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Relationships among Lower Extremity Muscle Circumference, Proprioception, ROM, Muscle Strength, and Balance Control Ability in Young Adults

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Purpose: The purpose of this study was to analyze the correlation between balance control ability and leg circumference, proprioception, range of motion (ROM), and muscle strength in young adults.
Methods: The subjects of this study were 30 university students who were enrolled in D university in Gyeongbuk province. We measured the dynamic balance and static balance using the Bioresue. The muscular strengths of the hip, knee, and ankle joints were measured using a muscle contraction dynamometer. The ROM and proprioception were measured using an inclinometer. Pearson correlation analysis was used to test the correlations between balance control ability and variables.
Results: Sway length was significantly correlated with knee and hip joint muscle strength, ROM, and proprioception of hip and ankle joints ($p < 0.05$). Sway speed was significantly correlated with ROM and proprioception in hip joints ($p < 0.05$). Limit of stability was significantly correlated with muscle strength and ROM in ankle joints, and proprioception in hip, knee, and ankle joints ($p < 0.05$).
Conclusion: The sway length was most related to hip extension and ankle joint plantar flexion in the range of motion and ankle joint plantar flexion in proprioception. Overall, balance training for young adults will be of effective help if the treatment focuses on the knee and hip joints, range of motion and the ankle and hip joints' proprioception.

Keywords: Balance, Range of motion, Muscle strength, Proprioception, Leg circumference

INTRODUCTION

Balance in the human body refers to maintaining the body center on the basal surface and maintaining body alignment and posture.[1] Balance in daily life is a continuous process to maintain the body center of the human body on the basal plane.[2] The recognition and function of the vestibular system, the visual system, the proprioceptive sensory system, and the musculoskeletal system are required to maintain balance. The sense of balance is a very complex human body function in which the senses, including the nervous system, are integrated to maintain posture through various elements.[3] Accurate awareness of the environment and correct response strategies are required for maintaining the body's balance.[4]

Balance can be divided into static balance and dynamic balance. Static balance refers to maintaining the body center of gravity without shaking on a fixed basal plane. It refers to balance when performing a movement independently when given.[5] The ability to control balance is closely related to daily life and is influenced by various factors in a complex manner.[6] Proprioception, muscle strength, and ROM of the lower extremities have the most influence. This has been proven in several previous studies.[5-7]

Proprioception refers to the sense used to recognize the joint position and movement information, grasp the position and movement of the body and joints without visual information, and perform them. Proprioception and vision are used mainly to control body sway in a standing posture,[8] and impairment of the balance control ability accompanies the loss of proprioception.[9] Proprioception is involved in weight sensation and muscle contraction. It works with the vestibular system and maintains a balance. In addition, if necessary, posture and movement are controlled through muscle activation. Therefore, the ability to balance im-

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proves when the sense of proprioception is improved.

A certain level of joint range of motion is also required for balance control. In particular, a joint range of motion above a certain level is essential for balance control and is closely related because the ankle joint is most frequently used for balance control, and the movement of the joint is large.[10] In balance control, the muscles of the lower extremities have considerable influence. Compared to the upper extremities, the muscles of the lower extremities reduce the resistance to gravity transmitted to the upper body, such as weight bearing and shock absorption. They play an important role in maintaining the stability of the knee by contributing to the role of maintaining balance. Among them, controlling the balance of the body to provide stability to the hip joint, and the ability to control the hip and ankle joints play an essential role. The hip joint acts in the case of a large range of body movement, and the ankle joint acts mainly in a small range.

Comprehensive examinations of the contents of preceding studies have shown that the main factors affecting the body's ability to control balance are proprioception in the lower extremities, joint range of motion in the lower extremities, and muscle strength levels in the lower extremities. Problems with balance control could occur if these factors decrease below a specific level. On the other hand, few studies have examined which of these factors have a stronger correlation or what the quantitative correlation is. Therefore, this study examined the correlation between muscle circumference, proprioception, joint range of motion, and lower extremity muscle strength on the balance control ability.

METHODS

1. Subjects

The subjects of this study were 30 healthy male and female college students attending University D located in Gyeongsangbuk-do. Before the experiment, the purpose of this study was explained to the participants, who then signed an informed consent form. Among them, those with musculoskeletal disorders, those who had surgery within the last 6 months, and those with back pain, visual perception and vestibular disorders were excluded. The mean age, height, and weight of the subjects were 21.5 ± 1.0years, 165.3 ± 7.7cm, and 60.0 ± 11.3kg, respectively.

2. Experimental methods

1) Measurement

(1) Bioelectrical impedance analysis & Leg circumference

The height, weight, muscle circumference, and body fat mass of the subjects were measured using an Inbody (Inbody270, Inbody, Seoul, Korea). The circumference of the thigh and calf was measured using a tape measure to determine the volume of the lower extremity muscles indirectly. First, the circumference was determined by measuring the length between the upper anterior iliac spine and the patella was measured. For the calf, the length between the patella and the malleolus was measured.[11]

(2) Biorescue (Postural balance)

The Biorescue (RM Ingenierie, Rodes, France) connects the decompression platform and the computer to detect the user's posture and movement, and measurement and training are possible. The area (mm), length (cm), and the average of the movement path line were determined by observing the movement path line of the pressure center during a specific movement. The limit of stability and the Romberg test were conducted using the measuring equipment. The postural sway length and sway speed were measured during both tests. The measurement was carried out after giving verbal explanations and demonstrations to the subjects. A 60seconds break between each measurement was allowed. In the limit of stability measurement program, the maximum movement length was measured by moving the center of gravity as much as possible along the arrows in eight directions. Feet were instructed not to fall off the floor. The subjects were asked to measure again if both feet fell off during the measurement. The subjects participated in the experiment by standing on a decompression platform at a distance of 1–1.5m in front of the monitor. Measurements were taken in a quiet, independent space to prevent deterioration of the subject's concentration. One researcher measured in all subjects, and another stood by during the measurement to prevent accidents.

(3) Hand–held dynamometer (HDD)

The muscle strength of the lower extremities was measured according to the method suggested by Richard et al.[12] The muscle strength for hip flexion and abduction in the supine position, knee flexion and extension in the sitting position, knee flexion in the supine position, dorsiflexion of the ankle joint, and plantar flexion in the supine position were measured. The same method was used in the present study. At this time, the measurer had the subject push the maximum amount that could be pushed, and measurements were taken.

(4) Inclinometer

An inclinometer was used to measure the proprioception and joint range of motion of the lower extremities. Proprioception was measured using the reposition error test. The difference between taking a motion at the angle before the motion and returning to the original position was used. The joint range of motion was measured as the angle after taking the motion in the upright posture. To measure proprioception and joint range of motion of the lower extremities, hip flexion, hip extension, hip abduction and hip adduction were measured in the standing position. Hip internal rotation and external rotation were measured in the supine position. In the prone position, knee flexion, and extension were measured. And at the side lying position, knee internal rotation and external rotation were measured. In the supine position, internal rotations and external rotation of the knee joint, and dorsiflexion and plantar flexion of the ankle joint were measured.[13]

3. Experimental Procedure

Before the experiment, all subjects were explained the experimental method and procedure. The experiment was conducted after the researcher provided a demonstration. The circumference of the lower extremity muscles, balance ability, proprioception, and joint range of motion were measured to ensure that the fatigue of the lower extremity muscles did not affect other measurement results during the experiment. Finally, lower extremity strength was analyzed. The measurement date was adjusted through consultation with the subject. The circumference of the muscle was measured using a tape measure. The balance ability was measured with the subject standing still on the balance board, and the shaking distance and shaking speed for one minute were measured. This performance was measured in the eye closed and eye open states of the subject. Proprioception and range of motion were measured using flexors and extensors of the three lower extremities (hip, knee, and ankle), and dorsiflexion and plantar flexion of the ankle joint were determined. The active range of motion and passive motion were used. All ranges were measured. For muscle strength measurement, quantitative values were evaluated for the flexors and extensors of the three lower extremities (hip joint, knee joint, and ankle joint) using a systolic dynamometer. Sufficient rest between measurements was allowed, so the subjects did not experience fatigue, and two therapists measured the joint range of motion and muscle strength. After all measurements were completed in one day, the measurements were retaken on another day after discussing the schedule with the subjects for repeated measurement. All measurements were taken three times; the results are expressed as mean ± standard deviation.

4. Data analysis

SPSS for Windows (version 23.0) was used for data analysis in this study.

Table 1. Correlation between lower extremity circumference, thigh muscle mass and balance control ability

	Thigh circumference (cm)	Calf circumference (cm)	Thigh muscle mass (cm)
	52.35±4.52[a]	35.40±3.39[a]	43.38±3.70[a]
Sway length EO (cm)	0.11	0.04	0.09
Sway length EC (cm)	0.11	0.04	0.08
Sway speed EO (cm)	-0.23	-0.12	0.11
Sway speed EC (cm)	-0.25	-0.16	0.08
LOS (mm^2)	0.03	-0.24	-0.04

EO: Eye open, EC: Eye close, LOS: Limit of stability.
[a]Mean±SD.

Descriptive statistics were used to obtain the general characteristics of the subjects. The Pearson correlation coefficient was used to examine the correlation between the lower extremity muscle strength, lower extremity thickness, joint range of motion, and proprioception and the correlation between each variable for balance control ability. Normality was tested using the Shapiro-Wilk test method. For grade classification of correlation coefficient, 1 to 0.7 was strong, 0.6 to 0.4 was moderate, and 0.3 to 0.1 was weak.[14] The statistical significance level was set to $\alpha = 0.05$.

RESULTS

1. Correlation between lower extremity circumference, thigh muscle mass and balance ability

There was no significant variation in the correlation between the thigh and calf circumference and thigh muscle mass for balance control ability ($p > 0.05$)(Table 1).

2. Correlation between lower extremity muscle strength and balance control ability

Regarding the correlation of lower extremity muscle strength to balance control ability, the sway length, and knee extension ($r = -0.32$) had a significant negative correlation with the eyes open, and the sway length and knee extension ($r = -0.30$) had a significant negative correlation ($p < 0.05$). As for the limit of stability, hip extension ($r = 0.45$) and knee extension ($r = 0.31$) had a significantly positive correlation ($p < 0.05$)(Table 2).

3. Correlation between ankle ROM and balance control ability

On the correlation between the range of motion of the lower extremity joint with the balance control ability, the sway length with the eyes open had a significant positive correlation with the hip extension ($r = 0.47$) and ankle plantar flexion ($r = 0.30$)($p < 0.05$). Even in the closed state, the sway

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Table 2. Correlation between lower extremity muscle strength and balance control ability

	MHF (lbs)	MHE (lbs)	MHAB (lbs)	MHAD (lbs)	MHEX (lbs)	MHINT (lbs)	MKF (lbs)	MKE (lbs)	MADF (lbs)	MAPF (lbs)
	25.13±6.63[a]	15.98±6.20[a]	26.08±7.03[a]	13.35±4.70[a]	15.40±5.23[a]	12.44±4.34[a]	26.40±6.85[a]	23.58±5.49[a]	22.12±5.35[a]	21.87±4.94[a]
Sway length EO (cm)	-0.13	-0.16	-0.09	-0.23	-0.15	-0.20	-0.22	-0.32*	0.06	-0.26
Sway length EC (cm)	-0.11	-0.14	-0.07	-0.21	-0.14	-0.17	-0.18	-0.30*	0.08	-0.24
Sway speed EO (cm/s)	0.13	0.07	0.11	-0.05	0.23	0.02	-0.16	-0.08	0.11	-0.01
Sway speed EC (cm/s)	0.09	0.00	0.04	-0.11	0.19	-0.04	-0.19	-0.15	0.07	-0.08
LOS (mm$^{2)}$)	0.10	0.45**	-0.11	0.26	0.08	0.24	-0.10	0.31*	-0.27	0.01

EO: Eye open, EC: Eye close, LOS: Limit of stability, MHF: MMT of hip flexion, MHE: MMT of hip extension, MHAB: MMT of hip abduction, MHAD: MMT of hip adduction, MHEX: MMT of hip external rotation, MHINT: MMT of hip internal rotation, MKF: MMT of knee flexion, MKE: MMT of knee extension, MADF: MMT of ankle dorsiflexion, MAFF: MMT of ankle plantar flexion.
[a]Mean±SD.
*p〈0.05, **p〈0.01.

Table 3. Correlation between ankle ROM and balance control ability

	RHF (°)	RHE (°)	RHAB (°)	RHAD (°)	RHEX (°)	RHINT (°)	RKF (°)	RKE (°)	RADF (°)	RAPF (°)
	108.38±17.28[a]	36.65±12.98[a]	58.08±15.72[a]	31.27±9.66[a]	60.58±16.94[a]	47.15±12.99[a]	146.31±17.46[a]	9.88±5.12[a]	54.35±9.71[a]	35.00±8.04[a]
Sway length EO (cm)	0.02	0.47**	-0.05	0.17	0.21	0.17	0.21	0.19	0.00	0.30*
Sway length EC (cm)	0.00	0.46**	-0.04	0.15	0.20	0.17	0.21	0.20	0.00	0.33*
Sway speed EO (cm/s)	0.26	0.41**	0.29*	0.29*	0.21	0.05	0.13	0.09	-0.21	0.04
Sway speed EC (cm/s)	0.25	0.36**	0.23	0.30*	0.18	0.08	0.13	0.07	-0.23	0.02
LOS (mm^2)	0.00	-0.10	-0.07	0.014	-0.11	0.10	-0.06	0.03	0.03	-0.36**

EO: Eye open, EC: Eye close, LOS: Limit of stability, RHF: ROM of hip flexion, RHE: ROM of hip extension, RHAB: ROM of hip abduction, RHAD: ROM of hip adduction, RHEX: ROM of hip external rotation, RHINT: ROM of hip internal rotation, RKF: ROM of knee flexion, RKE: ROM of knee extension, RADF: ROM of ankle dorsiflexion, RAFF: ROM of ankle plantar flexion.
[a]Mean±SD.
*p〈0.05, **p〈0.01.

length had a significant positive correlation with hip extension (r=0.46) and ankle plantar flexion (r=0.33)($p<0.05$). The sway speed in the open state had a significant positive correlation with hip extension (r=0.41), hip abduction (r=0.29)($p<0.05$), and hip adduction (r=0.29)($p<0.05$). There was a significant positive correlation between hip extension (r=0.36) and hip adduction (r=0.30). The limit of stability negatively correlated with ankle plantar flexion (r=-0.36)($p<0.05$)(Table 3).

4. Correlation between lower extremity proprioception and balance control ability

The limits of stability were hip external rotation (r=-0.27), hip internal rotation (r=-0.29), knee flexion (r=-0.45), knee extension (r=-0.36), and ankle dorsiflexion (r=-0.53) and plantar flexion (r=-0.35) had a significant negative correlation ($p<0.05$). In the correlation of lower extremity proprioception with balance control ability, the sway length EO was hip extension (r=0.47), hip adduction (r=0.28), knee flexion (r=0.30), and ankle plantar flexion ware a significant positive correlation (r=0.76). The sway length in the closed state was significantly positively correlated with hip extension (r=0.46), hip adduction (r=0.29), knee flexion (r=0.28), and ankle plantar flexion (r=0.77)($p<0.05$). On the other hand, the sway length had a significant negative correlation with hip external rotation (r=-0.29)($p<0.05$). The sway speed in the open state had a significant negative correlation with the hip adduction (r=-0.33) and hip internal rotation (r=-0.32)($p<0.05$) and a positive correlation with hip joint lateral rotation (r=0.40)($p<0.05$). The sway speed in the closed state had a significant negative correlation between the hip adduction (r=-0.28) and hip internal rotation (r=-0.34)($p<0.05$) and a significant negative correlation with the hip external rotation (r=0.36)($p<0.05$). The limits of stability were hip external rotation (r=-0.27), hip internal rotation (r=-0.29), knee flexion (r=-0.45), knee extension (r=-0.36)($p<0.05$), and ankle dorsiflexion (r=-0.53) and ankle plantar flexion (r=-0.35) had a significant negative correlation ($p<0.05$)(Table 4).

DISCUSSION

This study examined the relationship between the muscle circumference

Table 4. Correlation between joint repositioning error and balance control ability

	RHF (˚)	RHE (˚)	RHAB (˚)	RHAD (˚)	RHEX (˚)	RHINT (˚)	RKF (˚)	RKE (˚)	RADF (˚)	RAPF (˚)
	3.52±4.44[a]	3.04±3.01[a]	4.31±2.20[a]	5.58±3.13[a]	4.38±4.08[a]	3.92±3.74[a]	4.08±4.58[a]	2.58±3.39[a]	3.73±4.21[a]	7.12±7.30[a]
Sway length EO (cm)	-0.20	0.47**	0.11	0.28*	-0.27	0.03	0.30*	0.13	0.10	0.76**
Sway length EC (cm)	-0.20	0.46**	0.14	0.29*	-0.29*	0.01	0.28*	0.10	0.80	0.77**
Sway speed EO (cm/s)	-0.20	0.24	0.02	-0.33*	0.40**	-0.32*	0.05	0.17	-0.06	0.14
Sway speed EC (cm/s)	-0.19	0.29*	0.04	-0.28*	0.36**	-0.34*	0.03	0.17	-0.06	0.18
LOS (mm^2)	0.01	-0.07	0.12	0.13	-0.27*	-0.29*	-0.45**	-0.36**	-0.53**	-0.35*

EO: Eye open, EC: Eye close, LOS: Limit of stability, PHF: Proprioception of hip flexion, PHE: Proprioception of hip extension, PHAB: Proprioception of hip abduction, PHAD: Proprioception of hip adduction, PHEX: Proprioception of hip external rotation, PHINT: Proprioception of hip internal rotation, PKF: Proprioception of knee flexion, PKE: Proprioception of knee extension, PADF: Proprioception of ankle dorsiflexion, PAFF: Proprioception of ankle plantar flexion.
[a]Mean±SD.
*$p<0.05$, **$p<0.01$.

of the lower extremities, proprioception, and joint range of motion strength on balance control ability in healthy young adults. In general, to maintain the body's balance, it is necessary to collect information continuously on the environment or the body's position through the sensory system. Therefore, an appropriate and effective reaction process is required according to the information, and including the response that should occur.[15] Maintaining body balance is difficult if any of these factors is defective. In addition, body agitation should be kept to a minimum to maintain the body's center of gravity within the support base.[15]

In this study, the correlation between the lower extremity muscle strength and balance control ability was negatively correlated with the extension of the knee joint when the eyes were open or closed. In the limit of stability, hip extension and knee joint extension had a positive correlation.

Gapeyeva et al.[16] reported that the dynamic inhibitory force of the quadriceps femoris muscle greatly contributed to the stabilization of the knee joint. Ratespsoo et al.[17] reported that strengthening the knee extensor muscle increased the postural stability. The muscle strength of knee joint extension increased with a smaller sway length. In addition, the most important muscles for maintaining balance are the dorsum of foot quadriceps, hamstrings, and soleus muscles. A previous study has shown that the hip joint is essential for static and dynamic balance.[18] For this reason, previous studies support the results of this study.

The improvement of the joint range of motion can have a direct effect on resolving difficulties in balance control.[19] In the correlation between balance and the range of motion in this study, hip extension and ankle plantar flexion had a significant positive correlation with the sway length. Hip extension, hip abduction, and hip joint had a significant positive correlation with the sway speed. The limit of stability had a negative correlation with ankle plantar flexion. In a previous study, the sway speed increased after training to increase the joint range of motion of the plantar flexor muscle.[20]

In the case of a normal person, a range of motion above a certain level was obtained, but a value in the range of motion exceeded the normal range from the average value, indicating looseness. In particular, since the movement of standing still and controlling the balance is a posture that is affected more by the structural stability of the ankle joint, it may be affected more than dynamic balance control.[20] In this study, the subject showed a higher value than the normal value, which meant an increase in laxity because the range of motion of the joint increased. Therefore, it is considered that there was a positive correlation between the balance control ability and the joint range of motion. Balance control and the joint range of motion are ideal when they have a normal range, and it has a positive correlation with the balance control ability when the range of motion is limited because it is small. There is a negative correlation when the range of motion is too large and loose.[21]

The joint range of motion of plantar flexion showed a positive correlation with the sway length. This result shows that the plantar flexion range is slightly larger than the normal range when looking at the joint range of motion of the subjects. Therefore, the joint range of motion of plantar flexion had a negative relationship with balance control ability. Kim[21] reported that the sway length of young adults significantly correlated with plantar flexion in the passive range of motion. Moreover, the correlation with the range of motion of the ankle joint for the ability to control static balance while standing still was confirmed. An increase in the range of motion above a certain level indicates the slackness of non-contractile structures. Furthermore, the ankle joint is affected more by structural stability in the balance control.[21] Previous studies conducted measurements with similar subjects, as in this study, and the results had similar values.[21,22]

The present study also examined the correlation between balance control ability and proprioception. The proprioception error was reduced,

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and hip extension, knee joint flexion, and plantar flexion were positively correlated with the sway length. The proprioception error also decreased with decreasing sway length. On the other hand, the sway length decreased because a negative correlation was obtained for lateral rotation of the hip joint.

Regarding the sway speed, hip adduction and internal rotation had a negative correlation. In addition, the error increased with decreasing sway speed, and a positive correlation was found in the hip lateral rotation. This means that the error of proprioception decreased with decreasing sway speed. At the limit of stability, lateral and medial rotations of the hip joint, extension and flexion of the knee joint, and dorsal flexion and plantar flexion all had negative correlations.

In particular, the ankle joint will help improve the balance and gait ability because it solves various problems in the ankle joint and proprioception disorders during movement retraining for body balance control. In addition, when proprioceptive sensation is reduced, it causes problems with the joint load or position recognition of the lower extremities, indicating the difficulties in patient balance.[23] According to a study of proprioceptive sensorimotor control for stroke patients for three weeks, the experimental group showed significant improvement in static and dynamic balance ability compared to the control group.[24] Therefore, the correlation of proprioception according to the balance control ability is supported by the results of previous studies. The muscle circumference of the lower extremities was measured in relation to the balance control ability. The body composition analyzer scale was used to measure the muscle mass of the thigh. There were no significant variables in the correlation between thigh and calf circumference and thigh muscle mass for balance control ability. This is because the amount of muscle measured by the body composition analyzer scale is not the amount of pure muscle but includes fat.

The sway length was most related to hip extension and ankle joint plantar flexion in the range of motion and ankle joint plantar flexion in proprioception. In the limit of stability (LOS), there was a strong relationship between the hip joint extension of the muscle strength, plantar flexion of joint range of motion, and three joints of proprioception (hip joint, knee joint, and ankle joint). Overall, balance training for young adults will be of effective help if the treatment focuses on the knee and hip joints, the range of motion, and the ankle and hip joints for proprioception.

The limitations of this study are as follows. The variety of balance ability variables was limited, and the age of the subjects was measured only in their 20s, so it was not representative of all age groups. Also, the degree of correlation coefficient was not strong. Future research will need to use a balance measurement method in addition to BioRescue and a muscle strength measurement tool that provides objective values or increases the diversity of age groups.

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