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Update: Delayed Onset Muscle Soreness (DOMS) – Muscle Biomechanics, Pathophysiology and Therapeutic Approaches

Update: Verspätet einsetzender Muskelkater – Muskelbiomechanik, Pathophysiologie und therapeutische Ansätze

CLINICAL REVIEW

ACCEPTED: July 2024

PUBLISHED ONLINE: August 2024

Schroeter S, Bloch W, Hirschmüller A, Engelhardt M, Grim C, Heiss R, Hotfiel T. Update: Delayed Onset Muscle Soreness (DOMS) – muscle biomechanics, pathophysiology and therapeutic approaches. Dtsch Z Sportmed. 2024; 75: 189-194. doi:10.5960/dzsm.2024.608

Summary

› **The term Delayed Onset Muscle Soreness (DOMS)** refers to a complex injury entity which is based on ultrastructural injury patterns. The injury is usually harmless and heals within a few days without sequelae. However, at the time of the manifestation there are (sometimes considerable) performance limitations and the risk of possible secondary injuries is increased. Thus, prevention and treatment of DOMS, especially in high-performance sports, are of particular value. Insights into muscle biomechanics are necessary to understand the background and mechanisms of DOMS.

› **The definition and classification** of overload-related muscle injuries has not yet been uniformly determined. Fluid transitions between physiological, metabolic and neuromuscular fatigue as well as the actual occurrence of injuries with clinical symptoms make clear delineation difficult. The "Munich Classification" terms Delayed Onset Muscle Soreness (DOMS) as Type 1b muscle injury, "delayed onset muscle pain".

› **The central target of prevention of DOMS** is to prevent or alleviate the onset of the initial damage, known as "Exercise Induced Muscle Damage" (EIMD).

› **In case of manifest DOMS,** the intention is both to relieve the attendant symptoms and to promote rapid restoration of muscle function. In clinical practice as in scientific research, diverse procedures and interventions have proven valuable, whereby especially physical therapy procedures like cryotherapy, heat therapy or compression therapy show promising study results.

KEY WORDS:
Muscle Physiology, Muscle Soreness, Muscle Injury, Performance, Regeneration

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Introduction

The term Delayed Onset Muscle Soreness (DOMS) refers to a complex injury entity which is based on ultrastructural injury patterns. The injury is usually harmless and heals within a few days without sequelae. However, at the time of the manifestation there are (sometimes considerable) performance limitations and the risk of possible secondary injuries is increased. Thus, prevention and treatment of DOMS, especially in high-performance sports, are of particular value. Insights into muscle biomechanics are necessary to understand the background and mechanisms of DOMS.

The striated skeletal musculature accounts for 30 to 50% of the total body weight - depending on constitution, age and gender. The musculature plays not only a decisive role in locomotion and the external form and shape of the human body but also fulfils other essential functions like keeping the body upright in standing or sitting, the stability of compartments and participating in communicative processes. Recent knowledge has revealed the importance of its function as an endocrine organ. A central role in the regulation and differentiation of target cells distant from the muscle is attributed to the musculature, since it secretes peptide hormones (myokines) (18).

Anatomy and physiology must be taken into account to understand injuries and overloading of the musculature. A hierarchical organization characterizes the muscular structure. From functional aspects, the sarcomere plays a ›

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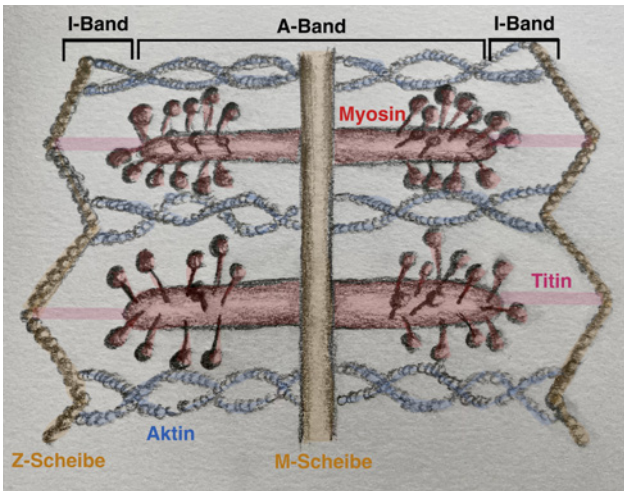

Figure 1

Illustration of a sarcomere in a non-contracted state with thin actin filaments (blue) which extend from Z-disc to Z-disc. The thick myosin filaments are anchored on the M-disc in the middle of the sarcomere. On contraction, the length of the I-band changes, the length of the A-band remains constant (Source: Sarah Schröter, Osnabrück).

central role as the smallest contractile unit of the muscle. Sarcomeres are separated by Z-discs. Set in a row, they form the functional unit of the muscle fibrils. The sliding filament theory, postulated for the first time by Huxley and Hanson in the 1950s, revolutionized the understanding of muscle biomechanics (17). Electronic microscopic images confirm that the length of the filaments remains unchanged when the whole muscle is lengthened, but the bundle of thin filaments (actin) is extracted from the arrangement of the thick filaments (myosin) (figure 1).

Building on this knowledge, Herzog identified in 2002 a significant increase in muscle strength during "active" elongation (Signal path via Ca^{2+}) (11). In addition to the filaments actin and myosin, the structure protein titin was found to be of decisive relevance in this. The three-filament theory concluded from this postulate a participation of titin under Ca^{2+} inflow during excentric muscle load and delivers a possible explanation for strength increase and increased stiffness in excentric muscle load.

The characteristic features of excentric modes include an increased strength development, structural increased load of the active fibers, energetic efficiency in the sense of "low cost and high force", influence on voluntary inner-

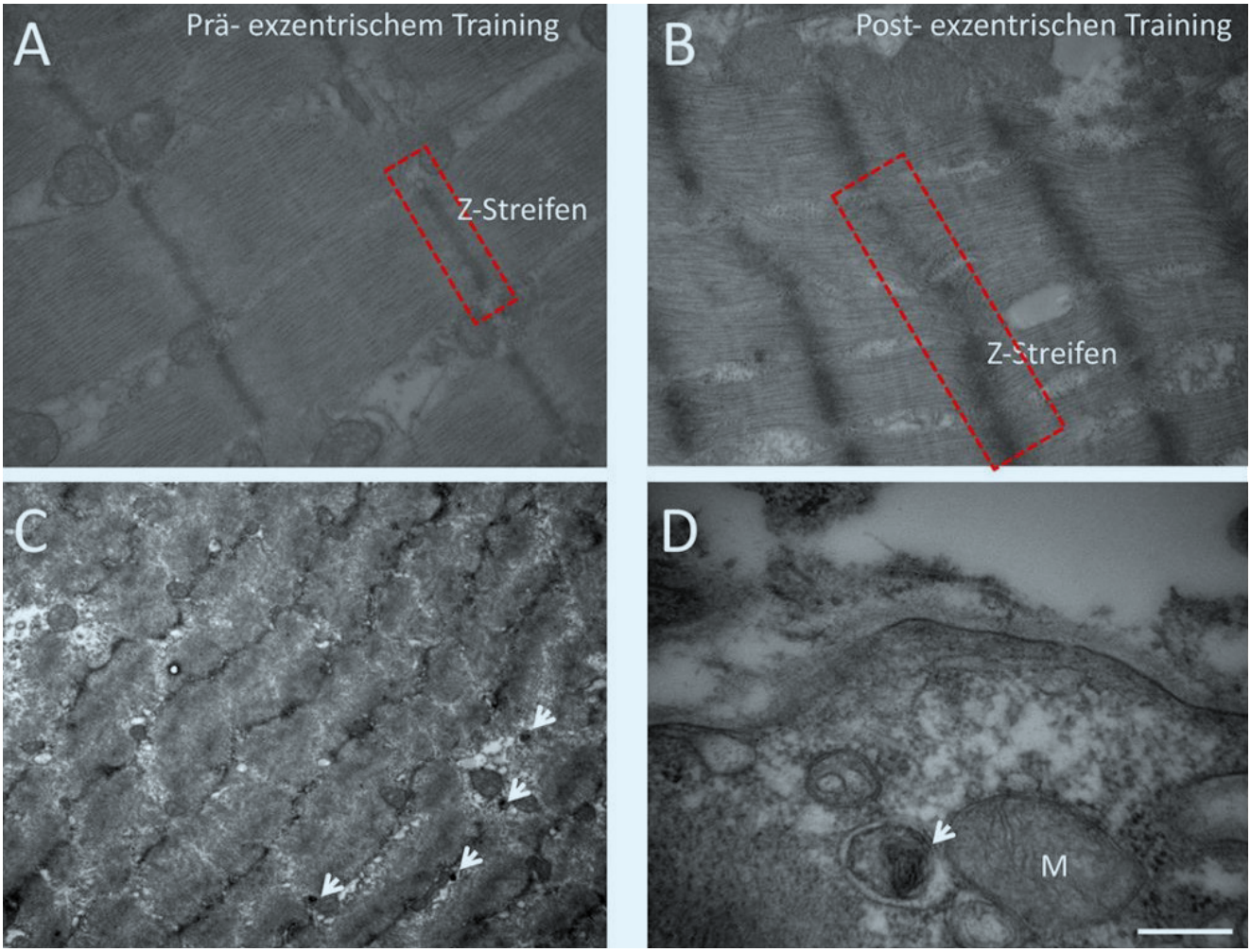

Figure 2

Electronic microscopic images of muscle fibers and the surrounding endomysium 24 h after excentric muscle exertion (from: Bloch W, Hotfiel T, Ueblacker P, Tischer T, Bily W, Englhardt M, Anatomie/Physiologie der Muskelheilung. In: Engelhardt M, Mauch F. eds. Muskel- und Sehnenverletzungen: Rolle-Verlag: 2017.10. www.gots.org). A) Biopsy before strength training with regularly formed sacomeres and clearly demarcated thin Z-striae. B) After strength training, there is a partial destruction of the Z-striae and a partial dissolution of the classic sacomere structure. C) Damaged sacomeres with intervening autophagosomes (arrows). D) Autophagosome in formation next to a mitochondrion (M). Autophagosomes were formed during autophagy. They take up cellular material such as misfolded proteins or entire organelles for degradation.

vation and on the modified neuromuscular innervation pattern. Last but not least, the excentric load has become established as an effective training form, not only in the therapy and prevention of muscle injuries, but also in the treatment of osteoporosis, sarcopenia and cardio-vascular diseases (28). Despite the many positive characteristics of excentric muscle work, this type of muscle contraction also correlates with the occurrence of acute and overload-related muscle injuries, and (peri)articular damage (figure 2).

Overload-Related Muscle Injuries: Origin and Development Process

The definition and classification of overload-related muscle injuries has not yet been uniformly determined. Fluid transitions between physiological, metabolic and neuromuscular fatigue as well as the actual occurrence of injuries with clinical symptoms make clear delineation difficult. The "Munich Classification" terms Delayed Onset Muscle Soreness (DOMS) as Type 1b muscle injury, "delayed onset muscle pain" (23). Excentric forms of contraction or unaccustomed muscle load are considered causal for this form of injury. Although the exact causal mechanism has not yet been precisely clarified, the mechanical load influence mentioned above, which exceeds the ultrastructural load capacity, is assumed as the primary damaging mechanism (13) more than the theory of metabolic stress (1). Particularly in endurance sports, a mechanism for the development of muscle soreness can be identified. A different mechanism can be found during long lasting endurance load. During a marathon, creatine kinase from the muscle-brain type (CK-MB) activity peaks resulting in ultrastructural changes after the competition that indicate local fiber damage and repair: intracellular edema with endothelial damage, myofibrillar lysis, dilatation and disruption of the T-tubule system as well as focal mitochondrial degeneration without inflammatory infiltrates (30). A protein degradation, autophagia and local inflammation reactions are elicited by the damage mechanism. Clinical symptoms after an initial low symptom interval are painful limitations of movement, swelling, reduced strength development, increased muscle tone and functional limitations. The first clinical manifestations occur between 6 and 12 hours after exercise and reach a peak at between 48 and 72 hours. Healing usually occurs within a week without sequelae (10, 13).

Coupled with the inflammatory process in laboratory tests is an elevation of damage and inflammation markers like creatinkinase (CK), lactate dehydrogenase (LDH), interleukin 6 (IL-6), pentraxin-3 (PTX-3) or C-reactive protein (CRP) (3). Imaging procedures should only be used in unclear cases due to the clinical diagnosis. Magnetic resonance imaging (MRI) is understood as the gold standard for evaluation of low-grade muscle injuries (figure 4). Intramuscular edema in DOMS may occur as signal increase in fluid sensitive sequences. In addition to intramuscular edemas, perifascial fluid accumulation may occur in advanced manifestations. Ultrasound shows limited sensitivity compared to MRI in DOMS and often provides only indirect evidence over time (7).

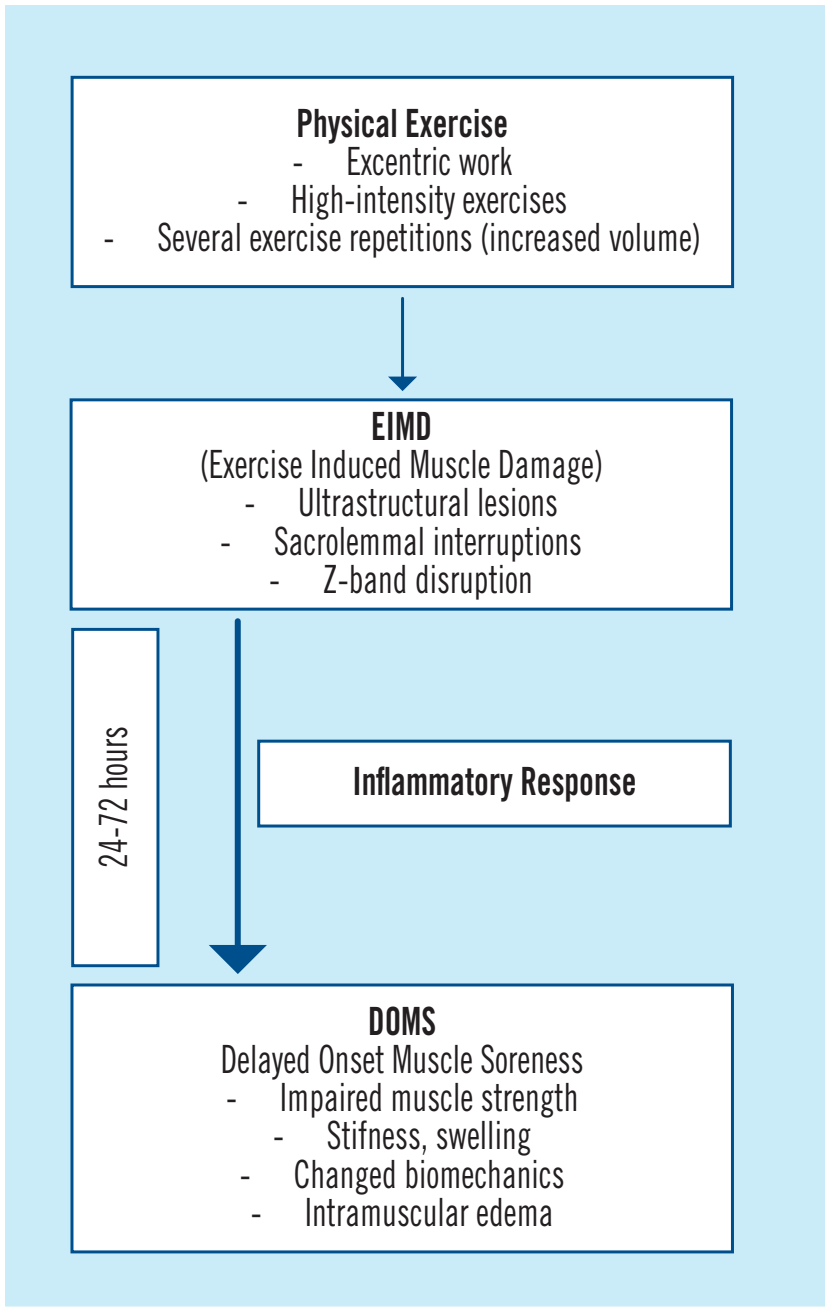

Figure 3

Depiction of the process of DOMS development. Due to excessive physical strain, microstructural lesions in the sense of exercise-induced muscle damage (EIMD) are elicited, which result in DOMS within 24-72 hours via an inflammatory response.

Therapeutic Approaches to the Treatment of DOMS – Balance between Prevention of the Primary Damage and Symptomatic Relief of Secondary Symptoms

The pathophysiology of DOMS underlines the decisive influence of mechanical stress as the primary elicitor of this ›

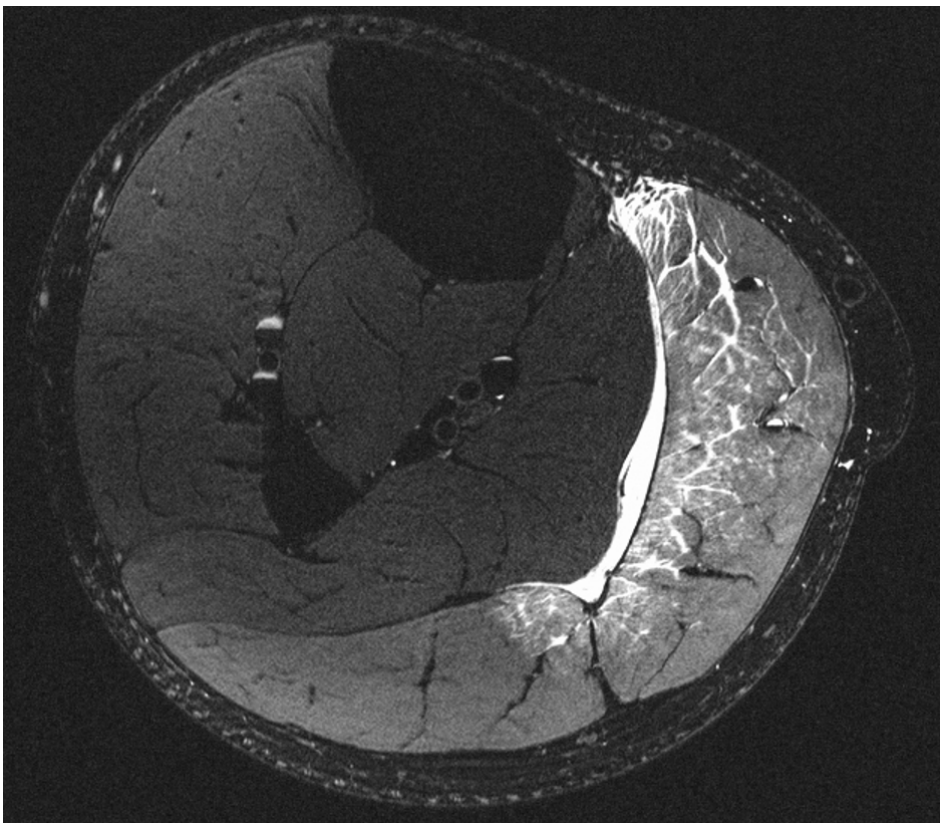

Figure 4

7-Tesla transversal T2-weighted MR image of a lower leg 60 hours after eccentric exercise. Muscle edema can be detected in the medial and lateral head of the gastrocnemius (Source: Friedrich-Alexander Universität Erlangen-Nürnberg).

injury entity. The central target of prevention of DOMS is to prevent or alleviate the onset of the initial damage, known as "Exercise Induced Muscle Damage" (EIMD). In order to avoid EIMD, generally low-intensity training involving less load can be performed (1). The load should be adjusted slowly and adapted to the athlete's training condition. In cases where EIMD is already present, therapy seeks to limit the inflammatory response, to guarantee a reduction of intramuscular fluid accumulation and to control the restoration of tissue homeostasis (10).

In case of manifest DOMS, the intention is both to relieve the attendant symptoms and to promote rapid restoration of muscle function. The complex pathophysiology creates fluid transitions between the aspects of regeneration, rehabilitation, prevention and therapy (14). In clinical practice as in scientific research, diverse procedures and interventions have proven valuable, whereby especially physical therapy procedures like cryotherapy or compression therapy show promising study results (10, 14).

Systemic cryotherapy including cold water immersion therapy or cold air exposure offers the advantage of effectively influencing numerous muscle groups. The underlying mechanisms of action are ascribed to both the changed local metabolic processes in the muscle tissue itself and systemic processes (among them vegetative nervous system), whereby the final clarification has not yet been accomplished (15). Local procedures like bandages soaked in ice water or cooling elements remain usually restricted to the acute therapy of structural muscle injuries, as applied in the classical PRICE-procedure (Protect, Rest, Ice, Compression, Elevation) (16). Cryotherapy is often applied immediately after exercise to alleviate the initial damage mechanisms and relieve the secondary inflammatory phase. Heat therapy is usually applied in clinical use when the specific symptoms of DOMS are already manifest. Heat therapy is an effective method especially to reduce pain of DOMS and regulate the frequent hypertonic tone of the musculature. It is assumed that heat therapy elicits spasmolytic and pain-relieving effects by consecutive perfusion increase and promotion of metabolism (21, 24). Numerous studies have shown that both heat and cold therapy can mitigate the effects of DOMS (10, 19, 21, 29). In a systematic review, however, there was no uniform conclusion about whether cold or heat therapy has the better pain-relieving effect (21).

Another method of relieving DOMS and accelerating recovery is the application of compression and massages. Compression garments, like compression stockings or pants and water immersion are said to improve perfusion as well as venous and lymphatic outflow and to reduce swelling and edema. However, the evidence on whether positive effects really exist remains uncertain due to the inconclusive data situation (8, 9, 12, 22, 26). Likewise, there is evidence of increased intramuscular perfusion by massage, which could contribute to more rapid regeneration (5). The evidence is unclear at what point in time massage should be applied. Systematic review articles on compression therapy and massages after physical strain describe primarily the reduction of DOMS symptoms.

Finally, optimal sports nutrition and targeted nutritional supplements to influence the onset and intensity of DOMS are important as well (10). The support of the endogenous immune response with nutrient supplements (such as antioxidants or branch-chained amino acids (BCAA) is a matter of controversial discussion (6, 31). Although reactive oxygen species (ROS) have been associated with detrimental biological events, they are essential for cell development and function (27). Based on the statement of the International Olympic Committee (IOC) there are several supplements considered as important in rehabilitation and performance. Gelatin and Vitamin C seem to have no functional benefits in recovery from injury. Omega 3 fatty acids are known to increase muscle protein synthesis, reduce muscle damage after eccentric exercise and enhance recovery from injury. Creatine has no clear effects on muscle damage (20). A differentiated consideration of specific individual application criteria in the use and selection of nutrient supplements is essential. The authors refer to further detailed literature (2, 4, 6, 10, 20, 25).

Conflict of Interest
The authors have no conflict of interest.

Summary Box

This review outlines the muscle biomechanics, the pathophysiology as well as prevention and treatment of Delayed Onset Muscle Soreness (DOMS). The pathophysiology of DOMS underlines the decisive influence of mechanical stress as the primary elicitor of this injury entity. The central target of prevention of DOMS is to prevent or alleviate the onset of the initial damage, known as "Exercise Induced Muscle Damage" (EIMD). In case of manifest DOMS, the intention is both to relieve the attendant symptoms and to promote rapid restoration of muscle function and performance.

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