Evaluation of Muscle Activity just after Straight Leg Raising Exercise by using ^{18}FDG-PET

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Abstract

Background: Exercise therapy is one of the recognized treatment methods for knee osteoarthritis (KOA). One such exercise technique, straight leg raising (SLR), is widely known as a home exercise method for strengthening the quadriceps femoris muscle. However, whether this exercise truly strengthens the quadriceps is not known. The objective of the present study was to investigate which lower limb muscle is stimulated and shows increased activity with SLR.

Methods: A total of 14 lower limbs in seven healthy adult male volunteers (mean age: 31.3±2.2 years) were investigated. Participants were asked to perform SLR and subsequently underwent FDG-PET/CT examination for evaluation of the muscles of the entire lower limb. The maximum standardized uptake value (SUVmax) of each muscle (iliacus, psoas major, gluteus maximus, gluteus medius, gluteus minimus, vastus medialis, vastus intermedius, vastus lateralis, rectus femoris, biceps femoris, semimembranosus, semitendinosus, adductor, sartorius, gracilis, tibialis anterior, tibialis posterior, soleus, medial head of gastrocnemius, lateral head of gastrocnemius) was measured in four cross-sections: at the trunk, pelvis, thigh, and lower leg.

Results: SUVmax was significantly greater in: iliacus and adductor compared to vastus medialis, vastus lateralis, biceps, semitendinosus, gracilis, tibialis anterior, and gastrocnemius; psoas major compared to all muscles except for gluteus minimus and adductor; gluteus minimus compared to all muscles except for iliacus, psoas major, gluteus medius, and adductor; and gluteus medius compared to semitendinosus and gracilis.

Conclusions: After SLR, SUVmax was significantly greater in iliacus, psoas major, gluteus minimus, gluteus medius, and adductor compared to some of the other muscles. Performing SLR increased glucose metabolism of the above muscles in particular, and this may have increased their activity levels.

Introduction

Knee osteoarthritis (KOA) is one of the major disorders that causes locomotive syndrome and is known to impair the motor function and decrease the movement function. Yoshimura et al. reported that the prevalence of KOA (Grade 2 or higher on the Kellgren-Lawrence scale) in ≥40-year-olds was 42.6% in men and 62.4% in women

[1]. There are a variety of treatment methods. Exercise therapy is a method that can treat and prevent the onset of KOA in a non-invasive manner. This approach is excellent for improving pain and has also been described by the Osteoarthritis Research Society International (OARSI) guidelines [2] as beneficial. One of the primary types of exercise therapy includes strengthening the quadriceps femoris muscles. Straight leg raising (SLR) has been recommended by several reports as a home exercise method for strengthening the quadriceps femoris muscles [3,4], and it has also been introduced as a countermeasure especially for knee pain in locomotive syndrome (https://locomo-joa.jp/en/index.pdf).

To date, several methods have been used to evaluate the lower limb muscles during training, including glucose metabolism measurements, manual muscle testing or muscle strength tests using an apparatus, and muscle activity assessment using electromyography [5,6]; however, objective and simultaneous evaluation of exercise activities of multiple muscles is technically difficult using these methods. 2-[^{18}F]-fluoro-2-deoxy-D-glucose-Positron Emission Tomography (FDG-PET) scan is a type of nuclear medicine examination that uses FDG, a glucose analog labeled with a radioactive isotope of fluorine, and it has been used clinically in various settings, such as tumor diagnosis [7]. Because FDG-PET (PET) can examine cellular glucose metabolism, several authors have used this technique to determine muscle metabolism during exercise [8,9]. It has been reported that glucose metabolism determined through PET is correlated with the intensity of muscle activity, and that the muscle activity can be assessed by evaluating glucose metabolism in muscle [10]. Therefore, with PET, it is now feasible to simultaneously and objectively evaluate the activities of multiple lower limb muscles due to exercise, a process that had encountered difficulties with electromyography.

The present study focused on SLR, an exercise method that is typically performed to train the quadriceps femoris muscle in KOA, and investigated whether it indeed trains the quadriceps femoris muscle. It has been reported that the lever arm between the hip joint and the ankle is approximately twice the lever arm between the knee and the ankle [11], and we hypothesized that this exercise acts primarily on the muscles surrounding the hip joint. Therefore, PET were performed after SLR to determine which muscle in the lower limb had increased glucose metabolism and increased activity due to SLR.

Materials and Methods

Participants

Healthy adult male volunteers participated in this study. Recruitment criteria were: 1) could perform quadriceps femoris muscle training without problems; 2) no history of diabetes; 3) no history of cancer; and 4) no history of orthopedic disorder or injury of the lower limb. Eight healthy men participated in the study. One participant was excluded because data analysis could not be conducted due to distorted PET/CT (Computed Tomography) scan images. Fourteen lower limbs of seven men (mean age: 31.3±2.2 years) were ultimately analyzed in this study (Figure 1).

Methods

Similar to a previous report [8], the participants were asked to refrain from performing excessive exercise on the day before the examination and were instructed to abstain from eating six hours before the FDG injection. Participants were placed in a recumbent resting position for 20 minutes before FDG injection. Following FDG injection, they were asked to perform quadriceps femoris muscle training for 20 minutes. They rested again in a recumbent position for 30 minutes, and PET/CT scans were subsequently taken. PET scans were performed only after the exercise, similar to the method described by Lee et al. [9].

SLR was performed for training the quadriceps femoris muscle [3,4]. In a supine position, the lower limb on one side was raised 10 cm with the knee extended, held for 5 seconds, and lowered to rest for 5 seconds (with the knee on the other lower limb bent at 90°). The leg raise was repeated 20 times on one lower limb, followed by leg raises on the contralateral side. This was considered one set, and three sets were performed. A 1.5-kg weight was placed on each ankle.

PET/CT examinations were performed with a Siemens Biograph 16 (Siemens, Knoxville, TN, USA). FDG (5 MBq/kg) was injected intravenously. The standardized uptake value (SUV) was calculated from the FDG dose, participant’s body weight, and tissue FDG accumulation.

$$SUV = \frac{\text{Radioactive concentration in the ROI(MBq/g)}}{\text{Injected dose(MBq)/Patient's Body Weight(g)}}$$

SUV was evaluated in accordance with a previous report [8]. Specifically, PET/CT examination was used to measure the SUVmax of each muscle in cross-sections of the trunk (superior margin of the sacrum), pelvis (superior margin of the acetabulum), thigh (midpoint between the inferior margin of the femoral lesser trochanter and femoral condyle), and lower leg (proximal third) (Figure 2).

Each muscle was identified in each cross-section as seen in Figure 3, and the SUVmax was measured. The evaluated muscles were the iliacus (IL), psoas major (PS), gluteus maximus (GMax), gluteus medius (GMed), gluteus minimus (GMin), vastus medialis (VM), vastus intermedius (VI), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), semimembranosus (SM), semitendinosus (ST), adductor (Add), sartorius (Sar), gracilis (G), tibialis anterior (TA), tibialis posterior (TP), soleus (Sol), medial head of gastrocnemius (MG), and lateral head of gastrocnemius (LG).

Sample size

G*Power version 3.1 was used to determine sample size. The effect size was set at 0.8 with a significance level of 5% (α=0. 05) and power of 80% (1-β=0.8), yielding a total sample size of 12.

Statistical Analysis

SPSS (version 23; IBM Corporation, Armonk, USA) was used for statistical analysis. The *t*-test was used for comparisons between two groups, and one-way analysis of variance (ANOVA) with Tukey's HSD post hoc test was used for comparisons among multiple groups. $P<0.05$ was considered significant.

This study was approved by the Ethics Review Board of Gunma University Hospital. Participants were given written explanations of the study and provided their written, informed consent for participation in the study.

Results

Table 1 shows the SUVmax of each lower limb after SLR. Seven lower limbs on the nondominant foot side and seven lower limbs on the dominant foot side were assessed. There were no significant differences between the nondominant foot and dominant foot in any of the muscles. Figure 4, 5 shows a graph of the mean SUVmax of each muscle in each lower limb. SUVmax was significantly greater in: IL,PS, GMed, GMin, and Add compared to most of the other muscles(Figure 4); IL and Add compared to VM, VL, BF, ST, G, TA, MG, and LG; PS compared to muscles other than GMin and Add; GMin compared to muscles other than IL, PS, GMed, and Add; and GMed compared to ST and G. In the comparison of all evaluated lower limb muscles, there were no significant differences in SUVmax among each of the quadriceps femoris muscles (VM, VI, VL, and RF) (Figure 5).

Discussion

SLR is widely performed for training the quadriceps femoris muscle. However, the current study showed that performing SLR results in greater SUVmax values in IL, PS, GMed, GMin, and Add compared to other lower limb muscles, indicating increased muscle activity in these muscles. The primary actions of these muscles are: hip flexion for IL and PS; hip abduction for GMed and GMin; and hip adduction for Add. This signifies that SLR may primarily be training hip flexion, abduction, and adduction.

Wessel et al. proposed that SLR may have greater significance as a hip flexion exercise than as a quadriceps femoris muscle strengthening exercise based on a mechanical analysis that demonstrated that the lever arm between the hip joint and ankle is approximately twice the lever arm between the knee and ankle [11]. Similar to the evidence presented in their report, the present results also showed that the hip flexion muscles IL and PS had high SUVmax values. In particular, PS had the greatest mean SUVmax. Moreover, metabolism of the abductor and adductor muscles of the hip was also elevated, indicating that there may indeed be involvement of the lever arm.

Soderberg et al. [6] evaluated electromyographic activity in muscles during quadriceps femoris muscle setting and SLR. Specifically, they assessed the VM, RF, GMed, and BF, and they found that RF was significantly more active during SLR, and that VM, GMed, and BF were significantly more active during quadriceps femoris muscle setting than SLR. In the current study, no significant differences were observed between any of the quadriceps femoris muscles in the comparison of all lower limb muscles that were evaluated. It has been previously reported that the VM/VL ratio increases with knee extension exercise combined with hip adduction [12], and with tibial medial rotation [13]. Bose et al. reported that closed kinetic chain exercises with hip adduction strengthen the VM because the lower part of the VM originates chiefly from the tendon of the adductor magnus [14]. In the present study, SLR was performed without specifying an exact position of the lower limb. Based on previous reports, it is possible that the lower limbs were in a medially rotated position or that the exercise was performed with weak adduction.

Although it has been reported that SLR is effective in treating KOA [3,4], the present results suggest that SLR has a greater effect in strengthening the muscles surrounding the hip than the quadriceps femoris muscle. This poses the question: at which site does SLR have a beneficial effect in patients with KOA? It has been reported previously that varus deformity and thrust are mechanical factors that contribute to the onset and progression of KOA [15]. Yamada et al. reported that decreased hip adductor muscle strength is associated with varus deformity in medial compartmental osteoarthritis of the knee [16]. Bennell et al. found that strengthening the hip abductor and adductor muscles improved symptoms in KOA patient [17]. It is widely known that decreased hip abductor strength results in Trendelenburg's sign [18]. Patients with this condition have difficulties maintaining the pelvis horizontally in stance phase, and their pelvis drops on the unaffected side. Hip abductor is important in gait, and strengthening the abductor has been described to improve abnormal gait and to stabilize gait [19]. The results from the present study showed that SLR activates the muscles surrounding the hip. Activating these muscles may improve thrust or varus in patients with KOA and stabilize their gait, ultimately contributing to the treatment of KOA.

There are several limitations to this study. First, the SUVmax of each muscle was measured in four cross-sections. This means that each muscle was not evaluated comprehensively. In a previous report[8], evaluations were also conducted using similar cross-sections. While the evaluations were performed at the same cross-sectional levels as much as possible on each lower limb, there may have been differences in the results due to slight errors on the slice sections. Second, while there are reports claiming that glucose metabolism determined through PET is correlated to the intensity of muscle activity [10], there are no reports that longitudinally investigated whether elevated glucose metabolism observed on PET is associated with muscle strengthening. In the present study, glucose metabolism was greater in IL， PS， GMed， GMin， and Add compared to other muscles. Although there is a possibility that the activities of these muscles were also increased, it is not clear whether muscle strengthening had indeed occurred. Third, the subject of this study were adult male volunteers. KOA is more common among middle-aged and elderly women. Young people can unconsciously raise their legs at the knee extension position. However, the load for maintaining the knee extension position may be larger in middle-aged and elderly people who may have muscle weakness than in young people. Therefore, the results might have been different if the subjects had been patients with KOA. Fourth, in this study, SLR was performed in the supine position. Other muscles might have been stimulated if SLR had been performed in a different position. Arnold et al. showed that the moment arms of the iliopsoas with hip extension is larger than with hip slight flexion[20]. In some cases, it may be possible to stimulate the muscles other than the hip muscle.

Conclusion

Glucose metabolism was increased especially in IL, PS, GMed, GMin, and Add after SLR was performed by healthy adult male volunteers, signifying a potential increase in the activities of these muscles. It is therefore plausible that SLR increases the activity of muscles primarily involved in hip adduction, abduction, and flexion, thereby having a beneficial effect in the treatment of KOA.

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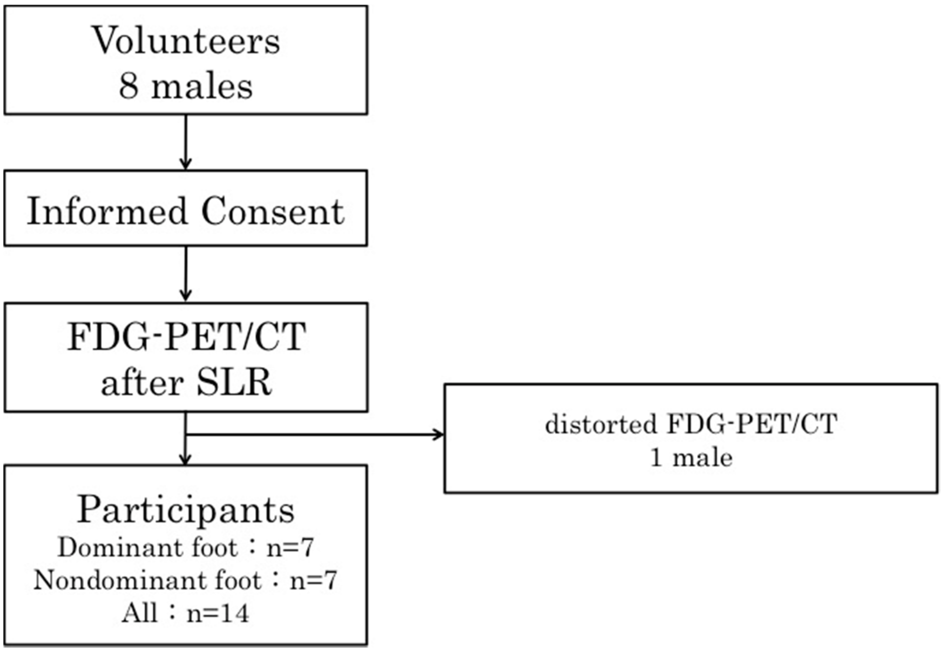
Figure

Figure 1.



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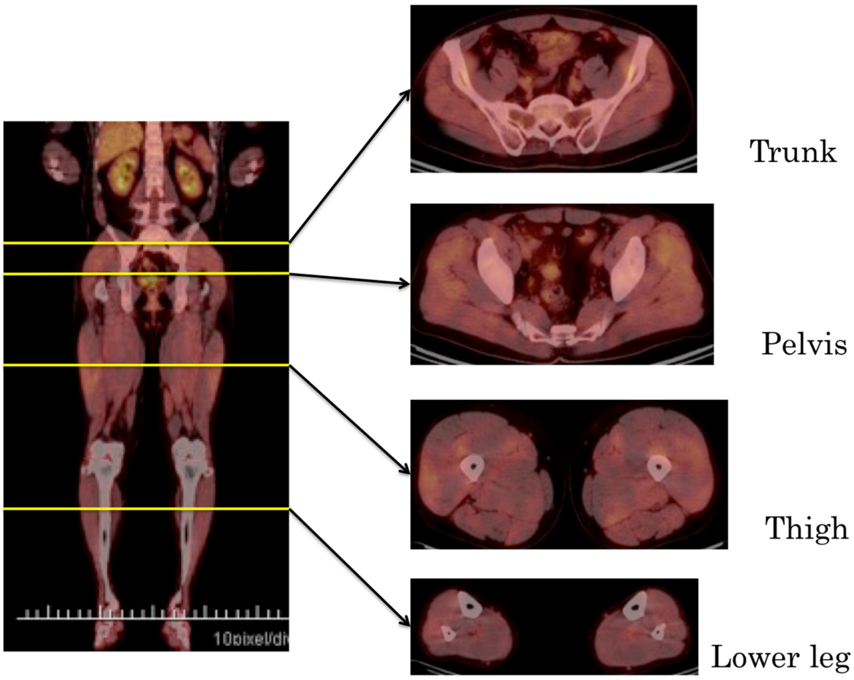


Figure 3.

Figure 3a.

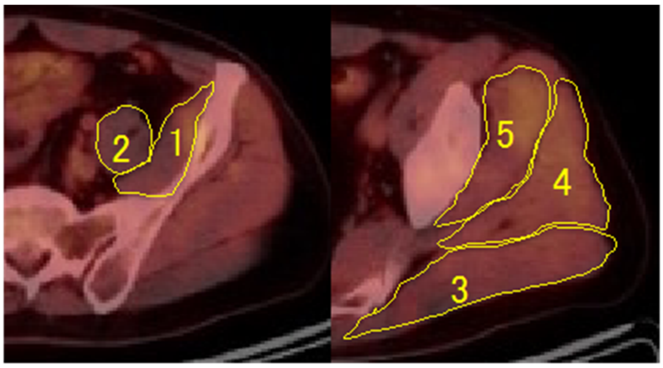


Figure 3b.

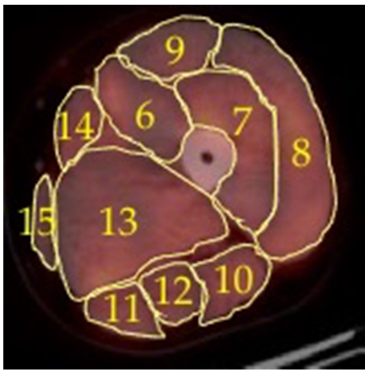


Figure 3c.

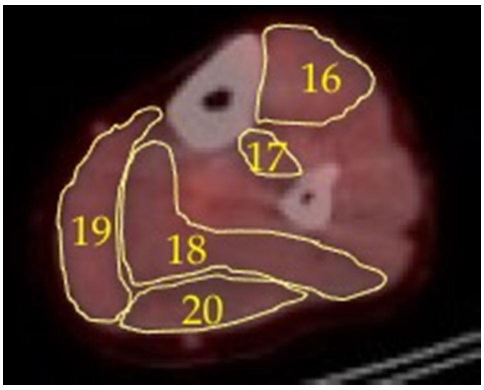
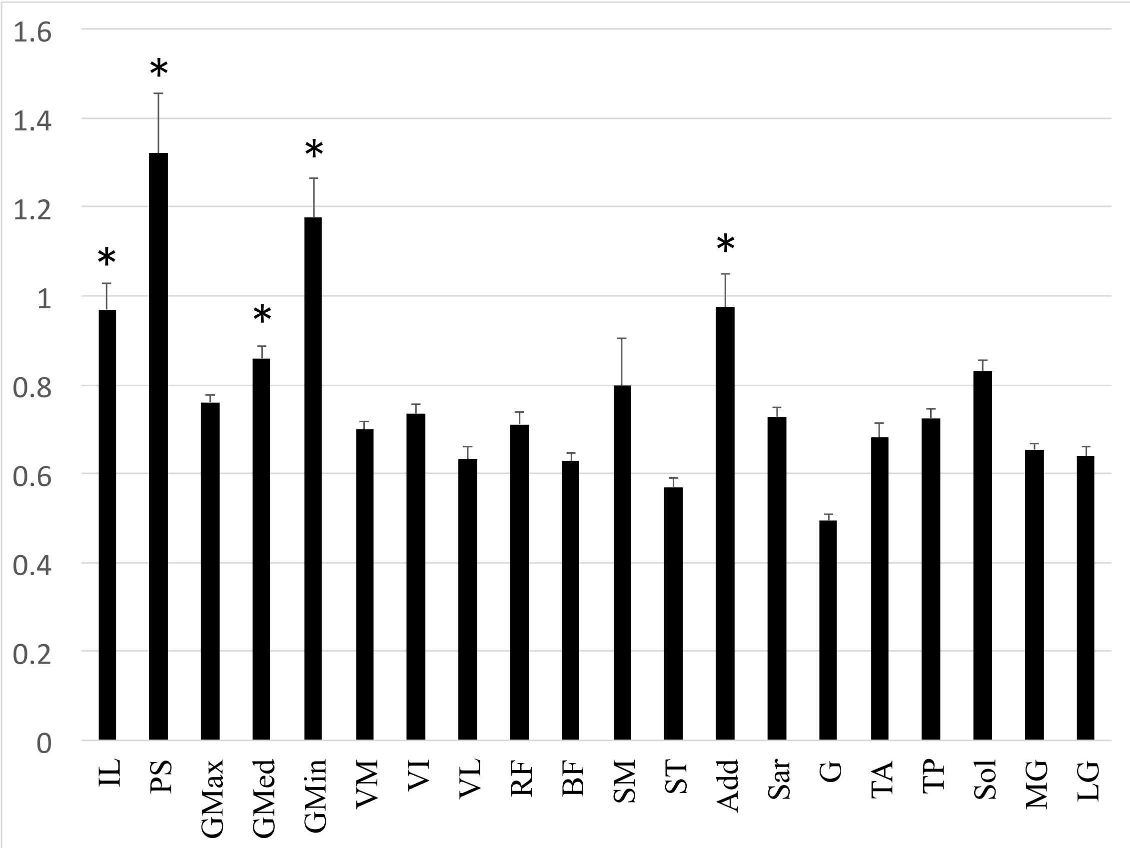


Figure 4.

Figure 4a.



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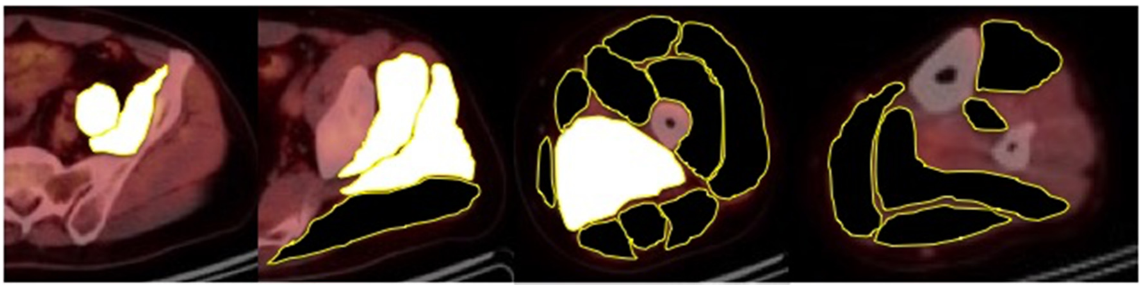

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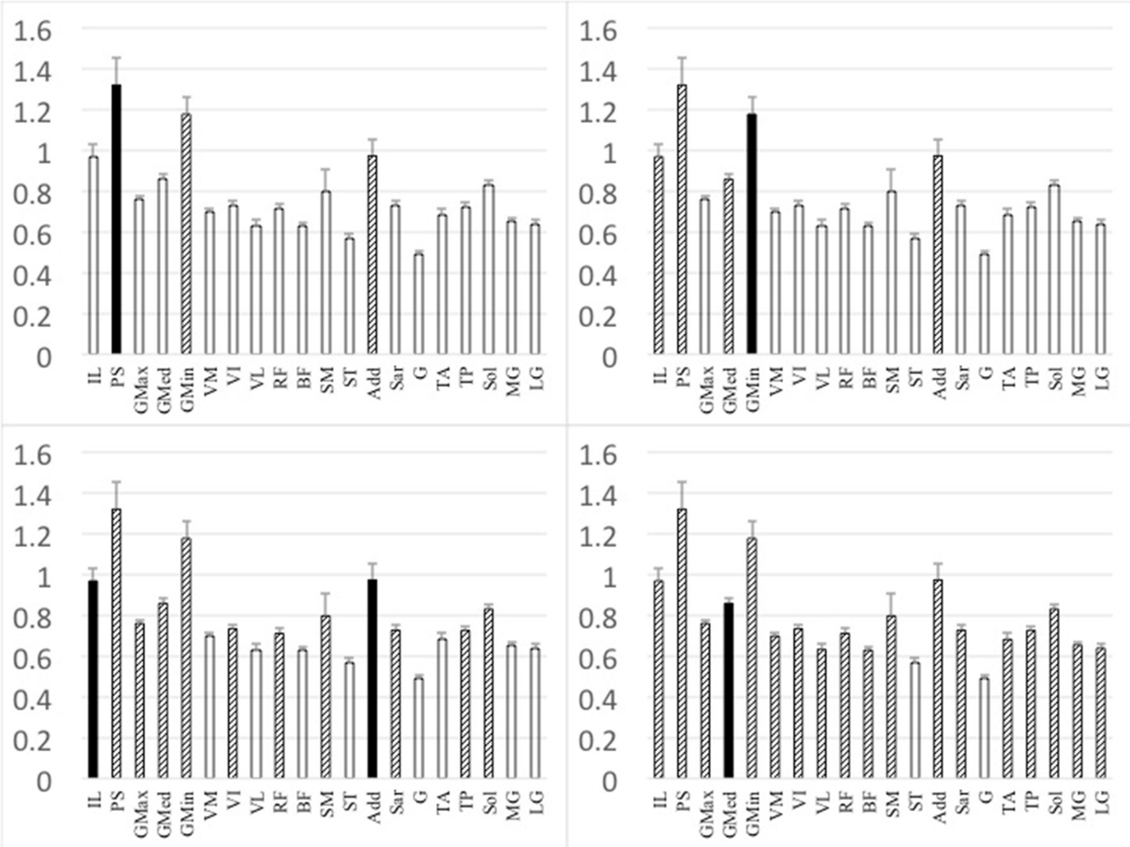
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IL PS GMax GMed GMin VM VI VL RF BF SM ST Add Sar G TA TP Sol MG LG

Figure caption

Figure 1. Eight healthy men participated in this study. One participant was excluded because data could not be analyzed due to distorted FDG-PET/CT scan images.

Figure 2. SUVmax of each muscle is measured in the cross-sections of the trunk (superior margin of the sacrum), pelvis (superior margin of the acetabulum), thigh (midpoint between the inferior margin of the femoral lesser trochanter and femoral condyle), and lower leg (proximal third).

Figure 3. the four cross-sections

Figure 3a. Trunk and Pelvis

1: iliacus, 2: psoas major, 3: gluteus maximus, 4: gluteus medius, 5: gluteus minimus

Figure 3b. Thigh

6: vastus medialis, 7: vastus intermedius, 8: vastus lateralis, 9: rectus femoris, 10: biceps femoris, 11: semimembranosus, 12: semitendinosus, 13: adductor, 14: sartorius, 15: gracilis

Figure 3c. Lower leg

16: tibialis anterior, 17: tibialis posterior, 18: soleus, 19: medial head of gastrocnemius, 20: lateral head of gastrocnemius

Figure 4. The mean SUVmax of each muscle in four cross-sections.

Figure 4a. SUVmax was significantly greater in IL,PS, GMed, GMin, and Add compared to most of the other muscles.

Figure 4b. The SUVmax of ○ was significantly greater.

Figure 5. The SUVmax of ● was significantly greater than that of ○.

Table 1. SUVmax(mean±standard deviation) of each lower limb

	all(n=14)	dominant foot (n=7)	nondominant foot (n=7)	dominant foot vs nondominant foot (*P* value)
iliacus	0.97±0.22	1.01±0.23	0.92±0.22	0.47
psoas major	1.32±0.50	1.37±0.52	1.27±0.52	0.71
gluteus maximus	0.76±0.06	0.76±0.06	0.76±0.07	0.88
gluteus medius	0.86±0.10	0.87±0.11	0.85±0.09	0.72
gluteus minimus	1.18±0.33	1.19±0.37	1.17±0.31	0.91
vastus medialis	0.70±0.07	0.69±0.04	0.71±0.09	0.62
vastus intermedius	0.73±0.09	0.74±0.09	0.73±0.09	0.87
vastus lateralis	0.63±0.11	0.65±0.12	0.62±0.09	0.60
rectus femoris	0.71±0.10	0.69±0.09	0.73±0.12	0.52
biceps	0.63±0.07	0.63±0.08	0.63±0.07	0.95
semimembranosus	0.80±0.40	0.83±0.53	0.77±0.27	0.80
semitendinosus	0.57±0.08	0.60±0.08	0.54±0.06	0.11
adductor	0.97±0.29	0.98±0.29	0.97±0.31	0.95
sartorius	0.73±0.08	0.72±0.09	0.74±0.08	0.68
gracilis	0.49±0.05	0.48±0.05	0.51±0.04	0.28
tibialis anterior	0.68±0.12	0.67±0.13	0.69±0.12	0.81
tibialis posterior	0.73±0.08	0.70±0.09	0.75±0.06	0.19
soleus	0.83±0.10	0.84±0.12	0.82±0.08	0.80
medial head of gastrocnemius	0.65±0.05	0.67±0.07	0.64±0.04	0.42
lateral head of gastrocnemius	0.64±0.08	0.64±0.08	0.64±0.08	0.89

SUVmax: mean±standard deviation