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Effects of an 8-week lunge exercise on an unstable support surface on lower-extremity muscle function and balance in middle-aged women

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[Purpose] This study aimed to develop a more effective exercise program for lower extremity muscle function by evaluating the effects of an 8-week lunge exercise performed on an unstable support surface on lower extremity muscle function, body composition, and body balance in middle-aged women.

[Methods] Twenty participants were divided into two groups (control group: exercise on a stable support surface, n=10; experimental group: exercise on an unstable support surface, n=10). Each participant performed the exercise program for 8 weeks (three sessions a week, 50 min/session).

[Results] The results revealed that body fat percentage decreased significantly in the experimental group ($p<0.01$). Additionally, lower-extremity muscle mass and function increased significantly in both groups ($p<0.05$), but with no significant difference between the groups. Moreover, the results of the static and dynamic balance tests indicated that balance improved in both groups, with significantly greater improvements in the experimental group than in the control group ($p<0.05$).

[Conclusion] Lunge exercise on stable and unstable support surfaces improves muscle function and static balance in middle-aged women. In particular, lunge exercise on an unstable support surface was more effective at reducing body fat than lunge exercise on a stable support surface and was also found to improve dynamic balance. Therefore, a program consisting of lunge exercises on an unstable support surface may be suitable for body improvements in middle-aged women.

[Keywords] body composition, Y-balance test, dynamic balance, static balance, lower extremity muscle, muscle mass

INTRODUCTION

Middle-aged women undergo various physical changes during aging in the later stages of life[1]. During this process, multiple climacteric symptoms, including menopause and estrogen loss, result in an increased incidence of osteoporosis, cardiovascular disease, and musculoskeletal and joint problems[2]. A representative musculoskeletal symptom in middle-aged women is estrogen deficiency, which leads to a decrease in muscle mass, physical balance, activity by limited joint motion range, and an increase in body weight due to fat accumulation[3]. Muscle strength exercises are preferred for muscle function, mass, and balance prevention, while weight-bearing exercises, which apply physical force to the bone, are reportedly more effective at increasing health in middle-aged women than non-weight-bearing exercises[4,5].

Lower extremity muscle strength is important to achieve effective body control, and developing postural and pelvic muscles that maintain the center of the body enables safe and efficient lower extremity exercises[6]. Therefore, strengthening the leg muscles is essential to improve the quality of life and recover walking ability, balance, and function, because a decrease in lower-extremity muscle strength can disrupt body balance, reduce walking ability, and leads to falls through abnormal gait due to functional impairment[2,7-9]. The lunge exercise involves an eccentric contraction of the quadriceps femoris that characteristically strengthens the vastus medialis oblique. This selectively strengthens the lower extremities, restores the normal joint range of motion, and reduces displacement of the tibia[10]. In addition, Yeo et al.[11] discovered that lower extremity muscles are important in preventing unspecified injuries related to weakened lower extremity strength and trunk stabilization. Therefore, it is necessary to exercise the lower extremities in middle-aged women with reference to lower extremity muscle strength, trunk stability, and balance.

A lunge is a movement-related exercise method used in daily life[12]. Lunge exercises ensure multijoint muscle stability and require hip, knee, ankle, and foot mobility and stability. In addition, the lunge is an exercise in which a weight is attached to the leg to be stepped on, which absorbs the propulsion force, stores it as elastic energy, and converts it into propulsion force when returned to its original position. This exercise requires more movement and control of both leg functions than squats[13,14]. A previous study discovered that lunge exercise activates lower-extremity

PAN Physical Activity and Nutrition

muscle activity by using the hip joint and ankle strategies to move the body's center of gravity to a stable surface[15]. This posture is widely used in clinical practice to strengthen the quadriceps femoris and reduce muscle imbalance on both sides[18], as it causes eccentric contraction of the quadriceps femoris and calf muscles[16] and isometric contraction of the muscles of the back of the thigh[17]. Moreover, it is often used in lower-extremity strength training, including in the initial rehabilitation stage[19].

A previous study demonstrated that exercising on an unstable rather than stable support surface activates proprioceptors in the joints and muscles, thereby increasing dynamic stability in patients with low back pain[20]. Moreover, exercises using an unstable support surface place less strain on the joints than weight-bearing exercises, improve dynamic balance ability and postural control, and stimulate a greater number of neuromuscular systems, while improving muscle strength[21-23]. However, the above-mentioned studies focused on reducing pain in patients with lower back or knee pain, and the effect in normal participants has not yet been established.

Many studies have examined the effects of lunge exercise on improving lower-extremity muscle strength in middle-aged women; however, no studies have yet investigated the effect of lunge exercise performed on an unstable support surface on lower-extremity muscle strength, body composition, or body balance. Therefore, this study aimed to provide an effective exercise for lower extremity strength by evaluating the effects of 8 weeks of lunge exercise on an unstable support surface on lower extremity muscle strength, body composition, and body balance in middle-aged women.

METHODS

Participants

This study enrolled 20 middle-aged women aged 40–59 years. The purpose of the study and the experimental method were sufficiently explained to the participants, and those who understood were allowed to participate in the experiment after signing a consent form. The inclusion criteria included participants who i) agreed to participate voluntarily in this study, ii) had never experienced lunge exercise, and iii) had not reached menopause. Exclusion criteria included participants (i) with uncontrolled clinical diseases such as neuropsychiatric disorders, (ii) who wanted to discontinue due to uncomfortable feeling of vibration stimulation during the experiment, and (iii) those with physical deformities, diseases, or pregnancy. The participants were divided into two groups: the control (CON, n = 10) and experimental (EXP, n = 10) groups. The CON and EXP groups performed lunge exercises for 8 weeks on stable and unstable support surfaces, respectively. The Institutional Review Board of Konkuk University approved all research contents, procedures, and protocols (7001355-202107-HR-453).

Exercise program

Participants in each group performed appropriate exercise for 8 weeks, three times a week, for 50 min, according to their physical strength level, which was based on the rating of perceived exertion using the OMNI scale ranging from 6 (somewhat difficult) to 8 (difficult). OMNI is a rating of perceived exertion scale with broadly generalizable properties. The OMNI scales include mode-specific pictorials, numerical ratings (0–10), and corresponding verbal descriptions distributed along an increasing intensity gradient. OMNI-RES is an effective tool for beginner exercisers as it provides a simple, subjective guide for determining the safe and appropriate resistance training intensities. The EXP group performed lunge exercises on an unstable support surface using a Togu balance cushion (Togu, Germany) (Figure 1). Additionally, walking lunges were performed over two sets of 10 repetitions each, with each set used as a warm-up movement. Three sets of 10 front lunges were performed, with two sets of 10 side lunges each, and two sets of barbell lunges at 10% of the subject's weight, each with 10 repetitions. The rest period between exercises was set to 1 min and 30 s. As a finishing exercise, whole-body stretching was performed for 15–20 min, and the total exercise time was 50 min. The CON group performed the same exercise program as the EXP group, but on a stable support surface. The CONSORT diagram for data collection and analysis is shown in Figure 2.

Measurements

Body composition

Body weight, body fat percentage, and lean mass were analyzed using the bioelectrical resistance method (In body 720, Korea) to evaluate the body composition of each participant.

Muscle strength

A Lonpick Fit Visor Mini Plus (RONFIC, Korea) isokinetic device was used to measure the function of the quadriceps femoris and lower-extremity hamstring muscles. Squats and deadlifts were repeated thrice for each movement to collect reliable data, while minimizing the physical burden on the participants. The detailed measurement method was as follows: The squat (lower extremity pushing force test) evaluates the force of the quadriceps femoris muscles attached to the front of the lower extremities. This exer-

Figure 1. Unstable support surface.

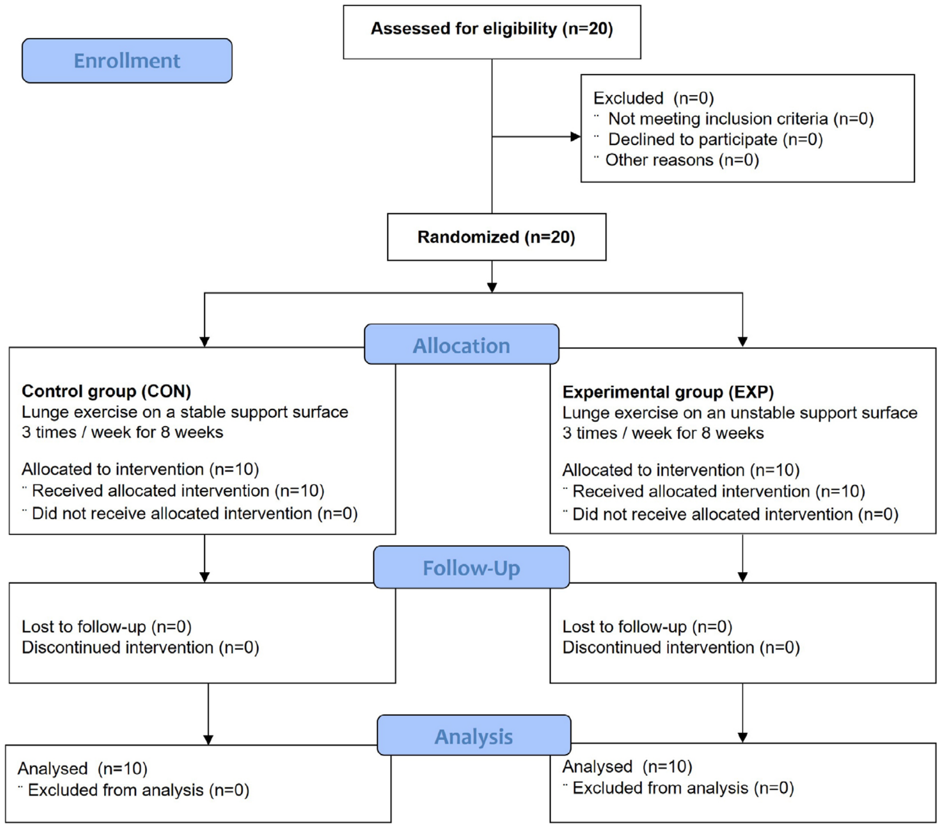

Figure 2. CONSORT 2010 flow diagram of the study.

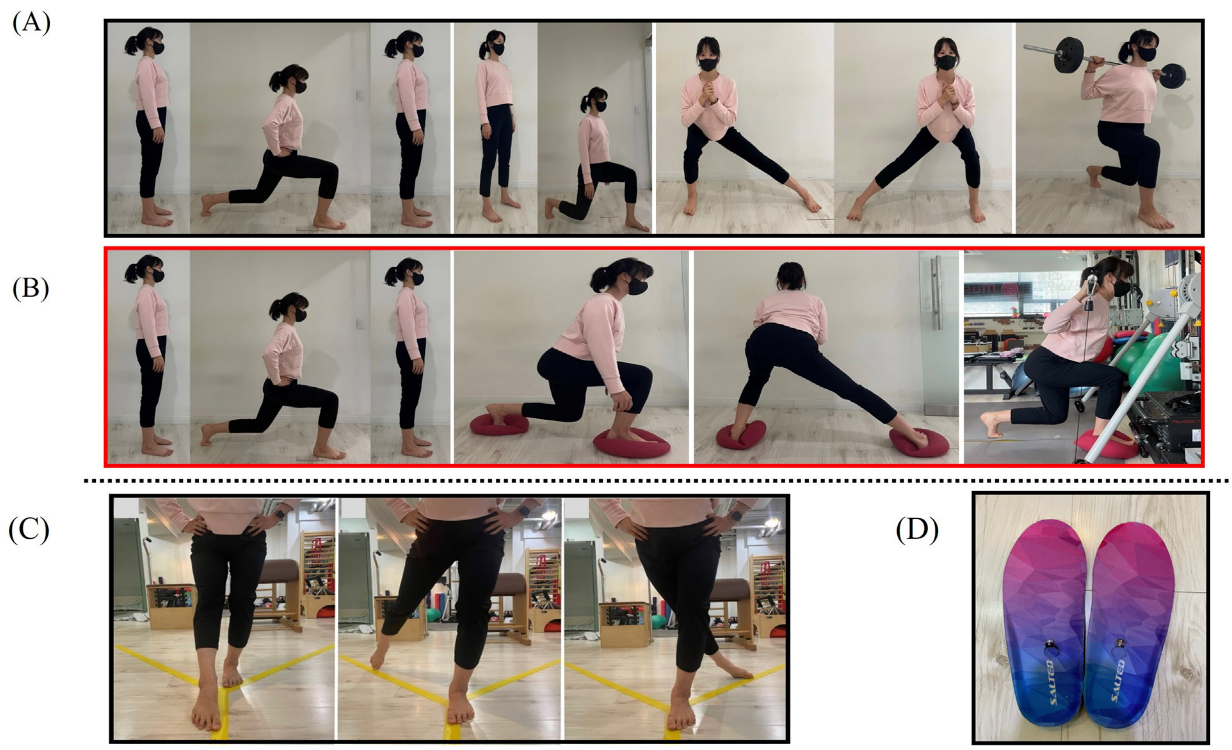

Figure 3. Lunge exercise method on the stable and unstable support surface. (A) Lunge exercise on a stable support surface. (B) Lunge motion on an unstable support surface. The same exercise was performed for 8 weeks. Exercises were performed in the order of the picture, as follows: the walking lunge, front lunge, side lunge, and barbell lunge. (C) Y-balance test (anterior, posteromedial, and posterolateral). (D) Smart insole.

cise involves the participants slowly crouching and rising, pressing down quickly and strongly on the floor as the participant stood up. The deadlift (low-limb pulling force test) evaluated the force of the hamstring muscles attached to the back of the lower extremities. This exercise also involves the participants slowly crouching and rising, pressing down quickly and strongly on the floor. The average values of the five movements after three repetitions were used to compare the anterior and posterior muscle functions of the lower extremities. Figure 3 A, B show the lunge exercise method on stable and unstable support surfaces.

Body balance

The Y-balance test (YBT) is a simple and reliable test used to measure dynamic balance (Figure 3 C). In the YBT, the participant maintained their balance on one leg while extending the other leg as far as possible in three directions: anterior, posterior, and posterior medial. Using this test, the participant's strength, stability, and balance can be measured in various directions. Using a 1.5-inch tape, the posterior medial and posterior medial lines were marked at 135 degrees on both sides based on the anterior line, and the distance from the center line to the point where the participant stretched their leg was measured in cm. Six measurements were taken to minimize the learning effect[24]. Measurements were recorded thrice. Furthermore, the following events were deemed to have resulted in test failure, and any applicable recordings were excluded and re-measured.

i) when the foot supporting the ground fell off the line
ii) when the weight was placed on the outstretched foot for balance
iii) when the foot was unable to return to the starting position after stretching

To compensate for differences in leg length, the following standardization equation was applied to calculate the reach distance:

$$\mathit{composite\ reach\ distance}(\%) = \frac{\text{Anterior} + \text{Posteriomedial} + \text{Posterolateral}}{3 \times \text{Limb length}} \times 100$$

A smart insole (Salted, Korea) was used to evaluate the dynamic plantar pressure and balance (Figure 3 D). Four sensors were built into the insole for each foot area (the first metatarsal, toe, metatarsal, and heel). The electrical signals for the landing time and foot pressure in the static and dynamic states for each foot part could be evaluated using these sensors, and the data may be saved and monitored in conjunction with the application. The EMED-LE measurement system (Novel®, USA) is a standard test tool used to prove the convergent validity of the smart insole by measuring the foot pressure distribution for each foot area on flat ground. This tool corrects body balance and body shape by analyzing plantar pressure and gait pattern algorithms using 2,816 sensors to measure and evaluate the force, pressure, contact area, and landing time applied to the feet in static and dynamic states[25] to analyze the real-time center of pressure movement.

Statistical analysis

All statistical analyses were performed using the SPSS software (version 24.0, IBM Corp., Armonk, NY, USA). An independent t-test was performed to assess prior homogeneity between the groups of participants after calculating the descriptive statistical values of all data. Moreover, repeated two-way analysis of variance followed by Tukey's post-hoc test, was performed to evaluate the differences between the groups before (0 weeks), during (4 weeks), and after (8 weeks) the experiment and assess the changes by the measurement period. Statistical significance was set at $P < 0.05$.

RESULTS

Table 1 presents the differences in body composition (body fat percentage, lower extremity muscle mass, and abdominal muscle mass) between the groups before, during, and after 8 weeks of exercise on unstable and stable support surfaces. All variables involved main and interaction effects. Body fat percentage decreased in the EXP group, and post-hoc analysis revealed a significant decrease at 0–8 and 4–8 weeks ($p<0.01$ and $p<0.001$, respectively). However, no significant differences were observed over time in the CON group. Moreover, the CON group showed a significant increase in the left lower-extremity muscle mass after 8 weeks of exercise compared to the pre-exercise (0 week) measurement ($p<0.05$), and there was no statistical difference in the right lower extremity muscle. In the EXP group, the muscle mass in the lower extremities on the left and right sides increased significantly at 0–8 and 4–8 weeks ($p<0.001$). The EXP group showed a significant effect on abdominal muscle mass at 0–8 and 4–8 weeks ($p<0.001$).

Table 2 shows the differences in lower extremity muscle function changes between the two groups before and after exercise. No significant interaction effect was observed for the anterior and posterior muscle function changes. However, there was a significant main effect, and anterior muscle function increased significantly in the CON group at weeks 0–4 ($p < 0.05$), 4–8 ($p < 0.05$), and 0–8 ($p<0.01$) in the post-hoc analysis. The EXP group showed a significant increase from weeks 4–8 and 0–8 ($p<0.001$).

Table 3 shows the differences in static balance between the two groups before and after exercise. There were no differences in interaction effect between the groups in all variables because of the left, right, anterior, and posterior measurements using a smart insole; however, a time-based effect was observed. In the case of the left and right sides, the EXP group showed significant differences at 0–4, 4–8, and 0–8 weeks, while the CON group showed a statistical difference at 0–8 weeks ($p<0.01$). Interestingly, there was a significant difference in anterior and posterior balance according to time in the CON group ($p<0.05$, $p=0.01$, and $p=0.001$, respectively), but no statistical difference was observed in the EXP group.

Table 4 shows the differences in dynamic balance changes between the two groups. No significant interaction effect was observed for any of the variables; however, a significant

Table 1. Changes in body fat and muscle mass during the 8-week experimental period.

Variables		Group	Time			p	
			0–4 weeks	4–8 weeks	0–8 weeks		
Body fat percentage (%)		CON	27.99 ± 7.93	27.42 ± 7.28	27.12 ± 6.81	G T	0.603 0.001 **
		EXP	30.73 ± 4.67	29.67 ± 4.60†	26.38 ± 4.53†	G×T	0.005 **
Lower extremity muscle mass (kg)	Left	CON	6.43 ± 0.52	6.73 ± 0.74	6.83 ± 0.71†	G T	0.172 0.000 ***
		EXP	5.66 ± 0.96	5.81 ± 0.90†	7.10 ± 0.74†	G×T	0.000 ***
	Right	CON	6.40 ± 0.65	6.68 ± 0.68	6.78 ± 0.69	G T	0.184 0.000 ***
		EXP	5.63 ± 0.96	5.75 ± 0.92†	7.09 ± 0.78†	G×T	0.000 ***
Abdominal muscle mass (kg)		CON	18.32 ± 1.28	18.45 ± 1.55	18.39 ± 1.44	G T	0.117 0.000 ***
		EXP	16.65 ± 1.81	16.77 ± 1.79†	18.14 ± 2.03†	G×T	0.000 ***

CON, control group; EXP, experimental group; G, group; T, time; G×T, interaction. †p<0.01, statistically significant difference in time.**p<0.01, ***p<0.001.
All values represent the mean ± standard deviation.

Table 2. Changes in anterior and posterior lower extremity muscle function over the experimental period.

Variables	Group	Time			p	
		0–4 weeks	4–8 weeks	0–8 weeks		
Anterior (Total_N)	CON	36.67 ± 4.30†	38.28 ± 5.19†	40.74 ± 5.93†	G T	0.079 0.022 *
	EXP	32.84 ± 5.51	33.70 ± 4.40†	36.69 ± 5.97†	G×T	0.679
Posterior (Total_N)	CON	36.91 ± 4.57	37.99 ± 4.60	40.87 ± 5.98	G T	0.096 0.005 **
	EXP	33.24 ± 5.89	33.98 ± 4.44	36.90 ± 6.32	G×T	0.951

CON, control group; EXP, experimental group; G, group; T, time; G×T, interaction. †p<0.01, statistically significant difference in time. *p<0.05, **p<0.01.
All values represent the mean ± standard deviation.

Table 3. Changes in static balance (standing in place) using a smart insole over the experimental period.

Variables	Group	Time			p	
		0–4 weeks	4–8 weeks	0–8 weeks		
Left (%)	CON	43.30 ± 10.50	44.70 ± 4.14	47.00 ± 3.97†	G T	0.361 0.003 **
	EXP	35.10 ± 10.43†	45.10 ± 5.36†	48.50 ± 2.55†	G×T	0.201
Right (%)	CON	56.70 ± 10.50	55.30 ± 4.14	53.00 ± 3.97†	G T	0.368 0.003 **
	EXP	64.90 ± 10.42†	54.90 ± 5.36†	51.40 ± 2.55†	G×T	0.146
Anterior (%)	CON	25.50 ± 19.53	34.40 ± 7.15†	42.90 ± 5.20†	G T	0.127 0.018 *
	EXP	33.00 ± 22.98	43.00 ± 14.42	46.50 ± 4.50	G×T	0.649
Posterior (%)	CON	74.50 ± 19.53	65.60 ± 7.15†	57.10 ± 5.20†	G T	0.127 0.018 *
	EXP	67.00 ± 22.98	57.00 ± 14.42	53.50 ± 4.50	G×T	0.649

CON, control group; EXP, experimental group; G, group; T, time; G×T, interaction. †p<0.01, statistically significant difference in time. *p<0.05, **p<0.01.
All values represent the mean ± standard deviation.

main effect was observed. Post-hoc analysis revealed significant differences in the EXP group on the left and right sides ($p<0.05$ and $p<0.01$, respectively). However, in the anterior and posterior balance tests, only the CON group showed a significant difference over time, whereas the EXP group showed no statistical difference ($p<0.01$).

Table 5 shows the differences in dynamic balance changes between the two groups using the YBT. There were significant interaction and main effects on the left side. There was a main effect on the right side, but no interaction effect was observed. Post-hoc analysis revealed that the EXP group showed a significant increase in dynamic balance changes compared to the CON group ($p<0.05$), and the difference in timing was improved at all points (0–4, 4–8, and 0–8 weeks). In the case of the right side, there was a statistical difference between the groups ($p<0.01$); specifically, there was a significant difference at 0–4 weeks and 0–8 weeks in the CON group, whereas there was a significant difference in the EXP group at all time points ($p<0.01$ and $p=0.001$, respectively).

Table 4. Changes in dynamic balance using squares over the experimental period.

Variables	Group	Time			p	
		0–4 weeks	4–8 weeks	0–8 weeks		
Left (%)	CON	39.50 ± 10.10	43.10 ± 4.18	44.90 ± 2.88	G	0.384
	EXP	40.90 ± 7.64†	44.10 ± 5.92†	48.60 ± 3.17†	T	0.003 **
					G×T	0.268
Right (%)	CON	60.50 ± 10.10	56.90 ± 4.18	55.10 ± 2.88	G	0.495
	EXP	59.10 ± 7.64†	55.90 ± 5.92†	52.40 ± 5.70†	T	0.007 **
					G×T	0.573
Anterior (%)	CON	25.30 ± 25.27	28.80 ± 11.44†	39.20 ± 6.39	G	0.126
	EXP	37.60 ± 19.55	45.70 ± 12.82	47.90 ± 2.92	T	0.025 *
					G×T	0.147
Posterior (%)	CON	74.70 ± 25.27	71.20 ± 11.44†	60.80 ± 6.39	G	0.126
	EXP	62.40 ± 19.55	54.30 ± 12.82	52.10 ± 2.92	T	0.025 *
					G×T	0.147

CON, control group; EXP, experimental group; G, group; T, time; G×T, interaction. †p<0.01, statistically significant difference in time. *p<0.05, **p<0.01.
All values represent the mean ± standard deviation.

Table 5. Changes in dynamic balance using the Y-balance test over the experimental period.

Variables	Group	Time			p	
		0–4 weeks	4–8 weeks	0–8 weeks		
Left (SCORE)	CON	47.37 ± 8.73†	61.76 ± 7.46†	66.32 ± 8.88†	G	0.015 *
	EXP	53.59 ± 13.29†	68.87 ± 7.52†	79.47 ± 5.24†	T	0.000 ***
					G×T	0.049 *
Right (SCORE)	CON	48.03 ± 8.21†	62.65 ± 6.98	66.02 ± 8.32†	G	0.009 **
	EXP	51.87 ± 12.89†	71.48 ± 7.28†	80.08 ± 5.64†	T	0.000 ***
					G×T	0.146

CON, control group; EXP, experimental group; G, group; T, time; G×T, interaction. †p<0.01, statistically significant difference in time. *p<0.05, **p<0.01, ***p<0.001.
All values represent the mean ± standard deviation.

DISCUSSION

This study analyzed the effects of an 8-week lunge exercise program on an unstable support surface on lower extremity muscle strength, body composition, and body balance in middle-aged women. Both lunge exercise groups on an unstable support surface and a stable support surface showed significant increases in lower extremity muscle mass and muscle function. However, there were no significant differences between the groups. Interestingly, the exercise group on the unstable support surface showed a significant decrease in body fat (%) during the exercise period. Moreover, the results of static and dynamic balance tests indicated that balance improved in both groups, and the balance in the experimental group (unstable support surface exercise group) improved significantly compared to that in the control group (stable support surface exercise group).

Haynes[26] measured the trunk muscle activity after exercise on various unstable support surfaces and discovered that the greater the instability, the greater the trunk muscle activity. Many differences between the two groups were not found in this study due to limitations such as the short experimental period of 8 weeks, the relatively small number of participants, and the lack of investigation of the participants' dietary habits and lifestyles. Nevertheless, exercise on an unstable support surface is more effective than that on a stable support surface. Recent studies have reported that exercise on an unstable support surface has a more pronounced effect on lower extremity muscle activity in young men and women than exercise on a stable support surface[27-29]. This is also consistent with the results of another study, which suggest that increasing the external agitation on the unstable support surface and effectively changing the movement to correct the posture stimulates the sensorimotor system[30]. Moreover, previous studies have suggested that balancing exercises on an unstable surface are more effective than those on a stable surface[31], and that balancing on an unstable support surface activates proprioception via various reflexes[32]. These results are consistent with the main findings of this study, including that exercise on an unstable support surface results in decreased body fat percentage and increased lower-extremity muscle mass.

No statistical difference in the change in lower-extremity muscle function was observed between the two groups; however, muscle function improved in both groups. In addition, the CON group showed a significant difference with time in anterior and posterior balance, but no significant difference was observed in the EXP group using the smart insole. However, in the case of the left and right sides, the EXP group showed significant differences at 0–4, 4–8, and 0–8 weeks, whereas the CON group demonstrated a statistical difference at 0–8 weeks. In particular, the reason for the improvement in anterior and posterior balance only in the CON group seems to be that the initial balance was greatly disrupted, as shown in Table 4. A study that evaluated the reliability and convergence validity of landing time for each foot part using a smart insole[33] found that the reliability between measurement tools was high in the normal foot, while the reliability within the measurement tool was high in all foot types. Measurement of static balance using this equipment in our study found that lunge exercise on an unstable support surface and a stable support surface for 8 weeks had a positive effect on improving static balance in middle-aged women.

There was a significant difference in the EXP group on the left and right sides because balance during squats was evaluated using a smart insole. However, only the CON group showed a statistically significant difference in time in the anterior and posterior balance tests, whereas the EXP group showed no statistical difference. This may be because anterior and posterior balance is disrupted during the pre-exercise stage, while lunge exercise is thought to improve dynamic balance.

The YBT results showed that the score improved in both groups, with the EXP group showing a significantly greater improvement than the CON group. Previous studies have demonstrated that exercising on an unstable support surface increases trunk stability and postural control[34,35] when healthy adults exercise to improve balance on a stable or unstable support surface.

In this study, we discovered that the effectiveness of lunge exercise, a closed chain exercise, showed significant difference between the use of stable and unstable support surfaces in middle-aged women who required many lower-extremity strengthening exercises. Park[36] demonstrated that lumbar stabilization exercises performed on an unstable support surface are more effective than exercises performed on a stable support surface. Lee[37] demonstrated that squat exercises on an unstable support surface increased core muscle activity. In addition, another study discovered using electromyography that performing waist stabilization exercises on an unstable surface using a ball for six weeks activated the abdominal and lumbar extensors. Mori[38] further reported that muscles passing through body segments generate joint contractions to maintain balance against surface instability. In other studies, muscle activity also found to increase as lower-extremity instability increases. In prior studies, muscle activity was confirmed using surface electromyography (EMG) during trunk exercises on an unstable support surface. There were significant differences in the activities of the internal oblique, external oblique, gluteus medius, semitendinosus, biceps femoris, medial gastrocnemius, and lateral gastrocnemius muscles during exercise. The authors suggested that research on lower extremity muscles through various exercise methods on unstable support surfaces is necessary[27,28].

Therefore, the effect of exercise on an unstable support surface stimulates the neuromuscular delivery system to co-contract the agonist and synergist muscles, improve stability, balance ability, and muscle strength, and maximize the effect of exercise[39]. These complex effects may work together to increase balance and lower-extremity muscle strength in middle-aged women.

This study had several limitations, such as the small sample size and the lack of consideration of dietary habits, participant lifestyles, exercise intensity, and exercise period; further studies that complement the limitations mentioned above are required.

Overall, our results show that lunge exercise on stable and unstable support surfaces improves muscle function and static balance in middle-aged women. In particular, lunge exercise on an unstable support surface was more effective at reducing body fat than lunge exercise on a stable support surface, and was also found to improve dynamic balance. Therefore, lunge exercises on an unstable support surface may be suitable to facilitate body improvements in middle-aged women.

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