus increases the hypertrophy and strength of these muscles. However, no scientific studies corroborate this contention. In this study, we investigated 3 hip positions, 0°, 30°, and 50° of external rotation, during the execution of 10RM of the parallel squat to determine which position elicits the highest myoelectric activity in the RF and HAs. We selected these muscles because they are biarticular, suggesting that alterations in hip position could change the participation of these muscles. This study would provide data as to whether external rotation hip positions alters myoelectric activity of RF and HAs, contributing to strength and conditioning coaches regarding the exercise selection aiming at increase athletes' performance.

Subjects

Ten healthy physical education students (5 men and 5 women) served as subjects for this study. They were informed of the nature of the study and voluntarily elected to participate in the testing. The Institutional Board of Ethics in Research approved the study. Before their participation, all subjects signed a university approved informed consent form. The participants' mean ± *SD* age, height, and body mass were 21 ± 1 years, 171.4 ± 9.4 cm, and 66.5 ± 11.36 kg, respectively. At the time of testing, each subject had been regularly engaging in a strength training program, which included the parallel squat, for at least one year. None of the subjects presented orthopedic injury.

Experimental Procedures

Before data collection, tests were performed to select the adequate load to 10 repetition maximum (10 RM) during the squat exercise using a weighted barbell (mass = 10 kg and length = 180 cm) across the posterior deltoids at the base of the trapezius. The distance between each subject's feet during the exercise was normalized to individual hip-width stance.

For each repetition, 2 phases related to trunk displacement were considered: a downward phase, eccentric contraction (E), and an upward phase, concentric contraction (C). Each contraction was divided into 3 subphases that were limited by knee angular displacement. E1 and C1 represented the ROMs from 0° to 30° of eccentric and concentric contractions, E2 and C2 represented the ROMs from 30° to 60°, and E3 and C3 represented the ROMs from 60° to 90°.

Each subject held the 10RM with the hip in a neutral position or at 30° or 50° external rotation (H0, H30, and H50). The order of execution was randomized, to avoid the influence of fatigue on the results. To allow adequate recovery, a 20-minute rest period was allotted between the 10RM test and the first execution, and 5 minutes of rest was provided between subsequent executions (25,31).

To ensure that the full ROM was reached, subjects received sensory feedback from a custom-made device positioned behind their lower limbs and oral feedback when the knee joint was at 90° of flexion. The sensory device was calibrated for each subject using a manual goniometer (CARCI, Rio de Janeiro, Brazil) to normalize intersubject variability.

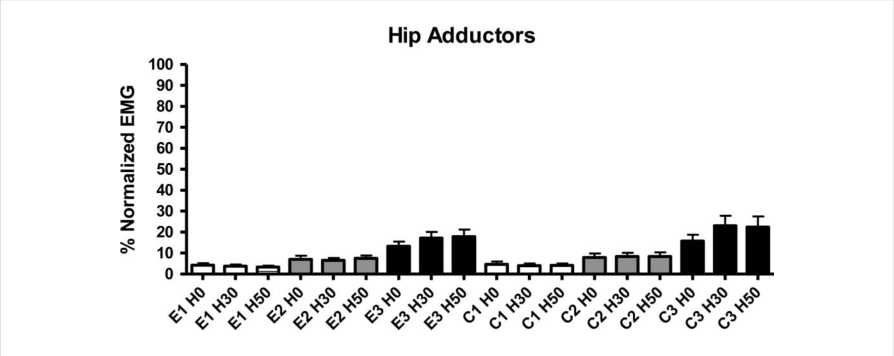

Figure 1. Normalized myoelectric activity of hip adductors for each range of motion (E1, E2, E3, C1, C2, and C3) at each hip position (H0, H30, and H50).

To control the frequency and rhythm of each repetition, a metronome (Qwiktime, Rio de Janeiro, Brazil) was adjusted to a frequency of 1 Hz, representing a mean velocity of $45°\cdot s^{-1}$. A flexible electrogoniometer (TSD 130B, BIOPAC Systems Inc., Santa Barbara, CA, USA) was positioned at the dominant knee to synchronize myoelectric activity (electromyography [EMG]) with the angular displacement of that joint. To calibrate the electrogoniometer, samples were

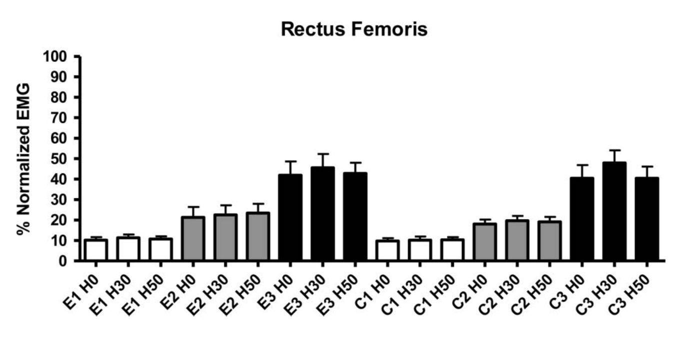

Figure 2. Normalized myoelectric activity of the rectus femoris for each range of motion (E1, E2, E3, C1, C2, and C3) at each hip position (H0, H30, and H50).

obtained at 0° and 90° of knee flexion, according to the MP100 Guide System (BIOPAC Systems Inc.).

Electromyography was obtained at a sample rate of 2,000 Hz (EMG 100B, BIOPAC Systems Inc.), amplified (differential bipolar amplification, input impedance = 2 MΩ, common mode rejection rate > 110 db, gain = 1,000), converted from analog to digital (12 bit, MP100WSW BIOPAC Systems Inc), and analyzed using Acqknowledge 3.5 software (BIOPAC Systems Inc., Holliston, MA, USA).

Silver/silver chloride (Ag/AgCl) electrodes (KOBME, Bio Protec Corp, Korea) were positioned over the RF and hip adductors (adductor longus and gracilis), according to Cram et al. (4). Rectus femoris electrodes were placed 2 cm apart, parallel to the muscle fibers, on the center of the anterior surface of the thigh, approximately half the distance between the knee and the anterior superior iliac spine; HA electrodes were placed parallel of the muscle fibers, in an oblique direction, 2 cm apart, on the medial aspect of the thigh, 4 cm from the pubis (4).

Before application of the electrodes, the skin was prepared by dry shaving the area and cleansing with alcohol to reduce surface impedance (6). To prevent movement artifact interferences in the signals, the electrode cables were fixed to the skin using adhesive tape (3M Ltda, Brazil).

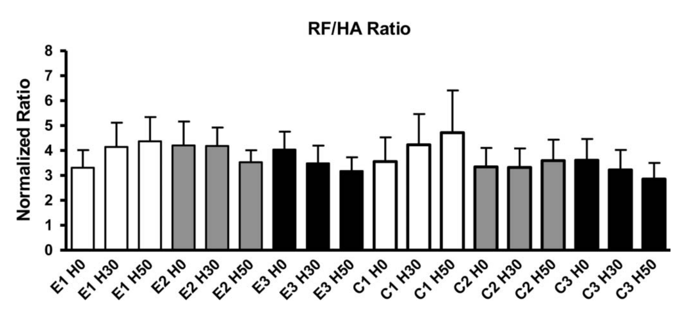

Figure 3. Normalized myoelectric activity of the rectus femoris in relation to the hip adductors (rectus femoris/hip adductor ratio) for each range of motion (E1, E2, E3, C1, C2, and C3) at each hip position (H0, H30, and H50).

Data Analysis

Electromyography signals were filtered using a fourth-order band pass Butterworth (10–500 Hz). An root mean square (RMS) value was calculated (at every 10 samples) for each repetition. To ensure the movement was being conducted in a regular and consistent pattern, and to avoid the influence of fatigue, the 2 initial and final repetitions were excluded from analysis. Therefore, the RMS value used to compare the myoelectric activity of each ROM (E1, E2, E3, C1, C2, and C3) in each hip position (H0, H30, and H50) was the arithmetic mean of the RMS value of each exercise's 6 central repetitions. This value was normalized using the greater mean RMS value obtained in 2 6-second maximum voluntary isometric contraction (MVIC) as a reference.

The angular positioning of the dominant lower limb in the MVIC corresponded to the joint angle at which the muscle could develop the greatest torque. For the RS, a resisted isometric knee extension contraction was performed at 60° knee flexion, with the subjects seated on a chair with 90° hip flexion, whereas for the HAs, a resisted isometric hip adduction was conducted at 0° hip abduction, with the subjects lying on a mat, with 0° hip flexion (15,18,20). All MVICs were-performed with manual resistance applied at the distal shank.

Statistical Analyses

To verify the influence of hip position (H0, H30, and H50) on the myoelectric activity of RF and HA within each ROM (E1, E2, E3, C1, C2, and C3) and on the RF/HA normalized activity ratio, the nonparametric analysis of variance for repeated-measures Friedman test was conducted, in addition to a post hoc Dunn's test. The same test was used to verify the influence of ROM on myoelectric activity at each hip position. Statistical significance was set at $p \leq 0.05$. All data analysis was performed using GraphPad Prism version 5.00 for Windows (GraphPad Software, San Diego, CA, USA).

RESULTS

Hip Adductors

Different hip positions had significantly different effects on HA activity in E3 and C3 ($p = 0.0008$). The post hoc Dunn test revealed significant increases

TABLE 1. Normalized EMG values (%) for the RF and HA and the RF/HA normalized ratio for 0–30° (1), 30–60° (2), and 60–90° (3) of knee flexion with the hip at neutral (H0) position or 30° (H30) or 50° (H50) of external rotation during concentric and eccentric contraction.*

		Concentric			Eccentric		
		RF	HA	RF/HA ratio	RF	HA	RF/HA ratio
H0	1	9.8 (1.4)	4.6 (1.4)	3.6 (1)	10.2 (1.5)	4.2 (1)	3.3 (0.7)
	2	18 (2.2)	7.9 (1.9)	3.3 (0.8)	21.3 (5.1)	7 (1.8)	4.2 (1)
	3	40.5 (6.4)	15.7 (3)	3.6 (0.8)	41.9 (6.7)	13.2 (2.3)	4 (0.7)
H30	1	10.2 (1.8)	4.0 (1)	4.2 (1.2)	11.4 (1.6)	3.8 (0.7)	4.1 (1)
	2	19.7 (2.3)	8.4 (1.7)	3.3 (0.8)	22.5 (4.7)	6.5 (1.2)	4.2 (0.7)
	3	48 (6.1)	23.1 (4.7)	3.2 (0.8)	45.5 (6.8)	17.1 (3)	3.5 (0.7)
H50	1	10.4 (1.3)	4.1 (1)	4.7 (1.7)	10.8 (1.3)	3.4 (0.7)	4.4 (1)
	2	19.1 (2.4)	8.4 (1.9)	3.6 (0.8)	23.4 (4.5)	7.5 (1.4)	3.5 (0.5)
	3	40.5 (5.6)	22.4 (5.2)	2.8 (0.6)	42.8 (5.2)	17.9 (3.3)	3.2 (0.5)

*Results are expressed as mean (*SEM*).
EMG = electromyography; RF = rectus femoris; HA = hip adductor.

from E3 H0 to E3 H30, from E3 H0 to E3 H50, and from C3 H0 to C3 H30. Meanwhile, the E1, E2, C1, and C2 intervals did not demonstrate statistically significant differences ($p > 0.05$).

Within each hip position, statistical analysis demonstrated significant interactions ($p < 0.0001$). A post hoc Dunn test revealed that in all hip positions, the activity in E3 was higher than that in E1 and E2. Additionally, the activity in C3 was higher than that in C1 and C2 (Figure 1).

Rectus Femoris

Hip positions did not differ significantly in their effects on RF activity ($p > 0.05$). However, within each hip position, statistical analysis demonstrated significant interactions ($p < 0.0001$). A post hoc Dunn test demonstrated that in all hip positions, the activity in E3 was higher than that in E1 and E2 and the activity in C3 was higher than that in C1 and C2 (Figure 2).

Rectus Femoris and Hip Adductor Ratio

The RF/HA ratio varied significantly between hip positions in the ROMs E1 ($p = 0.0115$), E3 ($p = 0.0179$), and C3 ($p = 0.034$). In E1, a post hoc Dunn test demonstrated an increase in myoelectric activity from H0 to H50. However, there was a statistically significant decrease from H0 to H50 in E3 and C3. For the other ROMs (E2, C1, and C2), no statistically significant differences between hip positions were noted ($p > 0.05$) (Figure 3).

Descriptive results are presented in Table 1.

DISCUSSION

In the present study, we examined the influence of hip external rotation on the myoelectric activity of the RF and HAs during parallel squat. The results suggest that HA activity is dependent on the degree of hip external rotation, whereas RF activity is not affected by external rotation.

Several bodybuilding books (14,22,23,26) propose that performing a squat with the hip in an external rotation increases HA activity. This purported increase in activity was evaluated subjectively by practitioners, who reported a "burning" sensation. Despite the lack of scientific evidence confirming these contentions, studies have shown a relationship between force production and muscle length, demonstrated by the force–length curve (8–10,24), which may explain this phenomenon.

Myoelectric activity in strength training exercises seems to be influenced by the position of body segments. McCaw et al. (19) identified greater activation of HA when performing squats with a hip abduction, suggesting that these muscles are dependent on the angular positioning of this joint. In the current study, we collected similar results with the hip in an external rotation. However, we only noted increased myoelectric activity during the final ROM, represented by the displacement from 60° to 90° knee flexion (E3 and C3). These results may be related to the greater hip torque during this ROM (11) and increased associated hip abduction while performing squats with an externally rotated hip, as proposed by McCaw et al. (19). Therefore, there may be an increased necessity for HA activity to counterbalance the hip abduction and external rotation displacement.

Meanwhile, we did not find statistically significant differences in the activation of HA when the hip was in a 30° (H30) or 50° (H50) external rotation. Based on these results, we concluded that HA activity only varies with hip position within a limited range of rotation. Although hip adductor activity is increased, the percentage of muscle activation is still relatively low throughout the ROM, which may limit the ability of this modified squat to increase the strength and hypertrophy of the hip adductors.

For the rectus femoris, there was more homogeneous myoelectric activity throughout the ROM. However, this muscle did not generate higher values compared with those in MVIC, suggesting limited participation in the movement (12,16,32). It is possible that RF, as argued by some researchers, is active mainly during uniarticular exercises, especially when the hip is not highly flexed. In contrast, the vastus lateralis and medialis may be more active during multijoint exercises because of their biarticular nature (7,12,19). Regarding RF activity in the 3 hip positions tested by this study, our results agree with the findings of McCaw et al. (19), Signorile et al. (27), and Ninos et al. (21). These authors suggest that unchanging muscle activation despite changing hip position reveals the limited influence of hip positioning on muscle length–force relationship.

The RF/HA ratio changed only from H0 to H50 in the C3 and E3 ranges. Consequently, repositioning from H0 to H50 changes the synergism between the HAs and RF, changing the specificity of the exercise and possibly avoiding an increase in sport performance. These data are very important, because of a basic principle in the training of athletes is respecting the Principle of Specificity (2). These results, associated with the individual muscles activities, confirm the ineffectiveness of externally rotate the hip more than 30° when using this strategy of exercise variation.

In comparing concentric and eccentric myoelectric activation of the 2 muscles in each ROM for each hip position, this study does not support earlier arguments that concentric contraction elicits greater activity (19,21). Some authors proposed that eccentric activity would be lower than concentric activity because of the ability of a muscle to generate greater force during the eccentric phase for a given level of activation when both contractions are performed at the same speed (19). However, this proposal can be applied basically to uniarticular muscles, because the biarticular nature of RF and gracilis makes it difficult to delineate muscle activity as concentric and eccentric (12,13). From this point of view, the lack of significant differences between concentric and eccentric contractions is in agreement with Ninos et al. (21). They demonstrated that both the RF and hamstrings, biarticular muscles, did not show statistically significant differences between concentric and eccentric contractions, despite hip external rotation position. However, McCaw et al. (19) reported that when the squat was performed with a wide stance width, RF demonstrated differences between concentric and eccentric phases.

We propose that new studies should be done comparing lower limbs muscles activity during the execution of squats with the hip externally rotated associated with a wide stance width to evaluate if the activity of HAs, RF and other muscles can be higher with these 2 variations in the same exercise.

PRACTICAL APPLICATIONS

Variation in the selection of exercises used in a strength training program is fundamental to training periodization. The squat is one common exercise that may be modified in the hope of improving muscle hypertrophy. The use of this exercise associated with a hip external rotation is one common strategy used by strength and conditioning coaches to increase activation of HAs. However, because of the low level of hip adductor activation through different ROMs in all hip positions tested, demonstrated in this study, we do not believe that this exercise significantly increases that muscle's strength. Thus, we suggest that squats with hip external rotation be used concomitantly with other exercises if the goal is to develop strength of hip adductors. We also recommend that this exercise be performed with a maximum of 30° of hip external rotation to a range of 90° of knee flexion. This recommendation is based on our finding that there were no significant changes in adductor activation from the positions H30 to H50, with activation increased between 60° and 90° of knee flexion. Individuals with little training experience can achieve knee rotation associated with hip rotation during knee flexion, which may increase the risk of injury because of augmented joint shear forces and stability changes.

REFERENCES

1. Adams, K, O'Shea, JP, O'Shea, KL, and Climstein, M. The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *J Strength Cond Res* 6: 36–41, 1992.
2. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
3. Caterisano, A, Moss, RE, Pellinger, TK, Woodruff, K, Lewis, VC, Booth, W, and Khadra, T. The effect of back squat depth on the EMG activity of 4 superficial hip and thigh muscles. *J Strength Cond Res* 16: 428–432, 2002.
4. Cram, J, Kasman, G, and Holtz, J. *Introduction to Surface Electromyography.* Gaithersburg: Aspen Publishers, 1998.
5. Da Silva, EM, Brentano, MA, Cadore, EL, De Almeida, AP, and Kruel, LF. Analysis of muscle activation during different leg press exercises at submaximum effort levels. *J Strength Cond Res* 22: 1059–1065, 2008.
6. De Luca, C. The use of electromyography in biomechanics. *J Appl Biomech* 13: 135–163, 1997.
7. Dionisio, V, Almeida, G, Duarte, M, and Hirata, R. Kinematic, kinetic and EMG patterns during downward squatting. *J Eletromyogr Kinesiol* 18: 134–143, 2008.
8. Edman, KA, Elzinga, G, and Noble, MI. Enhancement of mechanical performance by stretch during tetanic contractions of vertebrate skeletal muscle fibers. *J Physiol Lond* 281: 139–155, 1978.
9. Edman, KA, Elzinga, G, and Noble, MI. Residual force enhancement after stretch of contracting frog single muscle fibers. *J Gen Physiol* 80: 769–784, 1982.
10. Enoka, R. *Neuromechanics of Human Movement.* Champaign, IL: Human Kinetics, 2008.
11. Escamilla, RF. Knee biomechanics of the dynamic squat exercise. *Med Sci Sports Exerc* 33: 127–141, 2001.
12. Escamilla, RF, Fleisig, G, Zeng, N, Barrentine, S, Wilk K, and Andrews, J. Biomechanics of the knee during closed kinetic chain and open kinetic chain exercise. *Med Sci Sports Exerc* 30: 556–569, 1998.
13. Graham, J. Front squat. *Strength Cond J* 24: 75–76, 2002.

14. Holman, S. *Home Gym Handbook: A Complete Guide to Training at Home.* Los Angeles, CA: Homebody Productions, 1990.
15. Horstmann, T, Maschmann, J, and Mayer, F. The influence of age on isokinetic torque of the upper and lower leg musculature in sedentary men. *Int J Sports Med* 20: 362–367, 1990.
16. Isaer, JA, Erickson, JC, and Worrell, TW. EMG analysis of lower extremity muscle recruitment patterns during an unloaded squat. *Med Sci Sports Exerc* 29: 532–539, 1997.
17. Kritz, M, Cronin, J, and Hume, P. The bodyweight squat: A movement screen for the squat pattern. *Strength Cond J* 31: 76–85, 2009.
18. Kues, JM, Rothstein, JM, and Lamb, RL. Obtaining reliable measurements of knee extensor torque produced during maximal voluntary contractions: An experimental investigation. *Phys Ther* 72: 492–504, 1992.
19. McCaw, S and Melrose, D. Stance width and bar load effects on leg muscle activity during the parallel squat. *Med Sci Sports Exerc* 31: 428–436, 1999.
20. Narici, MV, Landoni, L, and Minetti, AE. Assessment of human knee extensor muscles stress from in vivo physiological cross-sectional area and strength measurements. *Eur J Appl Physiol Occup Physiol* 65: 438–444, 1992.
21. Ninos, JC, Irrgang, JJ, Berdett, R, and Weiss, JR. Electromyographic analysis of the squat performed in self-selected lower extremity neutral rotation and 30 degrees of lower extremity turn-out from self-selected neutral position. *J Orthop Sports Phys Ther* 25: 307–315, 1997.
22. O'Shea, P. The parallel squat. *Nat Strength Cond J* 6: 70–72, 1985.
23. Pearl, B and Moran, GT. *Getting Stronger.* Bolinas, CA: Shelter, 1986.
24. Peterson, DR, Rassier, DE, and Herzog, W. Force enhancement in single skeletal muscle fibers on the ascending limb of the force–length relationship. *J Exp Biol* 207: 2787–2791, 2004.
25. Richmond, S and Godard, M. The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. *J Strength Cond Res* 18: 846–849, 2004.
26. Schwarzenegger, A and Dobbins, B. The Arnold Schwarzenegger encyclopedia of modern bodybuilding. New York: Simon and Schuster, Inc., 1985.
27. Signorile, JF, Kwiatkowski, K, Caruso, JF, and Robertson, B. Effect of foot position on the electromyographic activity of the superficial quadriceps muscles during the parallel squat and knee extension. *J Strength Cond Res* 9: 182–187, 1995.
28. Stone, MH, Plisk, SS, Stone, ME, Margaret, E, Brian, K, O'Bryant, H, Harold, S, and Pierce, KC. Athletic performance development: volume load-1 set vs. multiple sets, training velocity and training variation. *Nat Strength Cond J* 20: 22–31, 1998.
29. Tricoli, V, Lamas, L, Carnevale, R, and Ugrinowitsch, C. Short-term effects on lower-body functional power development: Weightlifting vs. vertical jump training programs. *J Strength Cond Res* 19: 433–437, 2005.
30. Weber, KR, Brown, LE, Coburn, JW, and Zinder, SM. Acute effects of heavy-load squats on consecutive squat jump performance *J Strength Cond Res* 22: 726–730, 2008.
31. Willardson, J and Burkett, L. A comparison of three different rest intervals on the exercise volume completed during a workout. *J Strength Cond Res* 19: 23–26, 2005.
32. Wretenberg, P, Feng, Y, Lindberg, F, and Arborelius, UP. Joint moments of force and quadriceps activity during squatting exercise. *Scand J Med Sci Sports* 3: 244–250, 1993.