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15.1 Basics

The weight-bearing and locomotor system of the human body is basically composed of the skeletal muscles and of the systems that transfer the power of the muscles (i.e., the tendons and aponeuroses) in the torso, spine, and extremities. The construction and shape of individual muscles and their position in relation to the joints determine their function.

15.1.1 Anatomy

The microstructure of a muscle, with its individual mixture of different types of fiber, has a substantial effect on its physiological properties. While to a great extent the muscles can be trained, tendons and their origins in the skeleton cannot be strengthened in the same way, which explains their tendency toward ruptures and strain injuries. The copious blood supply to the musculature is the reason for its excellent capacity for regeneration, although increasingly severe damage to muscle fibers means that full recovery is no longer possible. In such cases fibrous scar tissue develops in the region of the rupture.

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15.1.2 Physiology and Pathophysiology

Muscle injuries can be subdivided according to their severity and thus their capacity for complete regeneration, or for a type of partial healing with scar formation, as follows:

- *Sore muscles* – microinjuries of the white, fast-twitch muscle fibers caused by overstrain. The tearing of parts of the muscle fibril accompanied by edema and the secretion of pain-inducing agents in the extracellular space are responsible for the symptoms. By reducing the intensity of the strain using stretching and mild dynamic-concentric contractions, complete recovery from sore muscle can be achieved.
- *Muscle stretching/overstretching* – the limit of the elasticity and stability of the muscle fibers is reached; complete recovery can generally be obtained. The distinction between overstretched and pulled muscle involving scarring and partial recovery is blurred.
- *Pulled muscle or muscle strain* – distinguished by the tearing of individual contractile elements. A complete return to the patient's former condition is impossible after this, the most frequent muscle injury. It is always repaired with scar tissue. Again, the distinction between muscle fiber rupture is blurred.
- *Tearing of muscle fibers* – defined as a more extensive lesion resulting from exceeding the limits of elasticity and stability of the muscle fiber bundles. It always results, to a greater or lesser degree, in partial repair with scar tissue.

From a pathophysiological point of view, sore muscles, pulled muscles, and the tearing of muscle fibers are considered to be similar lesions differing in severity.

- *Myorrhexis or rupture of a muscle* – can give the impression of a partial or complete gap in the continuity of a muscle and represents a further increase in severity in injuries to the skeletal musculature. Depending on the extent of the lesion in relation to the total cross-section of the muscle belly, surgical treatment may be indicated under certain circumstances. There is always some degree of partial repair regardless of the treatment strategy.
- *Myocele or muscle herniation* – always results from blunt trauma, causing a rent in the fascia. As the muscle contracts, herniation occurs, causing much pain. Surgical closure of the rent in the fascia yields good results if the suturing is resilient.
- *Myositis ossificans* – also caused by blunt trauma, where the blunt injury to the musculature leads to metaplasia of cells from the hematoma, resulting in the formation of osteoblasts. These are responsible for dystopic ossification.
- *Rupture of a muscle at its origin* – can be partial or complete and, as a rule, is easy to diagnose. It is particularly frequent in young people and can manifest as bony lesions that are detectable on radiographs (e.g., rupture of the rectus femoris muscle at the pelvis) [1].

15.1.3 Specific Causes of Muscle Injuries

The causes of muscle injuries and damage range from acute or chronic overstrain, uncoordinated movement causing sudden changes in tension of the contractile elements, increased resistance or tension in the antagonistic muscles, to blunt trauma. The predisposing factors for muscle injuries or damage are as follows:

- Insufficient warm up/stretching before sport activities
- Inadequate blood supply to the musculature (cold)
- Inadequate training
- Poor technique, bad equipment
- Generalized disease

The disparity between the condition of the muscle and the demands made of it is the cause of indirect lesions. The individual forms and severity of muscle injuries are considered by most experts to be different manifestations of similar pathogeneses and mechanisms. Given the blurred distinctions between diverse muscle injuries, damage is considered to be either reversible (sore muscles, stretching, and overstretching) or irreversible (tearing of muscle fibers, rupture of a muscle). Pulled muscle involving a greater degree of pathologically and anatomically detectable

overstretching, extending to rupture of individual contractile elements with subsequent scar tissue, represents the boundary between the two groups. In contrast, direct muscle trauma is a result of local damaging forces and involves a risk of compartment syndrome or myositis ossificans.

Most muscle injuries occur during rapid acceleration or takeoff during poorly coordinated sequences of movements and under unfavorable general conditions in the context of sport activity (e.g., track and field, ball and racket sports, and martial arts). Most direct lesions of the skeletal musculature occur in contact sports such as football or martial arts.

In accordance with the injury hypothesis, sore muscles are considered to be partial damage to the muscle fibrils in the sense of overstrain, accompanied by local edema, and are completely reversible [2].

15.1.4 Basic Principles of the Clinical Examination

The principle symptom in the diagnosis of muscle injuries is pain. The pain ranges from an unpleasant dragging pain on stretching the muscles, to the generally less severe pain accompanying a pulled muscle, and finally to the sudden burst of debilitating pain that occur when a muscle or muscle fiber is torn. In contrast, ruptures are generally less painful. The intensity of the pain is an indicator of the extent of the injury in the muscle. After documenting patient history, local inspection and palpation are the foundations of clinical diagnosis. Swelling, hematoma, changes in muscle relief, painful antalgic postures, and loss of function as well as a palpable gap in the continuity of the muscle belly (dimpling) are typical characteristics of acute muscle injury. Local pressure and indirect muscle tension pain are further diagnostic parameters.

15.1.5 Diagnosis by Imaging Procedures

The use of ultrasound to visualise the nature, localization, and extent of muscle injury plays an essential part in diagnosis as well as in the choice of therapeutic procedure. The size of the gap in muscle continuity, visualized in this way, as well as that of the accompanying hematoma, influence the choice of further procedures. In unclear cases, an additional magnetic

resonance imaging (MRI) scan can provide detailed information about the extent of injury. Radiographs, particularly of the adjacent joints, are sometimes indicated; they are obtained if myositis ossificans is suspected.

If compartment syndrome is suspected, measurement of the pressure in the compartment is indicated in addition to clinical diagnosis on the basis of pain and swelling and shiny skin.

Laboratory tests to determine muscle-specific enzymes are indicated only in the case of massive, extensive, muscle contusions in the context of high-speed or crush injuries. What is known as crush syndrome, with its life-threatening secondary phenomena (crush kidney), may be a consequence of these types of traumatic events. Electrodiagnostic testing such as electromyography is indicated only if there is accompanying nerve injury.

15.1.6 Organ-Specific Imaging

Apart from the ultrasound procedure described above as the standard procedure, no further imaging procedures are necessary except MRI, which is sometimes required, and radiography, which is ordered to exclude bone injuries.

15.2 Special Muscle Injuries and Damage to the Upper Extremity

- Deltoid muscle
- Biceps brachii muscle
- Triceps brachii muscle
- Compartment syndrome in the forearm

Muscle injuries in the region of the upper extremity generally give the impression of a strain or tear in the fiber, and less frequently of a partial rupture in the belly of the muscle. A compartment syndrome in the lower arm develops because of increased pressure in the fascial compartments as a result of edema and compression of the arterioles or venules. In general, injuries to the musculature of the upper extremity are rare. In contrast, acute lesions or damage induced by degeneration to their tendinous origins occur more frequently. Compartment syndromes in the forearm are concomitant phenomena of more severe, local, blunt force trauma. While indirect damage tends to occur in the context of sport activity (e.g., gymnastics,

throwing sports, boxing), direct muscle traumas are observed predominantly in the context of industrial or road traffic accidents (e.g., trapping the forearm in a machine).

Typical symptoms include pain of varying severity, local swelling and hematoma, as well as impaired function. Ultrasound can be used to detect the gap in muscle continuity and edema and/or hematoma.

Characteristic symptoms of compartmental syndrome in the forearm are increasing pain that does not respond to pain relieving measures, extensive swelling with shiny skin, and the onset of decreased sensation with impaired muscle function at the periphery.

The development of myositis ossificans is generally a result of a local traumatization or a compartment syndrome, which is either undiagnosed and untreated or incorrectly diagnosed and treated. This could result in permanent impairment of function.

15.2.1 Diagnosis

15.2.1.1 Recommended Diagnostic Measures in Accordance with the European Standard

- Inspection: swelling, discoloration from hematoma, abnormal muscle contours, antalgic postures, indirect muscle tension pain
- Palpation: pain on pressure, palpable dimpling (gaps in continuity)

15.2.1.2 Additional Useful Diagnostic Procedures

- Ultrasound: imaging the localization and extent of the gap in continuity and accompanying edema/hematoma
- Radiographs to exclude bone injury
- MRI: indicated only in individual cases to confirm diagnosis or to select the therapeutic procedure
- Measurement of compartment pressure: when compartment syndrome is suspected

15.2.2 Treatment

15.2.2.1 Conservative Treatment Recommended Therapeutic Measures in Accordance with the European Standard

Muscle injuries to the upper extremity are the domain of conservative treatment. As with all muscle injuries,

short-term immobilization (e.g., in a Desault or Gilchrist dressing) with local application of cold and concomitant anti-inflammatory treatment are indicated, followed by follow-up physiotherapy with muscular rehabilitation and manual therapy.

Additional Useful Therapy Options

The decision between conservative and surgical treatment for muscle tears can generally be made by taking the following criteria into account:

In favor of surgical care:

- Better assessment of the severity of the injury
- Potential evacuation of the hematoma
- Muscle length restoration through suturing
- Less scar tissue formation and thus better contractility
- Reduced rate of recurrent tears

15.2.2.2 Surgical Treatment

Recommended Therapeutic Measures in Accordance with the European Standard

The indication for a surgical procedure in the event of muscle tears to the upper extremity depends on the extent of the tear and its loss of function. Incomplete or complete muscle tears, especially in competitive athletes are considered indications for a surgical procedure, while partial tears, particularly in the deltoid muscle and triceps muscle need surgery only when a large hematoma has developed. In contrast, complete rupture of the biceps muscle at the tendon is an indication for surgical repair.

A manifest compartment syndrome is always an indication for surgery as this requires emergency surgery. The increased pressure in the muscle compartments should be diagnosed at the stage when it represents a threatening compartment syndrome and in certain cases prophylactic fasciotomy should be performed. The complete opening of all affected muscle compartments is an indispensable precondition for avoiding irreversible damage. Secondary closure after the swelling has regressed is achieved by direct suture or split-thickness skin graft [3].

Additional Useful Surgical Measures

An effusion of blood in the acute stage or non-absorption of the effusion can be an indication for evacuation and drainage of the hematoma and, in appropriate cases, can be combined with the intermittent application of a synthetic material such as Coldex® with drainage. Secondary restoration of

continuity to the biceps or triceps brachii muscle is likely to be difficult because of possible shortening.

15.2.3 Differential Diagnosis

These infrequent muscle injuries to the upper extremity can be unequivocally diagnosed; difficulties in differential diagnosis are not to be expected.

15.2.4 Prognosis

Restoring continuity to the muscle and ensuring sufficient immobilization until the tear has been repaired with scar tissue are the conditions essential for a good result. The smaller the scar that develops after suturing the tear, and the more thorough and definitive the control of local hematoma, the smaller the risk of secondary loss of muscle tension or the development of myositis ossificans that can cause drastic deterioration in the functional result.

15.2.5 Examples of Surgical Procedures

15.2.5.1 Procedure 1

Complete muscle ruptures in the upper extremity are most likely to occur in the biceps or triceps brachii muscles. Reattachment of the muscle to the tendon is performed after complete evacuation of the hematoma using U-shaped sutures in absorbable suture material. Insertion of drainage is obligatory. The sutures must be protected by adequate immobilization (e.g., a Gilchrist dressing for 3–4 weeks).

Potential complications are the secondary divergence between the sutures in the region of the former rupture, generally caused by the stitches in the muscular portion tearing out. A further potential complication is the development of myositis ossificans.

15.2.5.2 Procedure 2

Forearm fasciotomy may prove necessary either in the flexor or extensor compartments and, if the injury is sufficiently severe, on both sides of the forearm. It is important that the incisions extend beyond the hand joint and include the carpal tunnel. The insertion of meander-shaped sutures for secondary suturing of the wound margins and conditioning of the

wound bed with skin substitute are standard therapeutic procedures. Secondary closure is performed using adaptive sutures and/or split-thickness skin graft or mesh graft.

Complications include seriously delayed splitting of the fascia with manifest compartment syndrome or what is known as rebound compartment syndrome. The latter is the recurrence of a manifest compartment syndrome after pressure relief, generally incomplete, of the muscle compartments. Both complications can lead to irreversible damage.

15.2.6 Special Remarks

Muscle injuries of the upper extremity are rare, generally observed in athletes (e.g., gymnasts, throwers etc.) and, on the whole, have good results after appropriate conservative or surgical therapy. Irrespective of wound repair with scar tissue, good functional results can be achieved after careful and gradual training.

15.3 Special Muscle Injuries and Damage to the Torso

- Back musculature
- Chest musculature
- Stomach wall musculature

Ruptures in the region of these muscle groups generally result from pulling or tearing the fibers during sport activity. In general, these injuries are infrequent and are caused by indirect mechanisms such as sudden and excessive muscle contractions. Direct traumas occur predominantly during ball and contact sports, but also after falls from great heights and from traffic accidents.

The principle symptom is the sudden onset of pain that may result in the assumption of an antalgic posture. Partial tears or ruptures of the musculature of the stomach wall are prone to lead to the development of large hematoma and therefore present a clinical picture of peritoneal irritation as a result of massive tension in the stomach wall. Movements of the torso are observed in cases of both tear injuries of the stomach wall and of the back musculature.

Complications of a significant nature are not expected in cases of muscle ruptures because of the

indirect mechanisms, but may occur after direct trauma particularly to the stomach wall musculature with the accompanying risk of blunt injuries to the intraperitoneal organs.

15.3.1 Diagnosis

15.3.1.1 Recommended Diagnostic Measures in Accordance with the European Standard

- Inspection: swelling, discoloration from hematoma, asymmetry in the muscle contours in injuries to the stomach wall and back musculature, antalgic posture, impaired function.
- Palpation: pain on pressure, palpable gap in the course of the muscle, fluctuation during the formation of larger hematomas.

15.3.1.2 Additional Useful Diagnostic Procedures

- Ultrasound: presentation of a gap in the continuity of the affected muscle and the accompanying edema/hematoma. Abdominal ultrasound must be performed for injuries to the stomach muscles caused by direct trauma. A specific renal examination may be necessary in cases of blunt trauma in the region of the back musculature.
- MRI/Computed Tomography: required in individual cases only, particularly if there is suspicion of secondary intrathoracic or abdominal injury.
- Radiography: to exclude injury to the bones of the spine (e.g., fractures of the transverse processes of the lumbar spine).

15.3.2 Treatment

15.3.2.1 Conservative Treatment Recommended Standardized Therapeutic Measures in Accordance with the European Standard

Muscle injuries to the torso are almost exclusively treated by conservative therapy. This consists of protection, local application of cold and concomitant analgesic therapy, and later in carefully building up the muscle under the guidance of a physiotherapist.

Additional Useful Therapeutic Options

Apart from the measures mentioned above, no additional treatment techniques are used.

15.3.2.2 Surgical Treatment

Recommended Standardized Therapeutic Measures in Accordance with the European Standard

Surgical treatment is considered in individual cases when, as a result of complete rupture, severe hematoma formation is detected. Whether it is expedient during revision surgery to insert sutures with adaptation of the tear in addition to evacuating the effusion of blood and inserting drainage is a decision to be made on an individual basis. Because of the reduced potential for immobilization, all suturing is exposed to a high risk of secondary dehiscence. Only complete rupture of the pectoral muscle at its transition with the tendon (which is very rare) would be an indication for surgical repair.

Additional Useful Surgical Measures

The care of secondary injuries to the chest and abdomen that may be required and that must be undertaken in accordance with the standard for the treatment of this kind of lesion are the only additional measures that can be suggested.

15.3.3 Differential Diagnosis

Only injury to the musculature of the stomach wall prompts differential diagnosis of an intra-abdominal injury/disease because the reflectory contraction of the muscles can simulate peritoneal irritation.

15.3.4 Prognosis

The prognosis of muscle injuries to the torso is basically good, but is influenced to a great extent by sound diagnosis and potential therapy of secondary injuries to the body cavities.

15.3.5 Examples of Surgical Procedures

15.3.5.1 Procedure 1

In the case of extensive hematoma caused by a muscle rupture in the region of the stomach wall, the effusion of blood is evacuated surgically after clinical and ultrasound diagnosis and exclusion of a concomitant intra-abdominal lesion. Careful control of hemorrhage follows and a drainage tube is inserted. Suturing is then performed for reattachment if the stitches can be anchored with a reasonable degree of firmness through the muscle fascia. As far as complications are concerned, recurrent hematoma can be associated with secondary suture insufficiency. If another hematoma develops, a broad-minded approach should be taken for further revision.

15.3.6 Special Remarks

Athletes who are predominantly affected by muscle injuries to the torso are competitors in track and field events, gymnasts, ball players, and those participating in martial arts. Preparing for the return to sport activity must consist of closely monitored intensive muscle training.

15.4 Special Muscle Injuries and Damage to the Pelvis and Lower Extremities

In addition to muscular lesions, rupture injuries to the bone have been observed, particularly to the pelvis, above all in children and adolescents and predominantly in the context of sport activity such as sprinting, high and long jump, etc. In contrast, muscle injuries to the lower extremity most frequently involve older patients and are based on degenerative changes, and are generally caused by abrupt passive joint movements with tensed muscles (e.g., the quadriceps muscles). Overall, tears to the tendinous portions of the traction apparatus (quadriceps tendon, ligamentum patellae) occur most frequently.

The principle symptom is pain associated with loss of function. Complications consist of the formation of large hematomas, the development of heterotopic ossifications or myositis ossificans, and reduced muscle strength on complete recovery [4].

15.4.1 Diagnosis

15.4.1.1 Recommended Diagnostic Measures in Accordance with the European Standard

- Inspection: swelling and hematoma, changed external contour, antalgic posture, indirect muscle tension pain
- Palpation: pain on pressure, palpable dimpling in the course of the muscle

15.4.1.2 Additional Useful Diagnostic Procedures

- Ultrasound: visualization of the localization and extent of the injury and the size of the secondary hematoma/edema
- Radiography: exclusion of bone injury, particularly to the pelvis, presentation of possible rupture injuries to the bone
- MRI: in individual cases as an additional diagnostic measure
- Measurement of compartment pressure: particularly in the lower leg, less frequently in the thigh if there is extensive bleeding under the skin and/or the development of edema or hematoma

15.4.2 Treatment

15.4.2.1 Conservative Treatment Recommended Standardized Therapeutic Measures in Accordance with the European Standard

Muscle injuries to the pelvis and the lower extremity are subject to the general criteria for indicating conservative therapy (i.e., surgical treatment is indicated only in cases of more extensive types of rupture or large hematomas). All other muscle injuries can be treated conservatively. Temporary

immobilization with concomitant analgesia and thromboembolic prophylaxis, followed by intensive physiotherapy to build up the muscles, as well as manual therapy are the foundations of the therapeutic concept.

Additional Useful Therapy Options

In the case of competitive and highly competitive athletes, the indication for surgical treatment is somewhat broader in order to, at the very least, reduce the formation of troublesome scar tissue or ossifications by evacuating the hematoma or suturing the musculature. In individual cases, if fresh hematoma occurs, puncture under sterile conditions can contribute to relief. Every effort should be made to obtain definitive wound closure as early as possible after splitting the compartment.

15.4.2.2 Surgical Treatment Recommended Standardized Therapeutic Measures According to the European Standard

Extensive tears of the *gluteal and iliopsoas muscles* are an indication for surgical revision only when there is severe hematoma formation. This occurs only in exceptional cases; because this condition affects deep structures, the indication is proposed with reservations.

Tear injuries of the *adductors of the thigh* are treated surgically if large portions are affected. This applies particularly to competitive and highly competitive athletes. The same applies to muscle tears of the *hamstrings* or quadriceps muscle.

It is the *gastrocnemius muscles* in particular that are at risk from tears in the lower leg. Typical causes are racket and ball sports. The criteria given above, namely the extent of the injury, its localization, as well as hematoma formation are considered an indication for surgical treatment, as are the patient's expectations of subsequent sporting ability. The most important measure is the restoration of the continuity of the muscle using fine sutures following thorough evacuation of the hematoma. Surgical reconstruction is followed by temporary immobilization (e.g., in plaster); concomitant thromboembolic therapy is obligatory. Afterwards, intensive physiotherapy should lead to

gradual building up of the muscles and subsequently to muscle training specific to the type of sport in question.

If a threatening or manifest compartment syndrome occurs, emergency fasciotomy and delayed primary/early secondary closure should be performed. Evacuation of the hematoma alone requires sufficient drainage.

Additional Useful Surgical Measures

If intramuscular ossification occurs, which may contribute to deterioration in function, surgical removal of the foci of calcification may be indicated. A peri-operative ossification prophylaxis is then indicated.

15.4.3 Differential Diagnosis

Muscle tears of appreciable size in the region of the lower extremities can be diagnosed without difficulty by clinical examination and ultrasound. This is different with the somewhat less frequent muscle tears in the region of the pelvis, hip joint, and thigh, which because of their deep localization, cannot be confirmed definitively by clinical examination, but only by ultrasound, and in cases of doubt, by MRI. Their diagnosis should be differentiated from other possibilities.

15.4.4 Prognosis

Prognosis depends above all on the extent of the injury. Incomplete or complete muscle tears in the region of the thigh and calf muscles stand out specifically in terms of incomplete healing or extensive scar tissue even after surgical reconstruction. However, loss of function or strength is generally only slight (e.g., tear in the rectus femoris muscle).

15.4.5 Examples of Surgical Procedures

15.4.5.1 Procedure 1

Extensive tears of the gluteal, iliopsoas, or adductor muscles are revised surgically if a large hematoma has developed. After evacuation and multiple rinsing, the

temporary insertion of a synthetic sponge equipped with drainage (e.g., Vacuseal®) may be indicated and definitive wound closure is allowed only secondary to its removal.

15.4.5.2 Procedure 2

Partial or total tears of the thigh muscles (quadriceps muscle, hamstrings) or the gastrocnemius muscles are revised surgically. After evacuating the hematoma, the tear is resutured using fine, U-shaped sutures which should definitely not be tied under too great a tension. It is important to include the stable muscle fascia in the suture because they offer a better hold for the sutures inserted. What is problematic is the immobilization that is inherently necessary to protect the sutures and which, in the case of muscle tears to the thigh, is almost impossible to achieve.

15.4.6 Special Remarks

Muscle injuries to the lower extremity occur frequently in athletes and therefore a higher percentage than those to the upper extremity or torso are treated surgically. Despite repair with scar tissue after suturing, the affected muscle can still be trained and any loss of strength is generally only slight [5].

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