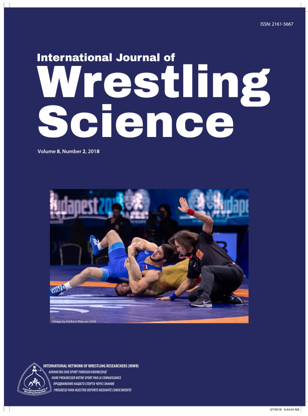

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DORSIFLEXOR MUSCLE OXYGENATION DURING ISOMETRIC CONTRACTION

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Abstract: Sustained isometric contractions of skeletal muscles produce intramuscular pressures that leads to blood flow restriction. In result an active muscle sustains deficit of oxygen and muscle fatigue. On another side during exercise we have physiological contradiction between raising of oxygen demand by working muscle and restriction of blood flow due to vessel pressing. To clarify this issue much research has been performed based mainly on measurement of blood flow in muscle tissue. The purpose of this study was to assess real-time changes in muscle oxygenation during a sustained isometric contractions of the dorsiflexor muscle with low (30%), moderate (60%) and submaximal (90%) intensity. Experiments were conducted using the subject's dominant leg. Volunteers was recruited from eight male students of USIPC (age: 19±2 years, weight: 75±6 kg). Tissue oxygenation index (StO_2) were recorded from the tibialis anterior using Near-infrared spectroscopy (NIRS) device (Nonin Medical Inc, Plymouth, Minnesota, USA). Saturation was higher at 30% compared with both 60% and 90% MVC at all time points after the start of exercise and higher at 60% than 90%. Oxygen consumption (VO_2) permanently increased from slow (30%) to moderate (60%) and submaximal contractions. After cessation of the each contraction there was a large and immediate hyperemic response. Rate of StO_2 increase after effort cessation reflects the resaturation of hemoglobin which depend on integrity and functionality of the vascular system and reflects blood vessel vasodilation. StO_2 resaturation rate permanently increased from slow (30%) to moderate (60%) and submaximal contractions. At last in final stage of the experiment arterial occlusion test was performed to determine the minimal oxygen saturation value in the dorsiflexors. Oxygen saturation reached 24±1.77% and was significantly higher then StO_2 after 60 and 90% MVC.

It can be concluded that oxygen saturations at 60% and 90% MVC are similar and sharply decreased after the start of exercise. It means that after a 60% MVC takes place, there is an occlusion of blood vessels due to intramuscular pressure. Oxygen consumption of active muscle increased depending on the intensity of exertion according to increasing of oxygen demand. StO_2 resaturation rate (RE) permanently increased from slow (30%) to moderate (60%) and to submaximal contractions. The RE increase after exercise cessation reflects the resaturation of hemoglobin, which depends on the integrity and functionality of the vascular system and reflects blood vessel vasodilation.
Key words: Oxygenation, skeletal muscle, isometric exercise, tissue oximeter

INTRODUCTION

Sustained isometric contractions (SIC) of skeletal muscles produce intramuscular pressures (IMP) that leads to muscle blood flow (MBF) restriction and limit its delivery to tissue (Degens, Salmons & Jarvis,1998). MBF plays a key role to regulate intensity and the type of muscle contractions (Saltin, Radegran, Koskolou & Roach, 1998), but SIC has a considerable impact on MBF, and as a result an active muscle experiences a deficit in oxygen and nutrients which leads to muscle fatigue. On the other hand, during exercise we have a physiological contradiction between the rising oxygen demand by working muscle and blood vessel pressure due to IMP during sustained isometric muscle contraction. To clarify this issue, much research has been performed based mainly on measurement of blood flow in muscle tissue (McNeil et al, 2015; Sjogaard, Savard & Juel, 1988; Vollestad, Wesche & Sejersted, 1990; Wesche, 1986). But in a dynamic regime during exercise there are limited measurements of MBF by using Doppler ultrasound. But it is important to note, that direct measurements of hemodynamic response of working muscle possible by using fMRI and PET but it is not accessible especially in field training setting (Hughson, Shoemaker, Tschakovsky, Kowalchuk, 1996).

Different methods indicate that complete occlusion of MBF during sustained muscle contractions take place at 50-60% of maximal voluntary contractions (MVC), but in some research the (McNeil et al, 2015; Sjogaard, Savard & Juel, 1988; Wesche, 1986) blood flow was not occluded at the level of the conduit artery during any of the contraction intensities. In some of published papers there was mention about insensitivity of blood flow to the muscle contraction intensity. So, at present our understanding about hemodynamic response of skeletal muscle to a wide range of muscle contraction (from low, moderate up to submaximal MVC) still remains limited.

Despite to advantages of above mentioned methods (fMRI, PET and Doppler ultrasound) only one paper in part has been devoted to measure hemodynamic response of contractile muscles to SIC tissue (McNeil et al, 2015) by using NIRS (near infrared spectroscopy) technology. Near-infrared spectroscopy (NIRS) is a well established optical technique that monitors changes in the concentration of the chromophores oxyhemoglobin

(O_2Hb), deoxyhemoglobin (HHb), total hemoglobin and tissue oxygenation index (StO_2) in a variety of tissues (Wolf, Ferrari, & Quaresima, 2007; Hamaoka, McCully, Quaresima, Yamamoto & Chance, 2007) NIRS utilizes the relative transparency of tissue to photons in the near-infrared (NIR) spectrum (700-900nm), and the oxygen-dependent absorption changes of these photons by hemoglobin (Hb) and myoglobin (Mb). NIRS instruments allows one to use the Lambert-Beer law and software algorithms to derive chromophore concentrations from raw optical data, and distinguish between oxy- and deoxy-hemoglobin/myoglobin. The majority of commercially available NIRS instruments are continuous wave (CW) spectrophotometers, and have proven reliability in the measurement of changes in O_2Hb and HHb. CW NIRS instruments have small size, particularly those with telemetric capacity, and represent an important advance in sport science and exercise physiology studies. The non-invasive nature of the transcutaneous NIRS interface, and the ability to monitor continuously even during physical movement and active exercise provide an important means of measuring oxygenation and hemodynamics in muscle tissue during exercise. The purpose of this study was to assess real-time changes in muscle oxygenation during a sustained isometric contractions of dorsiflexor muscle during low, moderate and submaximal intensity.

Materials and Methods

Subjects

The dorsiflexor muscle was selected for this experiment. Experiments were conducted using the subject's dominant (right) leg. Volunteers was recruited from eight male not trained students from the Uzbekistan State University of Physical Culture (age: 19±2 years, weight: 75±6 kg).Information regarding the purpose and potential risks about the experiment was given to the subjects. All participants were given adequate instructions on the study, and the study was conducted with the approval of the institutional review board at the Uzbek State Institute of Physical Culture in Tashkent, Uzbekistan. Subjects were seated in a hand-made apparatus with isometric torso-dynamometer (DC-200, Russia). Tissue oxygenation index (StO_2) was recorded from the tibialis anterior using a NIRS device (Nonin's SenSmart™ Model X-100, USA). Sensor head were placed over the belly of the tibialis anterior muscle. All subjects were right handed.

Protocol of experiment

Over one day male volunteers performed dorsiflexor contractions by using a handmade sitting apparatus, torso-dynamometer and NIRS device. The subject was seated for 15-20 min prior to the test. The right leg rested on a torso dynamometer with their ankle positioned at 30º in plantar flexion. The maximum voluntary contraction (MVC) force of the subject was determined before the test and 30%, 60% and 90% MVC were calculated. Protocol of experiment consisted of a pre-exercise stage (rest), and three successive stages of sustained isometric contractions (30%, 60% and 90% MVC) each lasting 1 min and separated by a rest period lasting 3 min (see figure1). To determine the minimal oxygen saturation value in the dorsiflexors, oxygenation parameters of the dorsiflexor muscle were measured at rest by using an arterial occlusion test (at the end of experiment protocol). For this purpose a blood pressure cuff was placed around their right thigh to occlude blood flow to the leg. Blood flow was occluded to the leg by inflating the cuff beyond 240 mmHg, and this occlusion was maintained until oxygen saturation researched a stable minimum level (last step of experiment, see figure 1). In this way, both venous outflow and arterial inflow are blocked and systemic circulatory changes are sufficiently eliminated in the limb. Lacking the supply of well oxygenated blood, muscle metabolism fully depends on the available O_2 in local capillaries and muscle cells. Depletion of local available O_2 stores during arterial occlusion was monitored by NIRS, as a decrease in O_2Hb and a concurrent increase in HHb while tHb remains constant. A hyperaemic response can be observed after release of the arterial occlusion. Blood volume increases rapidly, resulting in a fresh pool of O_2Hb and a quick wash-out of HHb. Using the arterial occlusion method including the recovery phase, it is possible to calculate O_2 consumption, reoxygenation rate and the half-recovery times of the signals (Gerovasili, et al, 2010).

Statistics

Differences in the StO_2, desaturation rate (De) and resaturation rate (Re) between muscle contraction intensities were analyzed by the Student's t-test in the statistical software package "Statistica" for Windows (version 13). Differences of $P < 0.05$ were considered as statistically significant. All data are presented as mean ± SD.

Results and discussion

Maximal force was 18N at the onset of the 100% MVC contraction. Calculated contraction intensities (F) for 30, 60 and 90% MVC shown in table1. Efforts of 30 ,60% and 90% MVC were held constant throughout exercise.

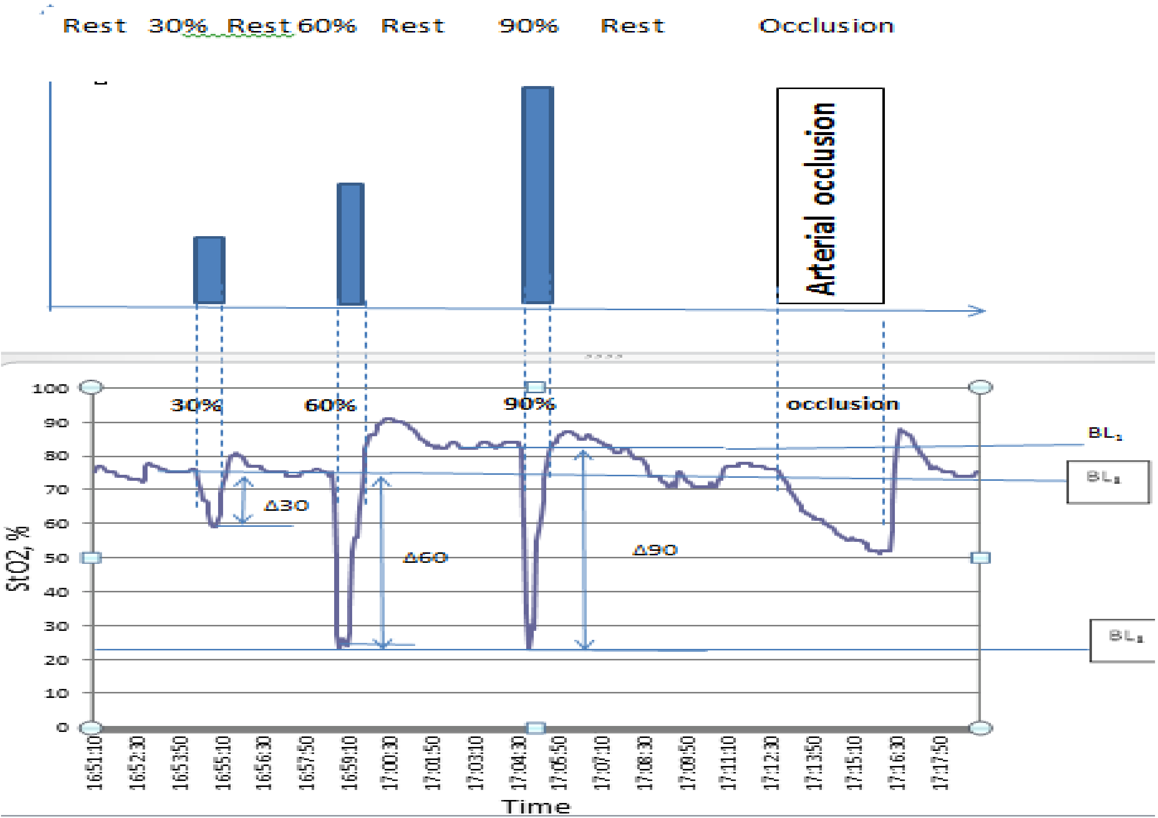

Figure 1. Protocol of experiment diagram (top) and real time tissue oxygenation (StO_2) (bottom)

The recovery baseline (BL) is the stable StO_2 value that occurs during the rest period following test time. The recovery baseline is determined after muscle contractions which will usually result in an increased StO_2 value owing to increased physiological function. Here we can distinguish different level of baseline recovery before and after each step of efforts. BL1 does not change after the warm-up step (30%MVC) (about 73% StO_2) but after moderate and submaximal contractions there are raised value of BL2 plateau (78%). The Performance Baseline is the minimum StO_2 value reached during a exercise. The performance baseline of oxygen saturation during 30% MVC have values about 30%, but after moderate and submaximal contraction reached minimal levels (20%) (see table 1).

Table 1. Muscle tissue oxygenation parameters during different levels of continuous isometric contractions and arterial occlusion test (AO). BL- baseline level of StO_2, De-desaturation rate during exersice and AO, Re-resaturation rate of StO_2 after cesation of efforts and AO, ΔStO_2-difference between recovery and performance baseline level of StO_2.

MVC	30%	60%	90%	AO
F,(N)	5.4	10.8	16.2	
BL, (%)	73.16±0.29	73±0.87	78.66±3.17	77.75±3.46
De, (%/sec)	-1.06±0.09	-4.19±0.16	-4.80±0.16	-0.23±0.03
Re, (%/sec)	0.84±0.19	1.54±0.25	2.65±1.44	2.5±0.08
ΔStO_2,(%)	18.83±4.62	38.5±9.24	44.51±5.14	24±1.77

The comparison of oxygen consumption under different sustained isometric contractions is shown in figure 2 with dorsiflexor muscle oxygen saturation at different levels of maximal efforts.

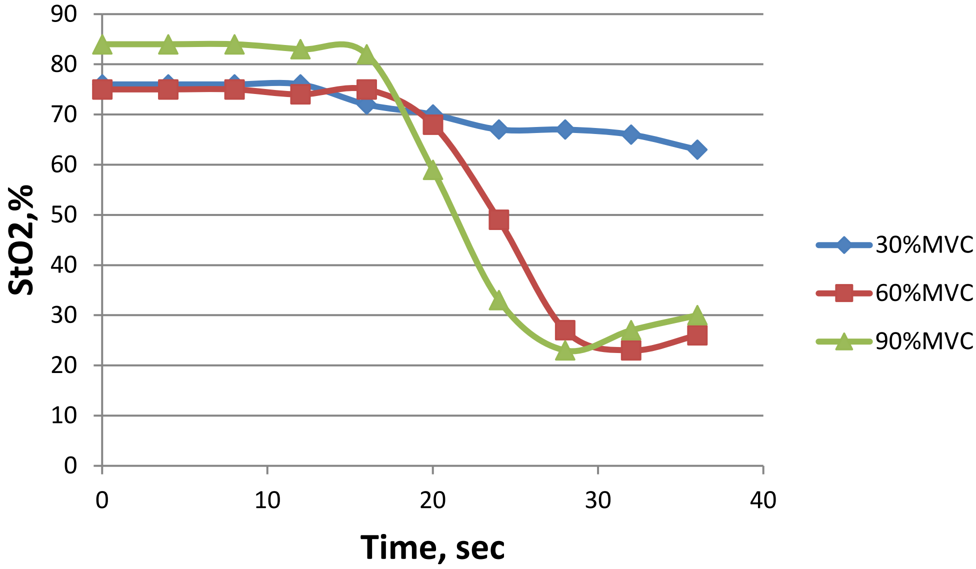

Figure 2. 1 Dorsiflexor muscle oxygen saturation during sustained isometric contractions under 30%, 60% and 90% of MVC.

Saturation was higher at 30% compared with both 60 and 90% MVC at all time points after start exercise and higher at 60 than 90% (figure 2). Oxygen consumption (De, see tab.1) permanently increased from slow (30%) to moderate (60%) and submaximal contractions. Separate De trends are shown on fig. 3.

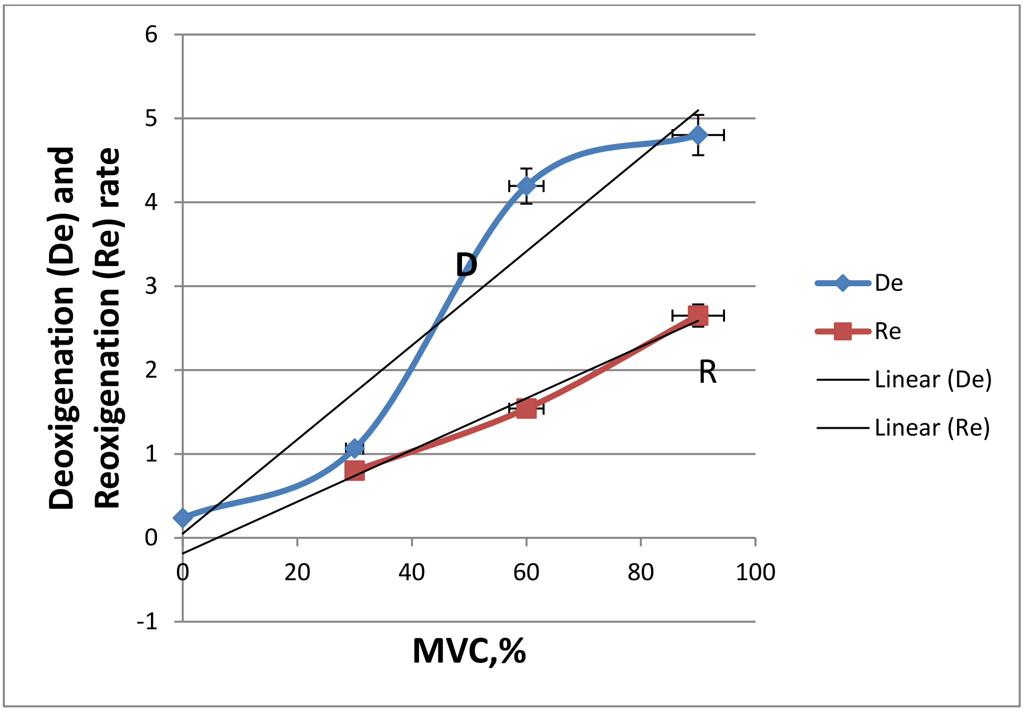

Figure 3. Deoxygenation and reoxygenation rate dependance on MVC

After cessation of the each contraction there was a large and immediate hyperemic response. This response is shown in figure 3 for the three levels of MVC. Rate of StO_2 increase after effort cessation reflects the resaturation rate of hemoglobin which depends on the integrity and functionality of the vascular system and reflects blood vessel vasodilation. StO_2 resaturation rate permanently increased from slow (30%) to moderate (60%) and submaximal contractions. (see table 1 and fig. 4).

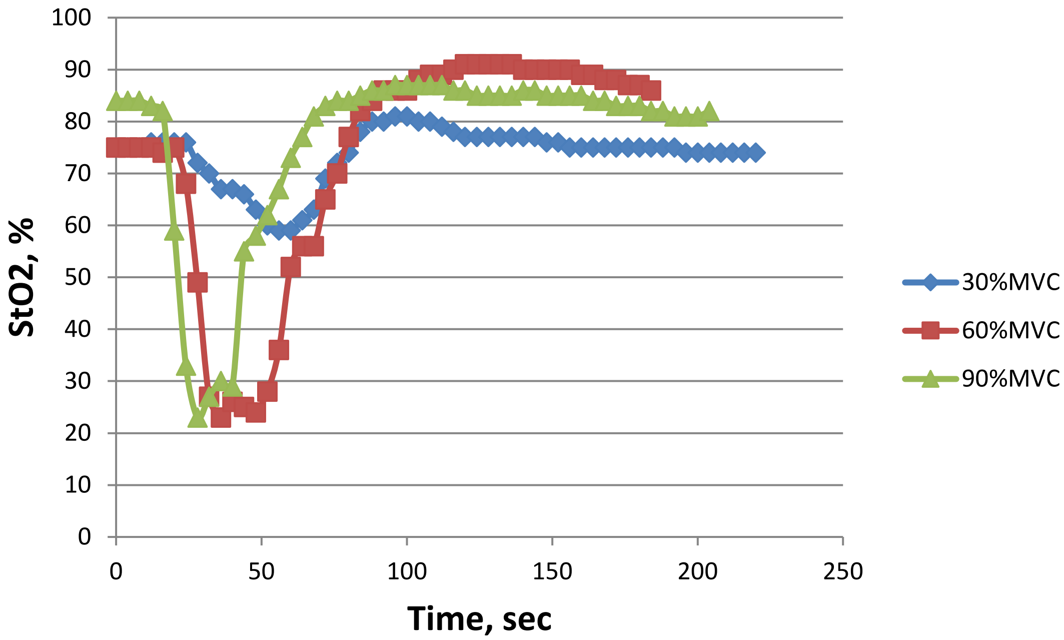

Figure 4. Dorsiflexor muscle oxygen saturation during different levels of SIC, recovery and reactive hyperemia phases.

During the final final stage of the experiment (see fig.1) an arterial occlusion test has been performed to determine the minimal oxygen saturation value in the dorsiflexors. Oxygen saturation reached 24±1.77% which is significantly higher then StO_2 after 60 and 90%MVC (see table 1).

CONCLUSIONS

- The recovery baseline (BL) after exercise increased due to increased physiological state of muscle.
- The Performance Baseline is the minimum StO_2 value reached during a exercise. Performance baseline of oxygen saturation increased after moderate and submaximal efforts and achieved its plateau.
- Oxygen saturation at 60 and 90MVC are similar and sharply decreased after the start of exercise. It means that after 60% MVC take place occlusion of blood vessels due to intramuscular pressure.
- Oxygen consumption of active muscle increased dependson intensity of exercise according to increasing of oxygen demand.
- StO_2 resaturation rate (Re) permanently increased from slow (30%) to moderate (60%) and in submaximal contractions. Increasing Re after effort cessation reflects the resaturation of hemoglobin which depends on the integrity and functionality of the vascular system and reflects blood vessel vasodilation.

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