Bone and Muscle

RESEARCH ARTICLE

# Sequential Changes in Activity of Hip Abductors Seen on Muscle Functional Magnetic Resonance Imaging after Hip Abduction Exercises

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## Abstract

The hip abductor muscles play an important role in postural control. Structural differences in the hip abductor muscles translate to differences in functional activity. This study sought to measure changes in T2 values of the hip abductors after hip abduction exercise over time and to identify variations in activity between the different hip abductor muscle groups. Ten healthy young men (mean age 28.4 [24−32] years) performed 5 sets of 40 repetitions of a hip abduction exercise at 30% maximum voluntary contraction with the right leg. Magnetic resonance imaging was performed before exercise, at intervals during exercise, and at the end of exercise. Subsequently, T2 values were measured for the tensor fasciae latae, gluteus minimus, the anterior, middle, and posterior segments of the gluteus medius, and the upper fibers of the gluteus maximus. T2 values for the gluteus minimus, tensor fasciae latae, and the anterior and middle segments of the gluteus medius were significantly higher at after all exercise compared with before exercise. However, T2 values for the posterior segments of the gluteus medius after 3, 4, and 5 sets of exercise were significantly higher than before exercise. T2 values for the upper fibers of the gluteus maximus after 4 and 5 sets were significantly higher than before exercise. Thus, the variable changes in muscle activity observed in this study were attributable to differences in anatomic structure and reflected intramuscular variation in activity between the hip abductor muscles.

**Keywords:** Hip abductors; Transverse relaxation times; Muscle activity; Hip abduction; Magnetic resonance imaging

## Introduction

The hip abductor muscles play an important role in maintaining neutral pelvic alignment during gait and other activities of daily living. Deficits in hip abductor muscle morphology, strength, activation patterns, and functional control of the pelvis and femur have been demonstrated in patients with osteoarthritis of the hip [1,2]. Therefore, the hip abductors, which comprise the Gluteus Maximus (GM), Gluteus Medius (GMED), Gluteus Minimus (GMIN), and Tensor Fascia Latae (TFL), are important for the biomechanics of gait at the hip. The function of each muscle at this anatomic site has not been defined completely, although several studies have reported that the varying anatomic structure of the hip abductor muscle fibers translates to differences in function [2,4-9]. Electromyography (EMG) is one of the most reliable ways of evaluating skeletal muscle activity. The patterns of orientation and insertion of the anterior and posterior portions of these muscles appear to reflect their probable role in internal and external rotation, respectively, and are in line with the findings of EMG studies [3,4]. A recent EMG study demonstrated significant differences in activation of the three divisions of the GMED during weight-bearing exercise [10]. Based on anatomic and EMG studies, the primary function of the entire GMIN and the posterior aspect of the GMED is to stabilize the head of the femur in the acetabulum during the gait cycle [6].

Muscle functional MRI can quantify all muscle activity within the imaging range by exploiting the process by which exercise induces signal changes that result primarily from increases in the transverse relaxation time (T2) of water in the tissues. Exercise is known to produce changes in the amount and distribution of water within skeletal muscle, and at present, a shift in water distribution is the purported mechanism for changes in T2 [11]. These T2 changes correlate well with integrated EMG findings [12,13], increase with increasing intensity of exercise [13-15], and relate to torque evoked by

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**Received:** April 18, 2018; **Accepted:** April 21, 2018; **Published:** April 24, 2018

electrical stimulation [12]. Moreover, T2 and EMG show similar changes during exercise at different joint angles [16]. This technique can be used easily and noninvasively to assess the extent of muscle activation after a task is performed. Kumagai et al. [17] studied the activity of the GMIN and that of the deep and superficial layers of the GMED, and demonstrated using T2 values that the activity levels of these differing portions of abductor synergy were not homogeneous and were influenced by the degree of hip abduction for which these muscles were recruited. Many reports have focused on the hip abductor muscles, but no studies have sequentially evaluated the activity of the hip abductor muscles after hip abduction exercise using MRI T2 values. The aims of this study were to measure the T2 values for the hip abductor muscles after hip abduction exercise over time and to clarify the variations in activity between the hip abductor muscles.

## Materials and Methods

### Subjects

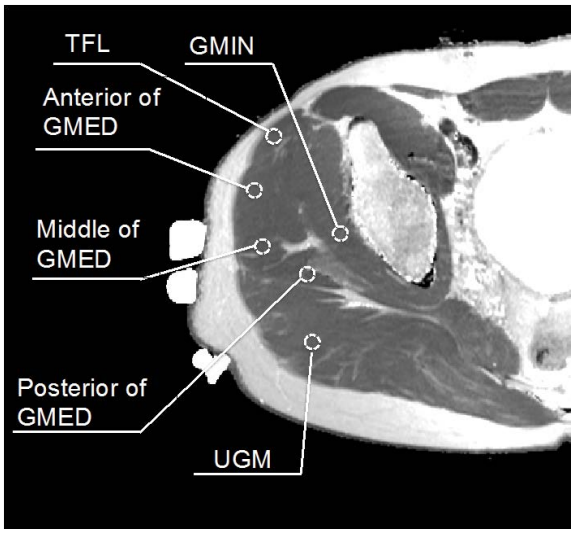
Ten young men of mean age 28.4 (range 24−32) years and mean (SD) height 1.71 (4.2) m and weight 62.0 (6.7) kg participated in the study. All subjects were in good health and had no orthopedic abnormalities. Written informed consent was obtained from all subjects after the aims of the study and its protocol had been explained to them in detail. The study protocol was reviewed and approved by the Ethics Committee of Tokyo Metropolitan University.

### Acquisition of magnetic resonance images

A 3.0-T MRI system (Achieva 3.0T; Philips, Tokyo, Japan) was used in all patients. T2 mapping was performed in addition to routine T2-weighted imaging. T2 measurement with single-slice acquisition was performed on the upper part of the acetabulum using a turbo spin echo sequence. The turbo spin echo scanning parameters were as follows: 6 echo times of 13-78 ms; repetition time, 4200 ms; field of view 350 × 350 mm; matrix size, 269 × 269; slice thickness, 5.0 mm; and number of slices, 7.

### T2 measurement

The images were processed with a DICOM viewer (OsiriX Lite, Pixmeo Sàrl, Geneva, Switzerland) to determine the relaxation times. A water capsule was placed along each segment of GMED to distinguish each type of fiber. T2 values were measured for TFL, GMIN, the anterior, middle, and posterior segments of GMED, and the upper fibers of the gluteus maximus (UGM). The region of interest was manually selected using a computer mouse, after which the mean of T2 values between the pixels of the region of interest was automatically calculated using the OsiriX Lite software (Figure 1). Care was taken to exclude subcutaneous and intramuscular fat, aponeuroses, and vessels from the selected regions. The mean T2 values were calculated from the MRI images obtained for 7 slices. The workload of each muscle was expressed as the T2 value in milliseconds. The rate of change in the T2 value was calculated as follows: (value after each set of exercise – pre-exercise value)/pre-exercise value × 100. Six regions of interest (one each in the TFL, GMIN, anterior, middle, and posterior GMED, and UGM) were used to measure changes in signal intensity.




GMED, gluteus medius; GMIN, gluteus minimus; TFL, tensor fascia latae; UGM, upper fibers of gluteus maximus.
**Figure 1:** T2 measurement of hip abductor muscles on T2 calculated map.

### Exercise protocol

The subjects performed 5 sets of 40 repetitions of a hip abduction exercise at 30% maximum voluntary contraction with the right leg in a lateral position. Isometric maximum voluntary contraction was measured in each subject, from which we calculated the 30% maximum voluntary contraction. The hip abduction angles were defined from 0° to 20°. The pelvis was fixed with belt so as to avoid compensatory movements as far as possible. In each subject, the hip was abducted 20° over 1 s and then returned to its initial position over 1s. No rest periods were allowed between repetitions of this movement. MRI scans were performed before exercise, at intervals during exercise, and at the end of the exercise. The exercise was performed inside the magnet bore of the MRI scanner, after which the subjects were immediately moved into the magnet for imaging.

### Statistical analysis

One-way analysis of variance was used to compare pre-exercise values with those after exercise. When significant differences were detected, post hoc comparisons were performed using Dunnett's test. AP-value < 0.05 was considered statistically significant.

## Results

(Table 1) shows the pre-exercise and post-exercise T2 values for the hip abductor muscles. The T2 values after all exercise for GMIN, TFL, and the anterior and middle segments of GMED were significantly higher than those recorded before exercise. However, the T2 values for the posterior segment of GMED after 3, 4, and 5 sets were significantly higher than the

| | Pre-Exercise | After 1set | After 2set | After 3set | After 4set | After 5set |
|---|---|---|---|---|---|---|
| TFL | 100 | 110.2(3.4)* | 112.7(5.4)* | 115.2(7.3)* | 116.8(5.7)* | 116.6(7.8)* |
| GMIN | 100 | 110.4(4.8)* | 112.0(4.6)* | 114.8(6.1)* | 114.5(3.5)* | 113.2(4.7)* |
| Anterior Of GMED | 100 | 112.0(4.3)* | 114.2(2.5)* | 117.6(4.1)* | 116.3(4.7)* | 117.1(5.0)* |
| Middle Of GMED | 100 | 115.5(5.1)* | 120.1(10.0)* | 125.2(8.5)* | 123.6(9.1)* | 124.0(7.6)* |
| Posterior Of GMED | 100 | 102.4(2.7) | 104.0(1.8) | 106.1(3.4)* | 105.6(4.3)* | 107.0(4.6)* |
| UGM | 100 | 100.5(3.2) | 101.4(2.8) | 103.1(3.4) | 104.5(3.9)* | 103.9(3.2)* |

Values are represented as mean (SD). P-value < 0.05 was considered statistically significant. *Significant difference versus pre-exercise. c, gluteus medius; GMIN, gluteus minimus; TFL, tensor fascia latae; UGM, upper fibers of gluteus maximus

**Table 1:** Pre-exercise and post-exercise T2 values in hip abductor muscles.

pre-exercise values. T2 values for UGM after 4 and 5 sets were significantly higher than those recorded before exercise.

## Discussion

The results of this study demonstrate that T2 values can be used to assess muscle activity. Use of MRI to quantify muscle function has been extensively investigated in the last 3 decades, but the exact mechanism responsible for the changes in T2 is not known [18]. In theory, many factors could contribute, including increases in intracellular and extracellular water content, accumulation of diamagnetic ions (e.g., lactate, phosphate, and sodium) and a decrease in pH [19,20]. Previous studies have shown strong correlations between the exercise-induced shift in T2 and integrated EMG [13,14], the force induced by electrical stimulation [12], and the intensity of exercise [13-15]. Moreover, relative agreement has been demonstrated between the exercise-induced shift in T2 and the EMG during plantar flexion exercise at different knee joint angles [16]. The muscle activation data evaluated using T2 values in the present study are consistent with those in the previous study. Furthermore, because T2 values increase with increasing intensity of exercise, the increase in T2 values associated with exercise was caused by factors described in the previous study. The hip abductor muscles include TFL, GMIN, GMED, and UGM, which have the primary roles of stabilizing the pelvis and controlling femoral movement during dynamic motion of the lower extremities. However, the hip abductor muscles differ in their sites of origin, sites of insertion, anatomic structure, and actions. The GMIN is located in the deepest layer and its muscle belly adheres directly to the superior joint capsule [21], which enables this muscle to augment and protect joint stability [21,22]. The TFL and UGM are located in the superficial layer [2] and their primary role is to abduct the hip joint, as well as flexion and internal rotation or extension and external rotation, respectively.

Cadaveric studies suggest that the GMED comprises three structurally unique regions (anterior, middle, and posterior) [7,23,24], the activity of which may be independent of central nervous system control [7,8]. This has led researchers to consider a broader role for the GMED in pelvic rotation, in addition to the role played by the anterior and posterior segments of the GMED in stabilizing the pelvis [7,23]. The results of this study show that hip abduction exercise immediately increases the workload of the TFL, GMIN, and the anterior and middle segments of the GMED, but causes a delay in the workload of the UGM and the posterior segment of the GMED. Our data show that the differences in changes in muscle activity reflect differences in anatomic structure and also indicate variation in recruitment of the different hip abductor muscles during hip abduction exercise. The results of this study show that the GMED, GMIN, and TFL make a substantial contribution to hip abduction. However, the type of hip abduction exercise used in this study may have caused delay in recruitment of UGM and the posterior segment of the GMED. Our data suggest that hip abduction exercise without hip rotation does not selectively recruit these muscles. Therefore, it is possible that hip abduction exercises combined with hip rotation or movement in multiple directions would activate these muscles. Further research is needed to examine the influence of hip abduction exercise on T2 values in the hip abductor muscles. There are several limitations to this study. Firstly, real-time muscle activity during exercise cannot be evaluated using T2 values. However, in this study, T2 values were measured immediately after exercise. Thus, interpretation of the change in T2 values is related to all the work performed by the muscle and not just to a single activity. An exercise-induced shift in T2 is detectable after as few as two contractions and increases to a work-rate-dependent plateau within a few minutes [19]. Recovery after exercise takes at least 20 min [15], which should have enabled us to measure exercise-induced shifts in T2 after exercise. Secondly, this study did not evaluate muscle activity using EMG. Even if there is no significant change in the intensity of the MRI signal, it is possible that the work of the muscle may be observed on EMG. Thirdly, as the exercise load increases, there is synergistic contraction of other hip joint muscles during hip abduction exercise, but T2 values of other hip joint muscles were not measured in this study. However, this study confirmed movement of free water inside and outside muscle cells when the level of activity increased in the hip abductor muscles. The results of our study suggest that the variation in changes in activity observed between the different hip abductor muscles was attributable to differences in their anatomic structure and was indicative of intramuscular variation of activity within the hip abductor muscles.

## Funding

There are no grants, fellowships, or donations to declare. No conflicts of interest, financial or otherwise, are declared by the authors.

## Acknowledgments

We thank the subjects for their participation and the other members of the study group. This study would not have been possible without them.

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**Citation:** Mitomo S, Usa H, Hata M, Ogawa D, Senoo A, et al. (2018) Sequential Changes in Activity of Hip Abductors Seen on Muscle Functional Magnetic Resonance Imaging after Hip Abduction Exercises. Bone Muscle 1: 001-004.