Muscle injuries are very common in persons who participate in sports. In addition to the inconvenience and discomfort associated with such injuries, they also have a significant economic impact if the work-related costs are considered.

The spectrum of these injuries is wide and includes contusion, laceration, delayed-onset muscle soreness, and muscle strain. Contusion is caused by a direct blow to the muscle and is treated with a three-phase treatment program, involving (1) a short period of immobilization with the muscle in a lengthened position, (2) passive and active range-of-motion exercises, and (3) strengthening.

Laceration is uncommon and is seen more often after trauma than after sports accidents. Treatment includes thorough irrigation and debridement followed by suture repair of the fascia, if possible.

Muscle strains are by far the most common muscle injury suffered in sports. The outcome of a muscle strain is generally good but depends on the severity of the injury. A full return to activity with no residual disability is usually possible after healing of a minor injury. However, a major injury can result in limited range of motion and weakness. The vast majority of muscle strains fall within the range of less severe injuries.

Etiology

Certain muscles are injured more often than others. The muscles most at risk are those in which the origin and the insertion cross two joints. One reason for their increased proclivity to injury is that many of these muscles can limit the range of motion of a joint they cross. For example, with the hip flexed, the hamstring muscles can limit knee extension; a hurdling maneuver can place high levels of...
passive tension on the hamstring muscles and potentially injure them. Frequently injured muscles act in an eccentric fashion (i.e., lengthening as they contract) as they regulate motion during sports activities. During running, for example, the muscles of the quadriceps group act primarily to limit knee flexion after heel strike rather than to power knee extension. Injury to these muscles usually occurs during an eccentric contraction.

Frequently injured muscles have a relatively high percentage of type II (fast-twitch) fibers. The high proportion of such fibers means that the muscles are used for high-speed activities, which may predispose to injury. Not surprisingly, muscle strain most often occurs in athletes whose sports require high speeds or rapid acceleration, such as track and field, football, basketball, and soccer. An example of a muscle that displays all of these risk factors is the biceps femoris. It crosses two joints and acts eccentrically at high speeds to decelerate the leg during sprinting.

**Biomechanics of Injury**

Muscle strain occurs as a result of forcible stretching of a muscle, either passively or, more commonly, when the muscle is activated. Most often this is during an eccentric contraction, when the muscle is being lengthened as it contracts. This is likely because eccentric contraction generates higher forces than concentric contraction. The connective tissue framework of the muscle also produces more force as it is stretched, although this is usually quite small until a relatively large amount of stretch has been applied.

Experimental data suggest that strain is crucial to the creation of injury. Initial studies demonstrated that activation of normal muscle by nerve stimulation alone did not cause injury. To produce either gross or microscopic injury, stretch of the muscle past its resting length was also necessary.

**Histology of Muscle Strain Injury**

Histologic studies have shown that muscle strain injuries cause a disruption of muscle fibers near the myotendinous junction. The fibers do not tear at the junction, but rather at a short distance from it. Acutely, the injuries are characterized by disruption and some hemorrhage within the muscle (Fig. 1). By day 2, an inflammatory reaction is evident, with the presence of edema and inflammatory cells (Fig. 2). By day 7, fibrous tissue has replaced the inflammatory reaction. Although some regenerating muscle fibers are present, the histologic appearance is abnormal, and scar tissue is persistent.

**Diagnosis**

Muscle strain will usually present with an episode of acute pain experienced during intense activity. Depending on the severity of the injury and the intensity of the activity, the pain may prevent the patient from continuing. If so, the pain will be most pronounced during eccentric activation of the muscle (e.g., hamstring injury will be most painful during the swing phase of gait while running).

**Physical Examination**

Localized tenderness over the myotendinous junction of the injured muscle will be evident on physical examination. In the case of a complete rupture of the muscle, a defect may be palpated. Swelling and ecchymosis may also be present. Active and sometimes passive range of motion of the joints that the muscle crosses will also cause discomfort and may be limited. Strength testing of the muscle will demonstrate weakness, but this may be attributable more to diminished central drive secondary to pain than to actual muscle damage.

**Imaging**

Plain radiographs may show soft-tissue swelling in a case of muscle strain injury but will usually appear normal. Computed tomography has only a limited capability to depict soft-tissue injury but may demonstrate hemorrhage into the...
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If radiologic evaluation is necessary, magnetic resonance (MR) imaging can most accurately define the injury site. T1-weighted images may show disruption of the normal architecture of the muscle-tendon junction. T2-weighted images will show increased signal in the injured muscle due to edema. In addition, T2-weighted images often show collections of high-signal-intensity fluid that track along the epimysium and escape to the subcutis. Magnetic resonance imaging is seldom necessary, however, as the diagnosis is usually evident from the history and physical examination. For example, its use may be warranted if a patient has a swollen calf but a history of only minor trauma. Although the diagnosis may be evident from the physical examination, MR imaging can be used to differentiate deep venous thrombosis from muscle strain. This modality may also be useful in determining the severity of a muscle strain in cases in which this may be important (e.g., in a professional athlete).

Classification Systems

There is no universal classification system for muscle strain injuries. Ryan published a classification system for quadriceps strain injuries that has been applied to other muscles. A grade 1 injury is a tear of a few muscle fibers, with the fascia remaining intact. A grade 2 injury is a tear of many fibers with partial tearing of the fascia. A grade 4 injury is a complete tear of the muscle and fascia (i.e., a rupture of the muscle-tendon unit). Recovery is longer with a high-grade injury, and the long-term outcome is potentially worse.

Treatment Options

The various treatment strategies for muscle strain injuries have usually been empirically adapted from clinical practice. Few clinical or basic science studies have been performed to determine the effects of different treatments.

Initial treatment usually consists of rest, ice, and compression for relief of pain and swelling. Nonsteroidal anti-inflammatory agents may also be used for pain relief for the first 2 to 3 days. As pain and swelling decrease, physical therapy can be initiated to improve range of motion and strength. When full range of motion and nearly full strength have been attained, the athlete may return to full activity. No specific criteria for adequate strength have been defined, but a cutoff of 80% of the strength on the contralateral side on isokinetic testing is recommended. In the early stages of return, it is advisable to avoid excessive fatigue to prevent reinjury. In addition, the muscle should be warmed up with low-level activity plus external heat before intense activity.

Although surgical treatment has been recommended for complete (grade 4) muscle ruptures, most surgeons believe that nonoperative treatment provides equivalent or superior results. Almekinders studied this issue by severing the extensor digitorum longus muscle in the rat and then treating it with either surgical repair or...
immobilization. At 7 days postinjury, the surgically repaired muscles were stronger. However, by 14 days, there were no differences between the two treatment groups. In contrast, a recent study evaluated the results of treatment of experimentally created laceration in the gastrocnemius muscle of the mouse and found that suture repair yielded significantly greater tetanus strength at 1 month compared with treatment by immobilization. Whether these results are applicable to the clinical situation is unclear. Another consideration is that muscle repair is technically difficult, as there is no way to securely fix the muscle to itself. For these reasons, nonoperative treatment of muscle strain injury is almost universal.

The time frame for healing of muscle strain injuries is directly related to the severity of injury. Minor muscle strain injuries may be healed in 1 week, whereas severe injuries may require 4 to 8 weeks.

**Rest**

In the acute inflammatory phase (days 1 to 5 after injury), rest promotes pain control. After the resolution of acute inflammation, only submaximal activity is recommended, to prevent further injury or reinjury. The tensile properties and contractile ability of the muscle-tendon unit are altered after injury, and an early return to full activity predisposes to additional injury.

Several researchers have demonstrated changes attributable to stretch-induced nondisruptive strain injuries. Taylor et al tested the extensor digitorum longus muscle in the New Zealand white rabbit and found that the postinjury load to failure was 63% that of the control value and length to failure was 79% of control. Obremsky et al also studied rabbit skeletal muscle and found that 1 day after injury, load to failure was 65% of control and maximum contractile force was 59% of control.

Seven days after injury, load to failure had returned to only 77% of the control value, while maximum contractile force was 91% of the control value.

Some authors recommend immobilization of the muscle-tendon unit to limit hemorrhage and edema in the acute postinjury phase. However, prolonged immobilization is discouraged because of detrimental long-term effects. Long-term immobilization in either a lengthened or a shortened position will result in a change in sarcomere number (i.e., sarcomeres will be added or deleted until the sarcomere length in the position of immobilization equals the sarcomere length before immobilization). The addition of sarcomeres occurs at the muscle-tendon junction. Immobilization in a lengthened position results in the reorganization of the passive elements of the muscle as well; the connective tissue is rearranged as the resting length of the muscle adjusts to its position of immobilization. Therefore, immo-
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immobilization of an injured muscle such that it is held at its resting length is recommended.

Immobilization also alters the biomechanical properties of the muscle-tendon unit. Laboratory studies have shown that immobilized muscle has a lower load to failure and a lower total deformation to failure compared with nonimmobilized muscle. Clinical studies also support using immobilization for only short periods of time; a 20% decline in muscle strength has been measured after 1 week of immobilization.

The only exception may be the complete rupture, in which case immobilization may allow some reappraisal of the torn muscle ends. Even in this instance, however, immobilization should be used for no more than 10 to 14 days.

Early tensile loading of muscle, tendon, and ligament can stimulate collagen fiber growth and realignment. Early motion also limits the formation of adhesions between healing muscle and adjacent tissue. proprioception also recovers faster with early motion.

Cryotherapy

Application of ice, or cryotherapy, is recommended to ameliorate the effects of the inflammatory reaction to strain injury by reducing edema and hematoma formation and diminishing pain. It has been hypothesized that cryotherapy retards hematoma formation because it constricts the capillaries and thereby decreases blood flow. Although a number of studies attest to these effects, there is also evidence that cryotherapy results in periodic vasoconstriction and vasodilation, known as the “hunting reaction.”

Cryotherapy can either increase or decrease swelling. Several studies have documented increased swelling with cold application to temperatures below 15°C due to the increase in the permeability of superficial lymph vessels that occurs at this temperature. With less extreme cooling, diminished swelling has been observed. McMaster et al studied crush injury of the rabbit forelimb and found reduced limb volume at 24 hours with cooling to 30°C. Similarly conflicting data relative to the inflammatory response have been reported. Studies have shown that cold can inhibit as well as enhance inflammation.

Cryotherapy also provides an analgesic effect. Numerous studies have shown an analgesic effect of cold application with cooling to 10°C to 15°C. The mechanism of pain relief is believed to be due to breaking of the pain cycle by shortening the central nervous system with impulses, which makes the receptors momentarily refractory to pain.

In summary, the effects of cryotherapy on inflammation and swelling after muscle strain injury are unclear. The analgesic effect is well substantiated. Although the duration of the effect is not well defined, even the temporary establishment of analgesia is helpful for early mobilization of the injured extremity. However, caution is necessary, as the theoretical possibility of worsening swelling exists with the application of extreme cold.

Nonsteroidal Anti-inflammatory Drugs

Nonsteroidal anti-inflammatory agents have been used to reduce the inflammatory response seen in muscle strain injury. This response involves vasodilation and extravasation of blood into the surrounding tissue. Inflammatory cells are recruited in this process, which results in increased swelling, erythema, pain, and impaired function.

Although these effects are detrimental, an inflammatory response is not absolutely undesirable after a strain injury. This response may be the only means by which the body can remove necrotic tissue. Therefore, a certain level of inflammation may be necessary to allow healing to take place. Healing of a muscle injury occurs in two ways. First, muscle can regenerate from intact viable muscle fibers and from satellite cells that act as muscle stem cells. Second, the defect can heal with bridging scar tissue. It is unclear whether treatment aimed at inhibiting the initial inflammatory response can blunt the scarring response and allow increased amounts of muscle regeneration.

In two studies, the effect of NSAIDs on muscle strain injury was investigated, but no significant effect on tensile strength was demonstrated. Contractile force was also evaluated in one study and found to be unaltered. However, both studies showed histologic evidence of delayed healing with NSAID use.

Another study evaluated the effect of NSAIDs on rabbits with exercise-induced muscle injuries. The group that received NSAIDs had a more complete functional recovery than untreated control animals at 3 and 7 days, but showed deficits in pertinent measurements when tested at 28 days. Evaluation of histologic and ultrastructural properties also suggested that the long-term effects of NSAIDs could be potentially harmful.

In summary, NSAIDs offer the potential benefits of analgesia and inflammation reduction when used to treat muscle strain injury. However, many questions remain regarding the long-term effects of these drugs on the recovery process. In addition, the choice of NSAID and the optimal timing and dosing schedules have not yet been established. The current recommendation of most authors is to use an NSAID immediately after

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injury but to continue administration for only a short period to prevent interference with the healing response.

Compressi on and Elevation

The use of compression and elevation in the treatment of muscle strain injury is thought to decrease pain and swelling. Although there are no studies that address the use of these modalities in muscle strain injury, their employment is generally recommended.

Physical Therapy

After the resolution of the acute pain and swelling, most authors recommend the institution of a program of physical therapy. This is beneficial for restoring normal muscle strength and flexibility to the muscle.

Restoration of muscle strength is important to prevent further injury or reinjury because of the role of muscle as an energy-absorbing structure. The ability of the muscle to resist lengthening is a measure of its capacity for energy absorption. Muscle can do this in two ways: passively, by the resistance of the connective tissue elements within the muscle, and actively, by contraction against the lengthening force.

These concepts have been demonstrated in a laboratory study of rabbit muscles stretched to failure in the activated and nonactivated states. In that study, the force to failure was 15% higher and the energy absorbed was 100% higher in muscles stretched to failure while activated. At small deformations of the muscle, most of the energy absorption was due to the active component rather than the passive component. Most physiologic activity in eccentrically contracting muscle occurs at relatively small deformations. Thus, muscle weakness should significantly impair the ability of the muscle to absorb energy, making it more susceptible to muscle strain injury. Continuing this logic, returning an injured muscle to full strength is important in preventing additional injury.

Passive stretching of muscle is thought to be beneficial because it reduces muscle stiffness. A laboratory study showed that much of the decreased stiffness is due to viscoelastic properties rather than reflex changes. Because of viscoelasticity, prolonged stretching can lead to diminished stress within the muscle for a given length change. Although the temporal characteristics of this effect are unclear, this property represents a plausible mechanism by which stretching might prevent further muscle strain injury in the postinjury setting.

Prevention of Muscle Strain Injury

Precautions can be taken to prevent the occurrence of muscle strain injury. A strong, flexible muscle is less likely to be injured than a weak, stiff muscle. Any factor that impairs the contractile function of the muscle will lead to a reduction in its energy-absorbing capabilities, making it more susceptible to strain injury. For example, fatigue has been associated with muscle strain; laboratory studies have shown that when fatigued muscle is failure-tested, it has diminished load to failure, total deformation, and energy absorbed prior to failure. Therefore, a warmed-up, nonfatigued muscle is more resistant to injury than a fatigued muscle that has not been adequately prepared for competition.

Mair et al examined rabbit muscle pulled to failure after being fatigued. In a simulated stretch to muscle failure, a decrease in energy absorption of 42% was seen in the first 70% of the length change (when most muscle injury occurs); there was only a 6% difference in the last 30% of the stretch.

Although it is impossible to eliminate fatigue in the competitive situation, it makes sense to limit fatigue in the postinjury rehabilitation period. At this time, not only is the muscle at less than full strength, but the athlete may also be deconditioned due to inactivity. As the athlete’s conditioning and muscle strength improve, exposure to intense activity in a relative state of fatigue may be increased. Rehabilitation should, therefore, focus on muscular endurance as well as strength. This can be accomplished by training with low levels of resistance for many repetitions.

Athletes commonly participate in warm-up routines to enhance performance and minimize the chance of injury. The benefit of such routines has been widely debated. Many authors believe that warm-up is protective because it increases the range of motion and reduces stiffness secondary to an increase in muscle.

Safran et al studied isometrically preconditioned rabbit muscle versus nonstimulated control muscle. The experimental muscle failed at a greater deformation and greater load than the control muscle, implying that a protective effect may have been gained from the warm-up period. It is unclear whether this effect occurred because of the temperature increase from the contraction (about 1°C) or because of stretching at the myotendinous junction.

In another study the effects of muscle temperature on failure properties were evaluated. Rabbit skeletal muscle was studied at 25°C and 40°C, temperatures considered to represent the extremes in human muscle temperature. Mean stiffness (load to failure/total deformation) was higher in the cold muscle,
implying that warming of muscle may be protective.

The functional aspects of muscle in relation to temperature have also been investigated. The temporal characteristics of contraction are significantly altered: time to peak tension and time to relaxation are decreased with increasing temperature, and maximum and sustained power generation are increased. Therefore, in the rehabilitation of a muscle strain injury, the use of heat is recommended before exercise to decrease the likelihood of reinjury. In addition, a period of low-intensity exercise is recommended before high-intensity activity to allow the body and muscle temperatures to rise.

Complications

Complications of muscle strain injury are relatively few. Most injuries heal with little, if any, residual defect. Potential complications include fibrosis, weakness, pain, and reinjury. Generally, only the most severe injuries will be associated with any of these problems. We are not aware of any study in which the incidence of these complications has been elucidated.

Reinjury is the most frequent complication. It can occur even in minor muscle strain injuries. Generally, this is the result of returning to sport too soon. Athletes can develop chronic muscle strain injuries that last several months, with reinjury occurring each time a return to high-level sports activity is attempted. In this situation, the athlete has usually attempted to return despite a persistent deficit in strength and/or flexibility.

Symptomatic fibrosis occurs less frequently. In some athletes, however, a severe muscle strain injury will result in a painful fibrotic area. Initial treatment should involve aggressive physical therapy with stretching and perhaps the use of modalities such as ultrasound and deep-tissue massage. Occasionally, the area remains painful; in a few cases, symptoms have been so severe that resection of the fibrotic portion of the muscle has been necessary. Although experience with this procedure is limited, our results have been good. Myositis ossificans may develop after a muscle contusion, but rarely occurs after a muscle strain.

Summary

Despite the high prevalence of muscle strain, treatment regimens have generally been based on empirical data. Initial treatment is aimed at reducing the inflammatory response. Compression and elevation are used to limit swelling and hematoma. Ice is effective as an analgesic, but its anti-inflammatory effects are unclear. Similarly, the use of NSAIDs helps to reduce pain acutely, but their role in reduction of inflammation has not yet been defined. Limitation from full activity is important to prevent reinjury. Although immobilization may be indicated, its use should be limited, as early mobilization is beneficial in the healing process.

With resolution of pain and swelling, the treatment emphasis changes to rehabilitation. Physical therapy is initiated, with the goal of restoration of muscle strength and flexibility. A full return to activity should not occur before these goals have been met. In the early stages of return, extreme fatigue should be avoided, and a thorough warm-up should always be performed. Adherence to these principles should lead to an excellent result with a minimal risk of reinjury.

References


