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## Current concept: Muscle injuries

### Summary

Muscle injuries are frequently encountered in sports medicine practice and usually are treated empirically. Often a first injury is benign, but a re-injury may be a formidable complication for any athlete. Recently, numerous scientific studies have been published revealing new information and concepts in this area. The purpose of

this paper is to review the classification and diagnosis of muscle injury, the biology of muscle healing, immediate treatment of muscle injury, and the treatment options after three to five days. We will also discuss complications of muscle injury, as well as a section devoted to injury prevention. And finally, we will present new treatment modalities such as the use of growth factor and gene therapy.

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### Introduction

Muscle injuries are common and their reported incidence varies from 10% to 55% of all injuries sustained in sports [21]. Muscle injuries are divided into two types. One is a shearing injury in which both the myofibers and the connective tissue framework are torn. The other one is an *in situ* injury in which only the myofibers are damaged and the basal lamina and connective tissue sheaths do not undergo significant damage. Shearing injuries are the most frequent muscle injury in sports, and may be contusions, strains or lacerations depending on the mechanism of injury [21]. Contusion occurs when a muscle is injured by a significant compressive force, such as a direct blow. This mechanism is common in contact sports. A strain occurs when a forceful eccentric contraction is applied to an overstretched muscle, especially in jumping or sprinting [9,21]. Such an injury is common near the musculotendinous junction (MTJ) of a superficial muscle which crosses two joints, such as the rectus femoris, semi-tendinosus, and gastrocnemius muscles (*fig. 1*). Although rather rare in sports, muscle laceration is a dramatic injury, which consistently incapacitates athletes for long periods of time and often jeopardizes their professional careers.

Chronic compartment syndrome is characterized by increased pressure within a closed compartment bounded by bone and fascia. The increased pressure diminishes tissue perfusion, which may lead to an ischemic muscle injury [27]. The presenting complaints are usually those of pain or a deep ache over the compartment. This discomfort usually occurs after a relatively long exercise period and is usually severe enough to cause the athlete to either stop his activity or reduce the intensity of the exercise. Sensory changes may also be present. Chronic or recurrent compartment syndrome is difficult to diagnose clinically, and corroboration by objective pressure measurement is desirable. The primary distinguishing characteristic of the chronic condition is pressure elevation above normal during exercise and a slower return to resting value at the end of the exercise. These findings have consistently identified chronic compartment syndrome.

### Muscle healing process

There are three phases in the healing process of an injured muscle [19]: *The destruction phase* is characterized by hematoma formation, muscle tissue degeneration, necrosis, and an inflammatory cell response. *The repair phase* includes the phagocytosis of the dam-

aged tissue, regeneration of the striated muscle, production of connective tissue scar, and capillary ingrowth. In the final *remodeling phase*, the regenerated muscle matures and contracts in addition to reorganization of the scar tissue. An incomplete restoration of the functional capacity of the muscle often occurs.

The regeneration of myofibers begins with activation of myogenic precursor cells, or satellite cells, located between the basal lamina and the plasma membrane of each individual myofiber. When activated, these satellite cells begin to proliferate and differentiate into multinucleated myotubes and eventually into myofibers. Many of these myoblasts have the ability to fuse with existing necrotic myofibers and may prevent the muscle fibers from completely degenerating [11,12]. In the same time, fibroblasts invade the gap and begin to produce extra-cellular matrix in order to restore the connective tissue framework [16,22]. The physiological role of this scaffold is to transmit load across the defect, thus enabling one to use the injured limb before the repair process is complete [19]. In extensive muscle trauma, proliferation of fibroblasts can rapidly lead to an excessive formation of dense scar tissue, which impedes muscle regeneration and results in an incomplete recovery [15,18]. This has been demonstrated in many types of muscle injuries including strains, contusions, and lacerations [4,6,8,9,20,24,28].



Figure 1: A strain occurs when a forceful eccentric contraction is applied to an overstretched muscle.

### Classification of muscle injuries

The clinical picture of a muscle injury depends on the severity of the injury itself as well as on the nature of the hematoma (intramuscular or intermuscular). The classification of a muscle injury is as follows:

#### I: *In situ muscle injury*

In its mildest form, it is very common in sports. Such injury is frequently exercise induced, especially after eccentric loading, and results in delayed onset muscle soreness.

#### II: *Shearing injury*

**1. Mild or first degree:** A tear of a few muscle fibers with minor swelling and discomfort. There may be minor loss of strength and restriction of movement. However, a mild strain may be very distressing for an athlete.

**2. Moderate or second degree:** A greater amount of muscle damage with a clear loss of strength, restriction of joint motion and pain with muscle stretching.

**3. Severe or third degree:** A tear extending across the whole cross-section of the muscle resulting in a total lack of muscle function, relatively low pain when stretched and a slight restriction in joint motion.

Muscle tissue is well vascularized. Therefore, a shearing type of injury results in the formation of a significant hematoma as intramuscular blood vessels are torn. With a muscle injury, two types of hematoma can be seen (*fig. 2*):

- **The intramuscular hematoma** may be caused by muscle strains or contusions. The intact muscle fascia limits the size of the hematoma and the increase in intra-muscular pressure due to the extravasation of blood compresses and further limits the hematoma. Clinical findings are pain and loss of function.
- **The intermuscular hematoma** occurs in those cases where the muscle fascia ruptures and the extravasated blood spreads into the interfascial and interstitial spaces without a significant increase in the pressure within the muscle, which results in pain of a lesser severity.

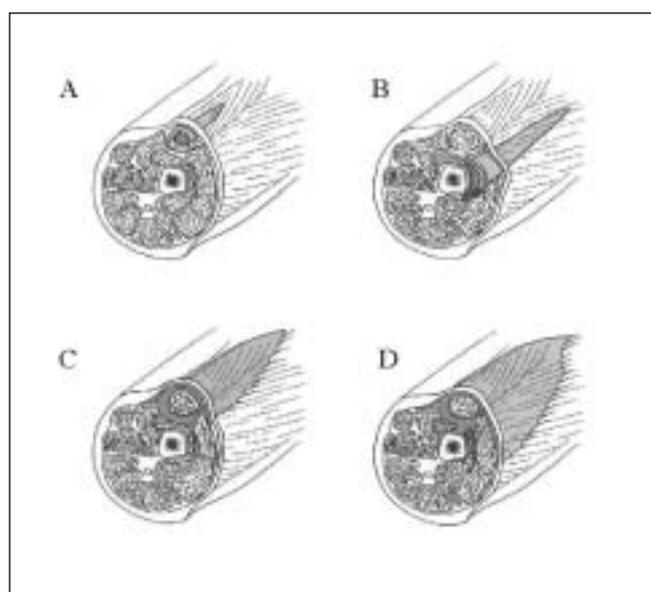


Figure 2: A: Superficial intra-muscular hematoma; B: Deep intra-muscular hematoma; C: Inter-muscular bleeding; D: Deep intra-muscular bleeding with inter-muscular spreading.

### Diagnosis of muscle injuries

An analysis of the cause of the injury is the first step in the clinical examination. This is followed by a careful and precise inspection and palpation of the involved muscle. The function of the injured muscle should be tested with and without resistance and the motion of the joint crossed by involved muscles should be noted. With a history of contusion or strain associated with evidence of swelling and ecchymosis distal to the lesion, the diagnosis is simple. Small or deep hematomas can be more difficult to diagnose clinically. Their extent can be determined by ultrasonography (US), computerized tomography (CT) or magnetic resonance imaging (MRI) (*fig. 3*) [2, 34]. On the basis of current knowledge, ultrasonography can be recommended as the method of choice to determine the anatomical location and the morphology of a muscle injury. In addition, the repair process following muscle injury can be followed with ultrasonography [2]. However, in case of discrepancy between clinical findings and US findings, an MRI should be considered, as MRI is more precise than US for certain types of muscle trauma.

### Treatment of muscle injuries

#### *Immediate treatment*

The immediate care following muscle injury consists of RICE (Rest, Ice, Compression and Elevation). The goal is to prevent hematoma formation and interstitial edema, thus decreasing tissue ischemia. However, if the immobilization phase is prolonged, it will be detrimental for muscle regeneration [24]. Non-steroidal anti-inflammatory medication should be instituted only in the early phase, because their long-term use may be detrimental [26,33]. Glucocorticoids should not be used since they have been demonstrated to delay the elimination of hematoma and necrotic tissue and retard muscle regeneration [19].

The use of ultrasound is thought to have a beneficial effect in the initial stage of treatment since the micromassage provided by high frequency ultrasound waves functions as a pain reliever. A recent study has demonstrated that while therapeutic ultrasound promotes

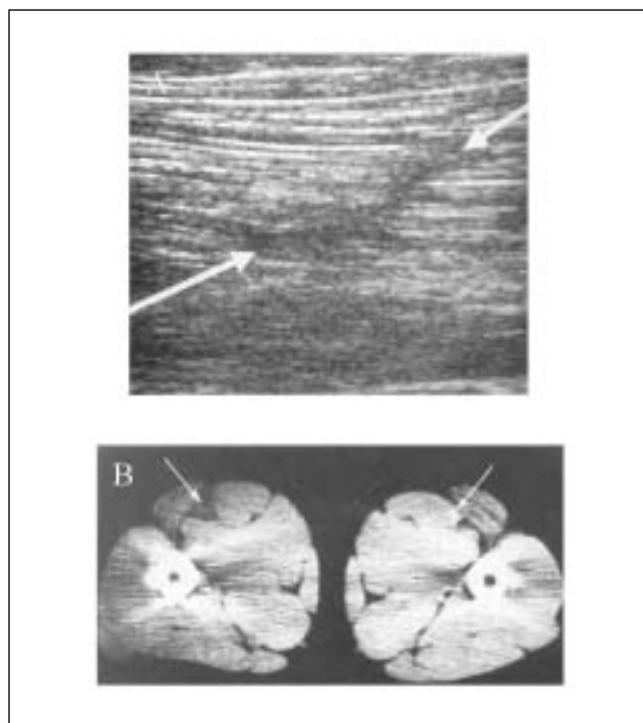


Figure 3: A: Typical picture of a muscle tear as seen by ultrasound; B: MRI: Acute left biceps femoris muscle tear and chronic right hamstring muscle injury.

the proliferation phase of muscle regeneration, it does not seem to have a significant effect on the final outcome of the regeneration process [31].

After an initial rest period (2 to 3 days) the contractile ability of the injured muscle should be evaluated. If it has not improved from the original post-injury level, a large intramuscular hematoma or total rupture of the muscle may be present and clinical reexamination is critical.

#### **Treatment after 3 days**

Two to four days after the injury, minor partial ruptures and minor intramuscular hematomas should be supported with an elastic wrap followed by early, active mobilization. Isometric training should be started as soon as possible and progressively increased according to the limits of pain. Isotonic training, with and without load should be started early on but under careful and strict control. Isokinetic dynamic training with minimal load should also be started at this time. Careful passive stretching of the injured muscle within the limit of pain should begin the second week post-injury.

The final phase of rehabilitation, the sports specific training, should always be started under the supervision of a coach or a trainer. Its goal is to re-program the injured muscle group on the field and to restore correct technique.

#### **Surgery**

Surgical intervention is indicated in cases of muscle laceration, as well as in those instances of large intra-muscular hematomas or third degree injury with complete rupture and loss of function.

#### **Chronic compartment syndrome**

The treatment of a chronic compartment syndrome consists of a fasciotomy of the involved muscle compartment. One must be aware that fascial release adversely affects the strength of a muscle. Therefore, such procedures should not be advocated without accurate diagnosis and counseling [7].

#### **Complication of muscle injuries**

A formidable complication of muscle strain or tear is a re-injury or re-rupture, which may result in ending the athlete's career. A re-injury should be preventable by appropriate treatment of the initial injury, especially during the sport specific phase. The major cause of a re-tear is too early a return to competitive sport. Other complications include: Myositis ossificans (*fig. 4*) after a severe contusion, especially in the quadriceps muscle; intra-muscular encapsulated hematoma; and painful hypertrophic fibrous scar tissue (*fig. 5*).



*Figure 4: Myositis ossificans after severe contusion.*

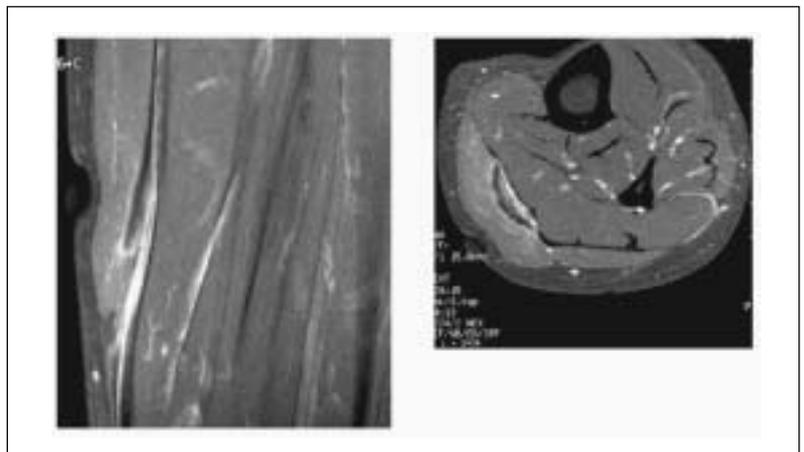
#### **Prevention of muscle strain**

The ultimate goal of treatment, of course, is prevention. Although there is no absolute protection against muscle strain injury, certain precautions can be taken to prevent their occurrences [30]. Indeed, we now have scientific evidence confirming muscle fatigue as a risk factor in muscle injury. A fatigued muscle shows a decreased load to failure and energy absorbed to failure [23]. Energy absorption is the primary function of muscle and a decreased capacity to absorb energy makes it at risk for injury. Although it is obviously difficult to limit fatigue during a competitive activity, it makes sense to decrease the frequency of competitive events, and as well to limit fatigue in the post-injury rehabilitation period. During this time, the muscle is at less than full strength and the athlete may be unconditioned due to inactivity secondary to injury.

Before competition, athletes commonly use a warm-up period to enhance performance and minimize the risk of injury. Although there is widespread opinion that warm-up decreases the risk of injury, little experimental work substantiates these assertions. Saffran et al [32]. studied this topic by stimulating preconditioned rabbit muscle versus control muscle. The preconditioned muscle failed at a greater deformation and load than control muscle, thus implying that a protective effect may have been gained from this warm-up period. Another study looked at the effect of temperature on muscle failure. Rabbit skeletal muscle was studied at different temperatures,  $-25$  and  $40$  degree C, which represent the minimum and maximum temperatures attainable in the human body. Mean stiffness (load to failure/total deformation) was higher in the cold muscle confirming that decreased temperature will impair the functional abilities of muscle [29]. Considering that impairment in contractile ability increases susceptibility to injury, most investigators support the concept that a warmed muscle is more resistant to injury. Thus, in the rehabilitation of a muscle strain injury, the use of heat prior to exercise is recommended in order to prevent a re-injury. A period of low intensity exercise prior to high intensity activity is also recommended to raise the temperature of the muscle and the body.

#### **New methods of treatment in muscle injury**

A severe muscle injury always heals with the formation of dense scar tissue, which impairs function, leads to muscle contractures, and chronic pain. The enhancement of muscle regeneration limits the formation of scar tissue. The use of growth factors and gene therapy represent new approaches to promote muscle regeneration. We have observed that basic fibroblast growth factor (b-FGF), insulin growth factor type 1 (IGF-1) and nerve growth factor (NGF)



*Figure 5: Hypertrophic muscle scar at the musculo-tendinous junction of a tennis-woman gastrocnemius muscle that sustained recurrent injuries.*

are potent stimulators of myoblast proliferation and fusion *in vitro* [25]. However, the successful clinical implementation of this technique is currently limited by the problem of maintaining an adequate concentration of growth factor in the lesion site or target tissue. The short half-life of growth factors and the systemic lavage may lead to a rapid clearance of the substances from the desired site. To address these issues, gene therapy may be an effective delivery system to the muscle. The genetic information (usually a cDNA) encoded for the therapeutic protein, is inserted with non-viral and viral vectors into living cells. The genetically modified cells express the protein, encoded by the transferred DNA, in a sustained manner. By using this new technology, growth factor can be delivered to the tissue locally, on a mid- to long-term basis, thus avoiding repeated injections or systemic administration.

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