A NEW NON-INVASIVE OPTICAL METHOD TO MEASURE BLOOD FLOW IN HUMAN ANTERIOR TIBIAL MUSCLE

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Introduction: Although skeletal muscle blood flow is an important physiologic parameter to study, non-invasive measurement of muscle blood flow has been constrained by many technical limitations. Photoplethysmography (PPG) is a common non-invasive technique used to assess changes in skin blood circulation and oxygen saturation. Optical radiation from a light source of a certain wavelength illuminates the skin. The light emitted is reflected, absorbed and scattered in the tissue and blood. The intensity of the reflected and scattered light recorded by the photodetector is assumed to be related to blood perfusion changes underneath the probe. Light penetration into the tissue increases primarily with the wavelength. The penetration depth depends also on the optical geometry of the PPG probe, mainly on the distance between the light source and the photodetector. By using a specially designed PPG probe, the local blood flow in human muscle may be determined.

The purpose of the present study was to validate the new non-invasive method for monitoring blood flow in human anterior tibial muscle. Invasive single-fiber laser-Doppler flowmetry (LDF) was used as a reference method during arterial occlusion, static and dynamic contractions of the human anterior tibial muscle.

Methods: Local muscle and skin blood flow in the right leg were measured in twelve healthy subjects (age range 20-30 years) with no history of leg pain. The study was approved by the Research Ethics Committee of the University of Gothenburg and all subjects provided their informed written consent.

A laser Doppler flowmeter (Multiflow 3, Linköping, Sweden) was used for the measurements. A local anaesthetic was injected into the skin with 1 - 2 ml of 1% lidocaine without epinephrine at a distance of about 7 cm below the knee joint and 2 cm lateral of the anterior margin of the tibia. Then a needle catheter (Venflon 2; 1.2 × 32 mm) was inserted in a distal direction into the anterior tibial muscle at an angle to the skin of approximately 30º. Through this catheter a single optical fiber with a diameter of 0.5 mm was inserted.

A two-channel PPG instrument (Linköping, Sweden) was used for recording blood flow in the skin and the anterior tibial muscle. The PPG probe (9.0 × 3.0 cm) was placed over the tibial muscle belly above the single-fiber LDF probe. The PPG probe consisted of three photodetectors and six light sources, light emitting diodes (LEDs). Four LEDs emitted light of a wavelength of 560 nm (green) and two LEDs emitted light in the near-infra-red region of 880 nm.

The center to center distance between the LEDs and the photodetectors were 3.5 mm and 20 mm for the wavelengths 560 nm and 880 nm, respectively. Two different wavelengths and the distance between each LED and the photodetectors were chosen in order to cover different monitoring depths in human tissue, namely 560 nm for skin and 880 nm for muscle. The PPG signal consists of two components; a pulsatile component (AC) synchronous with the heart rate and a slowly varying component (DC) that reflects total blood volume of the examined tissue area. A ratio between the two components provided a blood flow index.

The study was performed with the subject in a supine position. The subjects performed isometric dorsiflexion of the right ankle joint at maximal contraction level for 1 min and also full range-of-motion dorsiflexion and plantar flexion of ankle joint, i.e. dynamic contractions for 1 min. A thigh tourniquet was inflated to 240 mm Hg or at least 100 mm Hg above systolic blood pressure after a control period. This pressure was maintained for 3 min and then released. The muscle and skin blood flow were recorded continuously and simultaneously by PPG and LDF during each test.

Data were acquired using a LabWindows program. Data were normalized to resting baseline. The Wilcoxon signed-rank test was used to evaluate significant changes in blood flow before and after the provocation test. The correlation regression between PPG and LDF was also calculated. Significance was set to p < 0.05.

Results: During arterial occlusion, muscle blood flow was zero using both methods. The post-occlusive reactive hyperemia in the muscle at the end of 3 min arterial occlusion were 150% (SD=31, p=0.003), measured by PPG (880 nm) and 182% (SD=66, p=0.012), measured by LDF (compared to baseline=100%). Furthermore, skin blood flow increased to 135% (SD=57, p=0.026), measured by PPG (560 nm). The PPG (880 nm) signal was well correlated with the LDF signal (r=0.761, p=0.028) after arterial occlusion. After 1 min of maximal static contraction, the blood flow immediately increased to 150% (SD=51, p=0.003), measured by PPG (880 nm), and 169% (SD=43, p=0.005), measured by LDF. Following 1-2 min of maximal dynamic contraction, the muscle blood flow increased to 158% (SD=59, p=0.003), measured by PPG (880 nm), 170% (SD=99, p=0.008), measured by LDF, indicating post-exercise hyperemia. Skin blood flow, estimated by PPG (560 nm), showed no significant change either after 1 min of maximal isometric contraction or after 1 min of dynamic contraction (Fig.1).

Conclusions: Our results indicate that dynamic phenomena like reactive hyperemia after exercise and arterial occlusion can be measured in the human anterior tibial muscle using non-invasive photoplethysmography. These findings were supported by good correlation between the photoplethysmography measurements and the invasive single-fiber laser-Doppler flowmetry measurements. Although PPG only presents a relative blood flow measure, it may provide new possibilities for non-invasive and continuous assessment of local muscle blood flow.

Acknowledgements: This study was supported by the LUA grants from the University of Gothenburg.

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