

Dynamic changes in sodium levels in human exercising muscle measured with ^{23}Na MRI

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Introduction

For the first time we have measured the sodium content of exercising human muscle with fast ^{23}Na MRI. Studies of skeletal muscle potassium release during and after exercise¹ indicate that cation concentrations change in exercising muscle. These changes are almost certainly related to the Na^+/K^+ -ATP-ase pump function. Changes in intracellular potassium that may be measured indirectly in plasma by sampling, or with ^{201}Tl are likely to be mirrored in sodium moving in the opposite direction. With ^{23}Na MRI we observed large changes in the sodium signal, specifically in the exercised muscles, during and just after exercise.

Methods

^{23}Na images of the exercising forearm were recorded on a 1.5 T G.E Signa at 16Mhz. Healthy volunteers age 25-45 were studied, some on repeated occasions. The arm was immobilized over the coil. After recording scout images with ^1H -MRI two control ^{23}Na images were recorded. Exercise started 30 seconds prior to the begin of the exercise image. Exercise consisted of isometric hand grip, using all but the index finger, at 20-25% of a maximum short grip force (MVC) for 4.5 or 9 min. Then a series of six images was recorded during 40 minutes of recovery. A large 30x30 cm surface coil was used to determine the location of the sodium signal increase (see figures 1 and 2), or a 6 cm diam. surface receive coil placed under the flexor digitalis muscles was used for better S/N ratios. The TE/TR was 31/5.3 ms. Pixel size was 0.5x0.5x2.0 cm in a 64x64 grid. Four slices were recorded with 2 or 4 averages. Total scan time was 8.5 min. with the large coil or 4 min. with the 6 cm coil. Signal intensities were averaged over the whole arm and over a selected region with active flexor digitalis muscles identified by ^1H -MRI.

Results

Images of the forearm recorded with the large coil are shown in figure 1. A maximum sodium signal increase of about 25% is consistently observed in the first recovery image after exercise (see figures 1 - 3).

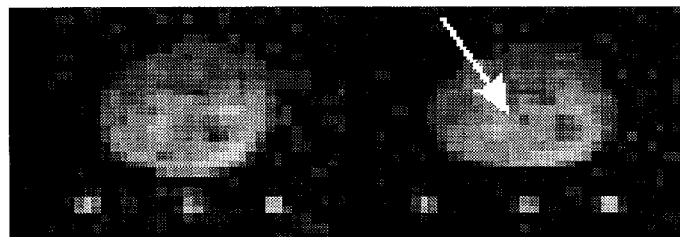


Figure 1 ^{23}Na images of the forearm before (left) and after exercise (+ 14 min. after start) The dots below the arm are three phantoms with sodium solutions.

Comparing signal intensities averaged over the whole arm or the region with exercising muscle clearly shows that the sodium signal intensity changes are localized to the exercising muscle groups (see figure 2). The maximum increase in signal appears after exercise and recovery appears to be slow. After about 20 min. the signal is still more than 20% over control values.

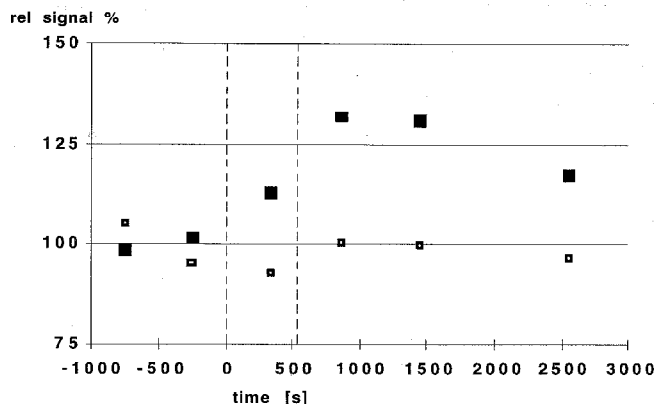


Figure 2 Signal intensities of images as shown in figure 1 as a function of time (normalized to pre exercise values = 100%). Values are mean pixel intensity in the region of exercising muscles (closed squares) and the whole arm (open squares) Exercise period indicated by the two vertical lines.

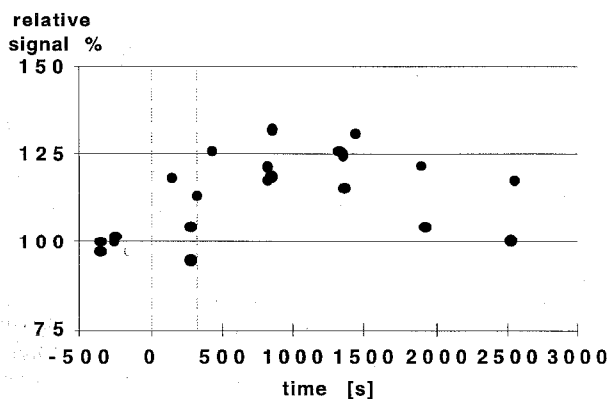


Figure 3 Localized ^{23}Na signals as a function of time in four studies. Signal is averaged over the image area of the exercising muscles and normalized to control image intensities (=100%).

Discussion

In the past measurement of cations in exercising muscle has been indirect through measurements of plasma potassium levels, or very invasive with micro electrodes. ^{23}Na MRI of exercising muscle is a unique non-invasive tool for studying cation homeostasis in the exercising muscle. The observed total sodium signal changes may be caused by a combination of exercise induced hyperaemia and a net influx of sodium into the muscle cells. It is unlikely that the large increase observed is exclusively caused by the hyperaemic effect. The intracellular cation changes may be related to muscle fatigue and thus sodium imaging of exercising muscle may be a good tool to study mechanisms of muscle fatigue in healthy subjects and disease.

References

[1] Byström, S. and Sjøgaard, G. *Acta Physiol. Scand.* 142, 59-66, (1991).

Acknowledgments

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