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MUSCLE INJURIES (SJ MCNEILL INGHAM, SECTION EDITOR)

Surgical treatment for muscle injuries

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Abstract Muscle injury causes functional impairment. The healing process takes time and fibrotic tissue can result. Recurrence and delayed recovery remain as unsolved problems. Surgical intervention can be a feasible alternative to avoid early and late complications associated with complete muscle tear in attempt to improve functional results. This article hopes to provide an update about surgical treatments for muscle tears in different scenarios.

Keywords Muscle injury · Surgical treatment · Repair · Scaffold · Myositis ossificans · Compartmental syndrome

Introduction

Muscle injuries (MI) are common in sports, and their prevalence is high in many modalities like soccer [1], rugby [2], basketball [3] and track and field [4]. The mechanism of injury can be direct, indirect or combined trauma [2, 3] and can result in disability that will take time to heal. The correct diagnosis is based on clinical history, physical examination and imaging findings (ultrasonography, CT or MRI) [1], while a safe return to sports and activities requires a specialized team for an enhanced recovery [4].

A judicious interpretation of all these elements is key to obtain a suitable approach. However, there is a myriad of classification systems with different terminologies that makes the accurate decision for a better MI treatment a difficult task [5]. Complications related with MI can occur: severe muscle haematoma, myositis ossificans and compartmental syndrome [1, 4, 5].

The majority of MIs can be adequately managed with conservative treatments [6]. There is no consensus when a surgical approach for MI should be implemented. Nonetheless, few studies have mentioned the need for surgical intervention. The main surgical indications include a large intramuscular heamatoma(s), a complete (III degree) strain or tear of a muscle with few or no agonist muscle or a partial (II degree) strain if more than half of the muscle belly is torn [7, 8]. Another situation can be taken into account, if there is a persistent pain for more than 4 months with functional impairment [9].

Muscle haematoma

The mechanism that causes a MI can occur after a direct trauma like an impact or contusion or indirectly following a stretch or a tear with muscle damage. In some situations after a MI, mainly in sports, a localized bleeding can form a haematoma [10]. There are two types of haematoma: intramuscular and intermuscular. The main differences are described in Table 1.

The prognosis for intermuscular haematomas is better than that of the intramuscular type. Poor prognosis indicators include increase and fluctuating swelling after 24 h, persistent swelling after 48–72 h, increased pain intensity, extension of

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Table 1 Types of muscle haematoma

	Intramuscular	Intermuscular
Fascia/muscle sheath	Remains intact	Torn
Bleeding	Within the muscle	Spread between muscle and fascia
Swelling	Persistent and increases beyond 48 h	Pronounced within few hours
Symptoms	Localized at the site of injury	Diffuse and distal the injured area
Discoloration	Appears few days after injury	Marked within few hours

tenderness from the site of injury, prolonged restricted limb range of motion caused by pain or muscle weakness and, potentially, diminished distal pulses or numbness and paraesthesia below the injury [10].

An overlooked muscle haematoma type, spontaneous, can occur in some scenarios. Risk factors that could contribute to haematoma formation need to be investigated: anticoagulation therapy (especially in the elderly); intense non-contact exercise, haemophilia, hypertension and following total hip arthroplasty [11–13]. The iliopsoas muscle is the most affected followed by the rectus sheath. Differential diagnosis with abdominal and gynaecological diseases should be remembered to avoid misdiagnosis [14].

Surgical haematoma drainage should be indicated when nerve and/or vascular compression is detected based on clinical signs and symptoms corroborated with subsidiary exam findings and when haematoma infection is clinically relevant. There is no gold standard rule to make a decision to bespeak surgery.

Muscle repair

Muscle repair can be advocated for partial or complete tears in the muscle belly when more than half of its volume is compromised associated with functional disability [7, 8]. However, the breakable muscle damaged tissue makes the repair technically challenging. This biological component does not allow us to achieve a mechanically strong end-to-end repair with an appropriate tension that would provide a beneficial environment to achieve an effective healing with a sutured contractile muscle tissue [9]. In attempt to minimize problems with surgeries for muscle repair and improve healing with a viable contractile muscle formation, the employment of scaffolds has been proposed as a biological augmentation for muscle repair. There are a plenty of suture techniques, mostly described for tenorrhaphy procedures: Kessler grasping suture, modified Kessler grasping, Mason-Allen suture, Chinese finger trap, horizontal, in "8", Bunnell suture, Nicoladoni technique and a combination of sutures [15–20] There is no consensus about which suture technique is the best. Aarimaa et al. (2004) showed, in an experimental study, that volumetric muscle loss greater than 20 % cannot be biologically repaired and, consequently, result in a loss of function [21]. Thereby, a complete muscle tear with loss of function, like a laceration, remains a challenge for a conservative treatment because it can bring about functional disability and muscle weakness [22]. Oliva et al. reported a case of a patient that underwent a muscle repair with common separated stitches in the quadriceps muscle, including the epimysium, with satisfactory functional recovery after functional tests and complementary imaging exams at a 6-year follow-up [16]. It has been noticed that the best muscle repair should enclose endomysium, epimysium and also perimysium. This way, combined sutures with Kessler stitches and Mason-Allen techniques provide a better repair with high-resistance tension forces in comparison with common separated stitches. He at al demonstrated, in an experiment with rabbits, that there is no difference between Mason-Allen and Kessler sutures related to maximal axial load. However, in the Mason-Allen technique, the failure point was near the sutures, whereas in the Kessler suture, the fibres breached longitudinally. Because of this, the best option to promote a firm muscle suture should be with combined different sutures [18, 23].

Scaffolds

The scaffolds keep the tridimensional pattern and composition of the original tissue and help to enhance muscle regeneration. These scaffolds can be acquired from different biological tissues like swine or bovine dermal tissue, mucous or pericardium. There are, in the American health market, nine scaffolds brands in commercialization, being that 06 derived from swine tissue, hereof 03 derived from non-cross-linked small intestinal submucosa, 01 cross-linked hydrated small intestinal submucosa and 02 cross-linked hydrated dermal. There are three other products derived from bovine tissue, being that 02 are non-cross-linked dermal tissue and 01 is a cross-linked pericardial tissue [24, 25••]. The biological scaffolds are efficient as they modify the tissue repair mechanism, produce less fibrotic tissue and more muscle tissue can be synthetized [24]. This is possible due to the scaffold's ability in altering the macrophages phenotypic delivery causing an increased release of tissue growth factors and promoting chemotaxis, from degraded tissue, attracting viable contractile tissue that enables tissue healing. Tissue differentiation into viable myoblasts, in the presence of a biological scaffold, is possible

due to the presence of macrophages with a M1 pro-inflammatory phenotypic differentiation (macrophages derived from monocytes that enter the injured tissue). M1 macrophages enhance tissue proliferation, stem cell and satellite cell migration. The M1 maturation process is only possible due to the presence of M2 macrophages. Studies have investigated macrophages function during the tissue repair process, and the question about anti-inflammatory drugs prescription in the early treatment after muscle injuries and its effect on the macrophages remains unsolved [21, 25••, 26, 24, 27].

It is desirable to have an adequate micro-environment for cell development as well as the presence of growth factors to optimize muscle tissue strength during the healing process. Growth factors help to modulate the myogenesis guiding tissue proliferation and differentiation. Some cells have the capability to produce growth factors that are activated by the presence of the biological scaffolds. These scaffolds activate latent growth factors, mainly the fibroblast growth factor (bFGF) and the vascular endothelial growth factor (VEGF) that are essential to angiogenesis and tissue repair [20]. Turner et al., in 2010, evaluated dogs that underwent a gastrocnemius muscle resection that was posteriorly imbedded with scaffolds. After 6 months, the resultant muscle presented with 48 % of muscle strength in comparison to the contralateral gastrocnemius, innervation and vascularization were similar to the original tissue. Scaffold use, for muscle tears, represents a promising treatment alternative for cases with volumetric loss. These scaffolds are able to increase migration and proliferation of progenitor cells in the damaged area [28].

Other studies have tried to elucidate which factors are related with tissue integration and mechanisms evolved to enhance the formation of the best viable and functional tissue. Scaffolds cultivated with stem cells can regenerate the damaged muscle and can be a good option to improve performance after a muscle injury [29]. However, even if the scaffolds are used with no cells, it is possible to restore muscle function. Valentin et al. (2010) demonstrated that acellular scaffolds were able to grow a tissue with 80 % functionally in comparison with the original tissue, after 6 months. Sometimes, these repaired healed tissues from scaffolds, even without stem cells implantation, can achieve a similar tissue with good vascularization and innervation [25••, 27].

The biological solution for muscle injury treatment will be one possible option to develop better function. It is necessary to ameliorate scaffolds that optimize tissue repair and growth factor delivery associated with improvement in suture techniques that upgrade the final viable tissue, with less fibrosis and with mechanical strength near the normal muscle.

Myositis ossificans

Myositis ossificans (MO) is a serious and relatively common complication after MI (Fig. 1). It is related to trauma from a single blow or repeated episodes of micro-traumas [30]. It can be diagnosed and monitored by serial X-rays, being radiologically evident 3–6 weeks after injury [31]. Common symptoms are tenderness, swelling, loss of motion and hardening of the tissue perceived by muscle palpation [32]. The erythrocyte sedimentation rate and white blood cell count may be elevated. The alkaline phosphatase can be helpful to establish the degree of different stages of maturation in MO. The most common reported sites of MO are in the thigh and arm muscles: quadriceps femoris, brachialis and the adductor muscles of the thigh [31, 32]. Other factors associated with MO are severe recurrent contusion or trauma resulting in haemorrhage or tissue necrosis, after hamstring graft harvest for knee surgery, after stress fracture in the foot [33–35]. In the majority of cases, it is asymptomatic and can be managed with non-operative treatments with spontaneous resolution monitored by imaging exams. Biphosphonate therapy with oral medication, which has potent anti-osteoclastic effects, can be prescribed in the acute phase with favourable outcomes [36]. If MO progress to permanently limit range of motion and function with pain or when the lesion is vulnerable to a repeated trauma causing disability, surgical intervention to remove persistent calcium deposits can be pointed out. Surgery should not be attempted until 4–6 months after trauma to allow for complete maturation of the process. When early open intervention is performed prior to maturation, recurrences are more likely to occur [32, 33].

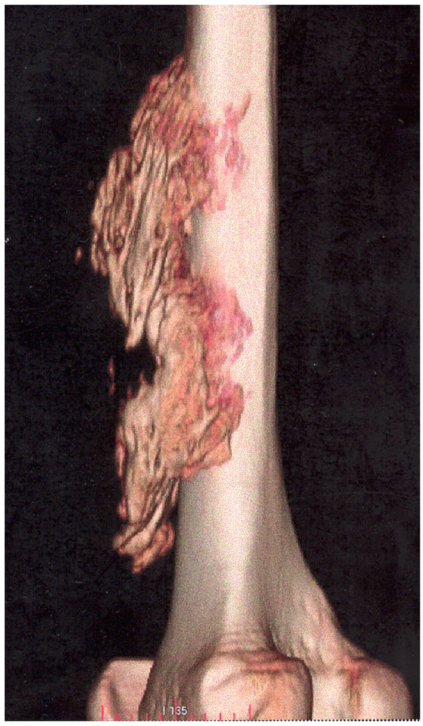

Fig. 1 3D CT showing myositis ossificans in the quadriceps

Compartment syndrome

Compartment syndrome (CS) results from elevation of pressure within a compartment and impaired tissue perfusion. Acute CS can be caused after a direct blow, crush injury, burns, penetrating trauma and haematoma after a muscle tear [37]. Male gender and age less than 35 years have also been shown to be risk factors [38]. Other factors should be investigated and can be associated with CS like prolonged exercises, some medicaments (anabolic steroids, simvastatin, gabapentin), diabetes mellitus, impaired mental status and neuropathies [39–41]. The most common areas affected are leg, thigh and forearm.

The most common symptom is a pain disproportionate to the injury, often associated with neurological abnormality [42]. Elevated intracompartmental pressure, obtained from a dynamic pressure measurement, is widely recognized as the most objective diagnostic parameter for CS. Whitesides et al. identified the pressure perfusion gradient at which ischemia is imminent and prophylactic fasciotomy should be done as <20 mmHg below the diastolic blood pressure [42]. Later, a pressure of 30 mmHg was suggested as an absolute threshold for the diagnosis of compartment syndrome [43]. Other methods to evaluate muscle oxygenation and CS can be used like near infra-red spectroscopy; intramuscular glucose concentration and partial pressure of oxygen rapidly help to identify muscle ischemia [44, 45•]. Early diagnosis is determinant for a good prognosis. Surgical intervention with open fasciotomy is mandatory when CS is confirmed [42]. It is crucial to identify all compartments involved to avoid incomplete or delayed fasciotomies that are associated with muscle necrosis and death [46–48]. If rhabdomyolysis occurs, haemodialysis should be considered when life-threatening hyperkalaemia and metabolic acidosis exist [49].

Conclusions

Surgical treatment for muscle injuries depends on several factors. Improvements in surgical suture techniques have evolved for muscle repair. Cell-based therapy with scaffolds has been shown as a viable option for a better functional recovery. Surgical intervention for myositis ossificans should be delayed if functional disability remains unresolved. Haematoma drainage and fasciotomy can be required, when symptomatic nerve and/or vascular compression inside the compartment is detected.

Compliance with Ethics Guidelines

Conflict of Interest Leonardo Addêo Ramos, Rogério Teixeira de Carvalho, Rene Jorge Abdalla, and Sheila Jean McNeill Ingham declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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