Effects of high-velocity resistance training on muscle function, muscle properties, and physical performance in individuals with hip osteoarthritis

（高速度筋力トレーニングが変形性股関節症患者の筋機能，筋特性および運動能力に及ぼす効果）

福元　喜啓

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Muscle Mass and Composition of the Hip, Thigh, and Abdominal Muscles in Women with and without Hip Osteoarthritis

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ABSTRACT

The objective of this study was to compare muscle mass and composition between individuals with and without hip osteoarthritis. Twenty-four women with hip osteoarthritis (OA group) and 16 healthy women (healthy group) participated in this study. Muscle thickness (MT) and echo intensity (EI) were measured as indices of muscle mass and composition, respectively, using ultrasound imaging. Seven muscles were examined: gluteus maximus, gluteus medius, quadriceps femoris, rectus abdominis, external oblique, internal oblique, and transversus abdominis. MT of only quadriceps femoris in the OA group was significantly thinner than that in the healthy group. EI of gluteus medius, quadriceps femoris and rectus abdominis was significantly higher in the OA group than that in the healthy group. Thus, actual contractile tissue of gluteus medius and rectus abdominis substantially decreased, although muscle mass was similar, whereas both quantitative and qualitative changes occurred in quadriceps femoris in patients with hip OA.

***Key words**:* hip osteoarthritis, ultrasound imaging, muscle thickness, echo intensity, muscle physiology

Introduction

Loss of muscle mass, also known as muscle atrophy, is caused not only by advanced age but also by muscle disuse because of certain diseases such as osteoarthritis (OA). Muscle atrophy is the primary reason for impairments in muscle strength and is related to limitations in mobility (Janssen et al. 2002). In addition to the loss of muscle mass, alterations in muscle composition, such as increased adipose tissue accumulation and water content within the muscle, is associated with poor muscle strength and functional limitations (Goodpaster et al. 2001; Sipila et al. 2004; Yamada et al. 2010; Fukumoto et al. 2012b). Muscle composition can be evaluated using ultrasound imaging, whereby an enhanced echo intensity (EI) represents changes caused by increased intramuscular fibrous and adipose tissue (Heckmatt et al. 1982; Reimers et al. 1993; Pillen et al. 2009a). Muscle thickness (MT) measured by ultrasound is strongly correlated with site-matched skeletal muscle mass measured using a magnetic resonance imaging (Dupont et al. 2001; Miyatani et al. 2004). Ultrasound imaging is a non-invasive, safe, and easily accessible technique. Thus, MT and EI using ultrasound imaging are useful ways of estimating muscle mass and composition in a busy clinical setting. Our previous study reported that both MT and EI using ultrasound imaging were independently associated with muscle strength in healthy middle-aged and elderly subjects (Fukumoto et al. 2012b).

Hip OA is a chronic joint disease that causes pain, muscle weakness, and loss of physical function. Reduced muscle strength is an important determinant of functional limitation in patients with hip OA (Steultjens et al. 2001; Pua et al. 2009). While muscle strength can reduce up to 31% in patients with hip OA (Arokoski et al. 2002), no significant losses in muscle volume or cross-sectional area (CSA) of the hip and thigh muscles were found when compared with those in healthy individuals (Arokoski et al. 2002; Grimaldi et al. 2009a; Grimaldi et al. 2009b). However, no study has compared muscle composition between individuals with and without hip OA. Additionally, changes in abdominal muscle mass and composition in patients with hip OA are unclear. Hip OA may cause abnormal sagittal alignment and difficulty maintaining proper balance with consequent low back pain ("hip-spine syndrome") (Offierski and MacNab 1983; Yoshimoto et al. 2005). Changes in the abdominal muscle mass and composition that provides stability to the lumbopelvic region (Hicks et al. 2005; Urquhart et al. 2005) may lead to these abnormal sagittal alignments.

Increased knowledge regarding muscle mass and composition of the hip, thigh, and abdominal muscles in patients with OA compared with those in healthy adults is very important for both a physical examination and treatment to improve muscle functions in patients with hip OA. The objective of the present study was to compare muscle mass and composition of hip, thigh, and abdominal muscles between individuals with hip OA and healthy adults.

Methods

Participants

The present study included 24 women with unilateral or bilateral hip OA (OA group) and 16 healthy women without hip OA (healthy group). The participants in the OA group were managed as outpatients at the Department of Orthopaedic Surgery of Kyoto University Hospital, but did not receive physical therapy. They had advanced hip OA, and their disease severity was assessed by the Kellgren/Lawrence (K/L) scale (Kellgren and Lawrence 1957) as grade 3–4 (moderate to severe joint space narrowing). All the OA group participants were independently living and could walk with or without assistive devices. Hip function in the OA group was evaluated using the Harris Hip Score (HHS) (Harris 1969), which is a disease-specific index containing eight items representing pain, walking function, activities of daily living, and range of motion in the hip joint. Participants in the healthy group were selected from in and around Kyoto by community advertisement. All the healthy group participants were independently living and could walk without assistive devices. Either the more severe side, or the more painful side if both hips were equally severe, was selected for analysis of participants with bilateral hip OA (n = 14).The non-dominant side (not preferred for kicking a ball) was selected for analysis in the healthy group. The exclusion criteria for both groups included: history of lower limb or back surgery; any symptom affecting the knees, ankle, or back; previously diagnosed rheumatoid arthritis, vestibular problems, and central or peripheral nervous system involvement; and dementia involving decreased cognitive function.

A written informed consent was obtained from all the participants after informing them about the objective and procedures of the present study. The ethics committee of Kyoto University Graduate School, Faculty of Medicine approved this study.

Ultrasound measurement

Transverse ultrasound images were obtained using a B-mode ultrasound imaging device (LOGIQ e; GE Healthcare UK Ltd., Chalfont, Buckinghamshire, UK) with an 8 MHz linear-array probe. Seven muscles were examined: gluteus maximus, gluteus medius, quadriceps femoris, rectus abdominis, external oblique, internal oblique, and transversus abdominis. Measurement sites for each muscle are shown in **Figure 1**. The ultrasound images of gluteus maximus and medius were obtained in the prone position and those of other muscles were obtained in the supine position. Equipment settings included dynamic range (69 Hz) and time gain compensation in the neutral position, and these parameters were maintained for all measurements. A 70-dB gain was used for gluteus maximus and gluteus medius, and a 58-dB gain was used for the other muscles. Dynamic focus depth was set to the depth of the muscle of interest. During examination, care was taken to maintain the same standardized position of the subjects and the exact location of the probe. A water-soluble transmission gel was placed over the scan head to improve acoustic coupling. All measurements were performed by the same investigator once for each muscle. Representative ultrasound images of a participant with hip OA and a healthy participant are shown in **Figure 2**.

MT and EI were assessed as muscle mass and composition indices, respectively, using an electric caliper on frozen ultrasound images by a radiologist who was blinded to the participants' health conditions. MT of each muscle was measured as previously described

(Hebert et al. 2009; Ikezoe et al. 2011; Fukumoto et al. 2012b). EI was determined by a computer-assisted 8-bit gray-scale analysis using the standard histogram function in Adobe Photoshop Elements (Adobe Systems Inc., San Jose, CA, USA). Regions of interest were selected at a depth of 3.0–5.0 cm for gluteus maximus and gluteus medius, 1.0–4.0 cm for quadriceps femoris, and 0.5–4.0 cm for the abdominal muscles, avoiding the surrounding fascia. The mean EI of the regions was expressed as a value between 0 (black) and 255 (white). Previous studies reported the reliability of ultrasound for measuring EI of the quadriceps femoris (Fukumoto et al. 2012b). However, the reliability of the EI measurement of hip and abdominal muscles has not been reported. Therefore, intra-class correlation coefficients (ICC) for test-retest reliability were evaluated for the EI measurement of these muscles, using two images taken on two separate days in seven participants of the healthy group. ICC values ranged from 0.87 to 0.99.

Sagittal alignment

Sagittal alignment during standing was measured using a 6-camera Vicon motion system (Vicon Nexus; Vicon Motion Systems Ltd., Oxford, England) at a sampling rate of 200 Hz. Reflective markers were attached to the body, according to the Vicon Plug-in-Gait marker placement protocol. During recording, all participants were instructed to maintain a natural standing posture for a minimum of 10 s. Data were low-pass filtered using a Woltring filter with a cutoff frequency of 6 Hz. The mean pelvic anterior obliquity for 10 s was calculated in the sagittal plane using Vicon clinical manager software.

Statistical analyses

Statistical analyses were performed using an SPSS version 17.0 (SPSS Japan Inc., Tokyo, Japan). Data are shown as means ± standard deviations. The Mann–Whitney U-test was used to compare MT, EI, and the pelvis anterior obliquity between the two groups. Statistical significance was set at $p < 0.05$.

Results

Participant characteristics are shown in **Table 1**. No significant differences were observed with respect to age, height, weight, or body mass index between the groups. The pelvis anterior obliquity was significantly larger in the OA group compared with that in the healthy group ($p < 0.05$).

MT and EI are shown in **Table 2**. MT of the quadriceps femoris was significantly thinner ($p < 0.01$) with no significant difference in the MT of other muscles in the OA group compared with the healthy group. EIs of the gluteus medius, quadriceps femoris and rectus abdominis were significantly higher ($p < 0.05$) with no significant difference in the EI of any other muscle in the OA group compared with the healthy group.

Discussion

The OA group showed a significant decrease in MT of the quadriceps femoris but not the hip muscles, when compared with that in the healthy group. Furthermore, EIs of the gluteus medius, quadriceps femoris and rectus abdominis were higherin the OA group than those in the healthy group. This is the first study to investigate and compare MT and EI of hip, thigh, and abdominal muscles in individuals with and without hip OA.

Patients with hip OA exhibit muscle atrophy due to long-term disuse of lower extremities because of minimized use of the painful limbs and decreased activity (Suetta et al. 2007). We investigated MT as a muscle mass index in patients with advanced hip OA (K/L grade 3–4) by comparing it with the healthy controls. The results revealed that MT of the quadriceps femoris was 23.0% thinner ($p <0.05$) in the OA group than that in the healthy group, whereas nonsignificant reductions were observed in hip muscles such as the gluteus maximus (5.4%) and gluteus medius (6.7%). Several studies have investigated and compared muscle mass in individuals with and without hip OA. Grimaldi et al. reported that muscle volume of hip muscles in patients with advanced hip OA (K/L grade 3–4) did not differ from those in healthy adults, which supports our results (Grimaldi et al. 2009a; Grimaldi et al. 2009b). Arokoski et al. studied patients with less severe hip OA (K/L grade 1–3) and found that CSA of the quadriceps femoris as well as hip muscles did not decrease compared with the healthy adults (Arokoski et al. 2002). Therefore, muscle atrophy in patients with hip OA may be distinct in the quadriceps femoris rather than in hip muscles when the pathology worsens, despite hip disease. Atrophy of the quadriceps femoris may occur due to the fiber-type characteristics of lower-limb muscles. A higher rate of muscle atrophy occurs among type II fibers, whereas only moderate losses occur among type I fibers in the elderly and individuals with hemiplegia and hip OA (Sirca and Susec-Michieli 1980; Hachisuka et al. 1997; Roos et al. 1997). The quadriceps femoris is predominantly of type II fiber proportion, whereas the gluteus muscles are predominantly type I fiber proportion (Johnson et al. 1973). Therefore, the quadriceps femoris may be susceptible to atrophy as a result of long-term disuse due to inactivity and antalgic weight shift. A recent study in the elderly reported that muscle atrophy related to walking disability was most remarkable in the quadriceps femoris among the lower-limb muscles (Ikezoe et al. 2011).

A unique aspect of this study was measuring EI as a muscle composition index. Enhanced EI is caused by acoustic impedance on the surfaces of fat and fibrous tissue cells. Therefore, infiltration of fat and fibrous tissues within muscles is responsible for the increase in reflective interfaces resulting in higher EI (Heckmatt et al. 1988; Pillen et al. 2009a). In fact, previous studies using muscle biopsy have shown a strong correlation between the amount of fat and fibrous tissues and muscle EI (Heckmatt et al. 1982; Reimers et al. 1993; Pillen et al. 2009a). Our findings showed no decrease in MT of the gluteus medius in the OA group. However, the EI of this muscle in the OA group was significantly higher, indicating that fat and fibrous tissue within muscle had increased. Thus, actual contractile tissue of the gluteus medius may substantially decrease in patients with hip OA, although muscle mass is not less. Physiological evidence suggests that both muscle mass and composition are important contributors for generating strength (Goodpaster et al. 2001; Fukumoto et al. 2012b). The hip abductor strength in patients with hip OA decreases by 69% in healthy adults, while CSA of the muscle does not decrease (Arokoski et al. 2002). Changes in muscle composition such as a decrease in contractile tissue, as well as neurological factors, may be partially associated with this inconsistency. Rasch et al. investigated the proportion of fat infiltration in the hip and thigh muscles using an attenuation coefficient on computer tomography in addition to muscle strength and CSA in patients with hip OA (Rasch et al. 2007). They found that the attenuation coefficient and muscle strength of the hip abductors decreased on the affected side compared with the unaffected side, whereas the side-to-side difference in CSA was small and insignificant. Although they did not compare their OA subjects with healthy adults, the results of their study support our findings. EI of the quadriceps femoris in the OA group was also higher than that in the healthy group, showing increase in intra-muscular fat and fibrous tissues. Thus, our results suggest that both quantitative and qualitative changes occurred in the quadriceps femoris muscle due to long-term disuse.

However, the proportion of muscle fiber type, which could affect EI of muscles, should be considered. Type I muscle fibers have a greater lipid content than that of type II fibers (Malenfant et al. 2001); therefore, a muscle containing a higher proportion of type I fibers may exhibit a higher EI. In patients with hip OA, selective atrophy of type II fibers and an increase in the relative proportion of type I fibers has been shown compared with those in healthy controls (Sirca and Susec-Michieli 1980). Our result of increased EI in the OA group may partially indicate changes in the proportion of muscle fiber types. However, quantitative studies in support of this hypothesis are scarce; thus, further investigation is needed.

Another important finding was that EI of the rectus abdominis in the OA group was significantly higher than that in the healthy group, suggesting that not only hip muscles but also abdominal muscle composition changed in patients with hip OA. Changes in spinopelvic alignment, such as increased lumbar lordosis, sacral slope, and pelvic obliquity, are caused by hip OA (Offierski and MacNab 1983; Yoshimoto et al. 2005). In fact, participants in the OA group showed excess pelvis anterior obliquity when compared with that in the healthy group.

Changes in rectus abdominis composition might lead to these abnormal sagittal alignments. Changes in muscle composition rather than trunk muscle mass are associated with low back pain in elderly individuals (Hicks et al. 2005). Participants in the OA group had no complaints of low back pain; however, increased EI of the rectus abdominis may be a future risk for it. A longitudinal study is needed to further investigate the association with low back pain.

The limitation of this study should be addressed. We examined muscle mass and composition of a small number of women with hip OA in a limited age group and physical characteristics. Therefore, generalizations of the results to male patients with hip OA or to patients in different age groups or physical characteristics should be made cautiously.

In conclusion, MT of only the quadriceps femoris was thinner and EI of the gluteus medius, quadriceps femoris and rectus abdominis was higher in the OA group compared with that in the healthy group. These results suggest that the quadriceps femoris rather than hip muscles may be susceptible to atrophy, and that muscle composition of the gluteus medius, quadriceps femoris and rectus abdominis changed in patients with hip OA.

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Table 1. Participant characteristics (mean ± standard deviation) in the osteoarthritis (OA) (n = 24) and healthy groups (n = 16).

	The OA group	The healthy group	p value
Age (years)	56.8 ± 6.4	57.7 ± 6.4	0.68
Height (cm)	153.9 ± 4.0	155.9 ± 6.0	0.21
Weight (kg)	52.3 ± 9.0	52.4 ± 6.4	0.96
Body Mass Index (kg/m^2)	22.1 ± 3.8	21.6 ± 2.6	0.67
HHS (0—100)	65.6 ± 16.4	—	—
Pelvis anterior obliquity (°)	12.9 ± 5.5	8.7 ± 4.2	< 0.05

HHS = Harris Hip Score

Table 2. MT (cm) and EI (0—255) (mean ± standard deviation) in the osteoarthritis (OA) (n = 24) and healthy groups (n = 16).

	MT				EI			
	The OA group	The healthy group	p value	(%)	The OA group	The healthy group	p value	(%)
Gluteus maximus	2.20 ± 0.40	2.32 ± 0.40	0.39	— 5.4	96.1 ± 12.4	91.4 ± 9.2	0.15	5.2
Gluteus medius	3.33 ± 0.65	3.57 ± 0.51	0.29	— 6.7	91.2 ± 13.2	79.8 ± 14.0	< 0.05	14.4
Quadriceps femoris	2.97 ± 0.48	3.85 ± 0.66	< 0.01	— 23.0	106.2 ± 14.9	95.2 ± 12.4	< 0.05	11.5
Rectus abdominis	0.81 ± 0.15	0.86 ± 0.14	0.59	— 4.3	117.4 ± 18.6	103.2 ± 18.0	< 0.05	13.7
External oblique	0.63 ± 0.14	0.56 ± 0.13	0.16	13.9	112.6 ± 22.2	113.4 ± 15.8	0.95	— 0.8
Internal oblique	0.70 ± 0.19	0.74 ± 0.16	0.61	— 4.9	97.5 ± 17.5	95.2 ± 14.8	0.93	3.1
Transversus abdominis	0.33 ± 0.11	0.34 ± 0.12	0.98	— 3.1	81.4 ± 18.1	76.2 ± 18.2	0.91	7.1

MT = muscle thickness; EI = echo intensity. Percentages indicate ratio between OA and healthy.

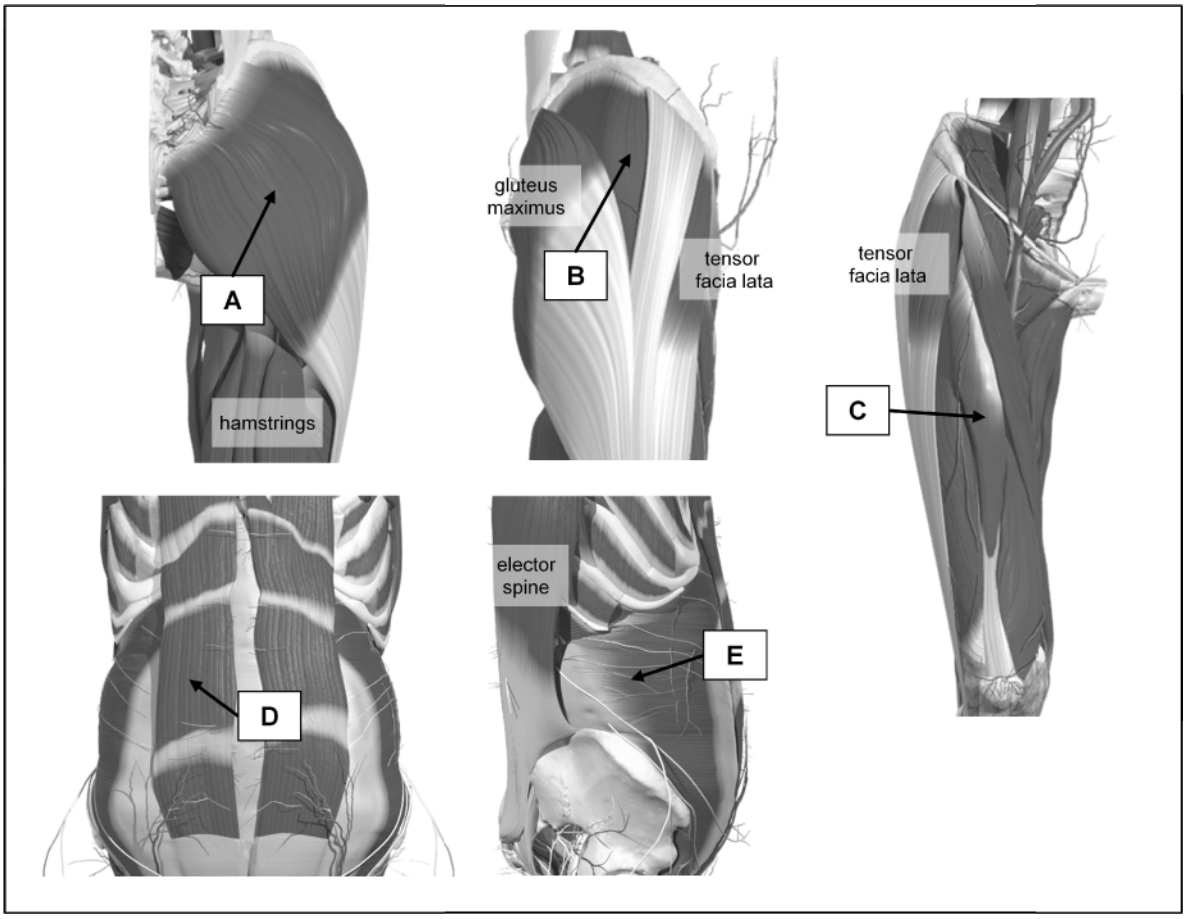

Figure 1. Ultrasound sites for each muscle. A: Gluteus maximus, One-third between posterior superior iliac spine and the greater trochanter. B: Gluteus medius, Midway between the proximal end of iliac crest and the greater trochanter. C: Quadriceps femoris, Midway between the anterior superior iliac spine and the proximal end of the patella. D: Rectus abdomimis, 3 cm lateral to the umbilicus. E: External oblique, internal oblique and transverse abdominis, 2.5 cm anterior to the mid-axillary line, at the mid-point between the inferior rib and the iliac crest. (These figures were cited from Primal Pictures on OvidSP.)

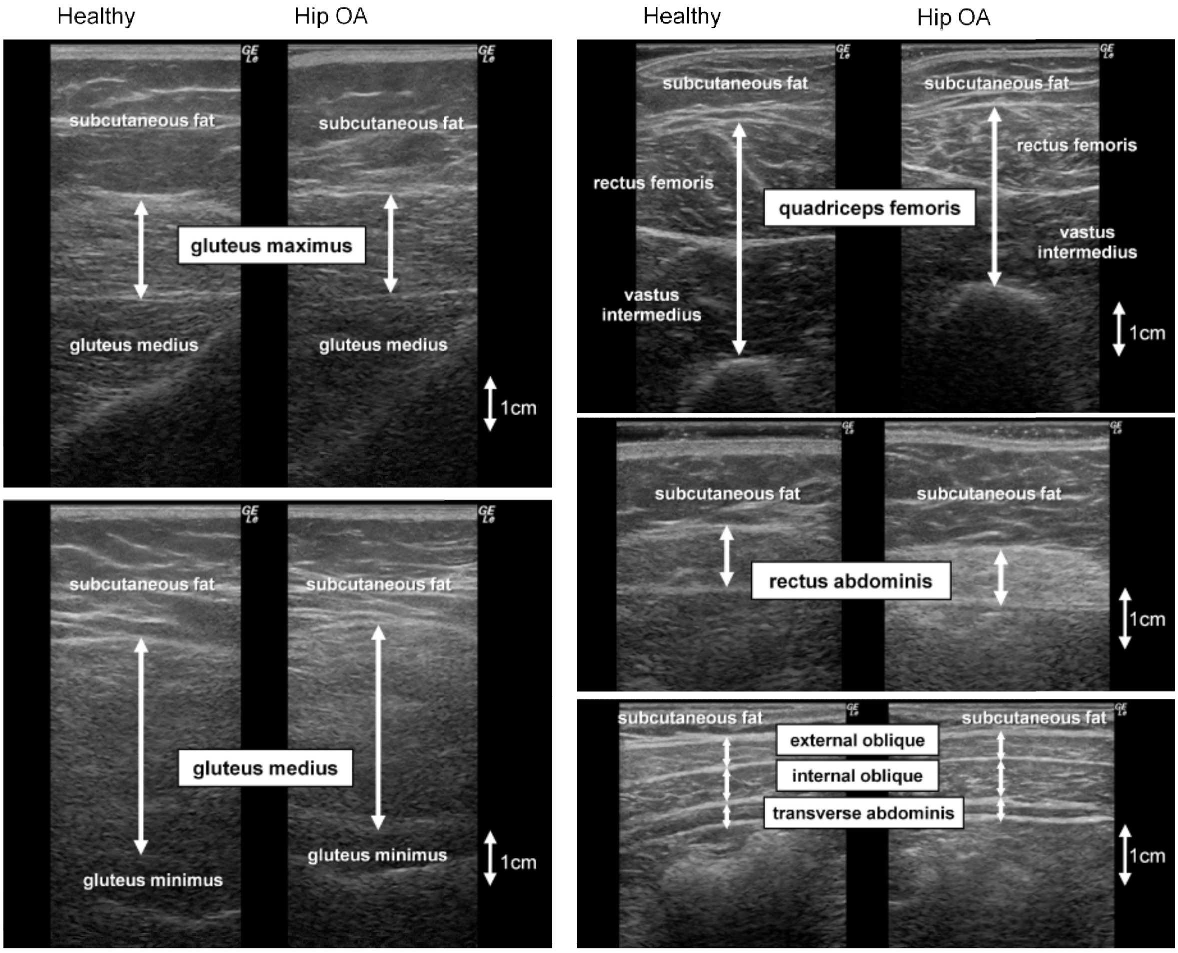

Figure 2. Muscle ultrasound images 55 years participant with hip OA and 55 years healthy participant.

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Effects of High-velocity Resistance Training on Muscle Function, Muscle Properties, and Physical Performance in Individuals with Hip Osteoarthritis: A Randomized Controlled Trial

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ABSTRACT

Objective: To investigate the effects of high-velocity resistance training on muscle function, muscle properties, and physical performance in patients with hip osteoarthritis by comparison with those of low-velocity resistance training.

Design: Single-blind randomised controlled trial.

Setting: Home-based exercise programs.

Subjects: Forty-six women with hip osteoarthritis were randomly assigned to the high-velocity (n = 23) or low-velocity (n = 23) training group.

Interventions: Both groups underwent an 8-week daily home-based resistance training program using an elastic band. Exercises involved hip abduction, extension, and flexion and knee extension. Participants in the high-velocity group performed the concentric phase of each repetition as rapidly as possible and returned to the initial position eccentrically in 3 s. Participants in the low-velocity group performed both the concentric and eccentric phases in 3 s.

Main measures: The following outcome measures were evaluated: isometric muscle strength, muscle power, muscle thickness, muscle echo intensity, maximum walking speed, Timed Up-and-Go test, 3-min walking test, Harris Hip Score, and hip pain.

Results: Decreases in the time for performing the Timed Up-and-Go test (mean changes: high-velocity group −0.46 s, low-velocity group −0.23 s) and echo intensity of the gluteus maximus (mean changes: high-velocity group −6.8, low-velocity group −1.0) were significantly greater in the high-velocity group than in the low-velocity group. No significant difference was observed in changes of other outcome measures between the groups.

Conclusion: This study revealed that high-velocity training for patients with hip osteoarthritis has partially a greater effect on muscle properties and physical performance than low-velocity training.

Key Words: Hip osteoarthritis, muscle power, physical performance, treatment velocity, high-velocity resistance training

Introduction

Osteoarthritis is a common musculoskeletal disorder. Lower limb osteoarthritis leads to pain, loss of mobility and muscle function, restricted activities of daily living, and decreased quality of life. In the clinical guidelines for patients with osteoarthritis of the hip or knee, therapeutic exercise is recommended to improve overall functioning (Zhang et al. 2005; Zhang et al. 2010). In contrast to knee osteoarthritis, however, far less research has been conducted into the role of exercise in hip osteoarthritis. Therefore, the most effective exercise for patients with hip osteoarthritis remains unclear.

In recent years, muscle power has been found to contribute more to improvement in physical function than muscle strength(Suzuki et al. 2001; Cuoco et al. 2004). Therefore, muscle power is becoming the focus of many resistance training studies in older adults. Previous studies in older adults reported that high-velocity resistance training (power training) resulted in significant increases in muscle strength, muscle power and whole muscle cross-sectional area (Hakkinen et al. 1998; Hakkinen et al. 2000). Some studies(Fielding et al. 2002; Miszko et al. 2003) compared high-velocity resistance training and conventional low-velocity resistance training in older adults and found that high-velocity training resulted in significantly greater improvement in leg press power and physical function than low-velocity training. Even at low intensity levels, high-velocity training improves muscle function and physical function(Earles et al. 2001; Miszko et al. 2003; Orr et al. 2006). Orr et al. (Orr et al. 2006) showed that high-velocity power training at low resistance produced the greater improvement in balance performance compared with that at high resistance, suggesting that training veolocity, but not intensity of resistance, may be a critical variable during high-velocity training.

High external resistance has been recommended in resistance training for older adults. Even for patients with osteoarthritis, high resistance was often used in resistance training.

However, in patients with osteoarthritis, high external resistance could cause overload of the joint and aggravate symptoms such as pain, swelling, and inflammation. In fact, some authors have suggested that exercise for patients with osteoarthritis should not include high joint load(van Baar et al. 1998; Kettunen and Kujala 2004). Therefore, low-resistance training may be preferable and safer for patients with osteoarthritis. High-velocity training for patients with osteoarthritis may result in greater improvements in the performance of functional tasks, even with low resistance. To our knowledge, however, no study has investigated the effect of high-velocity training at low resistance in patients with hip osteoarthritis.

In this study, low-intensity home-based exercise at high-velocity or low-velocity using elastic bands was evaluated in patients with hip osteoarthritis. The objective of this study was to investigate the effect of high-velocity training on muscle function, muscle properties, and physical performance in patients with hip osteoarthritis by comparison with those of low-velocity training. We hypothesized that high-velocity training would have a greater impact on muscle power and physical performance than low-velocity training.

Methods

This randomized control trial was conducted at the Graduate School of Medicine, Kyoto University in compliance with the Declaration of Helsinki. It was approved by the ethics committee of Kyoto University Graduate School and the Faculty of Medicine. Written informed consent was obtained from all participants prior to randomization.

The study recruited women diagnosed with bilateral or unilateral hip osteoarthritis who were managed as outpatients at the Department of Orthopaedic Surgery, Kyoto University Hospital, Kyoto, Japan and who had received no prior physical therapy. In this study, only women were recruited because muscle and physical function in women is lower than that in men, and gender difference is a major confounding factor that must be controlled. Inclusion criteria were as follows: ability to walk with or without assistive devices; absence of dementia; ability to understand the informed consent procedure; and no history of total hip arthroplasty, stroke, Parkinson’s disease, neurological gait disorders, neuromuscular disease, vestibular problems, or symptoms affecting the knees, ankles, or back. Muscle strength deficit was not an inclusion criterion because it could not be clearly defined as no optimal cut-off level for identifying the strength deficit has been established even in healthy subjects. Muscle strength in patients with hip osteoarthritis is lower than that in healthy individuals, even for those with mild osteoarthritis(Rydevik et al. 2010). Candidate study participants were screened by four orthopedic surgeons. Two study examiners conducted the study enrollment procedure.

Disease severity was assessed using a system based on the classification of the Japanese Orthopaedic Association(Takatori et al. 2010). This system defined 4 stages of hip osteoarthritis: the pre-osteoarthritis stage (morphological changes of the acetabulum and/or proximal femur related to osteoarthritis), initial stage (one or more osteoarthritis changes and possible narrowing of the joint space), advanced stage (partial loss of the joint space), and terminal stage (gross loss of the joint space). Either the more severe side, or the more painful side if both hips were equally severe, was selected for analyses. After recruitment, participants were randomly assigned to the high-velocity or low-velocity resistance training group using a stratified block randomization technique (four participants per block). The participants were stratified by age (<50 years and ≥50 years) and disease severity (pre-osteoarthritis or initial stage and advanced or terminal stage). In each block, permuted block randomization was then achieved using random numbers generated by Excel (Microsoft, Redmond, WA, USA). This procedure was conducted by a study examiner. Participants, but not study examiners (i.e., outcome assessors and a physical therapist who prescribed the intervention program), were blinded to group allocation.

For both groups, a physical therapist prescribed an 8-week daily home-based resistance training program. Four exercises were performed on both lower limbs: hip abduction in supine position, hip extension in prone position, hip flexion in sitting position, and knee extension in sitting position. Each exercise was performed using Theraband (Hygenic Co., Akron, OH, USA), and its color indicated its resistance level (yellow, red, green, or blue). Exercise loads (as indicated by band color) in resistance training were set at a level that was perceived as “somewhat hard” by the participants. Two sets of 10 repetitions of concentric and eccentric contractions through the full range of motion were performed for the first 2 weeks, and 3 sets of 10 repetitions were performed thereafter. In addition, participants in the high-velocity group were instructed to perform the concentric phase of each repetition as rapidly as possible and then return through the eccentric phase in 3 s. Participants in the low-velocity group performed both the concentric and eccentric phases in 3 s.

The physical therapist contacted the participants every 2 weeks by telephone, and exercise loads were increased when participants could perform the exercises comfortably. To assist in monitoring compliance, participants maintained training diaries. The compliance rate was deemed as 100% if the participant had completed a total of 56 days of exercise over 8 weeks.

Various parameters were evaluated at baseline and 8 weeks after the intervention. This included muscle function (isometric strength and muscle power), physical performance, clinical assessment, and muscle properties (muscle mass and echo composition). The primary outcome was physical performance, as this study investigated whether high-velocity training is more effective than low-velocity training in improving physical performance in patients with hip osteoarthritis.

Maximal isometric strength of the hip abductors, extensors, flexors, and knee extensors was measured as described previously (Fukumoto et al. 2012b; Tsukagoshi et al. 2012). A hand-held dynamometer (μTas F-1; Anima Co., Tokyo, Japan) was used for the measurement of hip muscles, and an isokinetic dynamometer (Myoret RZ-450; Kawasaki Heavy Industries Ltd., Tokyo, Japan) was used for the measurement of knee extensors. Isometric strength was measured twice with a 30-s rest interval, and the resulting maximal value (Newton, N), estimated lever arm length (m), and body weight (kg) were combined to determine the torque to body weight ratio (Nm/kg).

As a measure of muscle power, the stairs ascending test was performed. The participants were asked to walk up 10 steps, each with a height of 16.5 cm, as fast as they could safely manage without the use of handrails or aids of any form. Power (W/kg) was calculated according to the method of Suetta et al.(Suetta et al. 2008).

Maximum walking speed (Bohannon 1997) was measured over a 10-m floor length. Participants were provided with 2 m to accelerate and decelerate before and after the test distance and were asked to walk as fast as they could. Two trials were performed, and the faster speed (m/s) was used for analyses. The Timed Up-and-Go test(Podsiadlo and Richardson 1991) was performed using a chair that was 43 cm in height. The participants were asked to stand up from a sitting position, walk 3 m, turn, walk back, and sit down quickly and safely. The faster time (s) from 2 performances of Timed Up-and-Go test was obtained and used for analyses. The 3-min walking(Iriberri et al. 2002) was performed using a 25-m course, with cones as turning points. The participants were asked to walk as fast and safely as possible between the cones for 3 min. Distance traveled (m) in 3 min was recorded.

Clinical assessment was performed using the Harris Hip Score(Soderman and Malchau 2001) from 0–100, with 100 indicating the highest level of function. The Harris Hip Score is a disease-specific index containing 8 items representing pain, walking function, activities of daily living, and range of motion of the hip joint. In addition, the impact of hip pain on daily activity during the previous week was evaluated on a 100-mm visual analogue scale.

Ultrasound images were obtained using a B-mode ultrasound imaging device (LOGIQ e; GE Healthcare UK Ltd., Chalfont, Buckinghamshire, UK) with an 8-MHz linear array probe. Three muscles were examined after the practice in a previous study(Ikezoe et al. 2011): the gluteus maximus, gluteus medius, and quadriceps femoris. All measurements were performed by the same investigator once for each muscle. Muscle thickness of each muscle was measured as an index of muscle mass using an electric caliper on frozen images, as described previously(Ikezoe et al. 2011; Fukumoto et al. 2012b). In addition, echo intensity was assessed as a muscle composition index and was determined by computer-assisted 8-bit grayscale analysis using the standard histogram function in Adobe Photoshop Elements (Adobe Systems Inc., San Jose, CA, USA), as described previously(Fukumoto et al. 2012a; Fukumoto et al. 2012b). The mean echo intensity of the regions was expressed as a value between 0 (black) and 255 (white). Enhanced echo intensity has been shown to indicate changes in muscle composition due to increased intramuscular fibrous and adipose tissues(Pillen et al. 2009b). Ultrasound measurement of these muscles demonstrated high reliability for muscle thickness (intra-class correlation coefficients: 0.90–0.99) and echo intensity (0.87–0.91)(Ikezoe et al. 2011; Fukumoto et al. 2012a; Fukumoto et al. 2012b). In addition, ultrasound measurement was shown to correlate with magnetic resonance imaging and computed tomography in terms of muscle cross-sectional area and muscle composition(Sipila and Suominen 1993; Dupont et al. 2001; Miyatani et al. 2004).

Mann–Whitney U tests were used to analyze differences between the groups at baseline. To examine the differences in the effects of the intervention between the two groups, changes from baseline to postintervention were compared between the groups using analysis of covariance. Age, height, weight, and outcome measures at baseline were used as covariates. Mean differences and 95% confidence intervals were reported. On-treatment analysis, but not intention-to-treat analysis, was conducted. Missing values for participants who completed the study were not compensated. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using SPSS version 17.0 (SPSS Japan Inc., Tokyo, Japan).

Results

Between June 2010 and September 2011, 46 female subjects with a mean (SD) age of 53.4 (9.8) years were enrolled in this study. Figure 1 is a flowchart of study participation. Participants were randomly assigned to the high-velocity (n = 23) or low-velocity (n = 23) training group. Over the 8-week period of the study, 7 participants (4 high-velocity, 3 low-velocity) withdrew from the study. Of the 4 participants in the high-velocity group who withdrew from the study, 1 did so because of loss of motivation, 1 because of lack of time, and 2 because of hip pain during the exercise. In the low-velocity group, 2 withdrew because of lack of time and 1 because of low back pain that was unrelated to the exercises. All other participants (high-velocity group, 19 participants and low-velocity group, 20 participants) completed the study. The mean (SD) compliance rate was 81 (23) % for the high-velocity group and 86 (13) % for the low-velocity group. No significant difference was observed between the groups.

Participant characteristics at baseline are shown in Table 1. For 3 participants (high-velocity group, 2 ; low-velocity group, 1), muscle power was not measured before or after the intervention because of their inability to ascend stairs without the use of handrails or aids. In addition, for 1 participant in the high-velocity group, muscle properties of the gluteus maximus and gluteus medius were not measured before or after the intervention because of refusal to undergo ultrasound. No significant differences were noted between the groups in physical characteristics, muscle function, muscle properties, physical performance, or clinical assessment.

Table 2 provides data on muscle function. No significant differences were noted between the groups in increases of all measurements of muscle strength or muscle power.

Table 3 shows the data on physical performance and clinical assessment. A significantly greater decrease in the time for performing the Timed Up-and-Go test was observed in the high-velocity group than in the low-velocity group ($p < 0.05$). No significant differences were observed between the groups in changes of maximum walking speed, 3-min walking test, Harris Hip Score, and pain measured on the visual analogue scale.

Table 4 shows the data on muscle properties. No significant difference was observed between the two groups in increase in muscle thickness for all muscles measured. With regard to echo intensity, a significant difference of decrease was observed for the gluteus maximus; this decrease was greater in the high-velocity group ($p < 0.05$). No significant differences were observed in decreases in the echo intensity of the gluteus medius and quadriceps femoris muscles.

Discussion

Previous reports in older adults indicated a positive effect of high-velocity resistance training on muscle strength, power, and physical function(Hakkinen et al. 1998; Hakkinen et al. 2000; Earles et al. 2001; Fielding et al. 2002; Miszko et al. 2003; Orr et al. 2006). However, no studies have examined whether high-velocity training is more effective than low-velocity training for patients with hip osteoarthritis. The present study is the first to make this comparison. The primary findings of this study were a greater improvement in Timed Up-and-Go test in the high-velocity group than in the low-velocity group, while gains in hip and knee muscle strength in both groups. In addition, the decrease in echo intensity of the gluteus maximus was greater in the high-velocity group than in the low-velocity group.

Muscle strengthening is recommended as a key component of most exercise regimens for hip and knee osteoarthritis. In this study, the extent of increases in isometric muscle strength were the same in both groups following the intervention. Contrary to our hypothesis, high-velocity and low-velocity training were equally effective in improving muscle power because no significant difference in change was found. Previous studies in healthy older adults reported that high-velocity training induces an increase in muscle power (Hakkinen et al. 1998; Hakkinen et al. 2000; Earles et al. 2001; Fielding et al. 2002). However, other studies reported no difference in gain of muscle power between high-velocity and low-velocity training (Miszko et al. 2003; Henwood et al. 2008). Taken together, the results of this study may indicate that both types of training increase muscle power.

High-velocity training has been reported to improve physical performance beyond what can be achieved by traditional strength training(Miszko et al. 2003). In this study, the decrease in the time for performing the Timed Up-and-Go test was greater in the high-velocity group (−0.46 s) than in the low-velocity group (−0.23 s), indicating that a more effective improvement in physical performance from high-velocity training for patients with hip osteoarthritis than from low-velocity training. Interestingly, the high-velocity group required less absolute total time than the low-velocity group during each exercise session, yet physical performance improved more in the high-velocity group than in the low-velocity group. However, no significant difference was found between the groups in levels of improvement in the other physical performance measures, maximum walking speed and 3-min walking test. The Timed Up-and-Go test includes multiple movements and high-velocity movement, such as standing up, walking, turning, walking back, and sitting down quickly. Therefore, the Timed Up-and-Go test may require more muscle power than walking ability, which is better measured by maximum walking speed and 3-min walking test. Thus, high-velocity training may not be more effective than low-velocity training for improvement of all physical performance measures, and our hypothesis was only partially supported.

The present study assessed physical disability using the Harris Hip Score scale, and found that the high- and low-velocity training similarly improved Harris Hip Score. The extent of decreases in pain measured on a visual analogue scale were the same following high- and low-velocity training. Previous studies in patients with hip and knee osteoarthritis reported improvements in physical disability and pain due to resistance training(van Baar et al. 1998; Jan et al. 2008). Our results indicate no association of differences in movement velocity in resistance training with the extent of improvement in physical disability and pain of patients with hip osteoarthritis.

Unlike most previous studies, the present study assessed muscle properties, muscle thickness as an index of muscle mass, and echo intensity as an index of muscle composition. Hip osteoarthritis has been reported to cause changes in skeletal muscle properties, such as loss of muscle mass (muscle atrophy) and altered muscle composition including increased intramuscular adipose tissue(Rasch et al. 2007; Fukumoto et al. 2012a). Previous studies demonstrated that resistance training led to an increase in muscle mass and a decrease in intramuscular fat tissue in the elderly(Sipila and Suominen 1996; Taaffe et al. 2009). However, no study has investigated the effect of resistance training on these muscle properties in patients with hip osteoarthritis. Hence, the unique contribution of the present study is to compare the effects on muscle properties between high- and low-velocity training in patients with hip osteoarthritis. The results revealed that the extent of increase in the thickness of all muscles was the same following both types of training. However, a greater decrease in the echo intensity of the gluteus maximus was observed in the high-velocity group than in the low-velocity group. These results suggest that high-velocity training for patients with hip osteoarthritis effects positive changes in muscle composition, rather than changes in muscle mass. The results of this study showed that fat and fibrous tissues within the gluteus maximus may have decreased substantially following high-velocity training. One recent study demonstrated that ectopic fat cell formation in skeletal muscle was associated with action of the mesenchymal progenitors, which can be inhibited by satellite cells(Uezumi et al. 2010).

Mechanical stress due to high-velocity contraction during high-velocity training may have caused activation of muscle satellite cells and subsequent inhibition of mesenchymal progenitors. However, quantitative studies in support of this hypothesis are scarce; thus, future studies are needed. Physiological evidence suggests that muscle composition as well as muscle mass are important elements in generating muscle contraction and physical function(Visser et al. 2002; Fukumoto et al. 2012b). The improvement in physical performance observed in the high-velocity group may therefore have been caused by changes in muscle composition.

The results of this study revealed that the effect of high-velocity training for patients with hip osteoarthritis was limited to the Timed Up-and-Go test and muscle composition of the gluteus maximus, among a range of outcome measurements, when compared with the effect of low-velocity training. Nevertheless, these results have important implications for the future design of training programs for patients with hip osteoarthritis, especially as changes resulting from high-velocity training occurred in less total time per exercise session. However, 2 participants in the high-velocity group discontinued the exercise program because of increased hip pain. Thus, high-velocity training for patients with hip osteoarthritis may not always be safer and may increase the risk of hip pain, even at low resistance.

This study has several limitations. First, the number of study participants was small, and the dropout rate was relatively high. The small sample size may have resulted in type 2 errors. Second, the outcome assessors and the physical therapist who prescribed the intervention program were not blinded to group allocation, which may have led to bias in the results. Third, the compliance rate relied on participants' completion of the training diary, and the exercise load was determined subjectively. However, the study examiners made every effort to confirm the compliance and exercise load during the intervention by telephone confirmation every 2 weeks.

In conclusion, 8 weeks of high-velocity training at low resistance for patients with hip osteoarthritis had partially a greater effect on muscle composition and physical performance compared with low-velocity training. Although further study is needed, our results have important implications for the future design of training programs for safe and effective enhancement of physical function in patients with hip osteoarthritis.

Clinical message

Home-based resistance training at high velocity for patients with hip osteoarthritis has a slightly greater effect on physical performance and muscle composition than low-velocity training.

High-velocity training is an efficient intervention program for patients with hip osteoarthritis because it required lesser absolute total time per exercise session than low-velocity training.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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Table 1 Characteristics of participants in the high-velocity (n=19) and low-velocity groups (n=20) at baseline

Characteristic	high-velocity group (n = 19)	low-velocity group (n = 20)	p value
Age (years)	52.4 (9.2)	52.5 (10.1)	0.97
Height (cm)	156.6 (5.6)	156.0 (5.5)	0.70
Weight (kg)	54.0 (7.5)	52.7 (7.6)	0.60
Body mass index (kg/m^2)	22.1 (3.5)	21.7 (3.5)	0.77
Disease severity (no)			
Pre-osteoarthritis or initial stage	9	10	
Advanced or terminal stage	10	10	
Muscle strength (Nm/kg)			
Hip abductors	0.96 (0.33)	0.99 (0.29)	0.77
Hip extensors	1.15 (0.44)	1.21 (0.31)	0.60
Hip flexors	0.98 (0.35)	1.07 (0.32)	0.41
Knee extensors	1.64 (0.59)	1.65 (0.41)	0.98
Muscle power (W/kg)	16.2 (3.3)	16.8 (2.5)	0.56
Physical performance			
maximum walking speed (m/s)	2.03 (0.41)	2.19 (0.37)	0.23
Timed Up-and-Go (s)	5.64 (1.18)	5.43 (1.04)	0.56
3-min walking test (m)	286.4 (60.0)	300.5 (40.4)	0.41
Clinical assessment			
Harris Hip Score (0—100)	75.4 (17.7)	77.2 (13.3)	0.72
Pain (0—100)	32.0 (24.9)	21.2 (18.0)	0.13
Muscle thickness (cm)			
Gluteus maximus	2.28 (0.49)	2.29 (0.37)	0.98
Gluteus medius	3.75 (0.74)	3.72 (0.52)	0.91
Quadriceps femoris	3.45 (0.65)	3.57 (0.61)	0.57
Muscle echo intensity (0—255)			
Gluteus maximus	91.4 (20.1)	89.1 (14.6)	0.70
Gluteus medius	85.9 (16.8)	82.7 (16.7)	0.55
Quadriceps femoris	94.9 (17.8)	91.6 (15.0)	0.53

Values are means (SD).

Table 2. Effect of intervention on muscle function in the high-velocity and low-velocity groups.

	high-velocity group			low-velocity group			F-value	Difference between groups
Variables	Before	After	Changes	Before	After	Changes		(95% Confidence interval)
Muscle strength (Nm/kg)								
Hip abductors	0.96 (0.33)	1.12 (0.40)	0.16 (0.14)	0.99 (0.29)	1.18 (0.24)	0.19 (0.18)	0.264	-0.02 (-0.138. 0.082)
Hip extensors	1.15 (0.44)	1.34 (0.50)	0.19 (0.19)	1.21 (0.31)	1.44 (0.31)	0.22 (0.18)	0.673	-0.04 (-0.159, 0.068)
Hip flexors	0.98 (0.35)	1.10 (0.37)	0.13 (0.16)	1.07 (0.32)	1.19 (0.33)	0.12 (0.15)	0.181	0.00 (-0.114, 0.075)
Knee extensors	1.64 (0.59)	1.79 (0.55)	0.15 (0.18)	1.65 (0.41)	1.93 (0.51)	0.29 (0.25)	3.475	-0.14 (-0.285, 0.012)
Muscle power (W/kg)	4.11 (0.85)	4.36 (0.82)	0.25 (0.24)	4.24 (0.62)	4.36 (0.65)	0.12 (0.38)	0.720	0.13 (-0.136, 0.329)

Values are means (SD).

Table 3. Effect of intervention on physical performance and clinical assessment in the high-velocity and low-velocity groups.

	high-velocity group			low-velocity group			F-value	Difference between groups
Variables	Before	After	Changes	Before	After	Changes		(95% Confidence interval)
Physical performance								
maximum walking speed (m/s)	2.03 (0.41)	2.10 (0.43)	0.07 (0.16)	2.19 (0.37)	2.26 (0.36)	0.07 (0.16)	0.058	0.00 (-0.121, 0.095)
Timed Up-and-Go test (s)	5.64 (1.18)	5.18 (0.98)	- 0.46 (0.27)	5.43 (1.04)	5.31 (0.79)	- 0.23 (0.39)	6.638 *	-0.23 (-0.343, -0.040)
3-min walking test (m)	286.4 (60.0)	302.7 (42.4)	16.4 (26.7)	300.5 (40.4)	313.3 (41.5)	11.6 (22.6)	0.069	4.8 (-11.739, 15.219)
Clinical assessment								
Harris Hip Score (0—100)	75.4 (17.7)	80.0 (15.5)	4.6 (10.5)	77.2 (13.3)	82.2 (13.4)	5.0 (11.2)	0.081	-0.3 (-7.714, 5.823)
Pain (0—100)	32.0 (24.9)	24.7 (24.6)	- 7.3 (21.7)	21.2 (1.80)	14.0 (20.6)	- 7.2 (20.3)	0.528	-0.01(-8.730, 18.430)

Values are means (SD).

*$p < 0.05$: significant group difference adjusted for age, height, weight, and outcome measures before training.

Table 4. Effect of intervention on muscle property in the high-velocity and low-velocity groups.

	high-velocity group			low-velocity group			F-value	Difference between groups
Variables	Before	After	Changes	Before	After	Changes		(95% Confidence interval)
Muscle thickness (cm)								
Gluteus maximus	2.28 (0.49)	2.48 (0.53)	0.20 (0.37)	2.29 (0.37)	2.37 (0.44)	0.08 (0.23)	0.978	0.12 (-0.096, 0.276)
Gluteus medius	3.75 (0.74)	3.88 (0.64)	0.13 (0.30)	3.72 (0.52)	3.82 (0.58)	0.06 (0.48)	1.104	0.07 (-0.219, 0687)
Quadriceps femoris	3.45 (0.65)	3.55 (0.63)	0.10 (0.18)	3.57 (0.61)	3.62 (0.61)	0.05 (0.28)	0.214	0.05 (-0.121, 0.192)
Muscle echo intensity (0—255)								
Gluteus maximus	91.4 (20.1)	84.4 (18.0)	- 6.8 (9.0)	89.1 (14.6)	88.1 (13.3)	- 1.0 (7.5)	5.264 *	-5.8 (-9.406, -0.547)
Gluteus medius	85.9 (16.8)	79.3 (15.4)	- 6.7 (6.6)	82.7 (16.7)	81.3 (14.8)	- 2.4 (9.2)	2.540	-4.3 (-7.847, 0.963)
Quadriceps femoris	94.9 (17.8)	91.4 (16.6)	- 3.5 (8.9)	91.6 (15.0)	89.6 (15.0)	- 2.0 (8.0)	0.108	-1.5 (-6.366, 4.595)

Values are means (SD).

*$p < 0.05$: significant group difference adjusted for age, height, weight, and outcome measures before training.

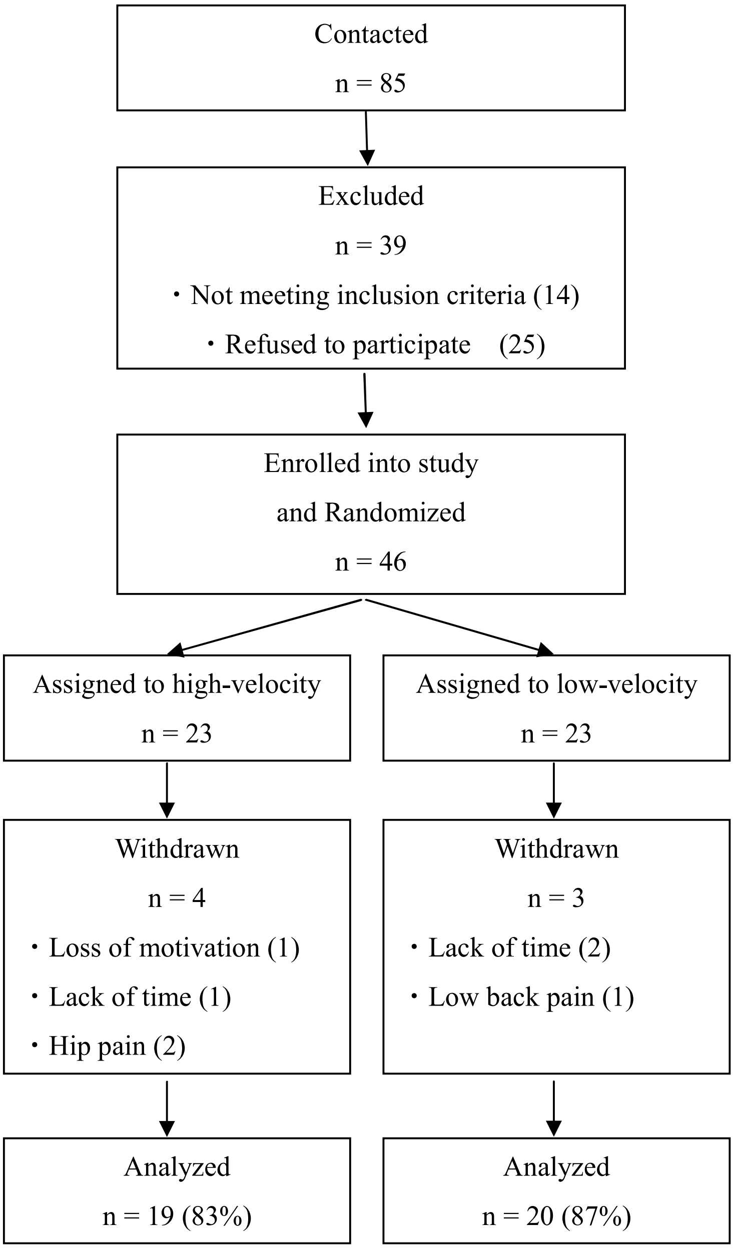

Figure 1. Flowchart of study participation.

主論文 1

Muscle Mass and Composition of the Hip, Thigh, and Abdominal Muscles in Women with and without Hip Osteoarthritis

Ultrasound in Medicine and Biology. 2012; 38(9):1540-5.

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主論文 2

Effects of High-velocity Resistance Training on Muscle Function, Muscle Properties, and Physical Performance in Individuals with Hip Osteoarthritis: A Randomized Controlled Trial

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