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Opinion

Eccentric exercise: Muscle damage to the new normal

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1. Introduction

When you hear the term "eccentric exercise", what comes to mind first? For many, it might be "muscle damage". Indeed, unaccustomed eccentric exercise is often associated with muscle damage characterized by delayed onset muscle soreness (DOMS) and a reduction in muscle force-generating capacity lasting more than a day.[1] However, this effect diminishes or at least is attenuated when the same eccentric exercise is repeated (known as the repeated bout effect).[1] Muscle damage can be largely prevented by preconditioning exercises consisting of low-intensity eccentric contractions or maximal isometric contractions at a long muscle length, and by gradual increases in intensity and volume from low-intensity non-damaging eccentric contractions.[2] Therefore, muscle damage should not deter people from engaging in eccentric exercises.

Eccentric exercise offers unique advantages over concentric or isometric exercise, particularly in promoting neuromuscular adaptations.[3] Eccentric exercise training provides numerous benefits for physical fitness and overall health, making it suitable for a wide range of individuals from children to older adults, clinical populations to athletes, and sedentary to highly active people. These benefits deserve much greater emphasis than the potential risk of muscle damage. We should establish eccentric exercise as standard practice, and make it common, accessible, and widely accepted as the "new normal" of exercise to improve life performance and high (athletic) performance. This article summarizes the key characteristics of eccentric exercise including muscle damage and the repeated bout effect, as well as its applications for athletic performance, physical fitness, and health, with the aim of promoting the broader and more effective use of eccentric exercises in practice.

2. Characteristics of eccentric contractions

Muscle contractions are traditionally classified as isometric, concentric, and eccentric, referring respectively to force generation without length change, shortening, and lengthening of prime movers. Although alternative terminology was proposed,[4] in this article the conventional labels are used. In eccentric contractions, force generated by muscles is smaller than the load applied to the muscles, while muscle force is greater than the external load for concentric contractions, and muscle force is equal to the external load in isometric contractions.

Eccentric contractions are distinguished by their ability to generate greater (>20%) force than concentric or isometric contractions, while requiring less metabolic cost.[5] The greater force generated in eccentric contractions results from the engagement of titin (connectin) upon activation; however, the exact mechanisms of the cross-bridge behavior in eccentric contractions have not been fully clarified.[6] This force advantage in eccentric in comparison to isometric and concentric contractions enables greater mechanical loading with lower perceived effort, making eccentric exercise appealing for strength development and rehabilitation. Eccentric exercises can be categorized by the intensity of eccentric contractions as follows:[5]

(a) Maximal eccentric loading: Loads exceed concentric 1-repetition maximum (RM) and require assistance or specialized devices.
(b) Accentuated eccentric loading: Load is greater during the eccentric than concentric phase.
(c) Prolonged eccentric loading: Extending the eccentric phase duration compared to the concentric phase duration (e.g., 3 s eccentric *vs.* 1 s concentric) using the same load for both phases.
(d) Eccentric-biased and low-load exercises: Activities like downhill walking, stair descent consist of low-intensity eccentric contractions.

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Eccentric contractions are less fatiguing, allowing more repetitions at comparable relative intensities, and they produce smaller declines in force output during repeated maximal efforts. Metabolically, eccentric exercise requires significantly lower oxygen consumption and is accomplished with a lower heart rate than concentric exercise at the same workload.[7] However, eccentric contractions impose greater cognitive demand, requiring heightened attention and control.[8] Another notable characteristic is the cross-education effect, whereby unilateral eccentric training enhances strength and muscle size not only in the trained limb but also in the contralateral, untrained limb. This effect appears to be stronger with eccentric than concentric training and has important implications for rehabilitation during immobilization or unilateral injury.[9]

3. Muscle damage induced by eccentric exercise

Eccentric contractions are the primary stimulus for exercise-induced muscle damage, whereas concentric exercise produces little or no damage, but isometric contractions at a long muscle length have been shown to induce damage but to a lesser extent than eccentric exercise.[5] The hallmark symptoms of eccentric exercise-induced muscle damage include DOMS, loss of muscle function, reduced range of motion, increased stiffness, and swelling.[1]

DOMS typically develops several hours after exercise, peaking between 24 h and 72 h following an eccentric exercise bout, while maximal strength loss is greatest immediately after exercise and recovers gradually over subsequent days. Importantly, the time course of DOMS and strength loss differ, indicating that these symptoms arise from partly distinct mechanisms. DOMS is understood as a form of mechanical hyperalgesia resulting from sensitization of nociceptors in connective tissue, mediated by inflammatory and neurotrophic factors such as nerve growth factor (NGF) and glial cell line-derived neurotrophic factor (GDNF).[10] Crucially, DOMS is not directly caused by muscle fiber rupture, as severe soreness can occur in the absence of substantial muscle fiber damage.

The constellation of symptoms following eccentric exercise closely mirrors the classic signs of inflammation; pain, swelling, stiffness, reduced function, and local heat, suggesting that inflammation, rather than structural muscle damage alone, underpins much of the post-exercise response.[5] Muscle damage is commonly assessed using blood biomarkers such as creatine kinase (CK), myoglobin, and other muscle-derived enzymes and structural proteins that have been shown to increase after eccentric exercise as a result of increased membrane permeability or membrane disruption. Fast-twitch skeletal muscle troponin I rises after eccentric exercise, indicating that fast-twitch fibers appear to be preferentially affected.[11]

Imaging techniques such as ultrasound and magnetic resonance imaging (MRI) reveal increased echo intensity and prolonged transverse (T2) relaxation times, respectively, reflecting muscle swelling and altered tissue properties.[5] These changes typically peak several days after exercise, coinciding with maximal swelling rather than initial force loss. Given the weak relationship between indirect markers and functional outcomes, it has been advocated that muscle function measures, particularly maximal voluntary contraction strength, are the most reliable indicators of the magnitude and time course of muscle damage.[12]

The classical model of eccentric muscle damage emphasizes increased intracellular calcium, activation of proteases, membrane disruption, and eventual fiber necrosis. However, evidence from human studies suggests that this pathway does not fully explain typical eccentric exercise-induced muscle damage. Instead, damage and inflammation appear to be more prominent in the extracellular matrix, including the endomysium and perimysium, where nociceptors are located.[5] Inflammatory cells are more commonly found in the extracellular matrix rather than within muscle fibers themselves after eccentric exercise.[13] This finding reinforces the idea that eccentric exercise primarily affects connective tissue structures surrounding muscle fibers rather than causing widespread fiber necrosis. Connective tissue damage provides a plausible explanation for DOMS, increased stiffness, swelling, and reduced range of motion, even in the absence of extensive muscle fiber injury.[5] Severe cases of eccentric contraction induced muscle damage, characterized by extremely high CK or myoglobin levels, likely do involve membrane damage and fiber necrosis, but these are not representative of most voluntary eccentric exercises performed in training or sport.[5]

4. Factors influencing the magnitude of muscle damage

Multiple factors determine how much muscle damage results from eccentric exercise. Key exercise-related factors include intensity, number of repetitions, velocity, and muscle length.[5] High-intensity, high-volume, and fast-velocity eccentric contractions performed at long muscle lengths induce the greatest damage.

Muscle group differences are evident, with arm muscles generally more susceptible than leg muscles, likely because leg muscles are more accustomed to eccentric loading through daily activities.[14] Age also influences susceptibility to muscle damage such that children experience less damage than adults,[15] and older adults experience less damage than younger adults,[16] possibly due to differences in muscle-tendon compliance and fiber-type composition. This suggests that less concern is required for children and older adults to perform eccentric exercises than young adults. Sex differences are less clear, with animal studies suggesting protective effects of estrogen, but human studies showing inconsistent results.[5] Training status is a major determinant; resistance-trained individuals experience far less muscle damage than untrained individuals, and flexibility training also confers some protection.[17]

The repeated bout effect refers to an adaptation by a single bout of eccentric exercise that confers long-lasting protection against muscle damage from subsequent bouts of the same or similar exercise.[2] This protection can persist for weeks to months, gradually diminishing over time. Importantly, substantial muscle damage during the first bout is not required to induce this protective effect. Low-intensity eccentric exercise or even a small number of maximal isometric contractions at long muscle lengths can provide significant protection against eccentrically induced muscle damage, a phenomenon known as the preconditioning effect.[2]

Protection can also transfer to the opposite limb, known as the contralateral repeated bout effect, which is shorter-lasting than the ipsilateral effect and is likely mediated by neural adaptations rather than structural changes.[2] The mechanisms underlying these protective effects are multifactorial, involving neural adaptations, changes in muscle stiffness, connective tissue strengthening, sarcomere addition, altered inflammatory responses, and heat shock protein expression. Neural adaptations at cortical and spinal levels appear particularly important for contralateral protection.[2]

While many therapeutic interventions (massage, vibration, light exercise, and nutritional supplements) have been studied, their effects are generally modest and inconsistent. Thus, the most effective strategy is prevention, achieved by careful exercise prescription. Introducing eccentric exercise gradually, and starting with low intensity, fewer repetitions, slower velocities, and shorter muscle lengths, significantly reduces the risk of severe muscle damage.[2] Progression should prioritize control and technique before increasing load or speed.

5. Eccentric exercise training in sport

Despite training adaptations, athletes in many sports still experience some degree of muscle damage following competition, particularly in team sports involving repeated accelerations, decelerations, and physical contact.[5] Soccer and rugby produce the greatest muscle damage and inflammatory responses, with recovery often requiring four or more days. Basketball, volleyball, badminton, and tennis generally induce less damage, allowing for shorter recovery intervals. Match scheduling plays a critical role in performance. Evidence suggests that teams with longer recovery intervals between matches often outperform those with shorter intervals, highlighting the importance of equitable scheduling in elite competitions.[18] Eccentric exercise training is essential for improving strength, power, speed, and change-of-direction performance, as well as reducing injury risk.[19] It induces unique neuromuscular and connective tissue adaptations that are particularly relevant for deceleration and force absorption tasks common in sport.[20]

It has been shown that eccentric-only isokinetic strength training is more effective for improving maximal voluntary contraction (MVC) eccentric strength, while it produces similar effects on improving MVC concentric and MVC isometric strength.[21] This may suggest that eccentric-only resistance exercise training provides versatile effects on neuromuscular function improvement necessary for athletic performance. It is interesting to investigate whether eccentric-only exercise training is enough to improve athletic performance in addition to training focusing on specific movements required for each sport. Further studies are necessary to investigate the mechanisms underpinning neuromuscular adaptations by eccentric-only training.

6. Eccentric exercise training for health

From a health perspective, eccentric exercise is suitable for older adults, clinical populations, and sedentary individuals. Research shows that eccentric exercise training can significantly improve muscle strength, power, lean body mass, balance, and functional ability.[3] Additional benefits include better cardiovascular health, metabolic function, and even cognitive improvements.[22] Traditional resistance exercise training may be difficult for individuals with reduced levels of muscle and cardiovascular function, since it induces elevated levels of perceived exertion, and loads used during exercise are limited by the maximum load handled in the concentric phase of an exercise. However, resistance exercises primarily employing low-intensity eccentric contractions appear ideally suited for these individuals.

Carrying out daily activities which emphasize eccentric contractions (e.g., descending stairs, walking downhill) has emerged as useful eccentric exercises. Chen et al.[23] showed greater benefits after descending than ascending stair walking performed by elderly obese women twice a week for 12 weeks such that greater improvement of cardiovascular function (resting heart rate: −10% *vs.* 4%; systolic blood pressure: −9% *vs.* 3%), insulin sensitivity (e.g., oral glucose tolerance test: −12% *vs.* 0%), blood lipid profile (e.g., low-density lipoprotein cholesterol: −13% *vs.* 0%) were achieved, in addition to increases in maximal voluntary isometric contraction strength (34% *vs.* 15%), and many other functional physical fitness measures. Importantly, it was possible to introduce descending stair walking exercise without muscle damage by gradually increasing the exercise volume. It seems that using submaximal intensity during eccentric exercise training is enough to elicit significant functional benefits. Future studies should investigate mechanisms underpinning the effects of eccentric exercises in comparison to other types of exercises (e.g., isometric exercises, concentric exercises, aerobic exercises). It seems likely that eccentric exercises could contribute to increasing health span, the length of time that we are healthy.

7. Body-weight eccentric exercises

Walking remains one of the most widely accessible forms of exercise as it requires no equipment, minimal skills, and poses a low risk of injury. Despite its benefits, walking may not provide sufficient mechanical loading to improve lower limb muscle strength and may not improve balance and flexibility. It appears that to increase lower limb muscle strength, especially for knee and hip extensors that are essential for daily functional activities, greater mechanical load needs to be added in normal walking. Thus, forms of body-weight eccentric exercises including downhill walking and descending stair walking have gained attention. As mentioned above, a 12-week training of descending stair walking performed twice a week resulted in greater improvements in lower limb muscle strength, bone mineral density, blood lipid profiles, glucose and insulin levels, when compared with ascending stair walking among elderly obese women. Despite these benefits, the practical implementation of descending stair walking and downhill walking is often limited by environmental constraints and safety concerns.

It was demonstrated that an 8-week eccentric walking program, which integrated controlled forward lunge steps into normal walking, resulted in significant improvement of lower limb muscle strength, physical function, and cognitive function that are not typically observed with regular walking alone.[24] These improvements were likely due to the greater eccentric loading to the lower limb musculature during the eccentric phase of each lunge, since the lower limb muscles, particularly the knee extensors, experience controlled eccentric loading while supporting body mass on a single leg. Kirk et al.[25] showed that a 5-min home-based eccentric exercise program involving four bodyweight-based exercises (chair squats, wall push-ups, chair-reclines, and heel drops) and their progressed variations significantly improved participants' muscle strength, flexibility, and mental health over an 8-week period with high adherence in healthy but sedentary individuals. Importantly, more than 90% of the participants continued to engage in regular exercise or physical activity beyond the intervention, highlighting the potential of this minimalistic approach to install lasting exercise habits. This sustained engagement illustrates the program's effectiveness in transitioning sedentary individuals to more active lifestyles. Such interventions could be crucial in public health strategies aimed at mitigating the risks associated with sedentary behavior by providing an accessible and sustainable gateway to regular physical activity.

8. Conclusion

Eccentric exercise is both a cause of muscle damage and a powerful stimulus for health and fitness promotion. Muscle damage is not inevitable, and it is not required for improvements in muscle size, strength, or performance. Through gradual progression, preconditioning, and intelligent programming, eccentric exercise can be used safely and effectively across populations, thus it should be recognized as an ideal intervention for all individuals. Future research should explore mechanisms and compare eccentric training with other modalities to optimize health span.

Declaration of competing interest

The author declares that he has no competing interests.

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