Different thigh muscle activation distribution after two specific eccentric exercises: evaluation by magnetic resonance imaging

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Purpose

Introduction

In 1988 Fleckenstein et al. (Fleckenstein et al 1988) used muscle functional magnetic resonance imaging (fmMRI) to show the acute effects of exercise on muscle T2 relaxation time. The transverse relaxation time (T2) is a quantitative index of muscle activation (Patten et al. 2003). Intensive exercise is known to produce changes in the amount and distribution of water in skeletal muscle. Following vigorous exercise the signal from those muscle groups that had been active was increased on T2-weighted images. This method can non-invasively monitor the physiological changes of the recruited muscle during exercise and depict the intensity and/or pattern of muscle activation.

MR imaging can be used to assess damaged muscles following intensive exercise (Leblanc et al. 1993; Clarkson and Hubal 2002). Many authors have reported that the T2 value increases following eccentric exercise (Jayaraman et al 2004; Larsen et al. 2007; Prior et al 2001; Segal and Song 2005; Sesto et al. 2005) and that T2 value is positively correlated with plasma creatine kinase (CK) activity, reflecting exercise-induced muscle damage (Larsen et al 2007; LeBlanc et al 1993; Schwane et al 2000). Moreover, earlier studies have investigated the intermuscle differences and intra-muscle regional differences of T2 value changes between proximal and distal regions (Akima et al 2004; Segal and Song 2005). Kubota et al (2007) has shown that the changes of T2 values following intensive knee-eccentric flexion exercise differed among hamstring muscles; these results suggested that the hamstring muscles that were activated similarly in knee-flexion tasks differed in their respective degrees of response following the exercise. Moreover, the semitendinosus muscle showed the region-specific differences of the MR measurements following the exercise, which affected the anatomical characteristics of the ST muscle.

Hamstring muscles include the biceps femoris (BF), semitendinosus (ST), and semimembranosus (SM). These muscles are recruited to produce knee flexion and hip extension torques.

Hamstring muscles have an important role in sports for sprinting or kicking and are the most prevalent muscle injuries reported in sport. (Arnason et al. 2008; Hagglund et al 2009; Brooks et al 2005; Woods et al. 2004). Hamstring muscles may be more likely to sustain strain injuries when subjected to lengthening contactions (eccentric contractions) (Thelen et al 2005).
Interventional studies aimed at reducing the incidence of hamstring injury have focused on the use of eccentric training with exercise such as the "leg curl" or "Nordic hamstring lowers" (Andersen et al 2006; Arnason et al 2008; Engebretsen et al 2008; Mesfar and Shirazi-Adl 2008). Clarifying the activation patterns of each hamstring muscle during eccentric knee flexion exercise would make it possible to increase the efficiency of strength training and thus improve sports performance or rehabilitation of sports injuries.

**Purpose**

The purpose of the present study was to use mfMRI to investigate the recruitment along the length of thigh muscles following two different eccentric exercises.
Methods and Materials

Subjects

Eleven adult men who played soccer on a professional basis were invited to participate in this study. Participants were excluded if they had an injury to their legs or back in the preceding 12 months or if they were unsuitable to enter the MRI scan room because of foreign metal bodies, electronic implants or claustrophobia. Before the start of the investigation, each participant’s height, weight, age, regular exercise programme (Table 1) and any previous injuries to the legs was recorded. The institutional Ethics Committee associated with our hospital approved the study and all participants gave an informed consent.

Procedures

Exercise Protocols

Two types of exercise were performed: **eccentric leg curl (Figure 1) on page**, or **lunge exercise (Figure 2) on page**.

For the forward lunge condition, subjects were instructed to step forward with their lower extremity to a predetermined distance while maintaining a vertical position of their trunk.

For the **eccentric leg curl**, subjects performed eccentric exercise of the hamstring muscles with one leg in a common hamstring curl machine which was adjusted to 120% of the 1 repetition maximum (1RM).

Subjects were instructed to lower the weight from a knee-flexed position (100°) to a knee-extended position (0°).

Group 1 (n= 6): performed leg curl with the right leg and lunge exercise with left leg.

Group 2 (n= 5): performed leg curl with the left leg and lunge exercise with the right leg.

Subjects were verbally encouraged to generate maximal force at the starting position and to resist maximally against the knee-extending action throughout the range of motion. The weight was raised after each eccentric repetition by an examiner; therefore, the overall exercise task was eccentric only for the subject.
Imaging Technique:

All MR images of the thigh were performed using a 1 T whole body imager (Magnetom Impact Expert; Siemens-Erlangen, Germany). For the MR imaging scans, subjects were positioned supine with their knee extended. Magnetic resonance imaging of the subjects' thighs was performed before and 48 hours after the exercise. Once the subject was positioned inside the magnet, the thighs of both legs were kept parallel to the MRI table and the feet were strapped together to prevent rotation. The length of the right femur (Lf), taken as the distance from the articular surface of the medial condile of the femur to the superior boundary of the femoral head, was measured on a coronal plane. Subsequently, 15 axial scans of the thigh interspaced by a distance of 1 / 15 Lf were obtained from the level of 1 / 15 Lf to 15 / 15 Lf (Figure 3) on page . Every image obtained was labelled as its location (i.e. slice 4 being closer to the coxofemoral joint and slice 12 closer to the knee). Great care was taken to reproduce the same individual Lf each time by using the appropriate anatomical landmarks as described earlier (Izquierdo et al). Then, T2-weightened transverse spin-echo MR axial images [repetition time (TR) = 2,100 ms, echo time (TE) = 22, 60, and 120 ms] were collected using a 256 x 256 image matrix, with a 350 mm field of view, 10-mm slice thickness using a body coil. The T2 relaxation mapping sequence provides the data that allow the objective assessment of signal abnormality (Patten et al 2003).

The MRI data were evaluated for T2 relaxation time (T2 value) of the hamstring muscles. In the evaluations, the three cephalic and three caudal images were excluded. The MR images were transferred to a personal computer in the Digital Imaging and Communications in Medicine (DICOM) format; image manipulation and analysis software (OSIRIX, University Hospital of Geneva, Switzerland) was used to measure the signal intensity of each hamstring muscle (BF, ST and SM), adductor magnus and gluteus major. Individual baseline SI readings, analysed with a standardized ROI, for each participant were established with the preliminary scan. The ROI was placed in the same position within the muscle for each measurement, avoiding blood vessels and bone, which may have affected the analysis of the intensity changes.

For each slice, a T2 map was generated from a pixel-by-pixel analysis from the multiecho images at the Siemens workstation. Images taken at different TEs were fitted to a monoexponential time curve to extract the T2 values based on the formula: $SI = M * e^{-TE/T2} + A$, where SI is the measured signal intensity, M is the steadystate magnetization, TE is the echo time, T2 is the T2 relaxation time, and A is the noise intensity; these T2 values were represented as a T2 map images.

The T2 values were measured in a region of interest (ROI, 10-30 mm²) within the muscles before and after exercise and a percentage difference was calculated. Each ROI was selected to avoid any visible blood vessels or fat. For any given T2 map slice image, the positioning of a region of interest (ROI) within the image results in a value in milliseconds
(ms), which represents the average T2 relaxation time of the tissue within this ROI (Figure 4) on page __. The same person (FIS) performed the MR imaging scan and the T2 calculation.

**Statistical tests**

A paired t-test was used to compare the mean T2s changes before and after exercise in each muscle assessed. Level of significance was accorded when P<0.05. All statistical analyses were conducted using a statistical analysis software program (SPSS ver. 14.0; SPSS). Descriptive data are expressed as mean +/- SD.
Results

A total of eighteen subjects were randomized to either the "leg curl" or "lunge" groups. All subjects completed the exercise protocol. Baseline demographic data did not differ between the two groups (Table 1) on page . No adverse events or side effects occurred after the exercises.

Prior to exercise, no differences were observed between subjects in the MRI T2 relaxation times.

When comparison was made between pre-exercise and postexercise MRI scans, significant increases in mean SI were identified in all muscles of both the "leg curl" or "lunge" groups.

Table 2 on page lists the change in SI in each of the muscles assessed, in both the A and B group, respectively. T2s values increased significantly in the middle and distal STm, ADm and proximal BFm after leg curl exercise; after lunge exercise, homogeneous proximal to distal STm and proximal BFm significantly T2s increases were measured (Figure 5). on page
Conclusion

Discussion and Conclusion

This study examined differences of changes in MR measurements, represented as T2 values, among hamstring muscles after two different eccentric exercises. Results showed that almost all the hamstring muscles exhibited a T2 increase two days following intensive eccentric exercise. Moreover, the hamstrings muscles showed regional heterogeneous changes in MR T2 among the proximal, middle and distal regions after the two exercises. These heterogeneous changes were located more caudally on SMTm, and proximal BFm after leg curl exercise; after lunge exercise, homogeneous proximal to distal SMT and proximal BFm significantly T2s increases were measured.

Askling and colleagues (2006) reported a series of elegant and interesting articles where different types of hamstring strains related to specific patterns of injury where studied. They reported that hamstring injuries related to sprint actions affected more commonly the proximal part of the biceps femoris, whereas overstretching injuries mainly involved the free proximal portion of the semimembranosus muscle. Askling et al (2006), proposed anatomical and architectural reasons (fascicle length) to explain these associations. In this study, muscle functional magnetic resonance imaging (fmMRI) has been used to examine the intensity and/or pattern of muscle activation in eccentric leg curl or lunge; two commonly used preventive exercises. The results suggest that the degrees of response following different prevention exercises derived in different patterns of muscle recruitment, and this degree of response differs between proximal and distal regions. These findings together with those of Askling et al. (2007, 2008), and Kubota et al. (2007, 2009) suggest that the prescribed intervention will depend on the injured muscle and its specific anatomic location.

It is generally considered that the hamstring muscles are similarly activated in knee-flexion exercises. However, results of this study showed that two different intensive eccentric exercises directed to hamstrings muscles, changed the MR measurements in a different way. This result suggested that the exercise elected makes responses different locations the hamstring muscles.

Our study has some limitations. One limitation of was that the number of volunteers who performed the exercises was small. Another limitation of our study was that the measurements were performed 72 hours post exercise. However, Kubota et al (Kubota et al 2007) reported that the relationship between the changes of the plasma CK activity and of the T2 value of the ST was not statistically significant only immediately following exercise: it became statistically significant from the second day following exercise). The
plasma CK activity indicates much skeletal muscle damage, and reflects a delayed increase following unaccustomed eccentric exercise. Therefore, it is conceivable that the T2 increase that occurred immediately following exercise reflects the increased blood flow, and that the increase that occurred after the second day following exercise reflects severe muscle damage.

**Summary**

These results suggest that the degrees of response following different exercises derived in different patterns of muscle recruitment, and the degree of response differs between proximal and distal regions. This study shows that mfMRI can be used to evaluate the activity of individual muscles in the thigh following specific eccentric exercises.
 References


Personal Information

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