ASSESSMENT OF MUSCLE ACTIVATION RATIONS DURING LOWER EXTREMITY RESISTANCE EXERCISES

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The purpose of this study was to examine muscular activation ratios during lower extremity resistance training exercises. The literature implicates muscular activation ratios, such as quadricep-hamstring and insufficient semitendonosis activation as possible factors regarding ACL injuries. Twenty one subjects performed a series of 6 exercises. EMG activity was measured in the following muscles: Rectus femoris, vastus lateralis, vastus medialis, biceps femoris and semitendinosis. Data indicate that most of those exercises show favorable quadricep-hamsrting ratios and most of them also showed favorable medial-lateral hamstring ratios.It is possible that performing exercises that target the muscles that help against injury or produce favorable activation ratios could also help us avoid injuries in sports situations.

KEY WORDS: anterior cruciate ligament, EMG, muscle activation

INTRODUCTION: Female athletes are at an increased risk for anterior cruciate ligament (ACL) rupture when compared to male athletes of the same sports. ACL injuries are of concern because such injuries can lead to extreme discomfort, the interruption or discontinuation of an athlete's season, and even surgery.

One factor that has been examined regarding these injuries is a strength imbalance in the lower extremity. The most common imbalance that has been identified as a potential contributor to ACL injury is between the quadriceps and hamstrings, with the quadriceps typically being stronger than the hamstrings. It is known that during knee extension there is a shear force that is directed to the anterior aspect of the tibia with respect to the distally located femur. In the case of knee extension the ACL is the prominent ligament that acts to prevent the anterior shearing force of the tibia with respect to the femur.

During actions where the quadriceps are active, the hamstring acts supporting the function of the ACL. If there is significant strength imbalance between the two, it may result in reduced joint stability, causing increased shear forces on the knee, possibly leading to injury (Fledmann, 2010; Hewett, Myer, & Ford, 2001).

Ebben (2009) compared EMG activation of the hamstring muscle group and the rectus femoris during six resistance training exercises: squat (SQT), seated leg curl (LC), stiff leg dead lift (SDL), single leg stiff leg dead lift (SLSDL), good morning (GM), and the Russian curl (RLC). Results of this study indicated that the RLC and LC exercises resulted in the greatest hamstring activation, and that the SDL produced more than the SLSDL and the GM. The hamstring-to-quadriceps (HAM-QUAD) ratio was found to be higher for open-kinetic chain (OKC) exercises, such as the LC and RLC, than for ground based, closed-kinetic chain (CKC), exercises, such as the SDL, SLSDL, GM, and SQT, indicating that there is less quadriceps coactivation during OKC and non-ground-based exercises. Ebben (2009) does note however, that training with exercises that include quadriceps antagonism may also be useful for injury prevention since the hamstrings and quads need to function together during a variety of athletic movement such as jump landings during torsional stress associated with single leg support and cutting. Therefore, exercises such as the SDL, SLSDL, and GM may be useful to include in an exercise prescription. One potential weakness of that Ebben study was that the quadricep activation was measured only in the rectus femoris (RF). Of the 4 quadricep muscles, the RF is the only that is biarticular and activation patterns of the RF may not be representative of the other 3 quadricep

muscles.
Recently, Zebis (2009) reported that ACL injuries in elite female handball players may be more likely in subjects with a reduced semitendinosus (ST) and an increased vastus lateralis (VL) pre activation EMG. They speculate that ST may be important to compress the medial knee joint and thereby reduce valgus alignment and external knee rotation. These results seem to indicate that when designing an ACL injury prevention program, exercises should be chosen that upregulate ST activation. For both HAM-QUAD and medial/lateral hamstring, manipulating these muscle activation imbalances may help decrease the risk of injury.
The purpose of the current study was to evaluate differences in lower extremity muscle activation ratios. Specifically 1) HAM-QUAD activation ratio using data from all 4 quadricep muscles and 2) medial/lateral hamstring, and 3) vastus lateralis-semitendonosis activation ratios during lower body resistance exercises.

METHODS: After granting informed consent, 21 participants were asked to fill out a brief medical history questionnaire inquiring about current exercise practices, any prior injuries in the past 2 years to the legs, and if they were currently on a sports team. Height and weight were also collected. During the pretest orientation, each subject were familiarized with the testing procedures, including performing a Maximal Voluntary Isometric Contraction (MVIC) at 60° of knee flexion for the hamstring and quadriceps muscles, using prone leg curl and seated leg extension machines respectively, loaded with an immovable mass. In addition, each subject's 6-repetition maximum (RM) was assessed for each of the randomly ordered test exercises, including the squat, prone leg curl, stiff leg deadlift, single leg stiff leg deadlift, good morning, and the Russian curl. The exercises selected are frequently used and are commonly believed to be effective at training the hamstrings. The squat has been included in this study because is has previously been compared with two hamstring exercises, and serves as a useful reference for hamstring-quadriceps activation ratios under conditions where the quadriceps are typically dominant. During the primary testing session, each subject performed a MVIC for the hamstring and quadriceps muscles for approximately 5 seconds. Following the MVIC's, subjects performed two full range-of-motion repetitions, using their 6-RM loads, for each of the randomly ordered test exercises.
Electromyography: Surface Electromyography (EMG) was used to quantify muscle activity for the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), and semitendinosus (ST) using an 8-channel fixed shielded cabled, Noraxon TeleMyo 2400 G2 EMG system (Noraxon U.S.A. Inc. Scottsdale, AZ). The input impedance is $10^{15}\,\Omega$ with a common mode rejection ratio of >80 db. Bipolar, disposable, surface EMG electrodes with a 2.0-cm interelectrode distance will be placed on the medial portion of the VL, VM, and RF muscles of the quadriceps femoris muscle, and on the BF and ST muscles representing the lateral and medial hamstring muscle groups, respectively. Electrode placement was chosen based on recommendations provided by SENIAM.
Skin preparation included shaving hair, abrading, and cleaning the surface of the participants skin with alcohol. Elastic tape was applied to ensure electrode and cable placement, and to provide strain relief.
Surface electrodes were connected to an amplifier and streamed continuously through an analog-to-digital converter (Noraxon U.S.A. Inc.) to a laboratory notebook computer. All data was filtered with a bandpass filter allowing 10 Hz high pass and 450 Hz low pass frequencies, saved, and later analyzed with the use of computer software. Data was then cut to only the 2nd rep of lifting and Root Mean Squares were calculated of the duration of that repetition. Root mean Squares were calculated using Microsoft Excel 2010 with the equation:

$$RMS = \sqrt{\sum x^2/n}$$

Excel 2010 was also used to calculate ratios, means, standard deviations, and create charts.

RESULTS AND DISCUSSION: The results in figure 1 show the activation ratios the quadriceps and hamstrings muscle groups for the selected exercises. For SDL, GM, SLSDL, LC, and RLC, there was more hamstring activation relative to the quadricep. The order of the exercises regarding activation ratios was the same as in the Ebben et al. (2010) study. However, the proportions were much different; for example, the quadriceps showing much more relative activation than the hamstring during the squat. This was likely because we used three muscles for quadricep activation, but also because the vasti muscles showed a higher relative activation than the rectus femoris. The squat showed the largest discrepancy in the observed ratios, showing much more activation in the quadriceps relative to the hamstrings.

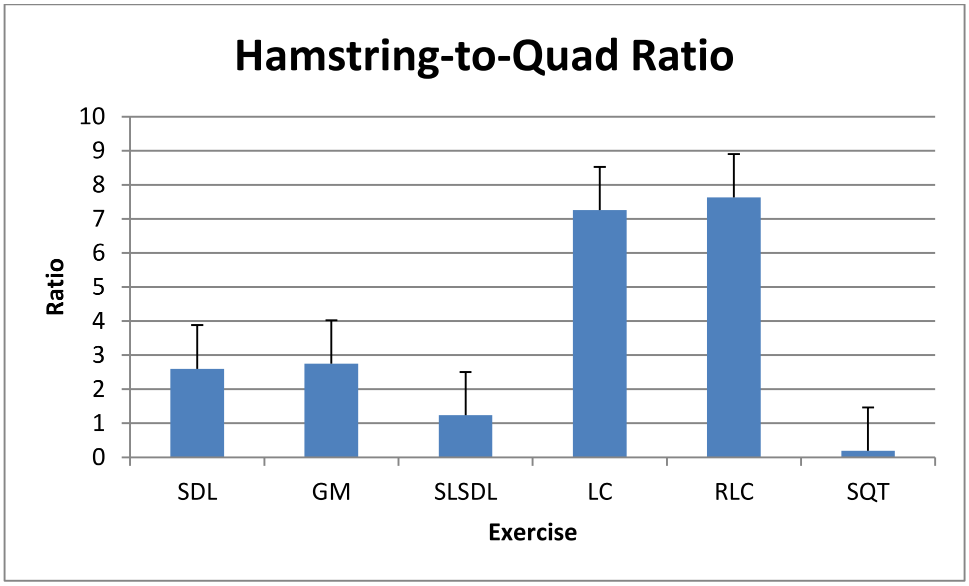

Figure 1: Hamstring-to-Quad activation ratio averages and standard error for each exercise

The results of figure 2 provide the activation ratios of the VL relative to the ST. In all exercises, with the exception of the squat, there was a significantly lower activation of the VL relative to the ST. Zebis (2009) reported that athletes who had preactivation ratios in which the ST activity was low and the VL activity was high had a greater incidence of noncontact ACL injuries. The squat proved to show the exact opposite, with a significantly larger activation of the VL relative to the ST.

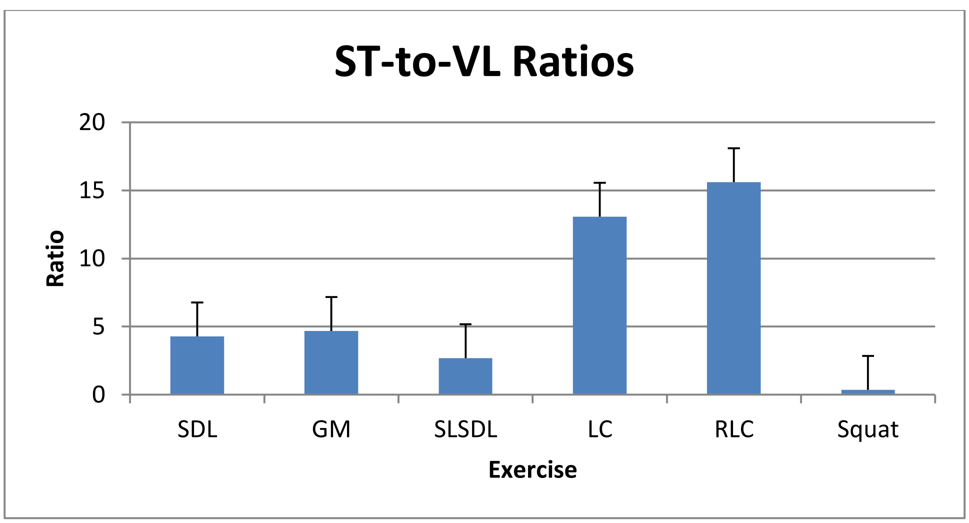

Figure 2: ST-to-VL activation ratio averages and standard error for each exercise

The results of figure 3 provide the activation ratios of the ST relative to the BF. These results show that in most exercises, with the exception of the RLC and LC, that there is larger ST activation relative to the BF. In the case of the RLC and LC these activation ratios were approximately equal. Zebis (2009) speculated that an increase in ST activation would tend to prevent a valgus movement at the knee.

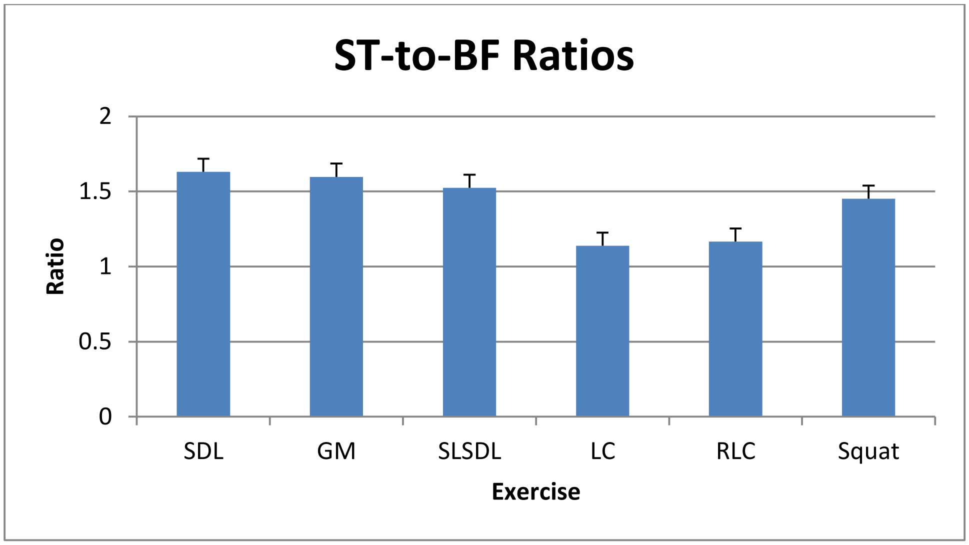

Figure 3: ST-to-BF activation ratio averages and standard error for each exercise

These data are important because knowing what exercises activate which muscles more will help coaches train athletes in a way to prevent ACL injuries. Coaches and strength trainers can apply this by adding more exercises that activate the hamstrings, thereby increasing hamstring strength, decreasing hamstring-to-quad strength ratio, and decrease the chance of ACL injury to their athletes. Leg Curl and RLC have demonstrated the highest activation ratios for hamstring muscles, and would be the most practical to recommend. Single Leg Straight Leg Dead Lift might have not had as high activation ratios due to subjects using the lower back more than hamstring or even quad muscle activity.

CONCLUSION: Results indicate ratios that were reported as favorable in the literature (Ebben et al., 2010; Zebis et al., 2009). That may indicate that the chosen exercise that showed favorable activation patterns can help reduce the risk of ACL injury. Our EMG results indicate that using the vasti muscles produce a greater HAM-QUAD ratio than using the rectus femoris. This should be considered when choosing muscles to determine quadricep-hamstring ratios.

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