Function of the Shoulder Muscles During Arm Elevation: An Assessment Using Positron Emission Tomography

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Introduction:
Electromyography has been the standard method to assess the in vivo function of the muscles. However, its application to muscles located deep in the body such as the subscapularis is limited because of technical difficulties.

Positron emission tomography (PET) is a nuclear medicine tool for noninvasive quantification of regional blood flow and tissue glucose metabolism in vivo. [18F]-2-fluoro-deoxyglucose (FDG), as a glucose analog, is absorbed by tissues after intravenous injection, which is converted into FDG-6-phosphate by hexokinase. Radioactive 18F is subjected to beta-decay, resulting in annihilation photon emissions, which are detected by PET scanner.

In the PET, the FDG accumulation in the muscle is used as a parameter of glucose uptake by the muscle, and accordingly, the muscle activity level. It is well known that active muscle cells exhibit increased glucose uptake. Therefore, FDG PET has been used for the assessment of skeletal muscle activities [1, 2, 3]. However, the application of FDG PET to the shoulder muscles was only sparse.

Based on these backgrounds, we attempted to investigate the activities of the shoulder muscles with special interest on the rotator cuff muscles during arm elevation using FDG PET.

Methods:
The experimental protocol of the present study was approved by the institutional ethics committee, and a signed consent form was obtained from each subject prior to the FDG PET examination.

Subjects: Six healthy volunteers without any histories of shoulder pain or trauma were examined using FDG PET in the present study. There were 4 males and 2 females and their average age was 42 (range: 28-65). Magnetic resonance imaging (MRI) was performed in all subjects to confirm that there were no pathologic conditions around the shoulder including rotator cuff tears. All the subjects refrained from eating and drinking for at least 3 hours before the examination, as well as from performing any kind of strenuous physical activity for at least 1 week prior to the experiment.

Experimental protocol: The FDG was injected intravenously via the cubital vein after 200 repetitions of arm elevation exercise (10 minutes) in the scapular plane with 0.25-kg weights (Steel Band; Tiger Medical Instruments, Osaka, Japan) fixed to the wrists. The mean dose and standard deviation of injected FDG was 86.0 ± 7.1 MBq for the exercise condition. After FDG injection, the subjects were asked to repeat the same exercise. The exercise was performed from 0 to 90 degrees of elevation in the scapular plane at a constant speed of 90 degrees/sec. In this study, we defined the scapular plane as a plane which inclines 30 degrees anteriorly from the coronal plane. For control data, PET scan was repeated for each subject on a separate day without any exercise. The mean dose of injected FDG for the control condition was 81.8 ± 22.7 MBq, giving no statistically significant difference of radiological doses in the two conditions.

PET Examination: A set of emission scan in three-dimensional data acquisition mode was performed 50 minutes after injection of FDG from the base of the neck to the middle of the upper arm, using a PET scanner (SET-2400W; Shimadzu Inc., Kyoto, Japan).

Image Analysis: To quantify the muscle activities, the volume of interests was established for each shoulder muscle using MR images. The subscapularis was divided into three portions (superior, middle and inferior). The standardized uptake value (SUV), which is considered as indication of muscle activities, was calculated in each muscle to quantify its activity. Statistical analysis was performed using the ANOVA and Tukey test.

Results:
There were no abnormal artifactual accumulations in the PET images at rest (Figure 1A). High FDG uptakes were observed in all the shoulder girdle muscles after exercise (Figure 1B). Interestingly, one of the areas with the highest uptake was located in the superior one third of the subscapularis (Figure 2).

The SUV increased significantly after exercise in the deltoid, supraspinatus and subscapularis muscles compared to those at rest (Figure 3A). In comparison among the 3 divided portions of the subscapularis, the SUV of the superior one third was significantly greater than the rest of the muscle after exercise (Figure 3B).

Discussion:
As expected, the activities of the deltoid and supraspinatus increased after the arm elevation exercises. However, the activities of the subscapularis also increased significantly. The subscapularis is believed to be an internal rotator and adductor. Kuechle et al. showed that the subscapularis had a function as an elevator [4]. In most of the previous reports, however, the subscapularis muscle was considered as one muscle unit from the functional point of view. In the current study, we clearly demonstrated that there were two functionally different portions in the subscapularis muscle and the superior one third played an important role during arm elevation in the scapular plane.