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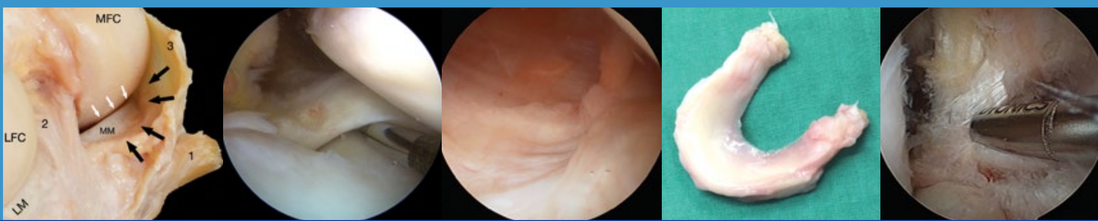

Surgery of the Meniscus

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5 Physiopathology of the Meniscal Lesions

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5.1 Introduction

The menisci have a major role in the function of the knee joint [57].

Meniscal lesions continue to represent the second most common intra-articular injury of the knee and are the most frequent cause of orthopedic surgeries [33, 81]. In the United States, the mean annual incidence of meniscal lesions has been reported to range from 61 to 66 per 100,000 inhabitants [5, 51], and most of them

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continue to be treated by meniscectomy [33]. Among the injuries of athletes affecting the knee, most involve the anterior cruciate ligament (ACL) (20.34 %), followed by the medial (10.76 %) and lateral meniscus (3.66 %) [53].

Meniscal injuries are more frequent in men than women, with a male to female incidence ratio ranging between 2.5:1 and 4:1. The peak incidence occurs at 20–29 years of age for both sexes [5, 33, 54] and is more common in the right knee [5].

Despite meniscal lesions can occur in all age groups, patient's age has a major influence on the etiological and pathophysiological factors [9, 66, 81]. The proportions of meniscus constitution concerning water content, cells, extracellular matrix, collagen, and adhesion glycoproteins present variations according to age, injury, and pathological conditions [88].

Anatomic features, biological and biomechanical characteristics, and the type of external forces acting in different zones and segments during normal and abnormal motion are decisive in the mechanism of injury of these structures [9, 34, 54, 59, 91].

It has been recognized that the partial or total loss of meniscus brings negative consequences to the knee, principally at long term [27].

Great changes have been introduced in recent years concerning the clinical approach to meniscus injuries. The paradigm has changed "from meniscectomy to preservation or substitution" [93]. Arthroscopic techniques have also created a revolution in treatment, and the ongoing development of implants and tools has contributed to a major increase in options for treatment of several injuries of the menisci [9]. Understanding the mechanism of injury and the biological response of the tissue to aggression might assist in further development of effective treatment strategies [70–72].

The meniscus is a complex tissue, and segmental variations have been reported concerning cells, ultrastructure, extracellular matrix, and biomechanical properties [70]. Different cells can also play different roles in meniscus function and response to aggression (injury) [92].

This work describes the most relevant injury mechanisms of the menisci, correlated to its ultrastructure and anatomy.

5.2 Anatomy, Biology, and Biomechanics: Relevance on Meniscal Injuries

The menisci are C-shaped wedges of fibrocartilage located between the tibial plateau and femoral condyles. The menisci contain 70 % of type I collagen interposed with cells and an extracellular matrix (ECM) of proteoglycans and glycoproteins [73]. The collagen bundles are combined in different orientations to oppose compressive, radial, and shear stresses [73]. The collagen bundles include three different layers [10, 17], as follows:

1. One more superficial with random orientation of fibers, which somewhat can mimic hyaline cartilage
2. Radial bundles (more frequent in the innermost one-third)
3. Circumferential bundles (in the outer two-thirds)

It has been suggested that fibers in the inner third mainly oppose to compression forces, while the outer two-thirds counteract radial tension forces [17].

Another group of collagen fibers, the so-called tie fibers, is radially orientated and its function is to oppose longitudinal splitting forces of the circumferential collagen bundles [17].

The medial meniscus is larger, has a "semilunar" shape, and is attached more firmly than the more circular shaped lateral meniscus [73].

The anterior and posterior horns of both menisci are firmly attached to the tibial plateaus. Anteriorly, the transverse ligament connects both menisci.

The meniscofemoral ligaments thus help stabilize the posterior horn of the lateral meniscus to the femoral condyle [36]. The coronary ligaments connect it in a somewhat "loose" way to the peripheral meniscal rim to the tibia. The lateral meniscus has no attachment to the lateral collateral ligament (LCL) despite the close anatomic correlation.

The joint capsule is attached to the complete periphery of each meniscus but adheres more firmly to the medial meniscus [54]. The popliteal hiatus allows the popliteus tendon to pass through to its femoral attachment site and represents an interruption in the attachment of the joint capsule to the lateral meniscus. During knee flexion, contraction by the popliteus pulls the lateral meniscus in a posterior direction and this way prevents it to become entrapped within the joint space [75].

There is no direct muscular connection to the medial meniscus. The medial meniscus is capable to move a few millimeters, while the less stable lateral meniscus may shift more than 1 cm [57].

Different mobility patterns of both menisci are believed to influence different injury mechanisms [9]. On kinematic MRI evaluation, the menisci tended to move significantly to the posterior side when moving from extension to flexion [44]. The anteroposterior meniscal movement was higher for the anterior horn of the medial meniscus and inferior for the posterior horn of the medial meniscus [44].

Under compressive loads, the medial porcine meniscus and its attachments undergo significant displacement by up to 2.66 1.2 mm ($P<0.01$) under knee joint loads of 200 % body weight (BW) [28]. Moreover an increase of 0.9 mm in the distance between posterior and anterior horn ($P<0.001$) was observed [28]. The meniscus and its attachments presented an average radial stretch of 0.6 %, an average circumferential stretch of 0.9 %, and an average axial compression of 11.6 % at 200 % BW [28]. An in vivo study of meniscus movements using dynamic MRI has shown that on weight-bearing conditions, the anterior horn of the medial meniscus moves through a mean of 7.1 mm and the posterior horn through 3.9 mm, with 3.6 mm of mediolateral radial displacement [91]. The height of the anterior horn increases by 2.6 mm and that of the posterior horn by 2.0 mm [91]. The anterior horn of the lateral meniscus moves 9.5 mm and the posterior horn 5.6 mm, with 3.7 mm of radial displacement [91]. The height of the anterior horn increases by 4.0 mm and that of the posterior horn by 2.4 mm [91]. The most significant differences between weight-bearing and non-weight-bearing conditions were the movement and vertical height of the anterior horn of the lateral meniscus [91].

Knee flexion normally leads to posterior movement and shortening of the anterior-posterior diameter of the menisci, which can be related to the positioning and curvature of femoral condyles at the tibiofemoral contact point at knee flexion [41].

This biomechanical behavior must be considered when aiming to understand the response of meniscal tissue to external loads.

The role of menisci on load transfer has been described by several biomechanical studies [31, 49, 50]. Understanding the biomechanical behavior of the joint is fundamental to understand is pathophysiology [47, 84].

Concerning load transmission, 70 and 50 % of the load are transferred through the lateral and medial menisci in its corresponding compartments [15].

The lateral meniscus carries most of the load transfer on the lateral compartment, while in the medial compartment the load transmission is more evenly distributed between the cartilage surfaces and the medial meniscus [94].

During normal knee kinematics the menisci are exposed to compressive, radial tensile, and shear stresses [1, 35, 65].

This knowledge (Fig. 5.1) has obvious implications in meniscus injuries and on global joint consequences of these injuries [27].

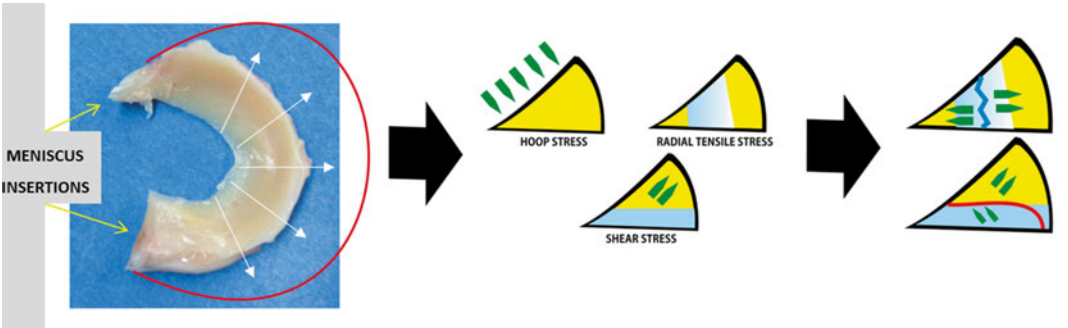

Fig. 5.1 Schematic representation of compressive (hoop), radial tensile, and shear stress forces (*green arrows*) implicated in pathophysiology of meniscus injuries

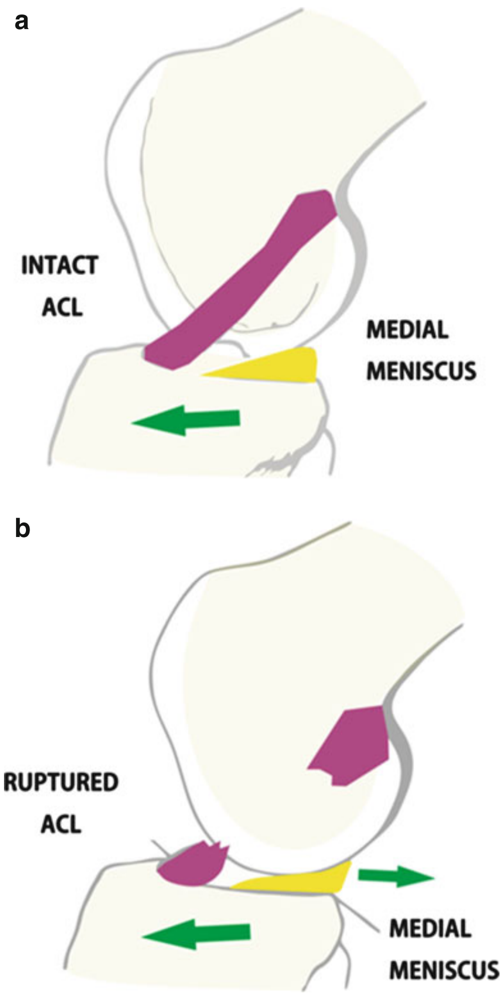

Fig. 5.2 Schematic representation of the primary role of ACL in impairing anterior tibial translation while the posterior medial meniscus horn acts as a secondary stabilizer (**a**); in the ACL-deficient knee the posterior horn of medial meniscus is frequently entrapped by the femoral condyle and tibial plateau during anterior tibial dislocation (**b**)

In the stable knee, with normal anterior cruciate ligament (ACL), the medial meniscus has a small function as secondary stabilizer when opposing to anterior tibial translation [57]. The ACL (primary stabilizer) impairs anterior dislocation prior to significant contact of the femoral condyle with the posterior horn of the medial meniscus (Fig. 5.2) [50]. However, in ACL-deficient knees this mechanism has been related to frequent patterns of meniscal injuries, including acute longitudinal and horizontal tears [9, 57].

The competence of collateral ligaments is also relevant once the absence of collateral ligaments increases the loads in cruciate ligaments and contact stresses transmitted through cartilage layers and menisci. Higher risk for injury consequently subsides, especially when varus-valgus forces are accompanied by other modes of loading as well [12].

The knee is a relatively incongruent joint (Fig. 5.3), thus producing quite different patterns of load transfer as compared to the ankle, being the latter a good example of a congruent joint of the inferior limb [90]. The menisci have an important role in increasing joint congruency. However, the lateral meniscus has a higher contribution in ensuring joint congruency when compared to the medial. Both these facts must be kept in mind when aiming to understand the physiopathology of meniscal injuries [61].

The meniscus has been divided for description and research purposes according to zones and segments [3].

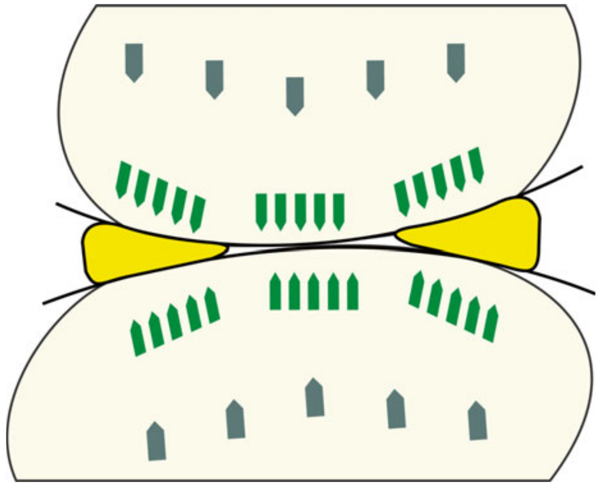

Fig. 5.3 Schematic representation of compressive load transmission (*gray arrows*) on an incongruent joint (e.g., the knee) and the important role of the meniscus in load transmission (*green arrows*)

The more vascularized zone 1 has higher quantity of stem cells than the less vascularized zones 2 and 3, and such cells might play a role in meniscal repair [67]. Meniscal vascularization is related to the healing capacity of meniscal tissue including recovery from repetitive loading. However, some healing of meniscal tissue has been described in avascular portions of the meniscus [9]. Anterior and posterior insertional horns are more richly irrigated [16].

Regional variations in viscoelastic properties [18] and regional and zonal variation in glycosaminoglycan coverage, size, and cellular density have also been reported in animal meniscal tissue [43].

For the first time, a recent study about regional variations in fresh human meniscus tissue concluded that medial meniscus presents higher stiffness (storage modulus – E') and loss factor (tan δ) as compared to the lateral [70]. Moreover, anterior segments present significantly lower stiffness (lower E') as compared to mid-body and posterior segments. Anterior segments of either lateral or medial menisci have higher tan δ, which suggests that they are more predisposed to dissipate mechanical energy [70]. Besides the fact that anterior segments have higher damping properties, they also have inferior cellularity as compared to other segments [19, 70]. The exact implication of such fact on injury and repair mechanism is subject to ongoing research.

Despite the material properties, stresses in the meniscus are also sensitive to the geometry of structures (meniscus width and radius of curvature of the femoral surface of the meniscus) [61, 62].

Biomechanics has implications in injury mechanism but it also can influence repair. It has been shown that joint loading through physical therapy may be beneficial in promoting healing of meniscal lesions under inflammatory conditions [60].

5.3 Traumatic Meniscus Injuries in Younger Population

Menisci can be traumatically injured during sports practice or high-energy trauma [78]. Meniscal tears might also occur in combination with fractures around the knee [78]. Clinical presentation of acute tears includes pain and/or swelling of the knee joint. Unstable, displaced tears might lead to mechanical symptoms such as clicking, catching, or locking of the knee joint [74].

Meniscal tears are more common in young and active individuals, particularly when enrolled in level 1 contact sports that comprise frequent pivoting, such as soccer, rugby, or American football [74]. However, such type of injuries can occur after apparently innocuous activities such as walking or squatting [6].

The most frequent traumatic mechanism is a twisting movement at the knee while the leg is bent (Fig. 5.4). Torsional loading or a high

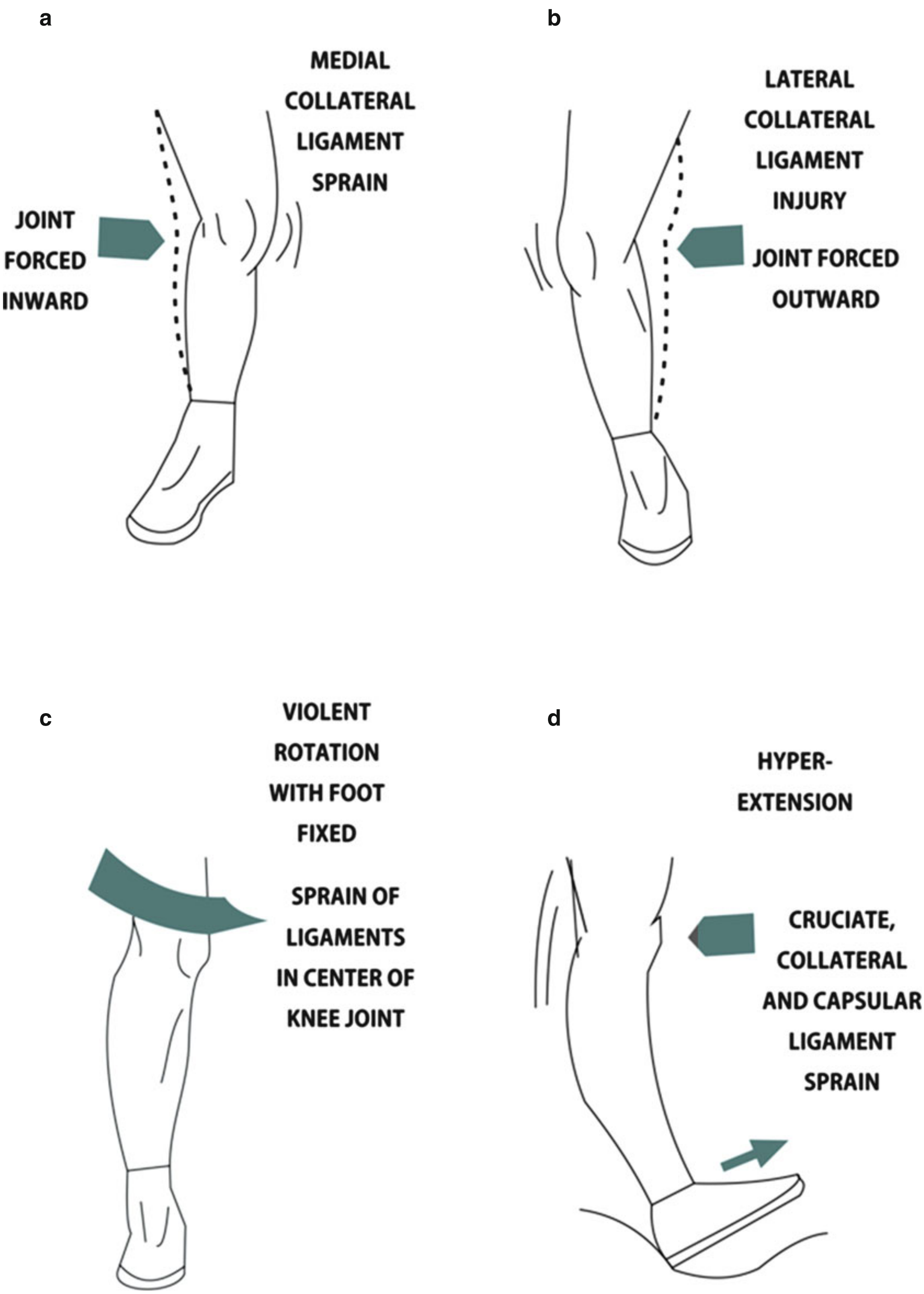

Fig. 5.4 Schematic representation of common injury mechanisms of ligaments, cartilage, and meniscus of the knee joint. (**a**) joint forced inward (often associated to medial colateral ligament injury); (**b**) joint forced outward (often associated to lateral colateral ligament injury); (**c**) violent knee rotation with the foot fixed (central pivot and menisci); (**d**) Hyperextension (multiple intra and extra articular injuries)

compressive force between femoral and tibial articular heads (axial loading) can cause meniscus damage at a different extent [30]. Valgus impact with external rotation of the tibia might also cause a triad of injuries involving meniscal damage with associated medial collateral and ACL tears [20, 83]. Another typical movement is a sudden transition from knee's hyperflexion to full extension, catching the meniscus trapped between the femur and tibia [30].

As aforementioned the lateral meniscus has a higher articular surface and is therefore more involved in absorption and load transmission. It is also more mobile and thus less susceptible to fracture as compared to the medial meniscus [55].

The patient's main complaints are usually knee pain and swelling. These are worse when the knee bears higher loads (e.g., when running). Another typical patient's complaint is joint locking, with patients referring that they are unable to straighten the leg completely. This can be accompanied by a sense of "clicking." Some patients also refer an impression of giving away [30].

The patients can often remember a specific trauma, activity, or movement during which the meniscus injury occurred. Diagnosis must be primarily based on clinical examination; however, MRI evaluation is often useful [80].

Meniscus tears (Fig. 5.5) can be classified in various ways: by anatomic location, by proximity to blood supply, etc. They can be referred as incomplete, complete, stable, or unstable [69]. Various tear patterns and configurations have been described [13, 40] (Table 5.1).

The functional importance of these classifications, however, is to ultimately help surgeons determine whether a meniscus is repairable or not.

More recently, the ISAKOS classification of meniscal tears has been developed for pooling of data from international clinical trials designed to evaluate the outcomes of treatment. The method has shown sufficient interobserver reliability [3].

Several risk factors have been implicated in the etiology of either degenerative or acute meniscal tears, with some of these factors being potentially modifiable [85].

There is moderate evidence that weight bearing during trauma is an important risk factor for acute meniscal tears [29]. Sports activity appears

Table 5.1 Type of meniscal tears

Type of lesion	Comment
Longitudinal lesion	Most frequent meniscal injuries Represent 29 % of all medial lesions and 33 % of all lateral lesions [69]
Bucket-handle lesion	More common in the medial meniscus A complete longitudinal lesion can progress to become a bucket-handle lesion
Oblique tears (or flap)	More frequent in the region between the mid-body and posterior segments of the meniscus
Complex lesions	Usually a consequence of repeated knee trauma
Radial lesions	More often originate from the free border to the meniscal periphery
Horizontal tears	Usually are degenerative lesions

Pellacci et al. [69]

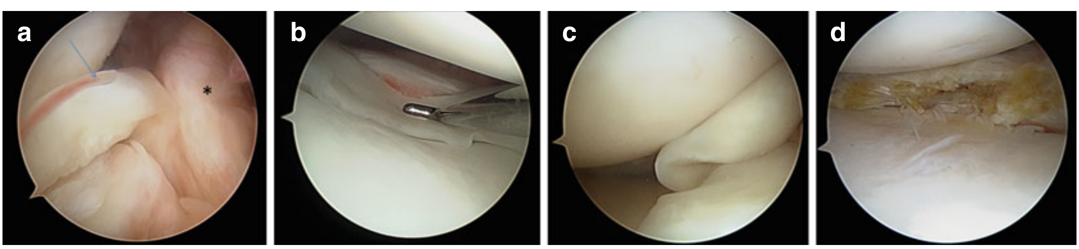

Fig. 5.5 Arthroscopic images of: lateral meniscus bucket-handle tear (*blue arrow*) with the ACL visible (*) (**a**), medial meniscus longitudinal peripheral tear (**b**), medial meniscus flap/parrot-beak tear (**c**), and degenerative, complex medial meniscus tear (**d**)

to be a relevant risk factor in such lesions [6, 7, 85]. Certain types of sports, described as contact sports, have been correlated with increased risk for meniscus tears. American football, basketball, soccer, baseball, and skiing in particular are the most frequently involved in meniscal lesions, accounting for more than 1/3 of all cases [54]. However, despite its low-contact profile, swimming has also been identified as risk factor for acute tears [7]. There is some evidence that running might also be considered as a risk factor [85]. Global joint laxity is another risk factor for meniscal tears [5]. These persons with higher risk should be included in pre-participation prevention programs [6].

Delayed ACL repair for more than 12 months after the ACL injury determines an overall *odds ratio* of 3.50 for medial meniscal tears when compared to early ACL repair [85]. Conversely, minimal to no evidence was found for the period of time comprised between ACL injury and reconstruction surgery as a risk factor for lateral meniscus tears [85]. These findings should be understood considering the above-mentioned different roles of medial and lateral menisci within knee joint [57]. Moreover, a delay in surgical treatment is also associated with a higher incidence of medial meniscal tears in pediatric and adolescent populations [63]. Increased age and body mass index are independently associated with a higher rate of medial meniscus tears [21].

Symptomatic horizontal meniscal tears (Fig. 5.6) in young patients are a rare entity and often correlate with severe meniscus injuries. It has been mostly considered as an overuse syndrome [76].

Complete radial tears (Fig. 5.7) significantly diminish the capacity to maintain hoop tension in the meniscus. However, the residual meniscus might continue to provide some load transmission and distribution functions across the joint [11]. Repair techniques for complete radial meniscal tears are focus of intense development and research [56].

Meniscal root tears (MRTs) can either be traumatic or degenerative (Fig. 5.8). Traumatic MRTs are often combined with ACL tear, particularly on the lateral meniscus [9]. The disruption of collagen fibers, which provide hoop strength, eventually results in diminished biomechanical properties leading to meniscal extrusion [68]. In high-energy trauma causing acute tibial plateau fractures, depression of the joint line is a potential predictor of specific meniscal (and ligamentous) injuries [86].

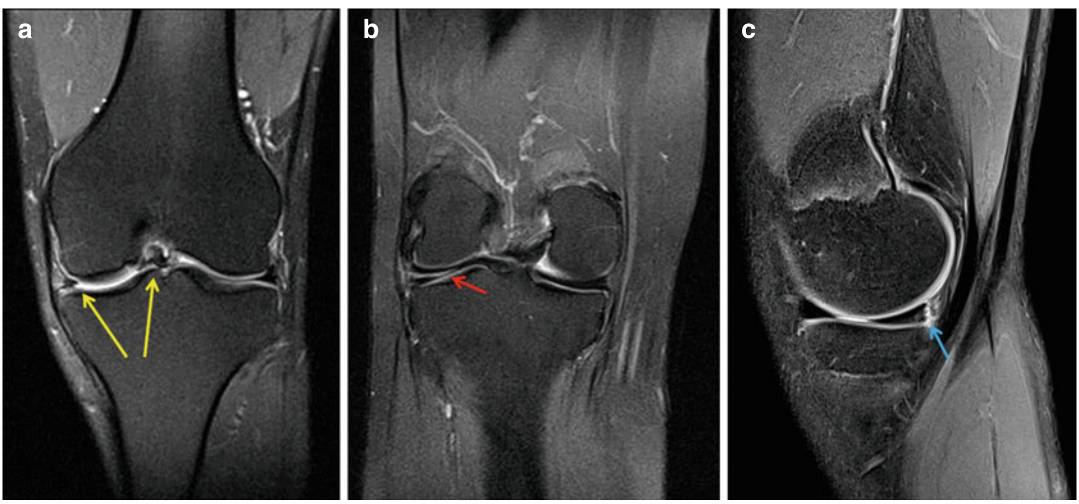

Fig. 5.6 MRI T2 images of: medial meniscus bucket-handle tear (*yellow arrows*) (**a**), lateral meniscus horizontal cleavage tear (*red arrow*) (**b**), and medial meniscus complete longitudinal peripheral tear (*blue arrow*) (**c**)

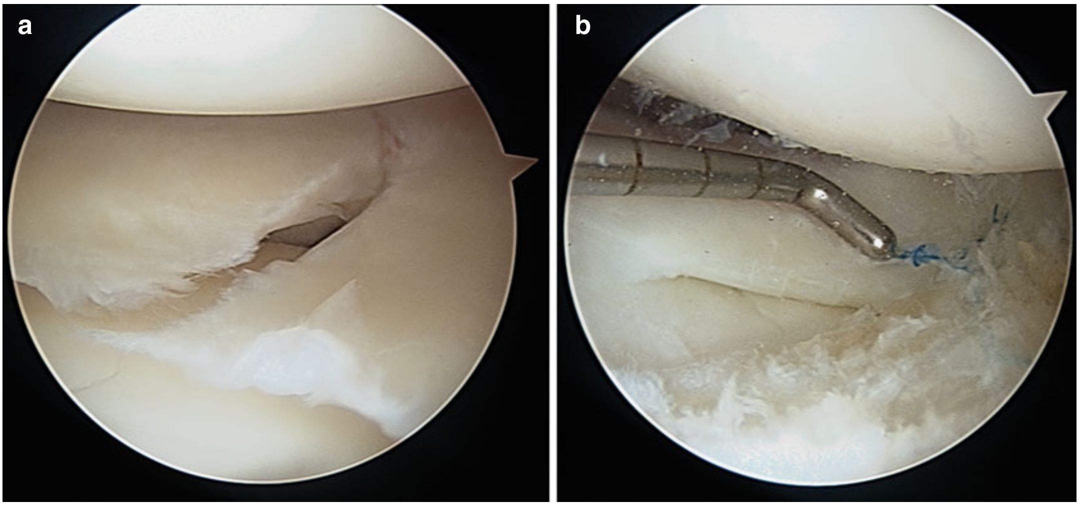

Fig. 5.7 Complete radial tear of the lateral meniscus (**a**) and postoperative look after suture of the same radial tear combined with limited excision of tissue in the most avascular zone (**b**)

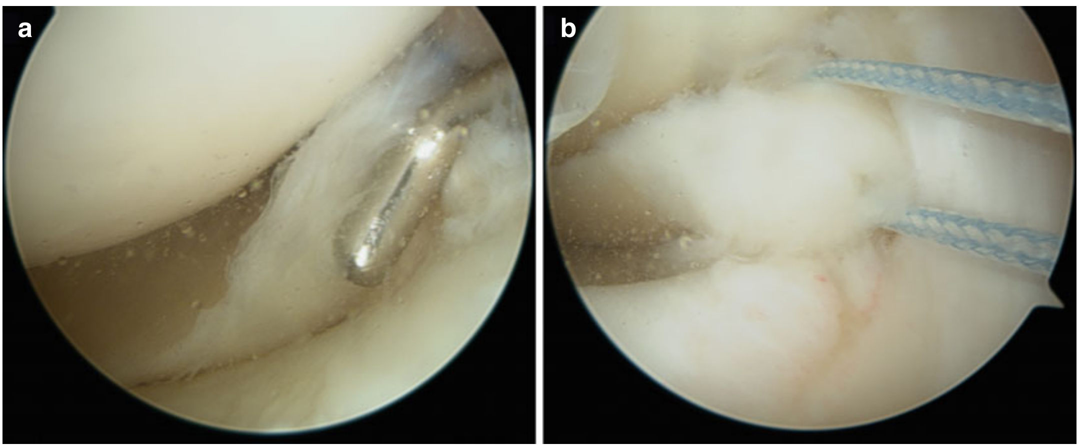

Fig. 5.8 Medial meniscus posterior root tear (**a**) and intraoperative look of sutures passed through the posterior root for subsequent reinsertion within a bone tunnel (**b**)

5.4 Degenerative Meniscus Tears in Older Population

Meniscal lesions can occur very frequently in middle-aged and elderly patients [23]. Typical configurations of these tears are horizontal cleavages and/or flap/oblique tears involving the medial meniscal body and or injuries of the posterior horn (Fig. 5.5d). Most meniscal tears exist in persons without knee symptoms. Hence, meniscal tears are an extremely common incidental finding on magnetic resonance imaging of the knee [23]. Most tears encountered in patients within this age group usually result from long-term degenerative changes. Such meniscal lesions might be implicated in joint swelling, joint line pain, and/or mechanical blocking [8, 23]. Among patients with clinical and radiographic findings of osteoarthritis, the reported prevalence of meniscal lesions is comprised between 68 and 90 % [26, 45]. This high correlation causes severe limitations for diagnostic and proper course of action. Only if the main pathology in a symptomatic knee is properly identified, one can choose the most effective treatment. It is highly unlikely that the treatment of meniscal tears with partial meniscectomy is effective in the reduction of symptoms caused by global joint osteoarthritis [9].

Meniscus repair in older people has been providing less promising outcome compared to younger age groups [8].

One fact supporting such unfavorable outcome is the degenerative etiology surrounding meniscal tears in such older patients, considering the previously referred changes in meniscus properties as well as the declining vascularization of the aging meniscus [9, 54].

The currently preferred surgical treatment for the majority of surgeons for treating symptomatic meniscus tears in older patients is meniscectomy, either partial or total, depending on the degree of meniscal damage [23].

Other risk factors associated with development of degenerative lesions besides self-reported knee injury include the malalignment of the knee (the more loaded compartment) and the presence of signs of hand osteoarthritis [22]. This screening method of x-ray screening might be useful to identify systemic or potentially a common environmental factor [22]. Occupational load also plays a role in the development of symptomatic meniscal tears [79].

When a meniscus is damaged, the degenerative processes leading to knee osteoarthritis dramatically increase, probably due to loss of meniscal function in load distribution and shock absorption. In elderly patients the presence of meniscal injury may often be considered as a sign of incipient osteoarthritis [22–25].

The prevalence of meniscal tears increases with aging, ranging from 16 % in the knees in 50–59-year-old women to over 50 % in the knees of men aged 70–90 years [23]. Moreover, among elderly patients, it has been reported about 10 % of cases with partial destruction or complete absence of normal meniscal tissue [23]. This shall not be classified as meniscal tear, but is a finding typically associated with radiographic evidence of osteoarthritis [23].

However, among elderly patients, most of meniscal tears do not cause knee symptoms as over 60 % of tears were seen in knees of subjects without knee pain, aching, or stiffness [23]. Hence, a meniscal tear is a common incidental finding when performing MR imaging of the knee in this population. However, having such meniscal damage on MRI has been associated with an almost sixfold increased odds ratio for development of radiographic knee osteoarthritis over 30 months [24].

Another key issue besides its morphologic integrity is the meniscus position within the knee joint once varying degrees of meniscal extrusion have been implicated after degenerative meniscus tears [48]. Meniscal extrusion of the meniscal body is more frequent in the osteoarthritic knee [32, 42, 87]. Moreover, meniscal extrusion lowers the coverage of the tibial surface and has been reported to be an important risk factor for cartilage loss [25, 38, 82] and joint space narrowing seen on conventional tibiofemoral radiographs [37, 39].

In brief, injury mechanisms of degenerative meniscus tears are usually multifactorial. Assessment of joint alignment, aging changes in the meniscus tissue proper, and osteoarthritic joint environment must be considered besides any possible traumatic event.

5.5 Meniscal Tears in Children

Meniscal lesions in children have different features when compared to adult patients. In children, most cases (>71 %) correspond to isolated meniscal lesions [4, 52, 77].

The most frequent mechanism of meniscal injury in children is sports-related twisting of the knee. One possible predisposing factor for a small percentage of cases is the presence of a discoid meniscus [46]. Diagnosis is based on medical history of the patient and clinical examination. If a meniscal tear is suspected, complementary imaging methods of diagnosis are often required. However, MRI has lower sensitivity and specificity for diagnosing meniscal lesions in children compared to adults [58, 89].

There is less knowledge available in literature concerning treatment of meniscal injuries in children compared to adults. However, most studies reported that the overall success rate for meniscal repair in children appears to be at least similar to that observed in adults, especially for cases of isolated tears [2, 14, 64].

Take-Home Message

There are important differences in the medial and lateral meniscus concerning biology, anatomy, and biomechanics, which have a decisive role in different types of tears and epidemiologic features for both. Moreover, there are regional and segmental variations within each meniscus with implications in their function and subsequently in their injury and repair mechanisms. The menisci must oppose to compressive, tensile, and shear forces.

Several traumatic events with different combinations of forces have been enrolled in etiology of different types of meniscal tears.

Despite the previous, other factors such as age, joint alignment, body mass index, level of activity, and age also play a role on the pathophysiology of meniscus tears.

The degenerative meniscus tears in older populations result from a multifactorial and complex combination of events and are usually difficult to separate from the global environment of a globally arthritic joint in many of the older patients. In addition, most degenerative tears that are found on MRI studies within these elder populations are asymptomatic.

This must be taken into account when preparing the treatment of such patients.

Meniscus injuries are rare in children and are mostly related to sports trauma, and in a small percentage of cases, a discoid meniscus might be implicated.

Growing insights from basic science studies promise to bring new insights for some difficult questions in the near future concerning this topic of physiopathology of meniscus injuries.

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