Correlation study between 31P magnetic resonance spectroscopy and electromyogram on muscle fatigue

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Introduction

31-Phosphorus magnetic resonance spectroscopy (^{31}P-MRS) has been used as a noninvasive tool for monitoring high energy phosphate metabolism in muscle tissue [1]. Since repeated isometric or concentric muscle contractions result in fatigue, muscle exercise leads to a change in PCr/Pi signal ratio so that we can trace a muscle fatigue using this ratio. Besides, the use of the shift in the median frequency (MDF) of the surface electromygram(EMG) power spectrum is a well known method of assessing muscle fatigue [2]. The median frequency is defined as the frequency that divides the power density spectrum in two regions having the same amount of power. The equation: $\int_0^{f_{med}} s(f)df = \int_{f_{med}}^{\infty} s(f)df = \frac{1}{2}\int_0^{\infty} s(f)df$. The purpose of this study is to investigate the non-invasive measurements of the electrophysiological signal and energy phosphate metabolism measured by EMG and ^{31}P-MRS, respectively, to examine the relationship of muscle fatigue during isometric calf-muscle exercise in human.

Materials and methods

MR Protocol: Single voxel spectroscopy data was acquired from a clinical MR scanner (Achieva 3T X-series, Philips, Netherlands) system equipped with a surface receiver coil. The phosphate spectra were obtained from the calf-muscle using ISIS PRESS sequence with TR/TE=4500/95.6ms, NEX=32, spectral width=3000Hz, the number of data points=2048, voxel size=40×40×40 mm^3, scan time=2min 33sec, adjustment time=30sec. In vivo ^{31}P-MRS (PCr/Pi) was analyzed by jMRUI4.0 software with AMARES fitting method.

Experiment protocol: Four healthy, male volunteers participated in this study. The mean age of the volunteers was 26±1.4 years. Before the experiment, maximum voluntary contraction (MVC) was measured for ankle plantar flexion exercise using force plate (Vernier, USA). MR compatible exercise equipment was developed in order to observe the fatigue of calf-muscle in MR magnet. The subjects performed the static ankle plantar flexion exercise at 45 degree with 30% MVC according to the exercise protocol as shown in Figure 1 and the exercise loading was controlled by rubber ropes.

Electromyogram: The differential-mode voltage gain was 1,000 because the amplitude of EMG signal spans 0~10 mV. The sampling frequency of the 12-bit A/D converter was 1 kHz. Data were filtered within the 10~500 Hz frequency range to be effective in the core signals [3]. And the spectrum of EMG signal was analyzed using Gaussian filter in order to remove the harmonics of 60 Hz. The disposable MR compatible surface electrodes were attached to the skin of the calf-muscle close to 2cm apart each other. The acquired data were analyzed using the lab-developed software based on MATLAB (Mathworks, MA, USA).

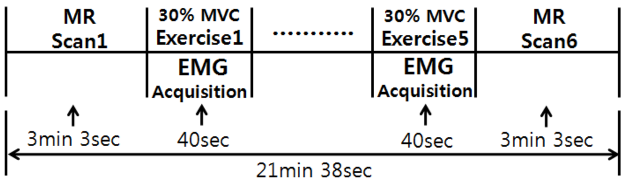

Figure 1. Exercise protocol: MR scan and EMG acquisition timing

Results

The average values of PCr/Pi ratio were calculated for each exercise and the regression analysis was performed as shown in Figure 2. The regression line has negative slope and the correlation was r^2=0.68. The MDF of the EMG signal was also shifted to the lower frequency range according to increasing the quantity of exercise or continuous contraction of muscle. Average MDF values of subjects were calculated to conduct the regression analysis as same as PCr/Pi analysis, and the slope of the regression line was computed for each scan. Slope of MDF at the scan 2 section had a lower slope than section of exercise 1, this brought decline of PCr/Pi ratio at the scan3 than scan2 as shown in Figure 2. Contrariwise, slope of MDF at the exercise 3 section has a higher slope than section of exercise 2, this brought an increment of PCr/Pi ratio at the scan 4 than scan 3. In order to analyze the correlation between both methods, interpolation and extrapolation of qubic spline were performed. Also min-max normalization method was performed for comparison of different scale data. The Pearson correlation coefficient were conducted to investigate the correlation of both methods from a statistical point of view. The correlation coefficient(r) was 0.866 and they had statistically significant (P<0.001) as shown in Figure 3.

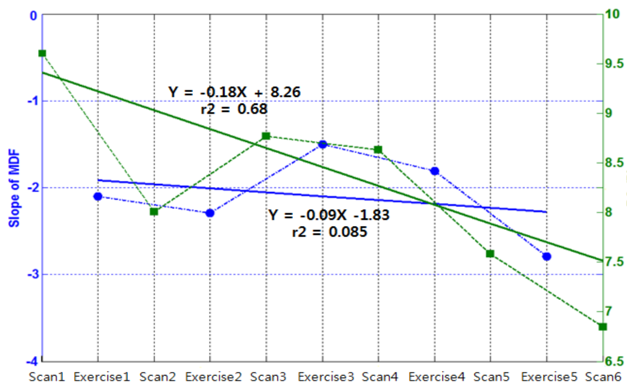

Figure 2. The regression analysis of PCr/Pi ratio and slope of MDF

Discussions and Conclusions

This study shows the change of the PCr/Pi ratio of ^{31}P MR spectroscopy and MDF time curve for the muscle fatigue during subject's exercise are significantly correlated with each other. Previous studies had been separately conducted to observe the muscle fatigue using the MDF of EMG and the high-energy metabolism change of ^{31}P-MRS. In this study, we confirmed that there is a strong correlation between MDF and PCr/Pi ratio. If it is possible to estimate muscle fatigue using the MDF and PCr/Pi, it will be widely used in the field of rehabilitation and healthcare.

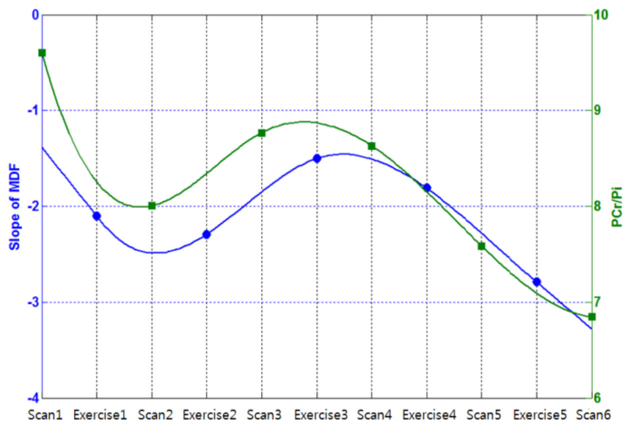

Figure 3. The correlation analysis of PCr/Pi ratio and Slope of MDF

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Reference

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