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Brief Review

Treatment and Prevention of Delayed Onset Muscle Soreness

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ABSTRACT

Eccentric exercise continues to receive attention as a productive means of exercise. Coupled with this has been the heightened study of the damage that occurs in early stages of exposure to eccentric exercise. This is commonly referred to as delayed onset muscle soreness (DOMS). To date, a sound and consistent treatment for DOMS has not been established. Although multiple practices exist for the treatment of DOMS, few have scientific support. Suggested treatments for DOMS are numerous and include pharmaceuticals, herbal remedies, stretching, massage, nutritional supplements, and many more. DOMS is particularly prevalent in resistance training; hence, this article may be of particular interest to the coach, trainer, or physical therapist to aid in selection of efficient treatments. First, we briefly review eccentric exercise and its characteristics and then proceed to a scientific and systematic overview and evaluation of treatments for DOMS. We have classified treatments into 3 sections, namely, pharmacological, conventional rehabilitation approaches, and a third section that collectively evaluates multiple additional practiced treatments. Literature that addresses most directly the question regarding the effectiveness of a particular treatment has been selected. The reader will note that selected treatments such as anti-inflammatory drugs and antioxidants appear to have a potential in the treatment of DOMS. Other conventional approaches, such as massage, ultrasound, and stretching appear less promising.

Key Words: DOMS, therapy, anti-inflammatory, eccentric exercise

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Introduction

Athletic performance and preparation are typically impaired when an athlete is sore or injured. Thus, any practice that limits the extent of damage or hastens recovery would be of interest and practical value to the coach, trainer, or therapist. Muscle soreness and damage often occur after selective exercise routines. This soreness typically peaks 24–48 hours after the exercise and subsides within 96 hours. The severity of damage and soreness vary as a function of several factors. For the practitioner, the most obvious would be familiarity with the exercise and the intensity at which it is performed. In general, more damage occurs with higher intensity and unfamiliar actions. Additional factors such as muscle stiffness, contraction velocity, fatigue, and angle of contraction have also been shown to play a role. However, these factors are more difficult to control in the field environment. Regardless, a basic understanding of the proposed mechanisms of injury and treatment for delayed onset muscle soreness (DOMS) will aid the coach or practitioner in program designs, allowing for minimal damage and optimum productivity over the training period. What follows is a review of proposed injury mechanisms followed by an evaluation of multiple proposed treatments.

Mechanisms of Injury

Exercise-induced muscle damage and its clinical corollary DOMS often result from unfamiliar predominantly eccentric exercise, such as downhill running. Furthermore, the degree of injury or damage is often a function of the trained state of the muscle. The injury itself is a mechanical disruption to sarcomeres (86) that proliferates secondary to an inflammatory response (28). A schematic of the events associated with DOMS and the interventions designed to target various aspects of the sequence (mechanical damage, inflammation and swelling, and free radical proliferation) is presented in Figure 1. Eccentric exercise results in injury to the cell membrane, setting off an inflammatory response that leads to prostaglandin (prostaglandin E_2 [PGE_2]) and leukotriene synthesis. Prostaglandin E_2 directly causes the sensation of pain by sensitizing type III and IV pain afferents to the effects of chemical stim-

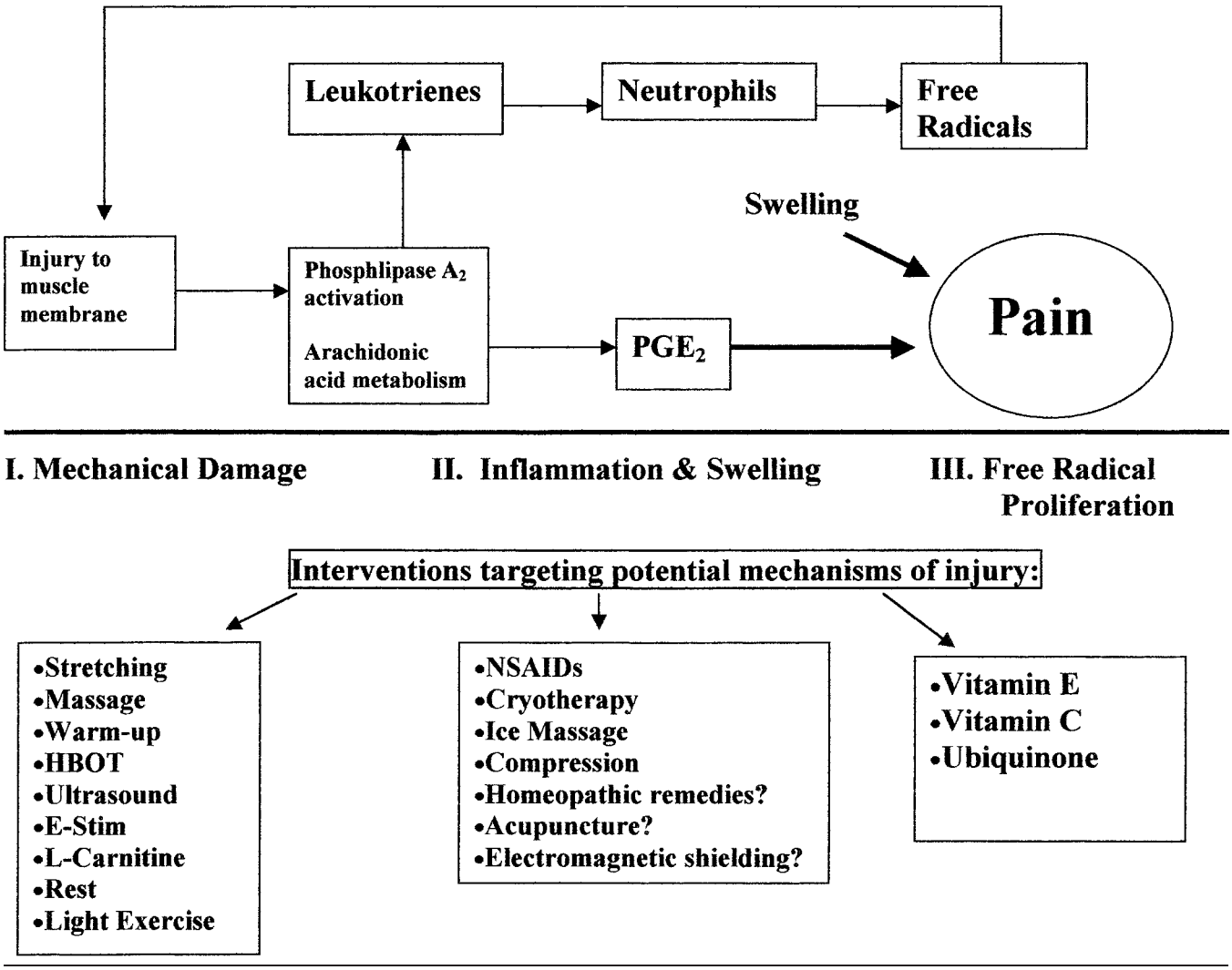

Figure 1. Schematic showing possible sequence of injury and treatment of delayed onset muscle soreness.

uli, whereas leukotrienes increase vascular permeability and attract neutrophils to the site of damage. The ''respiratory burst'' of the neutrophils generates free radicals, which can exacerbate damage to the cell membrane. Swelling results from the movement of cells and fluid from the bloodstream into the interstitial spaces with inflammation and can contribute to the sensation of pain. The injury pattern is relatively sporadic throughout the muscle (45), and the tenderness that occurs appears to vary regionally within the muscle belly itself (19). Sarcomere disruption does not extend the length of a myofibril and usually does not extend across a whole muscle fiber (45). In fact, adjacent fibers will appear relatively normal. This injury pattern is in contrast to a muscle strain, which is usually an isolated disruption of the muscle-tendon junction extending across the fibers (62). This is important because in the early phase after a muscle strain, vigorous muscle contractions, especially eccentric contractions, can exacerbate the injury. On the other hand, in a muscle that has been eccentrically damaged, additional eccentric contractions on subsequent days do not exacerbate the existing damage (63), although it appears that this response is localized (13). Hence, it is important to appreciate that exercise-induced muscle damage and muscle strains are different clinical entities and should be treated so.

There is some evidence indicating that fast-twitch fibers are more susceptible to eccentric contraction–induced damage (25, 26, 45, 49). This may be due to an inherent weakness in these fibers (49) or selective recruitment of fast-twitch motor units for eccentric exercise (20, 35, 53, 58, 59). The severity of damage and the time course of the subsequent symptoms are dependent on both the specific conditions of the exercise bout and the intrinsic factors related to the individual. For example, the length of the exercising muscle is more important than the actual contraction intensity, with greater damage occurring with exercise at longer muscle lengths (7, 11, 36, 46, 61). Individuals with greater muscle stiffness appear to experience greater DOMS after eccentric exercise (54).

Table 1. Selected indices evaluating muscle damage.

Index	Damage information	Cost	Difficulty of measure	Reliability	Comments
Biopsy	Local	High	High	High	Best indicator
Strength	Local	Low	Low	Medium	
Pain	Central	Low	Low	Medium-high	High subjectivity
Tenderness	Local	Low	Low	Medium	High subjectivity
Stiffness	Local	Low	Low	Medium-high	
Swelling	Local	Low	Low	Medium-high	
Creatine kinase	Central	Low	Low	Low	High inter- and intraindividual variation
Lactate dehydrogenase	Central	Low	Low	Low	High inter- and intraindividual variation
Glutamic oxaloacetic transaminase	Central	Low	Low	Low	High inter- and intraindividual variation

The Symptoms Associated With DOMS

The typical symptoms associated with DOMS are strength loss, pain, muscle tenderness, stiffness, and swelling (52). Many variables are reported in the quantification of muscle damage. Selected variables summarizing more common measures of muscle damage are presented in Table 1. Strength loss usually peaks immediately after exercise or within the first 48 hours, with full recovery generally taking more than 5 days. Pain and tenderness peak 1–3 days after exercise, subsiding within approximately 7 days. Stiffness and swelling usually peak 3–4 days after exercise and typically resolve within 10 days. These various symptoms can also present independently of each other. For example, pain and tenderness do not contribute to the strength loss as supported by the fact that there is no evidence of neural inhibition of damaged muscle (53) or changes in motor unit activation (74). The pain and stiffness may be more related to the inflammatory response than to the actual damage.

Most of the proposed treatments that are discussed later are directed at limiting the inflammatory response after eccentric exercise. Inflammation is often viewed as undesirable because of the pain and discomfort that accompanies this response. However, the resulting removal of necrotic tissue and the establishment of a cellular environment conducive to repair is a necessary and beneficial phenomenon (1). Very simply, a mechanical stressor such as eccentric exercise often results in injury to the cell membrane, initiating an inflammatory response that can result in further injury to the muscle and the sensation of pain. Cell membrane damage disrupts calcium homeostasis due to the influx of calcium from extracellular sources (8). When calcium invades the cell, various proteases and enzymes such as phospholipase A_2 are activated. This enzyme has the capability of cleaving arachidonic acid from the phospholipids of the cell membrane, resulting in free arachidonic acid. Once free from the cell membrane, arachidonic acid gives rise to important inflammatory mediators such as thromboxanes, prostaglandins, and leukotrienes. Arachidonic acid metabolism can follow 1 of 2 pathways, i.e., the cyclo-oxygenase (COX) pathway, with the production of prostaglandins and thromboxanes, or the lipoxygenase (LIPOX) pathway and the production of leukotrienes. Production of PGE_2 by way of COX increases vascular permeability and pain perception in the muscle (82) by sensitizing the type III and IV afferent nerve fibers to both chemical and mechanical stimuli. Leukotrienes are a potent inflammatory mediator that increases vascular permeability and acts as a chemoattractant to neutrophils (32). Once neutrophils infiltrate injured tissue, they can cause further damage by releasing cytotoxic factors and generating free radicals during phagocytosis (22). Thus, even though inflammation is a positive healing process in the body, its short-term effects may result in elevated pain and inhibited short-term recovery of muscle function.

Numerous pre- and postexercise interventions have been investigated with respect to preventing DOMS or treating the subsequent symptoms. These interventions can be grouped into 3 broad categories: (a) pharmacological treatments using nonsteroidal anti-inflammatory drugs (NSAIDs), (b) therapeutic treatments using physical modalities, and (c) interventions using nutritional supplements. In the following sections, each of these categories will be discussed.

Pharmacological Treatment of DOMS Using NSAIDs

One of the many treatment modalities advocated to facilitate recovery of muscle function and alleviate the symptoms of DOMS is NSAIDs. The value of NSAID therapy in the treatment of DOMS is equivocal, with the majority of studies showing no effect despite a strong theoretical basis for efficacy. The following sections will address the inflammatory response of the

Table 2. Studies demonstrating no efficacy of nonsteroidal anti-inflammatory drug (NSAID) treatment after eccentric contraction–induced muscle damage.

Study	*n*	NSAID	Dose (mg)	Treatment period*	DOMS (±/−)†	Muscle function (+/−)
Kuipers et al. (42)	6	Flurbuiprofen	150	−24 to 72 h Post	−	−
Donnelly et al. (16)	16	Ibuprofen	2,400	−25 to 72 h Post	−	−
Grossman et al. (29)	10	Ibuprofen	2,400	−24 to 96 h Post	−	−
Pizza et al. (67)	10	Ibuprofen	2,400	−5 to 10 d Post	−	−
Howell et al. (33)	15	Flurbiprofen	300	−24 h to 14 d Post	−	−‡
Howell et al. (34)	16	Ibuprofen	1,600 or 3,200	−24 h to 6 d Post	−	−
Semark et al. (75)	13	Flurbiprofen	40	−12 to 72 h Post	−	−
Bourgeoise et al. (5)	8	Naproxen	500	−4 h to 48 h Post	−	+/−§
Barlas et al. (4)	12	Aspirin	900	0 to 11 d Post	−	−

* − indicates treatment began prior to the damage session.
† DOMS = delayed onset muscle soreness.
‡ Impaired force recovery at 14 days.
§ Study used both eccentric and concentric contractions.

tissue to mechanical damage, the effects of NSAIDs on this response, and the potential mechanism for alleviating DOMS.

Nonsteroidal anti-inflammatory drugs work after strenuous exercise by inhibiting the COX enzyme and thus PGE_2 synthesis. Nonsteroidal anti-inflammatory drugs can be classified as single- or dual-action drugs. Nonsteroidal anti-inflammatory drugs such as aspirin, naproxen, flurbiprofen, and ibuprofen are COX inhibitors only and are single-action drugs. Other NSAIDs such as diclofenc and ketoprofen are dual-action NSAIDs blocking both the COX and LIPOX pathways of arachidonic acid metabolism. The latter NSAIDs may therefore have a more powerful anti-inflammatory effect than the single-action NSAIDs. Dual-action NSAIDs may be more similar to steroid hormones in their effects on inflammation. Corticosteroids, such as glucocorticoids, inhibit phospholipase A_2 and thus block the initial cleavage of arachidonic acid from the cell membranes, resulting in a more complete anti-inflammatory effect than most commonly used over-the-counter single-action NSAIDs. However, glucocorticoids have numerous side effects including facilitation of bone and muscle loss, edema, and hypertension (51); thus, their role as an anti-inflammatory agent should be limited. The NSAIDs also have negative side effects such as gastrointestinal distress and renal and hypertensive effects (6); however, these side effects are less frequent and of less severity than those of the glucocorticoids. At lower doses NSAIDs tend to exert an analgesic effect, whereas at higher doses an anti-inflammatory effect is achieved (32). One possible explanation for this is that NSAIDs at higher doses disrupt the activity of certain white blood cells such as neutrophils and macrophages (2). Thus, NSAIDs may have a direct inhibitory effect on inflammation, independent of the pain-reducing effects of PGE_2 inhibition.

The Efficacy of NSAIDs on DOMS

This review is limited to a discussion of human studies examining NSAIDs and their effects on DOMS and other pertinent indirect measurements of muscle damage. All studies used some form of eccentric exercise that standardized the injury protocol. However, the modes of eccentric exercise differed between studies and included isokinetic dynamometry (24, 30, 44), cycle ergometry (42), drop jumping (75), high-force eccentric exercise (18, 29, 33, 34, 67, 74), box stepping (66), and downhill running (16, 17). The NSAID therapy in these studies was either prophylactic, beginning before the eccentric exercise (as a prevention to exercise damage), or therapeutic, beginning after eccentric exercise (as a treatment to exercise damage). A summary of the results of studies demonstrating either no efficacy or some efficacy of NSAIDs on DOMS is shown in Tables 2 and 3, respectively. For organizational purposes, we first discuss studies showing no efficacy of NSAIDs on DOMS and then present those showing an effect on DOMS.

Studies Demonstrating No Efficacy of NSAIDs on DOMS

Most of the NSAID studies showing no effect on DOMS involved the use of ibuprofen or flurbiprofen. Both medications are from the same carboxylic acid classification and the same propionic acid subclassification (16, 29, 33, 34, 42, 67, 75). One study used aspirin (4). The reader should note that direct comparison among study findings is not always straightforward because of variations in study design, most noticeably medication dosage and damage protocol.

Table 3. Studies demonstrating some efficacy of nonsteroidal anti-inflammatory drug (NSAID) treatment after eccentric contraction–induced muscle damage.

Study	*n*	NSAID	Dose (mg)	Treatment period*	DOMS (+/−)†	Muscle function (+/−)
Francis and Hoobler (24)	10	Aspirin	2,600	−4 to 48 h Post	+	−
Donnelly et al. (17)	20	Diclofenac	150	−1.5 to 72 h Post	+/−	N/A‡
Hasson et al. (30)	5	Ibuprofen	1,200	−4 to 24 h or 24 h Post	+	+
Dudley et al. (18)	8	Naproxen	660	0 to 10 d Post	+	+
Lecomte et al. (44)	20	Naproxen	1,000	0 to 7 d Post	+	+
O'Grady et al. (66)	27	Diclofenac	150	−13 to 14 d Post	+	+§
Sayers et al. (74)	12	Ketoprofen	25 or 100	36 h Post	+	−

* − indicates treatment began prior to the damage session.
† DOMS = delayed onset muscle soreness.
‡ NA = not applicable.
§ Histological assessment of muscle.

Kuipers et al. (42) were the first to address the question of whether anti-inflammatory medications showed efficacy in the treatment of DOMS. This study used 6 subjects in a crossover design. Subjects were treated prophylactically with either 150 mg of flurbiprofen or a placebo 24 hours before eccentric cycling and then for 72 hours after exercise. Although the researchers reported no effect of flurbiprofen on DOMS, creatine kinase (CK), or muscle histology, there was significantly lower muscle soreness after the second eccentric exercise bout, which was administered 3 weeks after the first bout. This phenomenon has been described widely as the repeated bout effect (RBE) and has been shown by multiple investigators (52, 60, 63, 65). In light of the RBE, the exact effect of the flurbiprofen remains unclear. A similar methodological concern was also observed in a crossover design study by Donnelly et al. (16) using ibuprofen. Sixteen subjects were treated prophylactically with 2,400 mg of ibuprofen or a placebo 24 hours before and for 72 hours after a 45-minute downhill running protocol. Repeated bouts of this exercise were only 10 weeks apart, and although they report no efficacy of ibuprofen on DOMS, muscle strength, or endurance time, CK activity was actually higher in the ibuprofen group compared with the placebo after both eccentric exercise protocols. These results suggest that ibuprofen could contribute to greater levels of damage in the treated muscle. However, a study by Pizza et al. (67) showed that treatment with 2,400 mg of ibuprofen for 5 days before and 10 days after high-force eccentric exercise of the elbow flexors reduced CK activity in 10 men. It is unclear why inconsistencies were observed when using the same NSAID; however, differences in the mode and intensity of exercise or the length of the treatment period may have contributed to the observed differences.

Two studies, however, have reported impaired recovery of muscle function with NSAID treatment after eccentric contractions (33, 57). Howell et al. (33) treated 15 subjects prophylactically with either 300 mg of flurbiprofen or a placebo 24 hours before and for 14 days after eccentric exercise of the elbow flexors. They reported no efficacy of flurbiprofen on DOMS, swelling, or stiffness; however, maximal force was significantly lower 14 days later in the flurbiprofen group. Mishra et al. (57) similarly reported impaired recovery of muscle function 28 days after a 6-day flurbiprofen treatment in the animal model. Because most human studies have not evaluated recovery after 14 days, it is not known whether NSAIDs may contribute to long-term negative effects on muscle function reported in the Mishra et al. (57) study.

Other studies have also demonstrated a lack of efficacy of NSAID treatment after eccentric exercise (4, 29, 34, 75). Although the flurbiprofen and ibuprofen studies used dosages ranging from analgesic (34, 75) to anti-inflammatory dosages (33, 34), no efficacy was demonstrated consistently. Furthermore, the flurbiprofen and ibuprofen studies showed a lack of efficacy over both short (16, 75) and long dosing periods (33, 67). Thus, it appears that lack of efficacy of these 2 NSAIDs is neither dose dependent nor time dependent. Also, all flurbiprofen and ibuprofen studies that showed no efficacy (16, 29, 33, 34, 42, 67, 75) used prophylactic doses. The expectation might be that prophylactic NSAID treatment would maximize the anti-inflammatory effect by inhibiting the immediate response to the mechanical injury. However, this was not observed in any of the studies.

Studies Demonstrating Efficacy of NSAIDs on DOMS

In contrast to the aforementioned studies, work by Hasson et al. (30) found that 400 or 1,200 mg of ibuprofen ingested 4 hours before or in the 24 hours after eccentric exercise, respectively, significantly enhanced

recovery of muscle force and further reduced DOMS 48 hours after exercise in the quadriceps. The reader should note, however, that there were only 5 subjects in this treatment group. In contrast, both Donnelly et al. (17) and O'Grady et al. (66) used larger sample sizes when examining the effect of the NSAID diclofenac on DOMS after eccentric exercise. Donnelly et al. (17) treated 20 subjects with a prophylactic dose of diclofenac (150 mg) from 1.5 to 72 hours after exercise using a crossover design where 2 bouts of downhill running were separated by a 10-week interval. Despite the similar design concerns previously identified (42), significant reductions in measures of DOMS at certain sites were reported after the first bout in the diclofenac group compared with the placebo group. O'Grady et al. (66) treated 27 subjects with a prophylactic dose of diclofenac (150 mg) from 14 days before to 13 days after eccentric box-stepping exercise. Not only was DOMS reduced but CK activity also was lower and histological assessment of biopsied muscle suggested less damage. In humans, therefore, both short-term and long-term diclofenac administration appears to have some positive effects on DOMS and muscle damage. One possible explanation is diclofenac's role as a dual-action NSAID inhibiting both the COX and LIPOX pathways of arachidonic acid metabolism (6), thus providing a potentially greater anti-inflammatory effect.

Another NSAID that has shown potential in the treatment of DOMS is naproxen. Both Dudley et al. (18) and Lecomte et al. (44) demonstrated enhanced recovery of force and reduction of DOMS in the quadriceps with naproxen. Dudley et al. (18) reported that daily administration of 660 mg of naproxen up to 10 days after eccentric exercise enhanced force recovery and reduced thigh soreness 4 days after exercise when compared with a placebo. Lecomte et al. (44) reported that daily administrations of 1,000 mg of naproxen for 7 days resulted in reduced soreness 3 days after exercise and a greater recovery of quadriceps torque at $60°{\cdot}s^{-1}$ compared with a placebo. Interestingly, naproxen is structurally similar to ibuprofen and flurbiprofen with all 3 NSAIDs being carboxylic acids and propionic acid derivatives (32). However, ibuprofen and flurbiprofen have not demonstrated efficacy in treating DOMS. Design concerns in both Dudley et al. (18) and Lecomte et al. (44) may again limit the applicability of their findings. Dudley et al. (18) used a small sample size ($n = 8$), whereas Lecomte et al. (44) used an eccentric exercise that induced only 5 and 10% reductions in torque in the naproxen and control groups, respectively. It is possible that with so little damage to the muscle (and potential inflammation), differences in force recovery were due to factors other than naproxen. Moreover, a study by Bourgeoise et al. (5) using both concentric and eccentric exercise showed no effect of 48 hours of naproxen treatment on DOMS.

In contrast to the work of Barlas et al. (4) that showed no effect of aspirin on DOMS, a study by Francis and Hoobler (24) reported that treatment with aspirin after eccentric exercise resulted in a significant reduction in soreness and improved the range of motion when compared with a placebo. Conflicting findings may be explained by the fact that Barlas et al. (4) used 900 mg, whereas Francis and Hoobler (24) administered much higher dosages (2,600 mg for 48 hours). In addition, no placebo group was used in the Francis and Hoobler (24) study; thus, these results should be interpreted with caution. A recent study by Sayers et al. (74) reported enhanced recovery of force and decreased soreness in 36 subjects after eccentric exercise of the elbow flexors using ketoprofen. Whereas most of the aforementioned studies examined a particular NSAID and its effect on recovery of muscle function over several days, Sayers et al. (74) examined the acute effects of NSAIDs during the hours of peak muscle soreness, approximately 36–44 hours after exercise. This study design excluded those subjects who did not report at least moderate soreness (using a 50-mm cutoff criterion on a 100-mm visual analog scale [VAS]) 36 hours after eccentric exercise. It was reported that both 25 and 100 mg of ketoprofen administered at 36 hours resulted in a significant reduction in soreness over the following 8 hours when compared with a placebo. Furthermore, the 100-mg dose resulted in a significant recovery of force over the same 8-hour treatment period. These results could be due to the fact that ketoprofen, like diclofenac, which also showed efficacy, is a dual-action NSAID and may potentially exert a greater anti-inflammatory effect.

Why Discrepancies Exist Among Studies?

The reader will note the obvious contrast in the efficacy of various NSAIDs among the studies. One factor that must be considered is the mode of eccentric exercise used. Differences among studies may result in more or less soreness and damage (and perhaps more or less inflammation). Several researchers have suggested that eccentric exercise may not initiate a full inflammatory response in humans (33, 64). In addition, different eccentric exercise studies have demonstrated temporal discrepancies in the appearance of inflammatory mediators (9, 23, 38, 71). Perhaps different modes of eccentric exercise resulted in different magnitudes of the inflammatory responses that were either able or unable to be alleviated with a particular NSAID dosage. Other differences among the studies that may contribute to the disparate finding could be the type of NSAID used and its strength, the duration of the treatment, and the dosage administered. In addition, it appears that an arm-damage model results

in better control of damage than the leg-damage model.

A second explanation may be the fact that not everyone undergoing eccentric exercise demonstrates muscular soreness. Observations from our laboratories indicate that 30–35% of subjects do not demonstrate at least moderate soreness (at least 50 mm on a 100 mm VAS) during the hours of peak soreness after eccentric exercise (74). This could have important consequences in prophylactic NSAID studies because subjects with reduced muscular soreness after NSAID administration may not demonstrate the effects of the drug treatment but instead may simply not demonstrate a soreness response to eccentric exercise. In addition, if nonresponders are placed in a placebo group, efficacy of a particular NSAID may be masked by this aberrant response. Only Howell et al. (33, 34) have reported cutoff criteria in their studies, disqualifying subjects who do not demonstrate at least a 25% force loss after eccentric exercise. However, a poor relationship has been reported between muscular force and muscle soreness after eccentric exercise (69); thus, a cutoff criterion based on force loss may not be sufficient to detect nonresponders to muscle soreness.

Therapeutic Treatment of DOMS Using Physical Modalities

Numerous therapeutic interventions aimed at alleviating DOMS have been proposed. Standard physical therapy modalities such as cryotherapy, ultrasound, and electric stimulation have been used (12, 14, 21, 78, 89, 90). In addition, massage, stretching, light exercise, immobilization, and simple rest have been examined (48, 70, 73, 80, 85). Alternative treatments include hyperbaric oxygen therapy (HBOT) and electromagnetic shielding (55, 91). Despite the volume of work in this area, there is little consensus among practitioners as to the most effective way to manage the symptoms of damage. Reliance on anecdotal evidence or studies with poor experimental design may perpetuate ineffective treatments where, at best, placebo effects predominate.

Warm-up, Stretching, and Massage

Arguably the most commonly practiced treatments for DOMS are passive stretching and massage. Surprisingly, little scientific evidence to support the effectiveness of this treatment exists. Some studies have examined combinations of treatments, such as, warm-up, stretching, and massage (70), warm underwater water-jet massage (85) and ice massage (90). Other studies have examined single interventions of massage (80) and stretching (48). In yet another study, massage was compared with electric stimulation and light exercise (89). The combination of pre-exercise warm-up with stretching and postexercise massage (i.e., on subsequent days) had positive effects (70) as did warm underwater water-jet massage (85). Rodenburg et al. (69) randomly assigned 50 subjects to a treatment or control group. An eccentric elbow flexor exercise protocol was used as the treatment with pre-exercise warm-up and postexercise massage 15 minutes after exercise. There was evidence of less muscle tenderness, less strength loss, and greater elbow flexion ROM in the treatment group, but relaxed elbow extension, CK activity, and serum myoglobin were not different between groups. However, it is difficult to attribute these positive effects to massage. Pre-exercise warm-up has been shown to be effective in reducing DOMS (64), and such an effect alone could explain the results of Rodenburg et al. (70). As for the effectiveness of water-jet massage in reducing DOMS, these results cannot be generalized to the more commonly practiced manual massage. There is a similar lack of evidence to support postexercise stretching for treating DOMS. It could be argued that no study has adequately examined the potential therapeutic effects of stretching or massage with proper experimental design and sufficient sample size. However, more importantly, a sound rationale for why either stretching or massage would alleviate DOMS has not been established.

Cryotherapy and Compression

In contrast to massage and stretching, there is a sound rationale for the use of cryotherapy and compression in the treatment of DOMS. Various modes of applying ice and compression are used routinely in clinical practice to provide pain relief, diminish inflammatory responses, and reduce swelling for numerous types of injuries (76). With respect to DOMS, cold-water immersion (21), intermittent pneumatic compression (12), and compression sleeves (41) have been shown to be effective in providing some relief of DOMS. A treatment of cold-water immersion for 15 minutes immediately after eccentric elbow flexor exercise and every 12 hours for a total of 7 treatments was effective in reducing stiffness, as measured by relaxed arm angle, and resulted in lower values for plasma CK activity (21). A treatment of intermittent pneumatic compression for 20 minutes immediately after eccentric elbow flexor exercise and daily for the next 5 days was effective in reducing stiffness and swelling. However, these effects were only evident immediately after treatment. Longer duration effects were not investigated because a control group not receiving any treatment was not used (12). Recently, Kraemer et al. (41) demonstrated that wearing a compression sleeve garment for 5 days after a bout of eccentric elbow flexor exercise was effective in reducing the strength loss, soreness, swelling, and stiffness.

In contrast to these effective treatments (12, 21, 41), ice massage was an ineffective treatment (90). However, this may have been due to the fact that only 1

treatment was applied for 15 minutes immediately, 24 hours, or 48 hours after the exercise. Interestingly, the combination of ice and compression has not been studied specifically in relation to DOMS. Based on clinical practice and the encouraging results with ice (21) and compression (12, 41) separately, this combination might prove to be the most efficacious treatment.

Rest Vs. Therapeutic Exercise

The issue of whether it is better to exercise or rest when experiencing DOMS has spurred much interest. Recently, Sayers et al. (73) examined the potential benefits of light exercise or immobilization compared with those of simply resting. The elbow joints of 9 subjects were immobilized at 90° immediately after eccentric elbow flexor exercise. Light exercise was performed by 9 subjects (50 bicep curls with 5 lb), and 8 subjects simply rested their elbow flexors. Strength recovery was better after either light exercise or immobilization when compared with just rest. These results were encouraging because there is a natural tendency to perform light exercise to alleviate DOMS. The benefits of immobilization emphasize that interventions should be directed at enhancing the healing potential of the muscle tissue. Interestingly, immobilization with the muscle in a lengthened position is the recommended treatment for quadriceps contusions (72). This is thought to reduce scar tissue formation and facilitate sarcomere regeneration. Although a muscle contusion is a much more severe injury than exercise-induced muscle damage, the same principles of healing likely apply. Future work might examine whether immobilization at 0° (lengthened position) is more effective.

Alternative Therapies

Recently, HBOT has received increased attention as a possible treatment for DOMS. Hyperbaric oxygen therapy is a clinical treatment whereby subjects breathe 100% oxygen (O_2) in an attempt to supersaturate the blood with O_2. This mechanism of supersaturating the blood with O_2 has been shown to decrease healing time (15). In 1 study, subjects breathed 100% O_2 for 60 minutes a day for 7 successive days after an exercise session designed to eccentrically damage the elbow flexors (55). The authors reported no effect on soreness, strength loss, or rate of recovery in comparison to a control group breathing 8% O_2 for the same duration. The effects of acupuncture have also been investigated. Lin and Yang (47) evaluated the effects of acupuncture on DOMS in 20 male subjects and reported a significant decrease in muscle soreness at 72 hours after exercise. Acupuncture was administered immediately after and 48 hours after exercise. No effect on CK was reported. Interestingly, there were greater differences in mean soreness scores immediately after rather than at 72 hours after the exercise, even though they are not reported as significant.

Recent work by Zhang et al. (91) provided clear evidence of attenuation of DOMS by applying an electromagnetic shielding fabric to the eccentrically exercised muscle. Using a randomized, single-blind, placebo-controlled crossover design, Zhang et al. (91) showed that strength loss, pain, biochemical markers of damage, and markers of inflammation were all reduced by wearing the shielding fabric for 5 days after a bout of eccentric quadriceps exercise. Although the mechanism of effect was not apparent, it was postulated that the fabric facilitated an anti-inflammatory effect. This was a well-designed clinical trial in contrast to the majority of studies examining potential treatments for DOMS.

Practicality of Therapeutic Interventions

Although there is some evidence that DOMS may be alleviated by either cryotherapy or immobilization, this information may be of little practical value. In practice, muscle damage is rarely isolated to a single muscle group. The usual clinical presentation involves symptoms in multiple muscle groups after unfamiliar predominantly eccentric exercise involving numerous body parts, for example, a new exercise regimen or recommencing training after a long break. In this case, it is often not feasible to treat all affected areas with ice, and immobilization is not a realistic alternative option. Anecdotally, some American football players use whole-body ice immersion to treat nonspecific aches and pains. Although this may be beneficial, few athletes would tolerate the discomfort of such a treatment. The best advice might be to perform light exercise and simply wait for the symptoms to resolve. It should be emphasized that exercise-induced muscle damage is a normal exercise response that will in itself provide protection against damage from repeated exercise bouts. To assess the potential of a successful therapeutic intervention, it is important to (a) understand the mechanism of the injury and the structures involved, (b) appreciate potential methodological problems in both positive and negative studies, and (c) evaluate the practicality of potentially efficacious interventions. Potential mechanisms for injury have been discussed already, and methodological problems in all 3 treatment areas will be addressed in the relevant section as will the evaluation of proposed treatments.

Interventions using Nutritional Supplements

Nutritional supplements have become increasingly popular in the treatment of many conditions including DOMS. Of particular interest is the belief that presupplementation before exercise may induce a preventive effect. The results appear mixed.

Antioxidant Therapy

Free radical proliferation is a strongly suggested mechanism in the damage response to exercise occurring mainly by way of phacocytosis and activation of the respiratory burst by neutrophils generated during the inflammatory response (68). Recently, Hellsten et al. (31) reported that the level of xanthine oxidase was elevated after eccentric exercise. Because xanthine oxidase is capable of generating the superoxide radical, there is potential for proliferation of more dangerous free radicals and increased muscle damage (31). Hence, it seems plausible that supplementation with antioxidants before exercise may reduce damage. In general, the treatment of DOMS using conventional antioxidants (vitamins C and E) has been inconsistent, and few well-controlled studies exist, especially those using vitamin C. Kaminski and Boal (39) presupplemented subjects for 3 days with 1 g of vitamin C 3 times a day and then induced damage in the posterior calf muscles. Supplementation continued for 7 days after the exercise. Subjects treated with vitamin C reported reduced soreness ratings ranging from 25–44% less than a control group. To our knowledge no other published work exists to refute or support this finding. The effects of vitamin E have, however, been tested more widely. Cannon et al. (10) reported a decrease in CK and a faster recovery after supplementation of 400 $IU \cdot d^{-1}$ of vitamin E. Values were most noticeably different 48 hours after exercise. In agreement, Meydani et al. (56) reported a decrease in thiobarbituric acid after vitamin E supplementation of 800 $IU \cdot d^{-1}$ for 48 days before the exercise. In both studies, the mode of exercise was downhill running. In contrast, several investigators report contrasting findings. Warren et al. (87) reported no effect of vitamin E supplementation on selected markers of strength or CK after 5 weeks of supplementation in rats. Jakeman and Maxwell (37) also reported no effect of 400 $mg \cdot d^{-1}$ of vitamin E supplementation for 21 days before an eccentric exercise bout. Several factors may explain the inconsistencies between these studies. First, investigations have used both animals (87) and human subjects (37, 56), and there is disagreement as to the comparability between models. Second, both the muscle group damaged and the mode of exercise used to do so vary widely. Third, dosages varying in both concentration and duration have been used. Finally, not all investigators report on the same indices of muscle damage and recovery.

Additional Supplements

Additional supplements that have been investigated include homeopathic Arnica 30×, ubiquinone (coenzyme-Q), and L-carnitine. Work by Tveiten et al. (81) on 36 marathon runners suggested a protective effect of Arnica; however, damage was not directly induced in this study. Vickers et al. (84) administered homeopathic Arnica 30× to 519 runners completing distance runs (a quantity is not provided). They reported no effect on soreness scores. Similar findings were demonstrated previously by the same authors using a bench-stepping protocol (83). Giamberardino et al. (27) administered 3 $g \cdot d^{-1}$ of L-carnitine to 6 untrained subjects for 3 weeks before a bout of eccentric exercise. They reported decreased pain, tenderness, and CK scores in a treatment vs. placebo group. The authors hypothesize that the vasodilatory effects of L-carnitine may enhance recovery. Laaksonen et al. (43) supplemented subjects with 1,200 $mg \cdot d^{-1}$ of dietary ubiquinone. After exercise, they reported no effect on antioxidant activity. Of further interest, Malm et al. (50) actually reported an increase in cellular damage with exercise after 6 weeks of ubiquinone ingestion. The effect of ubiquinone on markers of DOMS remains unclear.

An Estrogen Effect in DOMS?

In other areas, there are suggestions as to the existence of a gender effect on the severity of DOMS. The suggested mechanism is that estrogen may have a protective effect. Bar et al. (3) reported lower CK activity after exercise in male vs. female rats. In agreement, Koot et al. (40) reported a decrease in CK activity after exercise in both male and female rats treated with estradiol. Thompson et al. (77) reported decreased soreness (4.0 vs. 7.8 on a scale of 10) in subjects using oral contraceptives. Interestingly, these authors would not support a direct relationship between estrogen ingestion and indices of muscle soreness and instead suggested a possible connection. A review by Tiidus (79) concluded that evidence suggests a gender effect and that estrogen possesses strong antioxidant properties that may ultimately limit CK leakage from damaged muscle. Further work is needed in this area. The reader should note that the reliability of CK activity as an indicator of muscle damage has been questioned (88) and that CK response alone should not be used as indication of effect on DOMS (for a more comprehensive review on this subject see Warren et al. [88]). The variability of CK response adds a cautionary note to interpretation of the aforementioned data.

Practical Applications

Multiple treatments have been advocated for the treatment of DOMS. The efficacy of these treatments is inconsistent, and both positive and negative results are reported. It appears that anti-inflammatory drugs such as ibuprofen, diclofenac, or ketoprofen have shown some potential in alleviation in some but not all symptoms of DOMS. However, variation in dosage and mode of damage used make generalization of results difficult. Treatment using more conventional therapies such as icing, massage, or stretching is also inconsistent. There appears to be some potential for the use of

icing as a treatment. Other variations of treatment including acupuncture, herbal remedies, and HBOT appear to have limited effect. Although some treatments such as antioxidant therapy appear promising, further work is warranted. In fact, much room exists for the implementation of more well-controlled, randomized studies to assess the effects of many of the aforementioned treatments.

In the interim, the therapist should be cautious in the selection of treatments for DOMS. One should consider the severity of damage and the individual response. The efficacy of the proposed treatment should then be balanced in conjunction with the natural time course for recovery.

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