Effect of muscle mass asymmetric between upper and lower limbs on the postural stability and shock attenuation during landing

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The aim of the study was to analyze the effect of muscle mass asymmetric between upper and lower limbs on postural stability and shock attenuation during landing. Twenty adults (without lower limb disorders and who could land from a 35-cm height) participated in this study (mean age, 21.85±2.97 years; mean height, 1.68±0.10 m; mean weight: 68.64±17.36 kg). Subjects performed one-leg landing from 36-cm vertical heights. Ground reaction force components and medial-lateral, anterior-posterior, vertical and dynamic postural stability index were obtained from force platform recordings. We found that muscle mass in right limbs more increased than that of left limbs. Medial-lateral force, vertical force, vertical stability index, and dynamic postural stability index in left leg showed higher value than that of right leg during landing. The asymmetry of muscle mass (%) and ground reaction force variables showed a similar correlation, including dynamic postural stability index (r=0.316). These findings allow us to conclude that the factor of muscle mass asymmetric is a contributor to impulse control and dynamic postural stability index asymmetry. Therefore, knowledge of bilateral limbs asymmetry may provide insights into exercise rehabilitation and performance.

Keywords: Muscle mass, Shock attenuation, Asymmetry, Bilateral limbs, Exercise rehabilitation, Performance

INTRODUCTION

The shock experienced on body due to landings must be attenuated by several structures and mechanisms in the body including bone, synovial fluids, cartilage, soft tissues, joint kinematics and muscular activity (Lafortune et al., 1996; Nyland et al., 1994). Passively, shock attenuation is achieved by soft tissues and bone (Coventry et al., 2006). Actively, shock attenuation is achieved through eccentric muscle action. This active mechanism is thought to be far more significant than the passive mechanism in attenuating shock (Mizrahi and Susak, 1982).

Therefore basic mechanism controllable an angular momentum during human movement may be to generate muscle strength. The muscle strength generates ground reaction force to not only maintain and recover dynamic rebound but also accelerate a spe-

cific body segment. But the assumption may support on the condition that motor performance and muscle strength have a symmetric relation. The assertion may be wrong when based on asymmetry (Bell et al., 2014).

Young adult in addition to sport athlete has the great extent of asymmetry in muscle strength between dominant and nondominant of lower leg (Lanshammar and Ribom, 2011). The flexors are weaker in the dominant leg and the extensors are weaker in the non-dominant leg. Thereby, the quotient between knee flexors and extensors is lower in the dominant leg.

Lean body mass which related directly with joint torque (Fukunaga et al., 2001), also contributes greatly to energy absorption at landing (Montgomery et al., 2012). Particularly Deficiency of muscular amount of lower limbs (thigh, shank, etc.) may result in reducing of motor ability and power (Bell et al., 2014). Thus repet-

itive activity of jumping, landing and cutting technique by one leg could still more deteriorate an extent of asymmetry in muscle amount (Bell et al., 2014).

Also injuries related with vertebrae parts can be occurred at rather low compressive load of 88 N (Granata and Marras, 1999; Punnett et al., 1991), but proper control of muscular activity can support stably against rather large vertebrae load (Quint et al., 1998; Wilke et al., 1995). But proper posture selection can control the neuromuscular system maintaining posture stability, which followed the compression force of inter-vertebrae on condition of asymmetric posture of 20° increased by 21% (Granata and Wilson, 2001).

Like this, it was reported that difference of muscle strength between both side of body segment contribute greatly to control an exercise amount and impulse absorption. But it was not clear whether relationship between asymmetry of muscle amount and impulse absorption and posture stability is or not. Thus information on asymmetry between intersegments may provide insight ability on the injurious possibility, exercise rehabilitation and motor ability.

Consequently the aim of this study was to grasp quantitatively relationship between asymmetry in muscle amount and ground reaction force parameters both dominant and nondominant of lower leg. This study assumed that fine difference of muscle amount in both side of segment on the basis of analyzed material of 167 subjects (Bell et al., 2014) firstly will induce asymmetry on impulse force and an extent of posture stability and secondly positive correlation between posture stability and variables of impulse force (%). Landing motion aligned in line with vertical direction was induced in order gravity effect to distribute evenly on center of gravity of body segment according to the assumption.

MATERIALS AND METHODS

Subject

Adult male and female without lower limb disorders and with all right dominant of leg (n = 20; mean age, 21.85 ± 2.97 years; mean height, 1.68 ± 0.10 m; mean weight, 68.64 ± 17.36 kg) participated in the experiment. All participants agreed to the experimental procedures voluntarily.

Experimental procedure

All participants prior to an experiment carried out measurement of muscle amount using Inbody 720 (Biospace, Seoul, Korea) and executed enough warming-up exercise. Landing motion

by only one leg (right or left) from vertical height of 35 cm performed randomly. Then landing procedure kept sight aligned with forward direction and positioned both hand on anterior superior iliac spine. Each experimental trial was defined until dynamic control was completed (static condition) after landing, and only 1 trial of 3–4 trials performed successfully was adapted for analysis. Collected sampling rate on GRF (AMTI-OR9-7, AMTI, Watertown, MA, USA) was set up at 1,000 Hz. Landing motion was performed on bare foot to reduce data error from shoe material.

Definition of analysis phase

Dynamic postural stability was defined as individual's ability to maintain a balance of body posture during converting from dynamic to static condition (Goldie et al., 1989). Also time to stabilization was defined as necessitated time which ground reaction force generated at landing can keep up with within range of static condition

Therefore the time for stabilization may be occurred rather difference relative to individual's characteristics and experimental procedure regardless of calculation by dynamic postural stability index (DPSI) (Wikstrom et al., 2005). Thus, this study calculated time for stabilization applied on peak value from each direction of ground reaction force for clear interpretation of data (Hyun and Ryew, 2017).

$$MLSI = \sqrt{[\sum(0 - x_{max.})^2/\text{number of data points}]}$$

$$APSI = \sqrt{[\sum(0 - y_{max.})^2/\text{number of data points}]}$$

$$VSI = \sqrt{[\sum(body\ weight - z_{max.})^2/\text{number of data points}]}$$

$$DPSI = \sqrt{[\sum(0 - x_{max.})^2 + \sum(0 - y_{max.})^2 + \sum(body\ weight - z_{max.})^2/\ \text{number of data points}]}$$

Medial-lateral (ML), anterior-posterior (AP), vertical (V), and DPSI mean that the higher an index value, the lower the stability, the lower an index value, and the higher the stability (Wikstrom et al., 2005). These indices mean square deviations assessing fluctuations around a 0 (zero) point, rather than standard deviation assessing fluctuations around a group mean.

Analysis and process of data

Then mean ± standard deviation was processed on variables with PASW Statistics ver. 22.0 (IBM Co., Armonk, NY, USA) program and paired t-test. Change rate (%) of each variables on muscle mass and landing posture was compared with Pearson correlation coefficients and set at $P < 0.05$.

RESULTS

Change of each muscle mass between upper and lower limbs are shown in (Table 1). Right muscle mass of upper and lower limbs showed more increased than that of left limbs, and showed significant ($P < 0.05$).

Change of ground reaction force variables during landing are shown in (Table 2). ML and peak vertical force at left leg showed significant difference with higher than that of right leg ($P > 0.05$). Also, vertical stability index and DPSI at left leg showed higher index than that of right leg and show significant difference ($P < 0.001$).

Correlation calculated with change rate between muscle mass asymmetric and ground reaction force variables are shown in (Table 3). Change rate of upper arm muscle mass showed positive correlation of $r = 0.562$ (A) with ML force, and $r = 0.316$ (B) with vertical stability index, and $r = 0.336$ (C) with DPSI. In addition, change rate of leg muscle mass and ML force showed a negative correlation of $r = -0.343$ (D).

Also, AP force and vertical force showed a positive correlation

Table 1. Results of muscle mass between both bilateral limbs (unit: kg)

| Section | Bilateral limbs | | % | t | P-value |
	Right	Left			
Muscle mass of upper limbs	2.56±0.95	2.49±0.92	-2.73	3.699	0.002**
Muscle mass of lower limbs	8.20±2.23	8.07±2.18	-1.59	2.500	0.022*

Values are presented as mean±standard deviation.
*$P < 0.05$. **$P < 0.01$.

Table 2. Results of kinetic variables between both legs during landing

| Section | Bilateral legs | | % | t | P-value |
	Right	Left			
Medial-lateral force (N/BW)	0.10±0.23	-0.15±0.24	50.00	2.808	0.011*
Anterior-posterior force (N/BW)	0.36±0.27	0.43±0.29	19.44	-0.92	0.369
Vertical force (N/BW)	5.57±1.30	6.40±1.16	14.90	-4.848	0.001***
Medial-lateral stability index	1.99±1.08	1.91±0.94	-4.02	0.292	0.773
Anterior-posterior stability index	5.56±1.48	6.34±2.14	14.03	-1.481	0.155
Vertical stability index	36.80±7.64	43.28±7.10	17.61	-5.99	0.001***
Dynamic postural stability index	44.48±8.56	51.54±9.24	15.87	-5.152	0.001***

Values are presented as mean±standard deviation.
*$P < 0.05$. ***$P < 0.001$.

Table 3. Correlation results using the asymmetry between muscle mass and ground reaction force variables (r)

Section	Lower limbs	M-L force	A-P force	Vertical force	MLSI	APSI	VSI	DPSI
Upper limbs	0.091	0.562* (A)	0.027	-0.099	0.175	0.110	0.316* (B)	0.336* (C)
Lower limbs		-0.163	-0.120	-0.291	-0.343* (D)	-0.070	0.199	0.075
M-L force			0.094	0.057	0.017	0.005	0.067	0.043
A-P force				0.335* (E)	-0.009	0.029	0.027	0.053
Vertical force					0.208	0.101	0.211	0.251
MLSI						-0.092	0.123	0.282
APSI							0.288	0.526* (F)
VSI								0.930** (G)

M-L, medial-lateral; A-P, anterior-posterior; MLSI, medial-lateral stability index; APSI, anterior-posterior stability index; VSI, vertical stability index; DPSI, dynamic postural stability index.
Regression equation: A: y=53.25x–1.0385, R^2=0.3093; B: y=1.5825x+0.2383, R^2=0.1057; C: y=1.6879x+0.2158, R^2=0.13; D: y=-7.0577x–0.0103, R^2=0.1264; E: y=0.0072x+0.1588, R^2=0.1124; F: y=0.8925x–0.0046, R^2=0.8617; G: y=0.1509x+0.1434, R^2=0.2715.
*$P < 0.05$. **$P < 0.01$.

of $r=0.335$ (E). DPSI showed positive correlation of $r=0.526$ (F) with AP stability index, and $r=0.930$ (G) with vertical stability index.

DISCUSSION

Jumping and landing motion for human is commonly locomotion for human (Kang, 2018; Kim, 2018; Ryew and Hyun, 2018; Titton and Franchini, 2017), but it was not clear whether asymmetry of muscle amount of both leg effects performance of landing motion or not. The study was to investigate relationship between fine difference of muscle amount and controllability of ground reaction force of both legs during landing motion.

Biomechanical difference between lower extremities of dominant or nondominant during physical activity has relation with physiological and anatomical asymmetry, but no specific evidence (Niu et al., 2011). But in results of assumption testimony, asymmetry of muscle amount showed more increased tendency in right hand-leg than left extremities. It showed similar result that asymmetry of muscle amount of thigh showed 84 samples (50%) of 0%–5% range, 56 samples (34%) of 5%–10% range, 22 sample (13%) of 10%–15% range, 5 (3%) of over 15% range, meanwhile asymmetry of muscle amount of shank showed 127 samples (76%) of 0%–5% range, 37 samples (22%) of 5%–10% range and 3 samples (2%) of 10%–15% range respectively (Bell et al., 2014).

ML and vertical ground reaction force variables at landing of one leg showed more increased pattern in left leg than that of right leg, and also higher index in left leg in both dynamic postural stability and vertical postural stability. Thus the first assumption that asymmetry of muscle amount in both sides of leg may induce asymmetry in impulse force and an extent of posture stability, was accepted partially.

The study showed that larger impulse force was occurred when landed by left leg formed with less muscle amount relatively, but impulse controlling time was decreased reversely. Fortunately the participants performed safe landing by one leg of 1–3 times during experiment, but a cumulated stress might increase an injury possibility on tissue like cartilage, ligament, and skeletal (Yeow et al., 2009). Because repetitive landing motion during sport situation and physical activity occurs, strategy for asymmetric impulse absorption and stabilization may contribute greatly to reduction of injury occurrence of lower limb.

But this study could not present the relative contribution on injury occurrence because it was difficult for us to grasp quantita-

tively the parameters of neuromuscular control (Walsh et al., 2012), muscle strength (Montgomery et al., 2012), cross sectional area of muscle (Fukunaga et al., 2001), joint coordination (Lees et al., 2004) etc. Also parameters like length of lower limb, tendon properties and tendon length could contribute to force controllability (Bell et al., 2014). But these parameters had little possibility of influencing on asymmetry between both sides of limbs (Bell et al., 2014).

Because it was sufficiently explained on asymmetry of muscle amount between both sides of lower limbs, if additional quantitative parameters like neuromuscular control, muscle strength, cross sectional area of muscle, joint coordination etc. secured more clear understanding on asymmetry and mechanism on injury prevention could be presented.

Thus the second assumption that relation between posture stability and variables of impulse force (%) will have positive correlation was accepted partially. Similar correlation between ground reaction force components of three directions and stability index had not relation with asymmetry of muscle amount, but rather due to calculation method of stability and direction of force generation. Thus more remarkable variables were relationship among asymmetry of muscle amount and ML force and ML and vertical DPSI. That is, asymmetry of muscle amount between both sides of leg segments have an effect on parallel force, thus may increase a uniaxial load on lower limbs and vertebrae. Thus the result of correlation among variables at landing by one leg could refer to possibility of slipping and falling injury. Consequently it was assumed that asymmetry factor between both sides of lower limbs contributed greatly to controllability of impulse force and dynamic posture stability. These results may be provided insight to exercise rehabilitation and motor performance.

CONFLICT OF INTEREST

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

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