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Repetitive shock wave therapy improves muscular microcirculation

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ABSTRACT

Background: Extracorporeal shock wave therapy (ESWT) is mainly applied in tendon as well as bone problems based on stem-cell activation and healing acceleration. The effect of ESWT on muscle tissue is much less understood to date. However, from a clinical perspective, muscle injuries are of distinct interest especially in elite athletes such as soccer players.

Material and methods: A total of 26 rats were randomized into two groups. Group A received a single application of high-energetic focused ESWT (0.3 mJ/mm^2, 4 Hz, 1000 impulses, 10 J), whereas group B underwent the same procedure every 10 min for three sessions (3×0.3 mJ/mm^2, 4 Hz, 3×1000 impulses, totaling 30 J). Blood flow at a depth of 8 mm was measured continuously and noninvasively by a combined Laser-Doppler-Imaging and photospectrometric technique (Oxygen-to-see, O2C, LEA Medizintechnik, Germany).

Results: One minute after the application of high-energy ESWT blood flow in group A increased by 16.5% ($P = 0.007$). Thereafter, it decreased from minute 2 after application and remained significantly unchanged to baseline value until the end of the measuring period at 50 min ($P = 0.550$). Group B showed a similar significant increase in blood flow of 16.4% ($P = 0.049$) and a decrease afterward, too. After the second focused ESWT blood flow was boosted to 26.6% ($P = 0.004$), remaining significantly elevated until the third application was initiated. Muscular blood flow was increased to 29.8% after the third focused ESWT ($P < 0.001$), remaining significantly increased for another 10 min.

Conclusions: Focused ESWT enhances blood flow in the muscle of rats. Moreover, repetitive ESWT extended this beneficial effect.

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1. Introduction

1.1. Extracorporeal shock wave therapy

Extracorporeal shock wave therapy (ESWT) is defined as a sequence of sonic pulses characterized by high peak pressure with fast pressure rise and a short life cycle. The first description was in the 1980s for the use of lithotripsy in urolithiasis [1], but shock wave treatment was emerging more and more for soft tissue regeneration and rehabilitation in orthopedics and sports medicine.

1.2. ESWT affects superficial and deep tissues

Recent data indicate that ESWT has improving effects on superficial soft tissue. Enhanced re-epithelialization was found in acute and chronic wounds [2–5]. Moreover, improvement of skin quality [6,7] and a reduction of inflammatory disorders were described [8,9]. However, as the original utilization in lithotripsy also affects deeper structures, ESWT became prominent in ischemic conditions of profound tissues. Malperfused flaps in plastic surgery showed improved blood perfusion as well as myocardial and limb ischemia under shock wave treatment [10–12]. In orthopedics and trauma surgery, shock wave treatment ameliorated fracture healing in delayed union and pseudarthrosis [13]. Moreover, the use of ESWT has shown its benefits in degenerated and also acute traumatized tissue in sports medicine. Various fields of chronic musculoskeletal disorders showed improvements, e.g., chronic calcific tendinitis of the shoulder [14], medial and lateral epicondylitis [15], greater trochanteric pain syndrome and patellar tendinopathy [16,17], medial tibial stress syndrome [18,19], achilles tendinopathy [16], and plantar fasciopathy [20]. Furthermore, faster regeneration was found after shock wave treatment in the case of stress fractures [21]. Recent data indicate that ESWT might slow down muscle atrophy after an acute nerve injury [22]. Especially in the treatment of tendon disorders in elite athletes, ESWT is a good option as noninvasive treatment that is capable of shortening the time for full rehabilitation. As protocols regarding treatment energy and frequency vary greatly, data are still inconsistent [15], but the dose dependency is regularly emphasized [23].

On the other hand, ESWT application in acute muscle disorders has rarely been evaluated. Current therapy is usually limited to nonsteroidal anti-inflammatory drugs (NSAIDs), physical therapy modalities, and use of the RICE principle (rest, ice, compression, elevation). In this context, the repeated application of high-energy ESWT might have beneficial effects due to an enhanced muscle perfusion. Therefore, we compared the single application of ESWT to repetitive use of ESWT in an established rat model to evaluate additive effects on microcirculation in the muscle.

2. Methods

2.1. Animal model and experimental protocol

The experimental procedures were conducted in accordance with the German legislation on protection of animals and the National Institutes of Health Guide for the Care and Use of Laboratory Animals (Institute of Laboratory Animal Resources, National Research Council). They were approved by the Ministry of Energy, Agriculture, the Environment, and Rural Areas and are in accordance with the EU Directive 2010/63/EU for animal experiments.

Twenty-six Sprague Dawley rats (Charles River Laboratories, Sulzfeld, Germany), weighing 250 to 350 g, were used in this study. Animals were housed in 12 h per d/night cycle 2/cages at 21°C and fed ad libitum. During the experiments, the rats were under sufficient pentobarbital sodium anesthesia (55 mg/kg bw ip; Narcoren, Merial, Hallbergmoos, Germany) monitored by stable heart rate and breathing frequency to minimize microcirculatory affection, due to pain reaction. Body temperature was maintained at 36–37°C using a heating pad. Rats were randomly assigned to the groups. Group A received single high-energy extracorporeal shock wave therapy (shock waves at 0.3 mJ/mm^2 and four impulses/s with a total of 1000 impulses totaling 10J). Group B received repetitive ESWT every 10 min (shock waves at 3 $\times$ 0.3 mJ/mm^2 and four impulses/s with a total of 1000 impulses totaling 30 J). ESWT was applied to the dorsal lower leg of the left hind limb of each animal with a short-range applicator (focus 0–30 mm) using a Storz Medical Duolith SD-1 "T-Top". Application was standard for both groups and performed by the same physician using contact gel without relevant pressure to the tissue.

2.2. Microcirculatory analysis

Each rat was allowed to stabilize for 10 min after anesthesia delivery before investigating the cutaneous microcirculation. Microcirculation was assessed at the lower leg of the hind limb before application as baseline measurement and 1, 2, 5, 10, 11, 12, 15, 20, 21, 22, 25, 30, 35, 40, 50 min after single ESWT application; respectively 1, 2, 5, and 10 min after the first and the second application and 1, 2, 5, 10, 15, 20, and 30 min after the third application of repetitive ESWT. Therefore, a noninvasive combined Laser-Doppler and photospectrometry system (Oxygen-to-see, 02C, LEA Medizintechnik, Giessen, Germany) was used.

The probe was fixed by a special apparatus to minimize measurement artifacts due to vibration. It was removed for shock wave therapy and then again attached to the same position on the hind limb. One minute before application of focused ESWT to the dorsal lower leg of the hind limb, baseline measurements were carried out.

The O2C system combines the determination of hemoglobin and the principle of blood flow measurement. As described before [24,25], the optical method allows measuring blood flow by Laser-Doppler-Imaging technique and hemoglobin oxygenation and hemoglobin concentration in the tissue by photospectrometric techniques. In short, an optical fiber probe, incorporating both the laser Doppler and the broadband light spectrometry technique, records the local oxygen supply parameters, the oxygen saturation of hemoglobin, the relative postcapillary venous filling pressures, and the blood flow. The probe detects changes at a depth of 8 mm