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RESEARCH ARTICLE

The Preventive Efficacy of Selenium Supplements on Muscle Soreness Post Heavy Eccentric Exercise

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Abstract

Delayed Onset Muscle Soreness (DOMS) is the muscle pain and stiffness following unaccustomed or strenuous physical activity that initially appears 8–20 h after exercise, peaks at 24–48 h after exercise and persists for several days and affect performance. The aim of the present study was to examine the physiological effects of selenium supplementation on delayed-onset muscle soreness and muscle damage. Thirty-two recreational male students of Sports Science Department, Universitas Negeri Surabaya were randomly and double-blindly assigned to either a selenium supplementation group (n=16) or a Placebo group (n=16) and were directed to take either a selenium capsule or a placebo for a period of 3-weeks. Following the 3-weeks supplementation period, both groups underwent a 10-set x 10-rep countermovement jump (1-min recovery between sets) as an eccentric exercise protocol. Pain of DOMS and CK level were measured prior to the eccentric exercise 1-hr before, 24-hr and 48-hr after eccentric exercise. the result of this study showed that both groups experienced Delayed Onset Muscle Soreness (DOMS) and increased total CK serum within 24 to 48 hours post heavy eccentric exercise. The results indicated that the selenium-supplemented group had a significantly greater reduction in plasma DOMS and total CK serum compared to the Placebo group ($p<0.05$). In summary, selenium supplementation might lower the risk of muscle injury after heavy eccentric exercise, as it effectively reduces plasma DOMS and CK levels in the bloodstream

Keywords
Exercise, Pain, Muscle Damage, Public Health, Supplements

INTRODUCTION

Delayed Onset Muscle Soreness (DOMS) is the muscle pain or tenderness that occurs after unfamiliar exercise (Sulistyarto et al., 2022), Different from acute injuries, DOMS initially appears 8–20 h after exercise, peaks at 24–78 h after exercise (Fleckenstein et al., 2021), and dramatically subsides within 96 hours (Irawan et al., 2022; Şentürk & Göbel, 2022).

This soreness is a natural response of the body to muscle damage and inflammation, as it tries to repair and adapt to the new level of exertion. In relation to DOMS, there are several accompanying symptoms. These include localized muscle weakness, increased swelling, decreased range of motion, and a rise in the blood level of creatine kinase (Lamb et al., 2019).

DOMS is commonly caused by exercises that involve predominantly eccentric movements which are unfamiliar to the body. Eccentric (lengthening) muscle contraction associated with microtrauma to connective and/or contractile tissue (Wiecha et al., 2021). The intensity of injury or damage related to DOMS is often influenced by the muscle's training level. At its core, this injury is a mechanical disruption within the sarcomeres, which are the basic functional units of muscle fibers (Doma et al., 2021). Delayed Onset Muscle Soreness (DOMS), which appears after unaccustomed or high-intensity eccentric exercise, can cause discomfort and anxiety among athletes. Although not classified as

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a disease or disorder, it can also attenuate exercise performance.

Delayed Onset Muscle Soreness (DOMS) occurs due to minor injuries within the muscle fibers, initiating an inflammatory reaction in the body. Athletes often experience pain associated with these micro-damages in their muscle fibers, enables the discharge of certain cellular contents, such as the enzyme creatine kinase (CK) (Ali et al., 2023). Numerous hypotheses have been suggested to explain the cause of Delayed Onset Muscle Soreness (DOMS), such as lactic acid accumulation (Harahap et al., 2023), muscle contractions, injury to connective tissues, muscle damage, and inflammation (Hanon et al., 2024; Keriven et al., 2023).

Numerous studies have identified the release of reactive oxygen species (ROS) due to oxidative stress as a significant contributor to Delayed Onset Muscle Soreness (DOMS) following exercise (Amalraj et al., 2020; Tanabe et al., 2021). Eccentric exercises, in particular, often lead to heightened muscle soreness, as they intensify oxidative stress levels beyond the body's antioxidant capabilities (Barker et al., 2023; Konrad et al., 2022). Moreover, the risk of cellular damage from free radicals can be lessened by the actions of skeletal muscle antioxidant enzymes, such as GPx, GR, SOD, and CAT (MS et al., 2020).

To address this issue, several studies have concentrated on the utilization of dietary supplementation with antioxidants. These substances are renowned for their capability to neutralize free radicals and alleviate the consequences of oxidative stress within the body, which could potentially lead to DOMS and inflammation. Numerous dietary interventions have been investigated for their potential to minimize damage or lessen inflammation following heavy eccentric exercise exercise, some of these include Branched-Chain Amino Acid (BCAA) (Cosentino et al., 2021), Omega-3 Fatty Acid (Mesta & Medithi, 2023), tart cherry Juice (Lamb et al., 2019), Astaxanthine (Barker et al., 2023), and Vitamins C and E (Konrad et al., 2022).

Selenium (Se), an essential trace element, has antioxidant and immune functions. It is an important component of selenoproteins, which play important roles in redox catalytic activity, structural function, and transport processes (Saito, 2022). The effects of Selenium (Se) are linked to providing antioxidant defense, supporting thyroid hormone production, regulating testosterone metabolism, preserving DNA structure, modulating vitamin E (alpha-tocopherol), promoting anti-cancer mechanisms, and improving muscle performance (Kuršvietienė et al., 2020).

Previous studies have shown that increased serum levels of Selenium and selenoenzymes (such as GPx and Se protein) have been noted in the early phase of serious diseases characterized by inflammation and oxidative stress (Hariharan & Dharmaraj, 2020). Therefore, further research is needed to confirm the potential benefits of Selenium, especially to reduce the risk of DOMS and muscle damage after eccentric exercise.

The aim of the present study was to examine the physiological effects of 3-week period of selenium supplementation on delayed onset muscle soreness and muscle damage.

MATERIALS AND METHODS

Participant

This study was a randomized, double-blind, placebo-controlled experiment. Thirty-two recreational male students of Sports Science Department, Universitas Negeri Surabaya were randomly and double-blindly assigned to either a selenium supplementation group (n=16) or a Placebo group (n=16). To ensure a fair comparison, all participants met specific criteria, including being healthy, having a normal Body Mass Index, and not being smokers or on any medications or supplements. Both group was low risk of bias.

All participants had not engaged in heavy or strenous exercise within the past 1 months, nor experienced from any pain. They were instructed to abstain from using any medications or therapies during the study duration. Additionally, throughout the 4-week study duration, participants were directed to refrain from participating in intense physical activities not only during the study but also for 48 hours after the experiment.

Before the study commenced, all anthropometric measurements were consistent across the groups. The research team provided a detailed explanation of the study's objectives and protocols to the participants, who subsequently gave their informed consent.

Prior to enrolling in the study, participants verified their absence of pain or injury through the Physical Activity Readiness Questionnaire (PAR-Q) pre-exercise screening. This Physical Activity

Readiness Questionnaire (PAR-Q) is a standardized tool used to assess an individual's readiness for physical activity to identify the participants who may be at risk of experiencing adverse health consequences due to physical activity (Varanoske et al., 2021). When completing the PAR-Q, participants are accompanied by a Fitness Expert from the Faculty of Sports and Health Sciences. This questionnaire consists of seven questions that inquire about the individual's medical history, symptoms, and physical limitations.

This study followed ethical standards and received approval from the Health Research Ethics Committee, Faculty of Public Health, Airlangga University, and has been deemed ethically acceptable with the identity number: 104/EA/KEPK/2023

Experimental Procedures

The aim of this study was to evaluate the efficacy of 200µg Selenium capsule supplementation over a 3-week period in reducing Delayed Onset Muscle Soreness (DOMS) and Creatine Kinase (CK) levels as indicators of muscle damage after eccentric exercise.

The research spanned a month, commencing with an initial assessment visit. Both the Selenium group and the Placebo group documented their baseline information, which included body weight, height, fat percentage, physical activity level, and VO2Max, to ensure comparable attributes between the groups. In this study, the Multistage Fitness Test (MFT) was used to determine VO2Max of the participants (Kristi et al., 2023). Prior to this, informed consent was obtained following a comprehensive explanation of the study.

Within this study, the Selenium group (n=16) administered capsules, each containing 200µg of selenium (commercially available products), and Placebo group (n=16) received placebo capsules containing 100mg of corn starch, both gruops consumed the capsules one per day after breakfast for 3-week period. Following the 3-weeks supplementation period (22nd day), the participants performed an exercise-induced muscle damage protocol based on 10 sets x 10 with 1-min recovery between sets of repetitions repeated countermovement jumps RCJ), to induce DOMS (Wolska et al., 2023). This protocol has been proven to cause pain sensation (DOMS) in the rectus femoris, tibialis anterior, and fibula muscles of the leg that underwent eccentric exercise (Figure1).

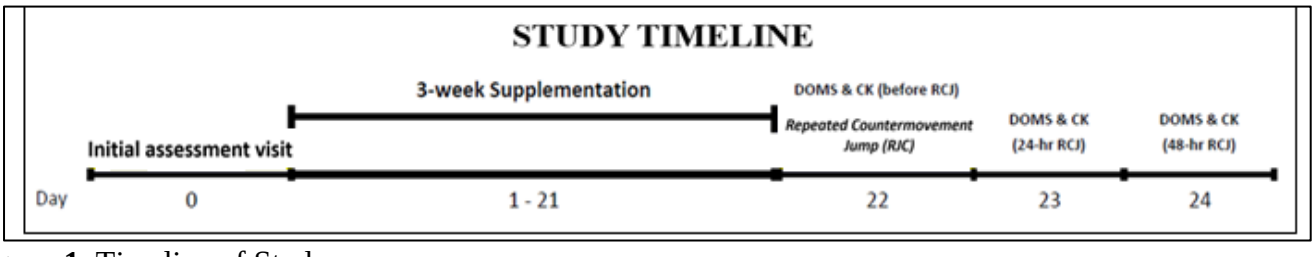

Figure 1. Timeline of Study

Data Collection Tools

Assessment of Muscle Soreness

Visual Analog Scale (VAS) of a 100mm range was used to assess soreness (0mm = no soreness, 100mm = unbearable soreness) before damaging protocol, 24-hr and 48-hr after damaging protocol. Subjects rated DOMS in the lower extremity, which involves three muscles (rectus femoris, tibialis anterior, and fibula muscles of the leg).

Assessment of Creatine Kinase

Blood samples was drawn from the elbow's cubital vein before damaging protocol, 24-hr and 48-hr after damaging protocol. The blood samples were preserved with EDTA to evaluate the total CK (Creatine Kinase) levels. After centrifuging samples at 3000 rotations per minute for 15 minutes, the obtained serum was refrigerated at 20°C in a freezer until further analysis.

Total CK is determined spectrophotometrically, at 30°C, using a commercially available kit (CK-MB Glory Diagnostics). The assessment of CK serum was conducted at the Inregrated Laboratory, Airlangga University Indonesia, to obtain the total CK serum data.

Statistical Analysis

Repeated measures ANOVA was used to analyze mean DOMS (2 x 3), serum CK (2 x 3) scores. Then, a Tukey post-hoc test was used to test the significant effects. The significance level was set at $p < 0.05$, and the value was reported as M ± SD.

RESULTS

Subjects

A total of 32 recreational male students of the Sports Science Department, Universitas Negeri Surabaya students, with an average age of 19.56 years (±0.89) and a mean BMI of 20.93 (±1.14), participated in this study. All participants willingly agreed to become respondents, providing informed consent. The participants were then randomly divided into two groups, Selenium group and Placebo group.

The mean age of the Selenium group (n = 16) was 19.69 (±0.87), while the mean age of the Placebo group (n = 16) group was 19.44 (SD ±0.89). The study presents the physical characteristics, including age, height, weight, BMI, fat percentage, IPAQ, and VO2Max, for both the Selenium group and Placebo group, with p-values greater than 0.05 ($p > 0.05$) to gain the homogeneity variables of both groups (Selenium group and Placebo group). The physical characteristics of both groups (Selenium group and Placebo group) are shown in Table 1.

Table 1. Physical characteristic

Variables	Physical Characteristic				
	Selenium group (M ± SD)		Placebo group (M ± SD)		*P-values*
Age (years)	19.69	±.87	19.44	±.89	.429
Height (cm)	167.63	±5.49	168.06	±2.98	.781
Weight (kg)	59.06	±5.23	58.88	±3.90	.909
BMI	20.99	±1.17	20.84	±1.14	.707
Fat Percentage (%)	12.95	±1.19	12.75	±0.97	.605
Physical Activity Level (MET)	1247.88	±229.03	1271.19	±125.30	.723
Maximum Oxygen Intake (mL/(kg·min))	37.13	±2.54	35.61	±2.60	.105

Muscle Soreness

Post-hoc testing revealed that soreness scores were significantly (P <.05) elevated over baseline in both groups. Selenium group soreness scores at 24 hours were 3.97 (±.62), and significantly decreased at 48 hours 2.5 (±.61) after exercise. Placebo group soreness at 24 hours was 4.05 (±.71), then significantly decreased at 48 hours 4.09 (±.80) after exercise. However, the soreness score in the Selenium group rose less than in the Placebo group (P <.05), this suggests that selenium supplementation may result in a more significant decrease in DOMS than the placebo

Creatine Kinase

Post-hoc testing revealed that Creatine Kinase serum was significantly (P <.05) elevated over baseline in both group. Selenium group Creatine Kinase at baseline was 92.42 (±11.81), then at 24-hours was 110.84 (±13.10) and at 48 hours 104.47 (±8.44) after exercise. Placebo group Creatine Kinase at baseline was 94.48 (±11.81), then at 24-hours was 110.84 (±13.10) and at 48 hours 104.47 (±8.44) after exercise. However, the soreness score in the Selenium group rose less than in the Placebo group (P <.05), which suggests that selenium supplementation may result in a more significant decrease in DOMS than the placebo

Table 2. Time after exercise, in hours

	Groups	Pre	24-Hr	48-Hr
DOMS	Selenium	1.00 ± .00	3.97 ±0.62	2.50 ±0.61
	Placebo	1.00 ± .00	4.50 ±0.71	4.09 ±0.80
Creatine Kinase	Selenium	92.42 ±11.81	110.84 ±13.10	104.47 ±8.44
	Placebo	94.50 ±13.03	131.04 ±13.31	139.62 ±13.49

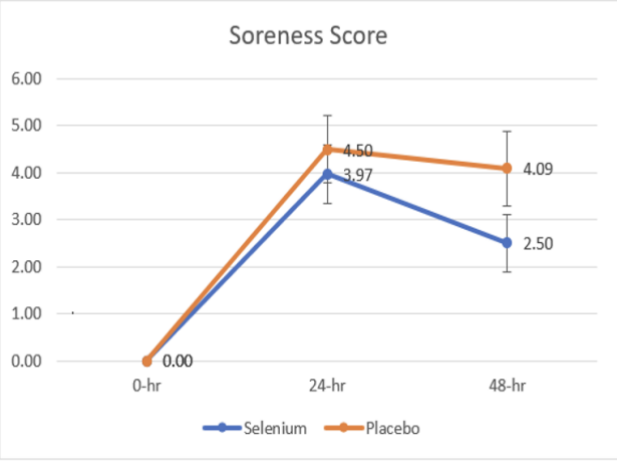

Figure 2.Soreness ratings *(M± SD)* for selenium group and placebo group subjects across time

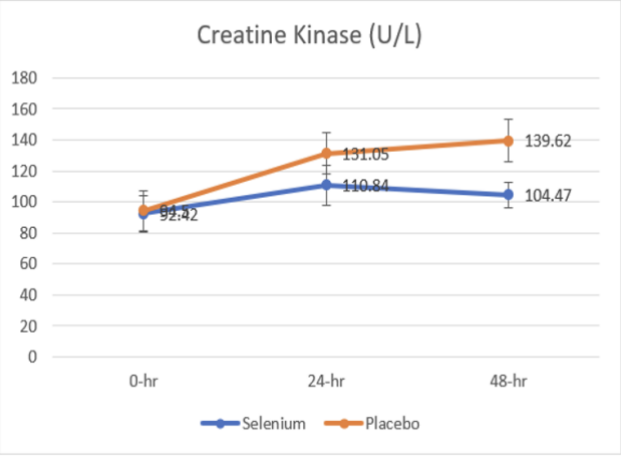

Figure 3. Creatine kinase ratings (M± SD) for selenium group and placebo group subjects across time

DISCUSSION

The aim of the present study was to examine the physiological effects of a 3-week period of selenium supplementation on delayed onset muscle soreness (DOMS) and Creatine Kinase (CK) serum as muscle damage marker. The result of this study indicated that there were increased DOMS and CK in both groups (Selenium group and Placebo group) which peaked at 24-hr after heavy eccentric exercise. The main finding of this study was selenium-supplemented group had a significantly greater reduction in plasma DOMS and total CK serum compared to the Placebo group ($p<0.05$) (see figure 2 and 3). The pain experienced 24-hr after heavy eccentric exercise in the Selenium group decreased significantly 24-hr after heavy eccentric exercise in contrast to the Placebo group. This indicates that selenium supplementation has a positive effect on pain reduction and perceived muscle soreness 24 to 48 h after the heavy eccentric exercise.

The symptoms of pain typically appear after exercise hours or days later, known as delayed onset muscle soreness (DOMS). DOMS initially appears 8–20 h after exercise, peaks at 24–78 h after exercise, and lasts for five-to-seven days (Angelopoulos et al., 2022). The main consequences of DOMS include increased muscle stiffness, loss of strength development and decreased exercise performance (Boukhris et al., 2020; Hotfiel et al., 2019) and muscle protein elevations in blood creatine kinase (CK) (Marathamuthu et al., 2022).

While the occurrence of Delayed Onset Muscle Soreness (DOMS) is well-known, there remains a lack of consensus among experts regarding the exact underlying cause (Sonkodi, 2021). Several studies have proposed that the cause of DOMS is attributed to the development of an acute-phase inflammatory response, stemming from metabolic, mechanical, and oxidative stress (Yoon et al., 2020). It has been shown that high intensity exericse leads to an increase in reactive oxygen species (ROS) production, which is linked to skeletal muscle damage and a decline in physical performance (Tokinoya et al., 2020). There is mounting evidence suggesting that ROS play a role in the muscle injury observed after demanding or unaccustomed exercise (Supruniuk et al., 2023).

Eccentric exercise may lead to heightened levels of ROS, which are a result of oxidative stress. This oxidative stress can trigger a range of systemic and local inflammatory responses, as demonstrated in a study by Zhang et al., (2020). In the context of this specific research, inflammatory responses were associated with increased muscle cell damage indicated by CK release and pain sensation, and in a delayed manner which is characteristic of muscle damage due to heavy eccentric exercise (Tanabe et al., 2021; Wolska et al., 2023).

Selenium (Se), a essential trace element, plays significant roles in antioxidant and immune systems. As a vital component of selenoproteins, it participates in redox catalysis, structure, and transportation tasks. Selenium's functions involve antioxidant defense, thyroid hormone synthesis, testosterone metabolism, maintaining DNA integrity, modulating vitamin E (alpha-tocopherol),

combating cancer, and enhancing muscle performance (Wesolowski et al., 2022; Zhao et al., 2021).

Several studies reported that Selenium supplementation increased the activity of plasma Gluthatine Peroxidase (GPx) (Ringuet et al., 2021; S. Wang et al., 2022), a highly efficient antioxidant enzyme, is significantly dependent on the presence of Se (Shen et al., 2022). This implies that the connection between GPx and Se might be vital for the antioxidant GPx defense, which helps neutralize an excess of ROS (Reactive Oxygen Species). The formation of radicals and other ROS during exercise in muscle, and the antioxidant defense provided by Se, may form a reciprocal relationship, in which they may play a key role of the mineral trace element Se in exercise performance (Ammar et al., 2020).

Furthermore, this study showed that supplementation with selenium significantly reduced the increase in creatine kinase (CK) serum levels as a marker of muscle damage triggered by heavy eccentric exercise. The decrease in CK serum levels in this study was attributed to Selenium supplementation's capacity to restrain the NF-kappa B pathway by adjusting the expression of selenoprotein genes (Wang et al., 2022) This is believed to be due to the fact that by inhibiting the NF-kappa B pathway, the production of inflammatory markers decreases. Selenium seems to lessen nitric oxide (NO) production by regulating the expression of nitric oxide synthase (NOS) and inducible NOS (iNOS) genes (Zachariah et al., 2021).

Conclussion

In summary, we found that Se supplementation could contribute to reducing the increase in DOMS levels and serum CK levels caused by vigorous eccentric exercise. This was suggested to be probably due to the high efficiency of the Se-dependent enzyme GPx, which increased during the supplementation period. Consequently, Selenium supplementation could potentially serve as an enhancer of antioxidant potential for physically active individuals

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Conflict of Interest

All authors have no conflict of interest regarding this article. This research was funded by the Faculty of Sports Science through the Policy Research grant program of the Faculty of Sports Science, Surabaya State University in 2024

Ethical Clearence

This study followed ethical standards and received approval from the Health Research Ethics Committee, Faculty of Public Health, Airlangga University, and has been deemed ethically acceptable with the identity number: 104/EA/KEPK/2023. Participants provided informed consent, with the volunteer form covering research details, risks, benefits, confidentiality, and participant rights. The research strictly adhered to the ethical principles of the Declaration of Helsinki, prioritizing participants' rights and well-being in design, procedures, and confidentiality measures.

Author Contributions

Study design, AS; Data Collection, RJI; Statistical Analysis, AS, RJI; Manuscript preparation, AS, RJI; Literature review, AS, RJI. All authors have read and agreed to the published version of the Manuscript.

REFERENCES

Ali, M. A., Pangestu, B., Rahayu, S., Anggita, G. M., Kurniawati, D. M., Noer, E. R., & Mohamed, A. M. D. (2023). Foam rolling reduced total creatine kinase in acute muscle inflammation following long-distance running. *Journal Sport Area*, *8*(1), 117–122. [CrossRef]

Amalraj, A., Divya, C., & Gopi, S. (2020). The Effects of Bioavailable Curcumin (Cureit) on Delayed Onset Muscle Soreness Induced By Eccentric Continuous Exercise: A Randomized, Placebo-Controlled, Double-Blind Clinical Study. *Journal of Medicinal Food*, *23*(5), 545–553. [PubMed]

Ammar, A., Trabelsi, K., Boukhris, O., Glenn, J., Bott, N., Masmoudi, L., Hakim, A., Chtourou, H., Driss, T., Hoekelmann, A., & El Abed, K. (2020). Effects of Aerobic-, Anaerobic- and Combined-Based Exercises on Plasma Oxidative Stress Biomarkers in Healthy Untrained Young Adults. *International Journal of Environmental Research and Public Health*, *17*(7), 2601. [PubMed]

Angelopoulos, P., Diakoronas, A., Panagiotopoulos, D., Tsekoura, M., Xaplanteri, P., Koumoundourou, D., Saki, F., Billis, E., Tsepis, E., & Fousekis, K. (2022). Cold-Water Immersion and Sports Massage Can Improve Pain Sensation but Not Functionality in

Athletes with Delayed Onset Muscle Soreness. *Healthcare*, *10*(12), 2449. [PubMed]

Barker, G. A., Parten, A. L., Lara, D. A., Hannon, K. E., McAllister, M. J., & Waldman, H. S. (2023). Astaxanthin Supplementation Reduces Subjective Markers of Muscle Soreness following Eccentric Exercise in Resistance-Trained Men. *Muscles*, *2*(2), 228–237. [CrossRef]

Boukhris, O., Trabelsi, K., Abdessalem, R., Hsouna, H., Ammar, A., Glenn, J. M., Bott, N., Irandoust, K., Taheri, M., Turki, M., Ayadi, F., Bragazzi, N. L., Engel, F. A., & Chtourou, H. (2020). Effects of the 5-m Shuttle Run Test on Markers of Muscle Damage, Inflammation, and Fatigue in Healthy Male Athletes. *International Journal of Environmental Research and Public Health*, *17*(12), 4375. [PubMed]

Cosentino, R. G., Churilla, J. R., Josephson, S., Molle-Rios, Z., Hossain, M. J., Prado, W. L., & Balagopal, P. B. (2021). Branched-chain Amino Acids and Relationship With Inflammation in Youth With Obesity: A Randomized Controlled Intervention Study. *The Journal of Clinical Endocrinology & Metabolism*, *106*(11), 3129–3139. [PubMed]

Doma, K., Burt, D., & Connor, J. D. (2021). The acute effect of a multi-modal plyometric training session on field-specific performance measures. *The Journal of Sports Medicine and Physical Fitness*, *61*(7). [PubMed]

Fleckenstein, J., Neuberger, E. W. I., Bormuth, P., Comes, F., Schneider, A., Banzer, W., Fischer, L., & Simon, P. (2021). Investigation of the Sympathetic Regulation in Delayed Onset Muscle Soreness: Results of an RCT. *Frontiers in Physiology*, *12*. [PubMed]

Güçlüer, E. Ö., Ural, İ. H., Özden, A. V., Alptekin, H. K., et al. (2024). Effects of Auricular Vagus Nerve Stimulation on Cardio-Respiratory Functions After Aerobic Exercise. *International Journal of Disabilities Sports and Health Sciences, 7(3), 494-501*. [PubMed].

Harahap NS, Manalu N, Siregar NS, Machrina Y. Effect of Massage Therapy with Lime (Citrus Aurantifolia) Essential Oil on the Recovery of Delayed Onset of Muscle Soreness in Athletes. Med Arch. 2023 Feb;77(1):24-28. [PubMed].

Hanon, L., Salameh, H., Qadoume, A., Abualia, M., et al. (2024). The Contribution of Some Anthropometric Measurements and Pulmonary Volumes to The Digital achievement of the Sprint 400-meter Competition Among Elite Runners in Palestine. *International Journal of Disabilities Sports and Health Sciences, 7(3), 541-550.* [PubMed]

Hariharan, S., & Dharmaraj, S. (2020). Selenium and selenoproteins: it's role in regulation of inflammation. *Inflammopharmacology*, *28*(3), 667–695. [PubMed]

Hotfiel, T., Mayer, I., Huettel, M., Hoppe, M. W., Engelhardt, M., Lutter, C., Pöttgen, K., Heiss, R., Kastner, T., & Grim, C. (2019). Accelerating Recovery from Exercise-Induced Muscle Injuries in Triathletes: Considerations for Olympic Distance Races. *Sports*, *7*(6), 143. [PubMed]

Irawan, R. J., Sulistyarto, S., & Rimawati, N. (2022). Supplementation of Kencur (Kaempferia Galanga Linn) Extract on Malondealdehyde (MDA) and Interleukin-6 (IL-6) Plasma Levels Post Aerobic Training Activity. *Amerta Nutrition* , *6*(1SP), 140–145. [CrossRef]

Keriven, H., Sánchez-Sierra, A., Miñambres-Martín, D., González de la Flor, Á., García-Pérez-de-Sevilla, G., & Domínguez-Balmaseda, D. (2023). Effects of peripheral electromagnetic stimulation after an eccentric exercise-induced delayed-onset muscle soreness protocol in professional soccer players: a randomized controlled trial. *Frontiers in Physiology*, *14*. [PubMed]

Konrad, A., Kasahara, K., Yoshida, R., Yahata, K., Sato, S., Murakami, Y., Aizawa, K., & Nakamura, M. (2022). Relationship between Eccentric-Exercise-Induced Loss in Muscle Function to Muscle Soreness and Tissue Hardness. *Healthcare*, *10*(1), 96. [PubMed]

Kristi, P. D., Utami, D., Hadiono, H., & Dewi, N. A. (2023). The differences of the multistage fitness test and multistage shuttle swim test on swimmer's aerobic ability. *Fizjoterapia Polska*, *23*(4), 18–20. [CrossRef]

Kuršvietienė, L., Mongirdienė, A., Bernatonienė, J., Šulinskienė, J., & Stanevičienė, I. (2020). Selenium Anticancer Properties and Impact on Cellular Redox Status. *Antioxidants*, *9*(1), 80. [PubMed]

Lamb KL, Ranchordas MK, Johnson E, Denning J, Downing F, Lynn A. No Effect of Tart Cherry Juice or Pomegranate Juice on Recovery from Exercise-Induced Muscle Damage in Non-Resistance Trained Men. Nutrients. 2019 Jul 14;11(7):1593. [PubMed]

Marathamuthu, S., Selvanayagam, V. S., & Yusof, A. (2022). Contralateral Effects of Eccentric Exercise and DOMS of the Plantar Flexors: Evidence of Central Involvement. *Research Quarterly for Exercise and Sport*, *93*(2), 240–249. [PubMed]

Mesta, K., & Medithi, S. (2023). Effect of Omega-3 Fatty Acid Supplementation on the Delayed-Onset Muscle Soreness (DOMS) and Inflammatory Response among Athletes and Non-Athletes. *Current Nutrition & Food Science*, *19*(8), 796–805. [PubMed]

MS, S. A. B., Waldman, P. H. S., Krings, P. B. M., Lamberth, P. J., Smith, P. J. W., & McAllister, P. M. J. (2020). Effect of Curcumin Supplementation on Exercise-Induced Oxidative Stress, Inflammation, Muscle Damage, and Muscle Soreness. *Journal of Dietary Supplements*, *17*(4), 401–414. [PubMed]

Ringuet, M. T., Hunne, B., Lenz, M., Bravo, D. M., & Furness, J. B. (2021). Analysis of Bioavailability and Induction of Glutathione Peroxidase by Dietary Nanoelemental, Organic and Inorganic Selenium. *Nutrients*, *13*(4), 1073. [PubMed]

Saito, Y. (2022). Essential trace element selenium and redox regulation: its metabolism, physiological function, and related diseases. *Redox Experimental Medicine*, *2022*(1), R149–R158. [CrossRef]

Şentürk, G., & Göbel, P. (2022). Sporcularda Egzersiz Sonrası Gecikmiş Kas Ağrısı (Doms) Ve Beslenme Müdahaleleri. *Spor ve Performans Araştırmaları Dergisi*, *13*(1), 101–115. [CrossRef]

Shen, Y., Huang, H., Wang, Y., Yang, R., & Ke, X. (2022). Antioxidant effects of Se-glutathione peroxidase in alcoholic liver disease. *Journal of Trace Elements in Medicine and Biology*, *74*, 127048. [PubMed]

Sonkodi B. Delayed Onset Muscle Soreness (DOMS): The Repeated Bout Effect and Chemotherapy-Induced Axonopathy May Help Explain the Dying-Back

Mechanism in Amyotrophic Lateral Sclerosis and Other Neurodegenerative Diseases. *Brain Sci. 2021 Jan 15;11(1):108*. [PubMed]

Sulistyarto S, Irawan R, Kumaat NA, Rimawati N. Correlation of Delayed Onset Muscle Soreness and Inflammation Post-exercise Induced Muscle Damage. Open Access Maced J Med Sci [Internet]. 2022 Nov. 4 [cited 2024 Jun.25];10(A):1688-94. [CrossRef]

Supruniuk, E., Górski, J., & Chabowski, A. (2023). Endogenous and Exogenous Antioxidants in Skeletal Muscle Fatigue Development during Exercise. *Antioxidants*, *12*(2), 501. [PubMed]

Tanabe, Y., Fujii, N., & Suzuki, K. (2021). Dietary Supplementation for Attenuating Exercise-Induced Muscle Damage and Delayed-Onset Muscle Soreness in Humans. *Nutrients*, *14*(1), 70. [PubMed]

Tokinoya, K., Ishikura, K., Ra, S.-G., Ebina, K., Miyakawa, S., & Ohmori, H. (2020). Relationship between early-onset muscle soreness and indirect muscle damage markers and their dynamics after a full marathon. *Journal of Exercise Science & Fitness*, *18*(3), 115–121. [PubMed]

Varanoske, A. N., Harris, M. N., Hebert, C., Howard, E. E., Johannsen, N. M., Heymsfield, S. B., Greenway, F. L., Margolis, L. M., Lieberman, H. R., Church, D. D., Ferrando, A. A., Rood, J. C., & Pasiakos, S. M. (2021). Effects of testosterone undecanoate on performance during multi-stressor military operations: A trial protocol for the Optimizing Performance for Soldiers II study. *Contemporary Clinical Trials Communications*, *23*, 100819. [PubMed]

Wang, Q., Huang, J., Zheng, Y., Guan, X., Lai, C., Gao, H., Ho, C.-T., & Lin, B. (2022). Selenium-enriched oolong tea (Camellia sinensis) extract exerts anti-inflammatory potential via targeting NF-κB and MAPK pathways in macrophages. *Food Science and Human Wellness*, *11*(3), 635–642. [CrossRef]

Wang, S., Chen, Y., Han, S., Liu, Y., Gao, J., Huang, Y., Sun, W., Wang, J., Wang, C., & Zhao, J. (2022). Selenium nanoparticles alleviate ischemia reperfusion injury-induced acute kidney injury by modulating GPx-1/NLRP3/Caspase-1 pathway. *Theranostics*, *12*(8), 3882–3895. [PubMed]

Wolska, B., Domagała, Ł., Kisilewicz, A., Hassanlouei, H., Makar, P., Kawczyński, A., & Klich, S. (2023). Multiple cryosauna sessions for post-exercise recovery of delayed onset muscle soreness (DOMS): a randomized control trial. *Frontiers in Physiology*, *14*. [PubMed]

Yoon, W.-Y., Lee, K., & Kim, J. (2020). Curcumin supplementation and delayed onset muscle soreness (DOMS): effects, mechanisms, and practical considerations. *Physical Activity and Nutrition*, *24*(3), 39–43. [PubMed]

Zachariah, M., Maamoun, H., Milano, L., Rayman, M. P., Meira, L. B., & Agouni, A. (2021). Endoplasmic reticulum stress and oxidative stress drive endothelial dysfunction induced by high selenium. *Journal of Cellular Physiology*, *236*(6), 4348–4359. [PubMed]

Zhang, T., Zhao, T., Zhang, Y., Liu, T., Gagnon, G., Ebrahim, J., Johnson, J., Chu, Y.-F., & Ji, L. L. (2020). Avenanthramide supplementation reduces eccentric exercise-induced inflammation in young men and women. *Journal of the International Society of Sports Nutrition*, *17*(1). [PubMed]

Zhao, X., Gao, J., Hogenkamp, A., Knippels, L. M. J., Garssen, J., Bai, J., Yang, A., Wu, Y., & Chen, H. (2021). Selenium-Enriched Soy Protein Has Antioxidant Potential via Modulation of the NRF2-HO1 Signaling Pathway. *Foods*, *10*(11), 2542. [PubMed]

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