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Original Article

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Comparing Dynamic Control Ratio and Lower Extremity Muscle Activity during Eccentric Hamstring Exercises

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| Abstract |

Purpose: This study aimed to suggest an effective exercise for treating anterior cruciate ligament (ACL) and hamstring injuries based on the dynamic control ratio (DCR) for the hamstring and quadriceps during eccentric hamstring exercises.
Methods: Twenty-four healthy participants participated in this study. The participants performed three eccentric hamstring exercises, including the Nordic exercise, the supine leg curl, and single-leg deadlifts. During the eccentric hamstring exercises, the vastus medialis oblique (VMO), vastus lateralis (VL), biceps femoris (BF), and semitendinosus (ST) were measured using surface electromyography.
Results: The DCR was significantly lower during the supine leg curl and single-leg deadlift than during the Nordic exercise ($p < 0.05$). The activity of the VMO and VL was significantly greater during the supine leg curl than during the Nordic exercise and the single-leg deadlift ($p < 0.05$). VL activity was significantly higher during the single-leg deadlift than during the Nordic exercise ($p < 0.05$). ST activity was significantly higher during the supine leg curl and Nordic exercise than during the single-leg deadlift ($p < 0.05$). BF activity was significantly higher during the supine leg curl than during the Nordic exercise and single-leg deadlift ($p < 0.05$). Finally, the BF showed significantly higher activity during the Nordic exercise compared to during the single-leg deadlift ($p < 0.05$).
Conclusion: Based on the DCR ratio and quadriceps activity, the supine leg curl should be introduced early in rehabilitation for ACL injuries.

Key Words: Eccentric hamstring exercise, electromyography, dynamic control ratio

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Ⅰ. Introduction

The hamstring is a muscle that provides dynamic stability to the knee joint through simultaneous contraction with the quadriceps during strenuous activity and plays a role in reducing the excessive shear force on the anterior cruciate ligament (ACL) (Biscarini et al., 2014; Maniar et al., 2022). Most exercises in the early rehabilitation of ACL injury are focused on strengthening the quadriceps power. However, this may cause an imbalance in the hamstring to quadriceps (HQ) ratio and increase the risk of ACL injury (Dedinsky et al., 2017).

The HQ ratio is evaluated based on the concentric contraction of the quadriceps and hamstring (concentric hamstring/concentric quadriceps) and is a widely used predictor of ACL or hamstring injury (Ruas et al., 2015; Wright et al., 2009). The recommended HQ ratio is 0.6 - 1.0 for the prevention of ACL injury (Cheung et al., 2012; Dedinsky et al., 2017; Wright et al., 2009), but the conventional HQ ratio is limited as it does not incorporate the role of the hamstring in the functional activity performance. Among human functional movements, concentric contraction of the quadriceps and hamstrings does not occur frequently, and the effects of muscle length must be considered (Coombs & Garbutt, 2002). In addition, the functional recovery of the hamstring with respect to eccentric contraction is as critical as the strengthening of the quadriceps in knee rehabilitation (Tan et al., 1995).

The eccentric contraction of the hamstring contributes to stabilizing the knee joint by dispersing the pressure on the joint surface or controlling the mechanical resistance, while ensuring the stability of the knee joint like surrounding ligaments during knee extension (Aagaard et al., 2000). Progressive eccentric hamstring exercise with a focus on agility is more effective than static stretching in facilitating the return of an individual to the field following a hamstring injury, and it also reduces the rate of recurrence of hamstring injury from 70% to 7.7% (Sherry & Best, 2004). In addition, the increased peak torque following eccentric hamstring strengthening lowers the risk of injury during an eccentric hamstring activity (Garrett, 1990) and is effective in increasing the muscle strength, mass, and function (Bregenhof et al., 2018).

Hence, the eccentric contraction of the hamstring plays a significant role in maintaining joint stability and preventing injuries; however, the HQ ratio is generally evaluated based on the concentric contraction. The dynamic control ratio (DCR) is a complementary form of the HQ ratio that incorporates the functional aspects during lower extremity movements. The DCR is estimated by dividing the quadriceps concentric contraction (Qcon) by the hamstring eccentric contraction (Hecc) (Croisier et al., 2008). This ratio (Hecc/Qcon) is higher than the conventional HQ ratio (Small et al., 2009) with the recommended DCR in the range of 0.9 - 1.3 (Coombs & Garbutt, 2002).

Thus, the highlighted importance of eccentric contraction of the hamstring has recently prompted numerous studies on related exercises. The most well-known ones are the Nordic exercise, supine leg curl, and single-leg deadlift, that are known to reduce the rate of injury by as much as 51% via eccentric hamstring contraction and are used to achieve swift results of hamstring muscle strengthening (Liebenson, 2014; van Dyk et al., 2009). However, there is a general lack of studies regarding the DCR for eccentric hamstring exercises. Thus, this study aimed to suggest an effective exercise for ACL and hamstring injuries based on the DCR for hamstring and quadriceps during eccentric hamstring exercises.

Ⅱ. Materials and Methods

1. Participant

The sample size in this study was estimated using the G-power (3.1.9.6, Düsseldorf University, Germany) at an effect size of 0.6, significance level (α) of 0.05, and testing power of 0.80. Based on the result, 24 individuals were recruited. In this study, the inclusion criteria of subjects were as follows. Those who voluntarily agreed to participate in the study, adults who can perform exercise, and those who have no pain and functional abnormalities in the last 3 months were selected. The exclusion criteria of subjects were as follows. Individuals with a congenital or acquired neurological or musculoskeletal disorder, those diagnosed with a lower extremity neurological or musculoskeletal disorder on either side in the past three months, and those with an experience of eccentric hamstring exercises were excluded. The entire study protocol was approved by the institutional review board at the Catholic University of Pusan (CUPIRB-2019-062). The general characteristics of the subjects are summarized in Table 1.

2. Measurements

1) Instrumentation

To measure the activity of the intrinsic foot muscles, surface electromyography (sEMG; Ultium system, Noraxon Inc., USA) was used. The sampling fraction and bandwidth were set to 2,000 Hz and 10 - 250 Hz, respectively. For the vastus medialis oblique (VMO), the device was attached to the point at 80% of the line connecting the anterior superior iliac spine (ASIS) and the medial collateral ligament (MCL); for the vastus lateralis (VL), the device was attached to the point at 2/3 of the line connecting the ASIS and the lateral side of the patella; for the biceps femoris (BF), the device was attached to the midpoint of the line connecting the tibia lateral epicondyle and ischial tuberosity; for the semitendinosus (ST), the device was attached to the midpoint of the line connecting the tibia medial epicondyle and ischial tuberosity (Hermens et al., 2000). The leg that could kick the ball furthest was selected as the dominant leg (Letafatkar et al., 2019). From the collected muscle activity signals, the root mean square values were analyzed using a statistical program.

Table 1. Descriptive statistics for subjects (n=24)

Variable	Mean±Standard deviation
Age (year)	24.33±1.74
Height (cm)	166.91±9.27
Weight (kg)	63.25±14.92
BMI (kg/m^2)	22.5±3.93
Sex	Male 9(37.5%), Female 15(62.5%)
Dominant foot	Right 22(91.7%), Left 2(8.3%)

2) Maximal voluntary isometric contraction (MVIC)

Maximal voluntary isometric contraction (MVIC) was performed to standardize the activity for each muscle. The MVIC for all muscles was performed according to a previous study (Rutherford et al., 2011). For the VMO and VL, the subject was made to sit on the treatment table with the knee joint bent at 15°, the anterior side of the calf was held, and resistance was applied on the distal part of the calf above the ankle. For the BF and ST, the subject was made to lie in the prone position with the knee joint bent at 55°, and the ankle was held to apply resistance. To prevent muscle fatigue or spasm, the subject was given a minute of rest between the MVIC measurements. MVIC was measured three times, and the average value was used.

3) Dynamic control ratio

To analyze the simultaneous the concentric contraction of quadriceps and the eccentric contraction of hamstring during eccentric hamstring exercises, DCR (Hecc/Qcon) was used. It was obtained as follows: the sum of the %MVIC values of biceps femoris and semitendinosus was divided by the sum of the %MVIC values of VMO and VL (Nimphius et al., 2019).

3. Experimental procedures

The subjects in this study received approximately 30-min of training on how to perform the eccentric hamstring exercises (the Nordic exercise, supine leg curl, and single-leg deadlift) prior to the experiment. All subjects were given sufficient rest time after educational training, and the experiment was started without the subject's fatigue. The start and end of each exercise were marked with a tone signal, and the measurements were taken from the dominant leg in all subjects. For the Nordic exercise, as the subject kneeled on the floor with the torso maintained in a vertical position, the rater applied pressure on the heels of the subject to fix the feet, the subject moved forwards to the maximum joint range of motion (ROM) with the torso maintained in a straight position, and held that position for at least 5-s through eccentric hamstring contraction (Fig. 1A). The subject was then given a 3-min rest and subsequently made to hold the position at 50% of the maximum joint ROM for another 5-s. For the supine leg curl, the subject was made to lie in a supine position with the arms on the floor, lift the hip from the floor, and extend the non-dominant leg (Fig. 1B). The dominant leg was placed on a towel on the floor with the knee joint flexed at 90°, which was performed in a maximally extended knee as much as possible. For the single-leg deadlift, the subject stood and lifted the non-dominant leg adequately away from the floor with support from the dominant leg and simultaneously stretched the dominant hand towards the floor (Fig. 1C). The subject then bent the torso and maintained the pose for 5-s. Each exercise was performed at random and the measurements were taken in triplicate. To minimize muscle fatigue, the subject was given a minute of rest after every session of each exercise, and a 3-min rest after a set of three sessions and before the next exercise. Each session was performed for 5-s, and the muscle activity for the middle 3-s, after excluding the first and last seconds, was used in data analysis.

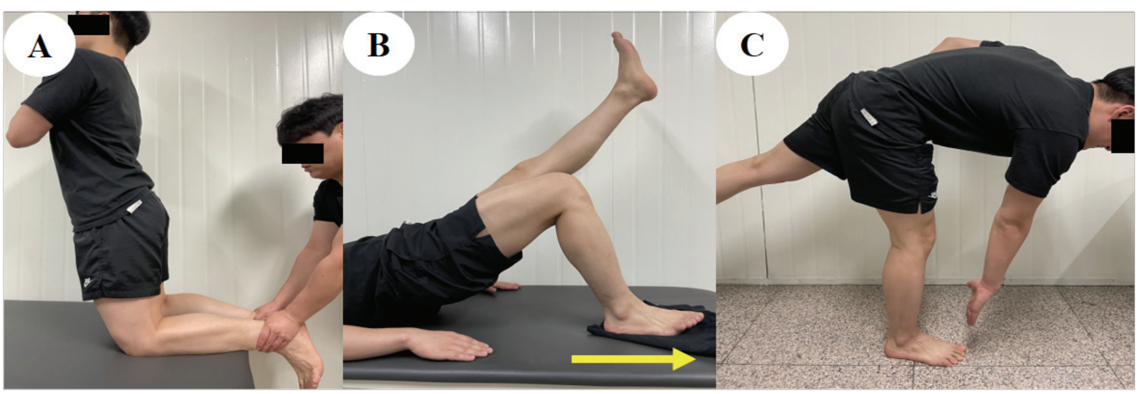

Fig. 1. Eccentric hamstring exercises: A) Nordic exercise, B) Supine leg curl, C) Single-leg deadlift.

4. Statistical analysis

In this study, one-way repeated measure analysis of variance was used to compare the DCR of hamstring and quadriceps based on eccentric hamstring exercises. To examine DCR variations based on eccentric hamstring exercises, the Bonferroni multiple comparisons was used as the post-hoc test. The collected data were analyzed using the SPSS 18.0 (SPSS Inc., USA), and the significance level (α) was set to 0.05.

Ⅲ. Results

The DCR varied significantly across the three eccentric hamstring exercises. The post-hoc test showed that the DCR was significantly lower for the supine leg curl and single-leg deadlift than for the Nordic exercise (F=59.85, p<0.05)(Table 2). The activity of the VMO and VL were significantly higher for the supine leg curl than for the Nordic exercise and single-leg deadlift (p<0.05)(Table 3). Compared to the Nordic exercise, the VL displayed significantly higher activity with the single-leg deadlift (p<0.05)(Table 3). The semitendinosus activity was significantly higher for the supine leg curl and Nordic exercise than for the single-leg deadlift (p<0.05)(Table 3). The biceps femoris activity was significantly higher for the supine leg curl than for the Nordic exercise and single-leg deadlift (p<0.05)(Table 3). The biceps femoris showed significantly higher activity for the Nordic exercise compared to single-leg deadlift (p<0.05)(Table 3).

Ⅳ. Discussion

This study aims to compare DCR and muscle activity, which are commonly referred to as functional HQ ratios, while performing various eccentric hamstring exercises. The DCR was significantly higher in Nordic exercise, and the activity of VMO and VL was significantly higher in SLC. The activity of ST was significantly lower in SLD, and the activity of BF was the highest in SLC.

The DCR measured in this study was significantly lower for the supine leg curl and single-leg deadlift than that for the Nordic exercise. The DCR for the supine

Table 2. Comparison of dynamic control ratio during eccentric hamstring exercises (N=24)

	NE	SLC	SLD	F	p
DCR	8.94±0.9[a]	1.76±0.18[b]	1.69±0.16[b]	59.58	0.01

NE: Nordic exercise, SLC: Supine leg curl, SLD: Single-leg deadlift, DCR: Dynamic control ratio, the values with different superscripts ([a,b]) in the same column are significantly different (p<0.05)

Table 3. Comparison of lower extremity muscle activity during eccentric hamstring exercises (N=24)

	NE	SLC	SLD	F	p
VMO(%MVIC)	7.80±1.32[a]	41.89±4.08[b]	12.11±1.70[a]	66.29	0.01
VL(%MVIC)	5.96±0.62[a]	43.07±4.26[b]	15.00±1.84[c]	59.01	0.01
ST(%MVIC)	52.26±4.47[a]	57.34±3.86[a]	16.41±1.55[b]	84.46	0.01
BF(%MVIC)	49.52±4.00[a]	72.73±5.65[b]	22.28±1.85[c]	52.58	0.03

NE: Nordic exercise, SLC: Supine leg curl, SLD: Single-leg deadlift, VMO; vastus medialis oblique, VL; vastus lateralis, ST; semitendinosus, BF; biceps femoris, MVIC; maximal voluntary isometric contraction, the values with different superscripts ([a,b,c]) in the same column are significantly different (p<0.05) leg curl and single-leg deadlift were 1.76 and 1.69, respectively. According to a previous study, the DCR is generally higher than the HQ ratio (Cometti et al., 2001), with the recommended ratio falling in the range of 0.9 - 1.3 (Chan et al., 1996; Coombs & Garbutt, 2002). The two exercises in this study showed a higher DCR than the recommended level, which is presumably due to the use of a different device, since most previous studies used an isokinetic device instead of EMG to measure the DCR.

In studies using an isokinetic device, the DCR is either measured in a posture that may generate the peak torque for hamstring and quadriceps or at 10° hip joint flexion and 0 - 30° knee joint flexion since it most frequently leads to a knee injury (Deighan et al., 2012; De Ste Croix et al., 2018). Forbes et al. (2009) stated that the use of peak torque at a specific joint angle in DCR measurement should be avoided since each muscle requires a different knee joint position to generate peak torque. The use of peak torque is also limited to conducting a continuous evaluation of muscle contraction and examining activation in motor units (De Ste Croix et al., 2017), implying the need for studies using EMG to measure the co-activation of the hamstring and quadriceps (Coombs & Garbutt, 2002; Hwang et al., 2019). In light of this, the DCR result in this study is clinically significant.

During the Nordic exercise, the activities of the biceps femoris and semitendinosus are ≥50% MVIC (Park et al., 2019; Tsaklis et al., 2015). Hwang et al. (2019) reported the activities of the two muscles as 49.06% MVIC and 47.39% MVIC while performing the Nordic exercise. Similarly, in this study, the activities of the biceps femoris and semitendinosus were 49.52% MVIC and 52.26% MVIC, respectively, during the Nordic exercise. As in the previous study that categorized the Nordic exercise as a medium-intensity (50 - 80%) hamstring strengthening exercise like the curl and hamstring bridge exercises (Tsaklis et al., 2015), the Nordic exercise in this study also showed the highest DCR despite a lower level of hamstring activity compared to the supine leg curl. This is due to the low quadriceps activity, and the result thus lent support to the previous study reporting the potential use of the Nordic exercise to strengthen the posterior muscles such as the trunk extensor and foot plantar flexor muscles in addition to the hamstring (Park et al., 2019).

The DCR for the supine leg curl was 1.76 but the quadriceps activity was ≥41% MVIC. On the contrary, the DCR for the single-leg deadlift was 1.69 with the activities of the hamstring and quadriceps being ≤22% MVIC and ≤15% MVIC, respectively. Thus, it is presumed that these exercises would prove more suitable in the early rehabilitation after ACL reconstruction. After ACL injury, quadriceps dysfunction including muscle atrophy and weakness, affects activity daily life and return to the sports scene (Baron et al., 2020). For this reason, various quadriceps strengthening training is conducted in rehabilitation after ACL injury (Charles et al., 2020). From this point of view, SLC may be more suitable for initial rehabilitation because it is an easier position while inducing proper quadriceps and hamstring activity.

The limitations of this study are as follows: first, since the subjects were healthy individuals, the results may not be generalized to those with ACL or hamstring injuries. Second, due to the lack of peak torque measurement using an isokinetic device, the comparative analysis for the DCR based on EMG is limited. In the future, the DCR should be comparatively analyzed between EMG and isokinetic analyses as the subjects with ACL perform eccentric hamstring exercises.

Ⅴ. Conclusion

Based on the DCR ratio and quadriceps activity, the

SLC will be available early in rehabilitation for ACL injury.

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