The meniscus tear. State of the art of rehabilitation protocols related to surgical procedures

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Summary

Meniscal injuries represent one of the most frequent lesions in sport practicing and in particular in soccer players and skiers. Pain, functional limitation and swelling are typical symptoms associated with meniscal tears.
Epidemiological studies showed that all meniscal lesions, in different sports athletes, involves 24% of medial meniscus, while 8% of lateral meniscus and about 20-30% of meniscal lesions are associated with other ligament injuries.
Meniscal tears can be treated conservatively or surgically. Surgery leads in many cases to complete resolution of symptoms and allows the return to sport activity. However many studies show that this treatment can induce more frequently the development of degenerative conditions if not correctly associated to a specific rehabilitation protocol.
The aim of this article is to compare different timing in specific rehabilitation programs related to the most actual surgical options.

Key words: knee lesions in sportler, meniscal tear, meniscal surgery and rehabilitation.

Anatomical background

Knee joint is composed of incongruent articular surfaces, therefore it relies on other structures to provide both static and dynamic stability: anterior and posterior cruciate ligaments, the medial and lateral collateral ligaments, the menisci, the capsule and the muscles crossing the joint. The menisci are two wedge shaped (in cross-section), semilunar fibrocartilage structures and are attached to the tibia, to the femur and to the patella. Medial meniscus appears 'C' shaped while the lateral meniscus appears more 'O' shaped[1].
Fibrochondrocytes are situated in menisci's inner portion and produce extracellular matrix. Fibroblasts are situated in menisci's outer portion and synthesize collagen and proteoglycans. This microstructure determines the physical-chemical properties of the meniscus: strength and stretch-, compression- and load- resistance[2].
The menisci are supplied by popliteal artery: a plexus of capillaries penetrates 10-30% of medial meniscus and 10-25% of the lateral meniscus widths. Meniscus can be divided into 3 zones: the "red zone", located in the peripheral third of the meniscal body and densely vascularized, the "red-white zone", located in the central third of the meniscal body, and "white zone", located in the inner third of the meniscus and with no vascularization[3].
Meniscus improves load distribution on knee joint and prevents the onset of early joint damages[4]. Medial and lateral menisci transmit respectively 50% and 70% of supporting load[2,5]. Meniscus transmits between 30 and 70% of the applied load through the knee, 50% of the joint compressive force (axial forces) in full extension and approximately 85% of the weight at 90° of flexion[1].
The knee has two degrees of freedom: flexion-extension and rotation. The movement of flexion-extension is allowed by the simultaneous rotation and translation of the tibia on femur, together with the translation of the patella on the femur. Menisci shift forward during the extension movement, while they are moving back during flexion movement. During rotation the menisci move in opposite directions[1].

Epidemiology of knee lesions

As reported by Majewski, injuries to the menisci are the second most common injury to the knee, with an incidence of 12% to 14% and a prevalence of 61 cases per 100,000 persons[6]. In his epidemiological study conducted on 17,397 patients in Germany and Switzerland, soccer, followed by skiing, are the sport with an increased risk of meniscal injuries. Among the injuries affecting the knee, he shows that most involve anterior cruciate ligament (ACL) (20.34%), medial meniscus (10.76%) and lateral meniscus (3.66%). He also observes that 85% of patients with meniscal and ACL injuries require arthroscopic treatment[7].
For Nielsen, the rate of anterior cruciate ligament injuries and meniscus tears was, respectively, 0.3 and 0.7 (injuries per 1,000 inhabitants per year). Only 27% of the injuries were associated with sports activities, but they were

found twice as often among athletes than people injured in nonathletic accidents. Ruptures of the collateral ligament and anterior cruciate ligament were four and seven times more common among athletes, respectively, while athletes sustained fewer meniscus tears than people involved in nonathletic activities[8].
Lohmander reported that the highest incidence of ACL tears is seen in adolescents playing sports that involve pivoting, such as football, soccer, basketball, and team handball. Based on an in-hospital clinical diagnosis of ACL rupture, the annual incidence was reported to be 30 per 100 000 in Denmark, but the annual incidence was 81 per 100 000 for the ages between 10 and 64 years in the general population in Sweden. For Lohmander the incidence of symptomatic isolated meniscus tears is difficult to ascertain. The previously quoted in-hospital study reported the annual population incidence to be 70 per 100 000 in Denmark. The majority of patients with an acute ACL injury are younger than 30 years, the age distribution of those diagnosed with an isolated symptomatic meniscus lesion is different, being very broad and with a group mean age around 35 years[9].

Types of meniscal tear

Sharp twist performed by unbalanced load (torsional loading) or a high compressive force between femoral and tibial articular heads (axial loading) cause often meniscus damage. The typical movement is a sudden transition from knee's hyperflexionto full extension, with meniscus stuck between the femur and tibia.
As reported in numerous studies, lateral meniscus has a greater articular surface and is therefore more interested in absorption and load transmission. It is also more mobile and is less susceptible to fracture than medial meniscus[10].
Jackson and Dandy's classification is the most commonly used for meniscal lesions[11] (Tab. 1). Lesions may be incomplete, usually superficial and asymptomatic, complete, stable or unstable.
Meniscal tears are called stable when they involve less than 50% of total thickness. Longitudinal lesions smaller than 1 cm or radial tears localized in 1/3 of the internal meniscus are belonging to this group as well. Usually they do not require specific treatment[13].
As described by Arnoczy and Warren, lateral region is well vascularized and therefore heals better after fracture. Longitudinal tears have greater healing potential than radial tears, as well as simple than complex lacerations and traumatic ruptures than degenerative tears[14].
Forriol reported in his study as the mechanism of meniscal repair follow two patterns: the *extrinsic* pathway in the vascular area, where there is a net of capillaries which supplied undifferentiated mesenchymal cells with nutrients to induce healing, and the *intrinsic* pathway, based on the self-repair capacity of the meniscal fibrocartilage and the synovial fluid. He described each healing's mechanical factors: immobilization and unloading are not relevant factors for meniscal healing in the vascular area, despite other authors found better results with meniscal immobilization. However a good fixation seems to be more important than joint immobilization[3].

Conservative treatment

Ice, application moist heat, compression, bandages and anti-inflammatory drugs are the conservative treatment, indicated for asymptomatic tears, for stable vertical longitudinal tears and horizontal cleavage (degenerative), while is not indicated for radial lesions. Rehabilitation treatment provides knee mobilization, muscle strengthening and no load restrictions. Resumption of sporting activities should be gradual and guided by symptoms[13].

Surgical treatment

Surgery is usually indicated in <50 years old- or in good health- and physically active- patients[4]. Knee osteoarthritis (OA) is the most frequent complication after surgery[15].

Table 1. Type of meniscal tears[12].

Type of lesion	Comment
Longitudinal lesion	Typical of the third decade Most frequent meniscal injuries As reported by Pellacci[12], longitudinal lesions represent 29% of all medial lesions and 33% of all lateral lesions
Bucket-handle lesion	A complete longitudinal lesion can become a bucket-handle lesion. Frequent in medial meniscus
Oblique tears (or flap)	Generally in the region between 1/3 back and 1/3 medium of the meniscus
Complex lesions	Typically produced by repeated knee trauma
Radial lesions	Usually originate from the free side to periphery
Horizontal tears	Degenerative lesions involving meniscus intramural portion

Partial-total meniscectomy
After total meniscectomy the tibiofemoral contact area decreased by approximately 50%, knee stress absorption capacity is reduced by 20% and therefore leading to an overall increase in contact forces by 2 e 3 times. Partial (16-34%) meniscectomy has been shown to lead to a >350% increase in contact forces on the articular cartilage[16,17]. Partial meniscectomy varies knee biomechanics: the peak local contact pressure is increased by 65%, while after total meniscectomy peak contact pressure is 235% of normal. A medial meniscectomy decreases contact area by 50% to 70% and contact stress increases by 100%, while lateral meniscectomy decreases contact area by 40% to 50% but contact stress increases by 200% to 300% secondary to the convex surface of the related lateral tibial plateau[18]. As reported by Metcalf, however, this surgery also bears heavily on degenerative joint disorders[19].
Partial meniscectomy is indicated for flap tears, radial tears in the inner or a vascular area, and horizontal cleavage tears[20].
Positive prognostic factors are: age < 40 years, one simple lesion (bucket handle, flap, radial), short time elapsed between trauma and surgery, minimal chondromalacia[21].
Risk factors for developing knee OA are: patients older than 40 years, abnormal bones alignment and lateral in respect to medial meniscectomy[18].

Surgical suture
High risk of OA degeneration after meniscectomy allowed the development of a less "invasive" surgical technique: surgical suture.
Meniscal sutures are indicated in longitudinal lesions, preferably acute, associated with ACL injury, between 5 mm and 3.4 cm length, in the red-red or red-white zone. Suture in white-white zone has little chance of healing[22].

Collagen meniscus implantation (CMI)
CMI (ReGen Biologics, Inc., Hackensack, NJ, USA) is made from purified type I collagen isolated from bovine Achilles tendons, which are minced, washed, purified, filtered, freeze-dried, molded, and cross linked by glutaraldehyde, producing a flexible C-shaped disk[23]. The CMI provides a 3-dimensional scaffold that is suitable for colonization by precursor cells and vessels and leads to the formation of fully functional tissue. Histologic studies showed that the lacunae of the implant are filled with connective tissue that contains newly formed vessels and fibroblast-like cells[24,25]. Rodkey has recently highlighted that CMI may be used to replace irreparable or lost meniscal tissue in patients with a chronic meniscal injury. The implant was not found to have any benefits for patients with an acute injury[26].

Meniscal allograft transplantation
Meniscal transplantation is indicated especially in patients who underwent subtotal or total meniscectomy and with compartmental pain or early OA evolution, while is contraindicated in advanced OA or knee excessive varus-valgus[5,27]. This treatment carries considerably difficulties: graft processing, donor cells preservation in the transplanted tissue, sterilization, graft's immunogenicity[28,29].

Recent developments
Recently, new strategies have developed to improve meniscal lesions treatment: non-vascularized meniscus lesions can be treated with free synovium or synovial pedicle flap too. It has been experimentally observed that fibrin clot alone[16] or together with endothelial cell growth factor or autogenous precultivated stem cells[30] and even implantation of porous polymers[15] leads to a better healing in the vascular region of meniscus. However, the strength of the generated scar tissue is weak and reaches only 40% of normality 4 months after implantation[30].
Synovial cells treated with hyaluronic acid and Hylan® increased the expression of TGF-b1 and VEGF, however the Hylan® decreased the connective tissue growth factor (CTGF) and the VEGF comparated with the hyaluronic acid[3].
One animal study showed that is possible to transplant the meniscus, partially or totally, by a porous composite Polycaprolactone and Hyaff® tissue, a class of polymers hyaluronan derivative obtained by a coupling reaction (Fidia Advanced Biopolymers, Abano Terme, Italy, Europe) with a pore size Between 200 and 300 m[31].
Zhang shows that the injection of bone marrow stromal cells goats with the hIGF-1 Gene Transfection of calcium alginate gel mixed with a meniscal lesion in the region localized White-white, facilitates the healing process to 16 weeks apart[32].

Rehabilitation protocol

Type of lesion, type of surgery, timing of biological healing and the patient's symptoms determine the various types of rehabilitation protocol available for a full recovery.

Rehabilitation after partial meniscectomy
After partial meniscectomy rehabilitation protocol can be aggressive, because in the knee joint anatomical structure should not be protected during the healing phase. Early objectives after surgery are: control of pain and swelling, maximum knee range of motion (ROM) and a full load walking. There is no load limitation, compatibly with the tolerance of the patient[20].
The rehabilitative treatment consists of ice-ultrasound therapy, friction massage, joint mobilization, calf raises, steps-ups, extensor exercise, bicycle ergometry[33]. Moffet et al. reported in a study of 31 subjects the importance of extensor muscles knee reinforcement[34]. Isokinetic testing data have shown significant strength deficits of the knee extensor muscles: Mattheus and St Pierre assessed muscle strength with isokinetic test before and after surgery. They found that muscle strength returns equal to preoperative state only 4-6 weeks after surgery and it is still reduced compared to non-injured limb up to 12 weeks[35]. Therefore, in a sportsman, rehabilitation plays a key role in restoring as soon as possible quadriceps' normal strength in both legs before returning to competitions.
Goodwin et al. showed as patients who receive overseen rehabilitation treatment get the same results in terms of quality of life (SF-36) and knee function than those who do not receive this treatment (going up and down stairs,

joint ROM) up to 6 weeks after surgery. In contrast, in a randomized, controlled study, Moffet showed that patients who received supervised rehabilitation had more rapid recovery of the quadriceps femoris muscle than patients in an unsupervised control group[34].
Prolonged immobilization has lost favor secondary to the well-documented deleterious effects associated with it. If Continuous Passive Motion (CPM) have repeatedly failed to demonstrate favorable outcome measures in evidence-based research studies, treatment under water cannot begin until wounds have properly closed in order to prevent increased risk of infection[36]. Kelln instead showed haw the bicycle ergometer's usefulness in the postoperative phase: exercise on a bicycle ergometer equipped with an adjustable pedal arm demonstrated promising results in patients after partial meniscectomy[36].
In the first week after surgery rehabilitation treatment consists in a progressive loading with crutches. In the subsequent 3 weeks the goal is to obtain a normal pace, increasing the knee ROM, depending on the patient's tolerability.
Intensive muscle strengthening, proprioceptive and balance exercises are carried out by the third week. The resumption of sport training is allowed when quadriceps' muscle strength is at least 80% in the operated limb compared to the contralateral limb, while the patient may return to competitions when the quadriceps muscle strength in the operated limb is at least 90% than healthy limb. Generally, patients return to work after 1 or 2 weeks, to sporting activities after 3 to 6 weeks and to competitions after 5 or 8 weeks[37].

Rehabilitation after meniscal repair

After meniscal sutures, there are two different rehabilitation approaches with regard to load granting, ROM recovery and sporting activities resumption timing.
Some authors in their studies allow a partial incremental loading for 4 weeks after surgery. Furthermore, knee joint is immobilizedin flexed position for 6 weeks after surgery and patient return to sports competitions is only after 5 or 6 months[6].
Other authors have instead formulated a protocol for accelerated rehabilitation, with early full bearing as tolerated, no brace and immediate mobilization of the operated knee[38].
A good percentage of meniscal healing, in patients undergoing accelerated rehabilitation protocol and a conventional rehabilitation program, has been reported by Shelbourne[39] and Mariani[40], but the accelerated group showed a more rapid return in full range of motion (6 weeks in the accelerated group versus 10 weeks in the standard group), a higher quadriceps strength at 2 months (82% in the accelerated group versus 71% in the standard group), and an accelerated return to full activity (10 weeks in the accelerated group versus 20 weeks in the standard group)[6].
Heckmann developed a treatment protocol by studying the postoperative phase of 500 patients undergoing meniscal repair and meniscal transplantation (170 patients). In his study the protocol was shown to patients before surgery. He highlights the importance of walking with crutches in a long-leg brace for about 6 weeks after meniscal transplant and complex meniscus repairs extending into central one-third region (but not routinely after repair of a peripheral meniscus tear); patient can walk with a progressive load varied depending on the injury and surgery (full load is granted after 3 weeks in peripheral suture and after 6 weeks in complex suture). His patients were also subjected to compression, bandaging and cold therapy[4].
At this stage, continuous ultrasound can be used to increase the blood supply in the healing tissue. Muchè shows how ultrasound therapy reduce pain and facilitate the mobilization of the operated knee[41].
Animal studies have demonstrated the importance of early mobilization. For example, Dowdy observed as joint mobilization facilitates the healing of the repaired tissue, early restoring structural characteristics similar to a not operated meniscus[42]. Noyes reported how early mobilization, after meniscal surgery in 224 patients, showed very low rates of osteoarthritis at 12 months apart[43].
Heckmann highlights in his study as the flexion is allowed up to 90° in the first 2 weeks post-op, up to 120° in the 3rd and 4th week, reaching the maximum flexion from 4- to 8-th postoperative week. Quadriceps isometric contraction exercises should be initiated immediately after the surgery, but only after 3-5 weeks (depending on the type of meniscal damage) more complex muscle strengthening exercises are undertaken, such as walking cup, toe raises, wall sits, mini-squats, hamstring curls etc.[6]
Between 3rd and 5th postoperative week the patient takes proprioceptive and balance exercises, even when the load is partial (tandem balance, shifting with crutches from side-to-side and front-to-back), while only from the 5^{th}-7^{th} week it's possible to do these exercises at full load, through devices such as Styrofoam half rolls and the biomecanical ankle platform system[4,6].
For Heckmann, straight run race and cutting exercises are possible only from 11^{th} to 16^{th} weeks; if quadriceps muscle strength in operated limb is equal to at least 90% to the healthy limbs strenght patient can return racing. The use of the "leg press" machine begins at 7^{th} -8^{th} week, while running must wait for the 25^{th}-26^{th} week and the return to full activity occurs around 30-35 weeks, but may be delayed up to 52^{th} week[4].
In a case study, a Professional Ice Hockey Goaltender is treated by Bizzini after lateral meniscus suturing surgery. He describes the importance of a neuromuscular sport-specific program in high-level athletes to enable more rapid recovery of sport activities. His rehabilitation program allowed the treated athlete to return to professional competitions after a 14 weeks treatment, with excellent results after 5 years. Bizzini specifies the need for a different rehabilitation program according to the kind of sport activity[44].
In another case study, Pabian shows the rehabilitation program carried out by a quarterback, treated by suture of the medial meniscus, which allowed him to return to full sporting activity 20 weeks after surgery with good results at 10 months[45].
A study of 55 patients showed how the return to sports that required cutting and jumping tasks was possible even between the third and fourth month after surgery[46].

Rehabilitation after cmi

Zaffagnini has developed a rehabilitation program consisting of early mobilization (0°-60°), to be increased to 90°

of flexion after 4 weeks with a maximum ROM up to 6 weeks.
The patient can ambulate with partial load up to 6 weeks and with a full load after this time. The complete recovery of physical activity takes usually place within 6 months[47].
Control after 6 and 8 years shows good results in terms of wound healing[25].
Recently, a review of Harston has shown that rehabilitation programs used on CMI treated patients allowed a return to physical activity without restrictions after 6 months of rehabilitation, but it was not specifiedhow advanced rehabilitation exercises or function testing contributed to the return to activity decision-making process and timetable[23].
In another study Zaffagnini shows that pain, activity level, and radiological outcomes are significantly improved by using medial collagen meniscus implant at a minimum 10-year follow-up compared to partial medial meniscectomy alone[48].

Rehabilitation after allograft meniscal transplantation
The meniscus transplantation technique has developed since ten years, therefore scientific study on rehabilitation timing after allograft meniscus surgery are still limited.
Manske claimed that meniscus transplants are under more stress in a joint with early degenerative processes, consequently a conservative rehabilitation protocol results more appropriate[49].
Fritz in a case study described the rehabilitation protocol used in the recovery phase of a young man after meniscus transplantation. Phase one involves the use of a knee brace locked. At this stage a progressive load is allowed until the fourth week. In the first 6 weeks the brace is locked in extension during walking that occurs with crutches and flexion is allowed up to 90°. Streight leg raises are performed to strengthen the muscles. The aim of the second phase (8^{th}- 16^{th} postoperative week) is to achieve a normal gait pattern. The muscle strengthening program continues through closed kinetic chain exercises and allowed flexionup to 100° with the granting of the operated limb loading. Closed kinetic chain exercises are performed (mini-squats, lateral steps-ups, leg presses) from 0 to 60°. In this phase, proprioceptive exercises are also initiated. The 3^{rd} phase can start if the patient has a painless gait, with the aim of improving strength and muscular endurance and joint ROM. Open kinetic chain hamstring exercises are initiated and proprioceptive exercises are amplified by means of less stable surfaces. The 4^{th} phase, from 9th month, is the resumption of normal activities, if there are appropriate strength, endurance and proprioception. The characteristics of the athlete are measured by isokinetic testing. Fritz, however, does not recommend the resumption of hard cutting and pivoting because of high risk of reinjury[5].
Heckmann in his study shows how transplanted patients require long-leg brace for up to 6 weeks, with a total load allowed only from the fifth to sixth postoperative week[4]. As for meniscal repair, flexion is limited to 90 degrees during the first 6 weeks, because meniscus is subjected to increased effort by the progressive knee flexion[28]. The ROM increases progressively after the sixth week. Sport specific activities restart after 4 months in order to develop further strength and proprioception. He recommends a return to racing not before 6 months (up to 12 months) while does not recommend squats and maximum flexion at least after 6 months from meniscal transplantation[5].

Conclusion

As shown in this article, after meniscal tear, there are varied surgical and rehabilitation treatments and the timing of recovery from meniscal injuries after surgery is very different.
Type of meniscal tear, patient's functional needs, state of the joint before surgery, recovery time and compliance/motivation of the patient are factors that orient at the type of surgery and rehabilitation program. Surgery is usually indicated in patients under 50 years or otherwise physically active[4]. Partial meniscectomy, sutures and meniscal allograft transplant techniques, as well as the latest methods developed, are actually used.
Meniscectomy leads to increase in peak stresses on the tibial plateau and this is directly correlated with the amount of tissue removed. If the meniscus is cut through its periphery, its load distribution function will probably be completely disrupted. Early after surgery, 92% of patients had excellent or good results, in term of knee pain, swelling, ROM, squatting, but at a mean of eight years after surgery, only 62% of the patients rated their knees as excellent or good[50].
Ideally, meniscal repair should result in healing of the tear and reestablishment of normal meniscal functions. Lesions in the red-red zone have the highest cure rate, while for red-white tears is also necessary to evaluate other parameters such as length, type, quality of the meniscal tissue and the injury-surgery interval before proceeding to a suture[21]. Repair of peripheral, longitudinal tears show a high frequency of healing and good functional results, with good long-term clinic result (13 years after surgery)[51]. Stein show how 94% of patients undergoing meniscal repair reached the preinjury sports activity level at the long-term follow-up (8.8 years after surgery), while only 43.75% of patient undergoing partial meniscectomy reached the preinjury level[52].
Meniscal transplantation is indicated in patients who underwent subtotal or total meniscectomy and with compartmental pain or early OA evolution, but presents numerous difficulties[2]. Over 75% of patients were satisfied with the procedure in terms of pain relief and functional improvement over a relatively short follow-up of up to 6 years[53]. Improvements in pain relief, activity level, general health, and radiological outcomes were documented with the use of CMI at a minimum 10-year follow-up[25,48].
Rehabilitation protocols for the resumption of sporting activities after surgery depend closely on type of meniscal tear and surgery, especially in the initial post-operative phase. The rehabilitation treatment begins from the first postoperative day with the pharmacological pain control, the resolution of swelling and individual exercises programs, to restore, as soon as possible and carefully, knee joint mobility, muscular forces, and physiological gait[4,43]. Proprioception and balance exercises are possible to do only with a good tone of the muscles of the thigh. After partial meniscectomy, athletes return to independ-

ent ambulation within 1 week, to run straight after 4-6 weeks and to train with the team after 6-8 weeks[37]. After peripheral suture, patients go back to walking independently after 5-8 weeks, to run straight after 12-16 weeks and to train with the team from 20th week onwards. After meniscal transplant patients resume normal ambulation after 8-12 weeks, return to straight running no earlier than 6 months, while the return to physical activity occurs after 12 months and is strongly discouraged the return of intensely stressful activities on knee joint[4].

As reported by Heckmann, the return to full physical activity is possible 6-8 weeks after partial meniscectomy, 20 weeks after a peripheral suture, at least 30 weeks (up to 12 months) after complex meniscal suture, while after meniscal transplant is strongly recommended to avoid physical activity that stimulates intensively and continuously the knee joint[4].

It is possible to establish a program of cardiovascular conditioning already after 2-4 postoperative weeks if the patient may use a bicycle ergometer for upper limbs[4].

The reported studies are conducted on selected patients, without relevant pathologies that could affect the timing of rehabilitation protocols. The concomitance of neuromuscular or ligament lesions, medical diseases or complications after surgery, as infections, can strongly affect the timing and the outcomes of rehabilitation protocols.

Moreover, new methods of treatment of meniscal lesions, such as the PRP or the CMI, were analyzed only in terms of cure rate, so it has not yet developed a specific rehabilitation protocol.

The analysis of various rehabilitation protocols used in different studies has been limited because numerous studies do not report in detail the type of rehabilitation program. As reported by the Logerstedt's recent guidelines, there is a lack of scientific evidence about the efficacy of the rehabilitation protocols and more studies are necessary[6].

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