Advanced Exercise Ergometer Setup for In Vivo MRS Studies of Skeletal Muscle Metabolism

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Introduction

Magnetic resonance spectroscopy (MRS) has become a popular means to assess dynamic metabolic changes in skeletal muscle during exercise. In order to study metabolism during muscle contractions in an MR scanner, ergometers have to be designed that are compatible with the unique field and material constraints which are imposed by the scanner. Several measurement setups have been constructed for the measurement of force/torque during isometric contractions [Ref. 1-3]. However, they were either limited in their ability to quantify forces, fixation of the patient on the scanner bed was insufficient or visual feedback on maximum voluntary contraction (MVC) was not available. *We have solved these issues and present here* a MRS dynamometer for the measurement of muscular force during isometric contractions of the plantarflexor muscles against the pedal. Key features of the setup are a pedal with an integrated strain gauge, adjustment of ankle joint angle over the physiological range, leveling of dynamometer height, and real-time visual feedback for subjects on MVC during contractions. To account for the specific design and material constraints imposed by the magnetic field, non-magnetic materials were used and force values were transmitted optically. Using this setup, we have been able to determine contractile cost (decline in phosphocreatine [PCr] during the first 15s of exercise), glycolytic flux (glycolytic H^+ production during exercise), oxidative capacity (recovery of the PCr after exercise), and pH during isometric contractions at targeted maximum voluntary force levels.

Materials and Methods

The ergometer was designed to fit into a standard 3T Philips whole-body MR scanner (Philips Healthcare, Best, the Netherlands). A support was built on which the pedal is held in a central position to enable measurements in the iso-center of the scanner, while still leaving enough space for comfortable positioning of the second leg. The angulation of the ankle can be adjusted from 70-120 degrees in steps of 5 degrees. The dynamometer is freely adjustable in height to account fo the foot size. Fabric straps are used to fasten the foot onto the footplate and to tighten the leg to the table. A custom built, MR-safe strain gauge (ETH Zurich, Sensory-Motor Systems Lab, Zurich, Switzerland) is positioned behind the footplate and measures the force produced by the plantarflexor muscles [Figure 1]. It contains an optical link to transmit the signal to a fMRI software (Presentation, Neurobehavioral Systems, USA), which converts the absolute force values to relative MVC levels. The relative MVC is displayed onto a screen that can be seen by the subjects through a mirror which is mounted on a head and shoulder holder.

In-vivo muscle ^{31}P spectroscopic measurements were acquired using a transmit/receive surface coil placed under the posterior compartment of the subject's lower leg [Figure 2]. MVC was measured, before a non-localized excitation was performed using an adiabatic excitation in a pulse-acquire scheme (TR = 1.5s). Twenty spectra were acquired in resting state before the subject was told to rapidly reach 85% MVC and hold it for 30s. Subsequently, recovery of the PCr peak was monitored for 4.5 minutes.

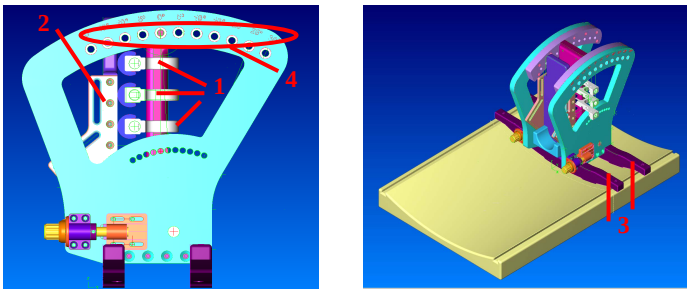

Figure 1 Foot pedal consisting of a custom-built, vertically adjustable foot dynamometer [1], a foot holder [2] and a support for fixation on the scanner bed [3]. Holes are present to adjust the angle of the ankle [4].

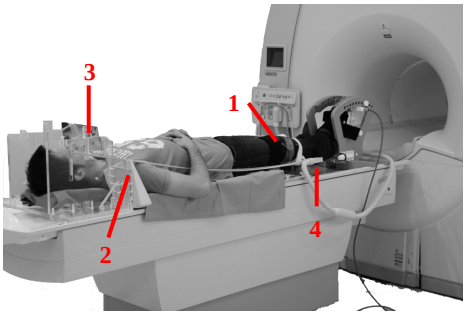

Figure 2 Setup at the scanner: The volunteer's leg is held in place with a leg fabric strap [1]. A shoulder support [2] ensures that there will be no movement during the measurement. The volunteer gets visual feedback for the applied pressure via a mirror [3], which is mounted on the head holder. The coil is placed beneath the lower leg of the volunteer [4].

Results

As shown in Figure 3, data of muscle metabolism can be acquired. Through the visual feedback on MVC, it is guaranteed that all subjects will apply the same percentage of their MVC for a given measurement. Importantly, this enables a standardization of the exercise protocol. Reliable force signal transmission is ensured through the use of an optical link. The setup allows for a comfortable positioning of subjects and guarantees identical joint angles during the measurement.

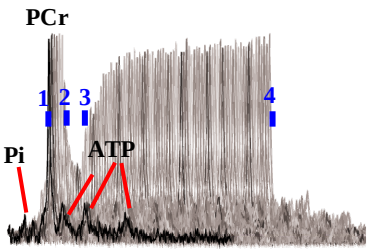

Figure 3 Phosphorus spectrum acquired with the above setup. The volunteer had to press at 85% of his maximal voluntary contraction for 30s [2-3] after the acquisition of 20 baseline scans [1-2]. Phosphocreatine [PCr] recovery [3-4] was subsequently measured.

Discussion

We have described a MR-compatible exercise ergometer setup suited for a wide variety of exercise protocols. The exerted force as well as dynamic changes of metabolic parameters can be accurately determined for both lower legs. This design permits new possibilities for the assessment of physiological and pathological metabolic changes in skeletal muscle in-vivo.

References

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3) Rayner et al, Med Eng Phys 2006;28 :489-94