Effect of Backward Versus Forward Lunge Exercises on Trunk Muscle Activities in Healthy Participants

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Key Words

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Visual feedback

Background: Lunge exercises are lower extremity rehabilitation and strengthening exercises for patients and athletes. Most studies have shown the effectiveness of the forward and backward lunge exercises for treating patellofemoral pain and anterior cruciate ligament injuries (by increasing lower extremity muscle activity) and improving kinematics.

Objects: However, it is not known how the two different lunge movements affect trunk muscle activities in healthy individuals. The purpose of this study was to investigate the electromyographic activity of the rectus abdominis and erector spinae muscles during forward and backward lunge exercises in healthy participants.

Methods: Twelve healthy participants were recruited. Electromyographic activity of the rectus abdominis and erector spinae was recorded using surface electrodes during forward and backward lunges, and subsequently normalized to the respective reference voluntary isometric contractions of each muscle.

Results: Activity of the erector spinae was significantly higher than that of the rectus abdominis during all stages of the backward lunge ($p < 0.05$). The activity of the erector spinae was significantly greater during the backward than forward lunge at all stages ($p < 0.05$).

Conclusion: Backward lunging is better able to enhance trunk motor control and activate the erector spinae muscles.

INTRODUCTION

The lunge exercise is a motion in which one foot steps forward and the knee is bent to about 90°. Lunge exercises can be performed in a variety of ways by stepping in different directions. Lunge exercises include the forward, backward, side, and walking lunges [1]. These exercises are well-known among the general public and athletes, and can easily be performed in the gym or at home to effectively train muscles, such as the quadriceps and gluteus maximus [2-6]. Among lunge exercises, the forward lunge is often used for training and rehabilitation of athletes without any special equipment. The stepping forward movement and flexing of the stance leg are very intense exercise components that contribute to muscle strengthening by providing eccentric force stimulation, particularly to the hamstring muscle group behind the thigh [7-9]. In addition, the lunge exercise is recommended for initial rehabilitation

and prevention of patellofemoral pain (PFP) syndrome and anterior cruciate ligament (ACL) injury [10-12]. The lunge exercise selectively strengthens the lower extremities, restores normal joint range of motion, and reduces displacement of the tibia. The weight load of closed chain motion exerts a compressive load on the joint surface, reducing anterior-posterior displacement of the tibia against the femur [12]. The forward lunge is effective for treating PFP. The lunging leg movement stimulates and strengthens the quadriceps and glutes, thereby increasing joint stability [13,14]. Moreover, the backward lunge, in which the foot steps backward and the knee is bent, is also effective for PFP. Park et al. [1] reported that the backward lunge reduces the shear force on the knee compared to the forward lunge, and decreases compression under the patella. Goulette et al. [15] reported that the backward lunge is a therapeutic exercise that should be considered for PFP, because the compression force on the patella-femoral joint is

lower compared to the forward lunge. Additionally, lunge exercises not only affect the lower extremities but also stimulate the trunk and core muscles [1,12]. Coordination of the trunk and core muscles is required to maintain balance, because the lunge exercise requires single-limb balance of the stepping foot, which modulates the ascending and descending movements of the body [16,17]. The rectus abdominis and erector spinae, which comprise the trunk muscles, contribute to core stability and postural control of the trunk during sports activities. These two muscles facilitate normal gait by creating and regulating movements between the trunk and pelvis [18,19]. Training the trunk muscles improves the alignment of the lower extremities, thus improving landing of the foot and reducing the risk of an ACL injury by reducing the valgus force of the knee [12,20–23]. One study reported that activities of the trunk and core muscles contribute directly or indirectly to knee joint alignment, stability, and mobility, in addition to hamstring and quadriceps rehabilitation exercises for the ACL, including the lunge [12]. As reported in previous studies, the activities of the trunk muscles are very important when performing the lunge. However, most studies have reported the effect of lunging on the lower extremities; no study compared trunk muscle activation between the forward and backward lunge. Thus, it is not known how the two different lunge movements affect trunk muscle activities in healthy individuals. Therefore, the purpose of this study was to compare the activities of the rectus abdominis and erector spinae muscles during the forward and backward lunge in healthy participants. We hypothesized that the backward lunge would result in higher activity of the trunk muscles than the forward lunge due to lack of visual feedback.

MATERIALS AND METHODS

1. Participants

The study subjects were 12 participants working at Mackenzie Ilsin Christian Hospital in Busan (Table 1). The experimental method and procedure were explained to all subjects who participated in this study after they signed the consent form. The criteria for selecting subjects were no damage to the nervous system or musculoskeletal system related to the trunk and lower extremities. Individuals with lower extremity pain were excluded, along with those who underwent lower extremity surgery within 12 months or had sustained trauma to their knees or ankles within the last 6 months.

2. Instruments

1) Relive 4D-MT 2 channel wireless surface electromyograph

In this study, electromyography (EMG) was used to measure the activities of the rectus abdominis and erector spinae muscles during forward and backward lunging. EMG signals are produced by physiological changes occurring in the muscle tissue membrane. Measurements from each muscle were collected and processed using the 2EM instrument (4D-MT; Relive, Gimhae, Korea) (Figure 1). The sampling rate of the EMG signal was set to 1,000 Hz, and the frequency bandwidth was 0–500 Hz. By using the 2EM instrument, EMG value of the muscles

Table 1. Characteristics of subjects (N = 12)

Sex	Age	Height (cm)	Weight (kg)
Male (n = 6)	28.0 ± 1.7	178.2 ± 3.8	77.2 ± 6.4
Female (n = 6)	26.2 ± 3.7	162.2 ± 2.7	52.4 ± 2.5

Values are presented as mean ± standard deviation.

Figure 1. (A) 2EM [Electromyography [EMG] sensors]. (B) Relive 4D-MT [EMG analysis program].

was analyzed after determining the root mean square (RMS).

2) Tempo Lite metronome

This study used the Tempo Lite metronome (Frozen Ape Pte. Ltd., Singapore, Singapore) application to accurately measure and standardize the time when the subject performs the forward and backward lunges, to measure activities of the rectus abdominis and erector spinae muscles. The metronome application flashes to signal the beats per minute (bpm) and generates a constant rhythmic sound, allowing the subject to perform actions in time to the beat. When each subject performed the forward and backward lunges, the metronome setting was 60 bpm to generate a sound every second.

3. Procedure

The subjects warmed up for 5 minutes by performing simple lower extremity stretching exercises. Participants kicked a ball to identify the dominant leg. Then, forward and backward lunges were performed randomly by stepping the dominant foot forward or the non-dominant foot backward, with the feet shoulder-width apart (Figure 2). During the lunge, as a

reference standard, the step length was marked with tape on the floor at a point corresponding to 75% of the length of the dominant leg. A 6-cm foam pad was placed on the floor so that the knee of the contralateral leg lightly touched it while descending; this was done to obtain the depth standard [10]. Ascending and descending motions were both measured for 2 seconds. During the exercise, the subjects were instructed to keep the trunk vertical and maintain the feet shoulder-width apart. Each exercise was performed three times, with a 1-minute rest period between each exercise.

1) Electromyographic data collection

An EMG pad was attached to the rectus abdominis and erector spinae muscles to measure activity during forward and backward lunging [24–26]. The electrode attachment points were selected by referring to a previous study, and through direct palpation by the examiner (Figure 3). The attachment point for the erector spinae was 3 cm lateral to the spinous process of the third lumbar vertebra. The electrode for the rectus abdominis was attached 3 cm from the navel and above the anterior superior iliac spine. Since it is a unilateral exercise

Figure 2. (A) Forward lunge start position (backward lunge end position). (B) Lunge position. (C) Backward lunge start position (forward lunge end position). Forward lunge exercise order: A to C, backward lunge exercise order: C to A.

Figure 3. Placement of electromyography electrodes. (A) Rectus abdominis. (B) Erector spinae.

RESULTS

that targets the bending knee, all electrodes were attached to the same side of the trunk. Hairy areas were shaved to minimize resistance, and the skin at the attachment site was rubbed three or four times with thin sandpaper to remove the dead skin layer. Then, the skin was cleaned with alcohol, and the surface electrode was attached. The ground electrode was attached to the anterior superior iliac spine. The reference voluntary isometric contractions (RVIC) test required to normalize each muscle was measured before obtaining the EMG values of two different lunges. The posture for measuring RVIC test was based on previous studies. For the rectus abdominis, the subject's arms were crossed at the chest, with the trunk bent while in the supine position until the inferior angle of the scapula increased. For the erector spinae, the subjects were asked to extend the trunk while in the prone position using the upper limbs (held next to the trunk) until the chest was lifted. All tests were performed without resistance, and the RVIC activity was repeatedly measured (three times for 5 seconds each). Then, the subject performed backward and forward lunges, and average RMS values for the rectus abdominis and erector spinae muscles were obtained. The RMS value was divided by the RVIC and multiplied by 100 (%RVIC) to calculate the activity of the rectus abdominis and erector spinae muscles during the backward and forward lunges.

4. Statistical Analysis

SPSS for Windows software (ver. 25.0; IBM Co., Armonk, NY, USA) was used to compare activation of the rectus abdominis and erector spinae between the forward and backward lunges. One-way repeated-measures analysis of variance was used to compare the muscle activities between the forward and backward lunges. When a significant difference was obtained, the post-hoc Bonferroni correction was applied. A p -value < 0.05 was considered significant.

The muscle activities of the rectus abdominis and erector spinae were measured during the forward and backward lunge exercises. The activities of the rectus abdominis and erector spinae during the ascending motion of the forward lunge were 54.75 ± 12.30 %RVIC and 52.09 ± 10.45 %RVIC, respectively, while during the descending motion they were 43.48 ± 11.94 %RVIC and 37.31 ± 9.03 %RVIC, respectively. The activities of the rectus abdominis and erector spinae during the ascending motion of the backward lunge were 50.33 ± 17.76 %RVIC and 72.94 ± 11.45 %RVIC, respectively, while during the descending motion they were 36.37 ± 11.28 %RVIC and 54.76 ± 15.70 %RVIC, respectively (Table 2). No significant difference was observed between the rectus abdominis and erector spinae muscle activities during the forward lunge, but a significant difference was detected during the ascending and descending motions of the backward lunge (Table 2). No significant difference in the activity of the rectus abdominis muscle was observed between the forward and backward lunges within the

Figure 4. Muscle activity of the rectus abdominis (RA) and erector spinae (ES) to forward and backward lunge. BLA, backward lunge ascending; BLD, backward lunge descending; FLA, forward lunge ascending; FLD, forward lunge descending; RVIC, reference voluntary isometric contraction. * $p < 0.05$.

Table 2. Muscle activities during lunge exercises (%RVIC) [N = 12]

Muscle	Lunge exercises			
	FLA	FLD	BLA	BLD
Rectus abdominis	54.75 ± 12.30	43.48 ± 11.94	50.33 ± 17.76	36.37 ± 11.28
Erector spinae	52.09 ± 10.45	37.31 ± 9.03	$72.94 \pm 11.45^*$	$54.76 \pm 15.70^*$

Values are presented as mean $\pm$ standard deviation. RVIC, reference voluntary isometric contraction; FLA, forward lunge ascending; FLD, forward lunge descending; BLA, backward lunge ascending; BLD, backward lunge descending. * $p < 0.05$.

same part of the lunge, but the activity of the erector spinae muscle was significantly higher during the ascending and descending motions of the backward lunge (Figure 4).

DISCUSSION

The rectus abdominis and erector spinae muscles of the trunk contribute to core stability and postural control of the trunk, and aid normal gait. In addition, training the trunk muscles through lower extremity rehabilitation exercises indirectly improves the alignment of the lower extremities and reduces the valgus force of the knee, thereby lowering the risk of ACL injury [12,20–23]. Therefore, it is important to understand the activity of the trunk muscles during the lunge exercise. The difference between the forward and backward lunges is that unlike the forward lunge, the backward lunge is performed blind. As vision plays an important role in maintaining balance during exercise, the backward lunge is expected to be more challenging than the forward lunge. Therefore, the purpose of this study was to compare activation of the rectus abdominis and erector spinae muscles during the forward and backward lunge exercises using EMG. No significant differences were observed in the activity of the rectus abdominis muscle, but the erector spinae muscle was significantly higher during the ascending and descending motions of the backward versus forward lunge. In addition, when comparing the two muscles for the same motion, erector spinae activity was significantly higher than rectus abdominis activity during ascending and descending motions of the backward lunge. Postural control mechanisms include feedforward control, which predicts and activates the muscles needed to perform the desired exercise through the central nervous system, and feedback control to rapidly regulate movement in situations where prediction is difficult [27]. In daily life, the human body is constantly subjected to mechanical forces in various directions, and is occasionally affected by mechanical forces even during a sudden postural perturbation or change [27,28]. In the case of the lunge exercise performed in this study, the movement was controlled by proactive activation of the trunk muscles through feedforward control before, and activation of the trunk muscles to cope with the sudden perturbation experienced during the exercise (feedback control). Previous studies have reported that visual information greatly contributes to feedforward and feedback control of the trunk muscles [28–32]. Therefore, it is rea-

sonable to assume that the insufficient vision during the backward lunge could lead to a lack of feedforward control, which makes the body vulnerable to sudden perturbations and could trigger postural collapse. In turn, this could lead to greater activation of the erector spinae muscle as a result of feedback regulation. For the backward lunge, the toes touch the ground first, while for the forward lunge the heel touches down first, so the base of support is relatively narrow when landing. Along with the lack of visual information on the direction of movement, this likely lowers dynamic stability, thus requiring stronger neuromuscular regulation and proprioception and resulting in greater activation of the erector spinae muscles [31,32]. Another reason for the significantly higher muscle activity of the erector spinae during the backward lunge is that the trunk is maintained vertically as much as possible, and the toe-heel landing pattern leads to a larger extension moment than the forward lunge. In addition, the muscle activity of the erector spinae was highest during the ascending part of the backward lunge. Stronger concentric contraction is required during the ascending than descending part to overcome gravity.

Several limitations of this study should be discussed. First, the subjects were all healthy participants. Therefore, a comparative study on the effect of posterior lunge exercise on activation of the trunk muscles in subjects with musculoskeletal or nervous system damage in the lower extremities is needed. Second, as this study measured only the activities of the rectus abdominis and erector spinae during lunging, the activities of the deeper trunk muscles, such as the transverse abdominis or multifidus, remain unknown. Third, as the number of subjects was small ($N = 12$), it is difficult to generalize the results. Fourth, since only the muscle activity of the one side of the trunk during lunging was measured, studies also measuring muscle activity on the opposite side of the trunk during lunging are needed. Finally, no kinematic data were obtained. In future studies, it will be necessary to address these limitations to more accurately determine the effect of lunge exercises on trunk muscle activation, and verify the clinical significance of these exercises.

CONCLUSIONS

The effects of forward and backward lunge exercises on trunk muscle activities were analyzed. The activity of the erector spinae was significantly higher than that of the rectus ab-

dominis during the backward lunge, and erector spinae activity was significantly higher during the ascending and descending motions of the backward compared to forward lunge. These results are attributed to the lack of visual feedback, and toe-heel landing pattern of the backward lunge exercise, which requires strong neuromuscular control and proprioception to increase the extension moment; this is likely to lower dynamic stability. The backward lunge can be considered a rehabilitation exercise for activating the erector spinae muscles that requires greater motor control than the forward lunge exercise. Future studies should obtain kinematic data along with measurements of the activity of other trunk muscles.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Conceptualization: JKS. Data curation: JKS. Formal analysis: JKS. Investigation: WGY. Methodology: JKS. Project administration: WGY. Resources: JKS. Supervision: WGY. Validation: WGY. Visualization: WGY. Writing – original draft: JKS. Writing – review & editing: WGY.

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