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12 Recovery of Hip Muscle Strength After ACL Injury and Reconstruction: Implications for Reducing the Risk of Reinjury

Sanjeev Bhatia, Jorge Chahla, Mark E. Cinque, and Michael B. Ellman

Abstract

Recovery of lower extremity muscular strength and neuromuscular control are two of the most vital aspects of anterior cruciate ligament (ACL) rehabilitation, as well as efforts to prevent noncontact ACL injury. There is strong evidence regarding the association between decreased hip range of motion, particularly internal and external rotation, and noncontact ACL injury. Given that females are at greater risk for ACL injury compared with males, increased emphasis has been placed on identifying risk factors in the hip as well as throughout the kinetic chain for this injury. In this chapter, we discuss the relationship between hip and knee injury patterns and its implications for ACL reconstruction and rehabilitation and noncontact ACL injury prevention efforts.

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12.1 Introduction

An anterior cruciate ligament (ACL) injury can be a debilitating entity, not only due to the lack of reestablishment of normal knee biomechanics in some cases, but also because of the muscular imbalance produced after ligament reconstruction. A staged and customized muscle rehabilitation program can be tailored to allow the patient to return to their activities in a timely fashion and diminish the risks of an ACL reinjury.

Identification of muscular deficits after an ACL injury is vital to prevent further injuries. In this regard, Petersen et al. [1] reported in a recent systematic review of 45 articles that all studies identified strength deficits after ACL reconstruction compared with control subjects. Of note, some of these deficits persisted up to 5 years after surgery depending on the rehabilitation protocol instituted. Knee flexion strength was more impaired with hamstring grafts and quadriceps strength was more impaired after bone–patellar tendon–bone ACL reconstruction. These authors suggested that muscular strength testing is important to determine if an athlete can return to competitive sports after an ACL reconstruction.

Female athletes are a specific population at increased risk for both primary and secondary ACL injuries. Prodromos et al. conducted a meta-analysis of 33 articles and reported that the mean ACL injury rate for females was significantly greater than males in basketball, (0.28 and 0.08 per 1000 exposures, respectively, $P < 0.0001$), soccer (0.32

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and 0.12 per 1000 exposures, respectively, $P < 0.0001$), and handball (0.56 and 0.11 per 1000 exposures, respectively, $P < 0.0001$) [2]. Such injury rates have resulted in a growing body of literature focused on the treatment of these injuries in addition to identifying risk factors and prevention programs [3]. Several studies have reported a reduction in the number of ACL tears after implanting a preseason neuromuscular training program [3–5]. Furthermore, studies have reported altered landing biomechanics in female athletes before and after ACL injury. The observed abnormal knee kinematics are associated with abnormal hip strength and movements [6]. Because of this, increased attention has been directed toward identifying the optimal balance of hip and knee motion in the female athlete, with the aim of preventing or reducing the rate of female ACL injuries.

For the abovementioned reasons, the purpose of this chapter is to describe important facts regarding the recovery of muscle strength after ACL reconstructions in female athletes and to outline the current interventions to diminish the risk of ACL reinjury. Combined lower limb biomechanics, pathogenesis, and prevention strategies will be presented.

12.2 Interaction Between Altered Hip Mechanics and Knee Injury Patterns

In the United States, approximately 200,000 ACL injuries per year are reported, resulting in an expense of billions of dollars for the health system [7]. Importantly, one of the most common causes of osteoarthritis (OA), but often overlooked, is the development of post-traumatic osteoarthritis after ACL tears in the young and active population [8, 9]. For these reasons, prevention and identification of risk factors for ACL tears are key to prevent the cascade of joint degenerative process. Importantly, female athletes are at an increased risk of injury. Potential explanations for this include increased knee valgus or abduction moments, generalized joint laxity [10], genu recurvatum [11], a comparatively smaller ACL [12], and the hormonal effects of estrogen on the ACL [13].

Although many risk factors have been identified such as age, sex, anthropometric measures, and psychological and inherent anatomical factors [3], limited evidence exists regarding the relationship between the range of motion of the hip (which acts as a "buffer" in forced rotation of the knee) in patients with an ACL injury. In this regard, available literature suggests an association between decreased hip motion in patients with ACL injuries, predominantly with decreased internal rotation of the hip. This suggests that an ACL injury may not only have an intrinsic knee etiology but can also be related to an adjacent joint-based problem [14–17].

Tainaka et al. [18] reported the possibility of an association between noncontact ACL injuries in high school athletes and hip range of motion. These investigators found that the incidence of ACL injury increased as hip internal rotation (IR) or external rotation (ER) decreased. However, the odds ratios were small and no other potential risk factors were included in the analysis. As previously reported, a restricted IR of the hip is in most cases associated with abnormal proximal femoral or acetabular anatomy [19] and has been correlated with ACL ruptures and reruptures in soccer players [20, 21] and in professional American football athletes [22].

Both femoral (decreased femoral head–neck offset or increased alpha angle) and acetabular (decreased center-edge angle [CEA]) bone deformities can place the ACL at risk [15, 23]. Yamazaki et al. [23] reported that the CEA of the ACL-injured patients group was significantly smaller than that of a control group, suggesting that ACL-injured patients may have a higher prevalence of acetabular dysplasia. Philippon et al. [15] reported that patients with a decreased femoral head–neck offset (alpha angle >60°) were at increased risk of having an ACL injury because of altered lower limb biomechanics. This increased risk was evident in both males and females, with a slight predominance in males. The ACL injury cohort had a mean alpha angle of 86° and 79° in males and females, respectively, the values of which are markedly higher than previously reported limits of normal alpha angles.

Beaulieu et al. [24] performed a simulated single-leg pivot landing study to assess the peak relative strain of the anteromedial bundle of the ACL in relation to the available range of internal femoral rotation. In their statistical model, peak ACL relative strain increased by 1.3% with every

10° decrease in femoral rotation. From this concept, these authors suggested that an athlete presenting with femoral acetabular impingement (FAI) with a 10° deficiency in internal femoral rotation would experience 20% more peak ACL strain during landing than a healthy athlete. Importantly, patients with abnormally elevated alpha angles may have diminished capacity at the hip to accommodate overall lower extremity internal rotation moments, potentially predisposing the knee (and other intra-articular structures) to a greater rotational stress. In this regard, Girard et al. [25] suggested that improving the femoral head–neck offset could result in an improved range of motion in the hip, specifically in flexion, thereby allowing knee forces to be normalized.

Given that females are at greater risk for ACL injury, increased emphasis has been placed on identifying risk factors throughout the kinetic chain for ACL injuries in female patients. In this regard, Imwalle et al. [26] studied lower extremity kinematics during 45° and 90° cutting movements and examined the amount of hip and knee internal rotation during each movement. Mean hip and knee internal rotation, in addition to hip flexion, were greater during the 90° cutting motion in female athletes. These authors concluded that increased knee abduction in female athletes was secondary to abnormal coronal plane motion of the hip. They proposed that neuromuscular training of the trunk and hips may be able to reduce ACL injury by improving extremity alignment. Similar findings were reported by Leetun et al. [27] who demonstrated athletes with greater hip abduction strength were significantly less likely to sustain a lower extremity injury. It has also been reported that adolescent males experience an equal hip abduction strength increase relative to their developing body mass, while their female counterparts have less hip abduction in relation to their developing body mass [28]. The lack of hip abduction strength in adolescent girls may be related to the elevated risk of ACL injury observed in adolescent females [6, 28]. Taken together, these findings demonstrate the need for young athletes, in particular young female athletes, to perform hip abduction strengthening exercises prior to high-level competition. Moreover, young female athletes should begin these strength training protocols around age 13, when their body mass grows disproportionally to their hip abduction strength.

Critical Points

- Potential association between decreased hip range of motion (especially decreased internal rotation) and ACL injury.
- Femoral and acetabular bone deformities may increase risk of ACL injury.
  - Decreased femoral head–neck offset
  - Increased alpha angle
  - Decreased center-edge angle
  - Femoral acetabular impingement
- Athletes with greater hip abduction strength may be less likely to sustain lower extremity injury.
  - Young female athletes should perform hip abduction strengthening exercises beginning around age 13.

12.3 Femoral Acetabular Impingement (FAI) and ACL Injury

As previously discussed, altered hip kinematics secondary to pathologic conditions such as FAI may increase a patient's susceptibility to ACL injury. FAI is a well-known hip condition caused by alterations in the bony anatomy of the hip. First described in 2003, Ganz and colleagues [29] coined the term *femoroacetabular impingement* to describe a "mechanism for the development of early osteoarthritis for most nondysplastic hips." FAI is due to abnormal contact between the proximal femur and acetabular rim that occurs during terminal motion of the hip, leading to lesions of the acetabular labrum and/or adjacent acetabular cartilage. Subtle, previously overlooked deformities of the proximal femur and acetabulum were recognized as the cause of FAI, including the presence of a bony prominence typically in the anterolateral head and neck junction (cam morphology), or changes caused by an abnormal acetabular rim abutting against a normal femoral head and neck (pincer deformity). Therefore, cam-type and pincer-type FAI deformities were introduced as two distinct mechanisms of FAI.

12.3.1 Cam FAI

Cam-type impingement is caused by an abnormal shear force between an aspherical femoral head and a normal acetabulum during hip flexion and internal rotation [30]. During motion, the cam deformity is rotated into the acetabular socket with a shearing-type injury pattern, causing a labral tear and delamination of the articular cartilage (Fig. 12.1). The damage is localized to the corresponding location where the abnormal head–neck junction and acetabular rim make contact. Eventually, there is separation of the labrum from the underlying subchondral bone (Fig. 12.2) that occurs at the transitional zone between the labrum and hyaline cartilage [31]. Johnston et al. [32] reported an association between the lack of femoral head–neck sphericity and the size of the cam lesion with the extent of acetabular chondral damage and delamination. These investigators noted more intra-articular damage in patients with a higher alpha angle (Fig. 12.3), including detachment of the labrum and full-thickness delamination of the articular cartilage. Bhatia et al. [33] and Ho et al. [34] have also noted this same finding.

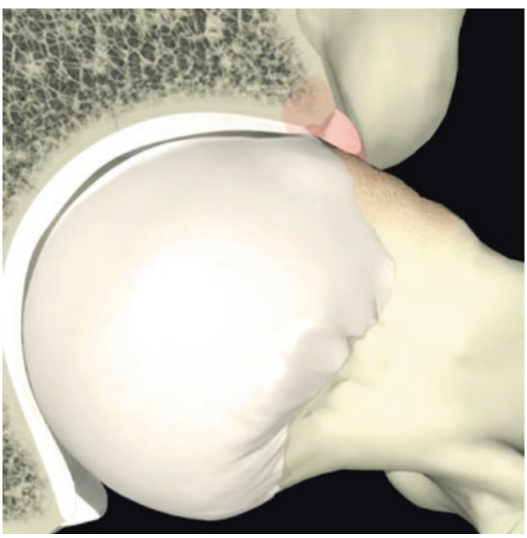

Fig. 12.1 During motion, the cam deformity is rotated into the acetabular socket with a shearing-type injury pattern, causing a labral tear and delamination of the articular cartilage

Fig. 12.2 MRI depiction of separation of the labrum from the underlying subchondral bone on the acetabular rim, occurring at the transitional zone between the labrum and hyaline cartilage

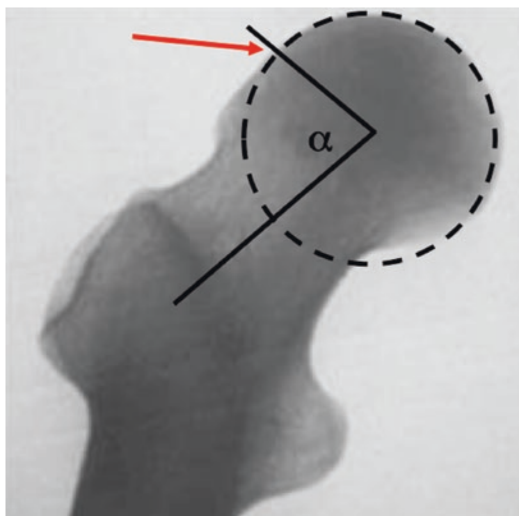

Fig. 12.3 Alpha angle measurement. There is an association between the lack of femoral head–neck sphericity and the size of the cam lesion with the extent of acetabular chondral damage and delamination. Higher alpha angles have been linked to more intra-articular damage, including detachment of the labrum and full-thickness delamination of the articular cartilage [20, 55, 61]

Advances in understanding the prevalence of cam morphology and the association with OA have improved our understanding of the pathophysiology of FAI. Several studies [35, 36] have established that cam morphology of the proximal femur (defined by a variety of metrics) is common among asymptomatic individuals. For example, Register et al. [36] revealed a prevalence of FAI in asymptomatic patients of 15%, while 69% of asymptomatic volunteers demonstrated a labral tear on magnetic resonance imaging. Frank et al. [35] revealed a prevalence of asymptomatic cam lesions in 37–54% of athletes and 23% of the general population. In light of these findings, a description of the femoral anatomy as a "cam morphology" rather than a cam deformity is now favored [37]. Similarly, FAI is better used to refer to symptomatic individuals and is not equivalent to cam morphology.

Interestingly, cam morphology appears to be significantly more common among athletes and may be a precursor for osteoarthritis in the future [35, 38, 39]. Siebenrock et al. [38] demonstrated the correlation of high-level athletics during late stages of skeletal immaturity and development of a cam morphology. A recent systematic review of nine studies found that elite male athletes in late skeletal immaturity were 2–8 times more likely to develop a cam morphology before skeletal maturity [40]. Finally, in a prospective study, Agricola et al. [41] found the risk of OA was increased 2.4 times in the setting of moderate cam morphology (α angle, >60°) over a 5-year period.

Therefore, given that FAI is quite common in the general population and especially in athletes, several authors have attempted to correlate FAI with downstream pathology along the lower kinetic chain. As discussed previously, Tainaka et al. [18] reported that hip rotation is inversely proportional to ACL injury risk. In other words, as hip rotation is reduced, the likelihood of experiencing an ACL rupture is increased. Further, in their single-leg pivot landing study, Beaulieu et al. [24] reported that peak ACL strain, which can predispose an athlete to an ACL tear, is increased by 1.3% with every 10° decrease in femoral rotation. Philippon et al. [15] reported that both males and females with a decreased femoral head–neck offset (alpha angle >60°) were at increased risk of having an ACL injury.

These findings suggest that that an athlete with cam-type FAI and a significant deficiency in hip internal rotation may experience significantly more peak ACL strain during landing than a healthy athlete, placing this structure at risk for injury [24]. Indeed, restricted internal rotation of the hip, as is the case in most patients with cam-type FAI [19], has been correlated with ACL ruptures and reruptures in soccer players [16, 21] and in professional American football athletes [22]. Patients with abnormally elevated alpha angles may also have diminished capacity at the hip to accommodate overall lower extremity internal rotation moments, potentially predisposing the knee (and other intra-articular structures) to a greater rotational stress. In this regard, Girard et al. [25] suggested that improving the femoral head–neck offset could result in an improved range of motion in the hip, specifically in flexion allowing the knee forces to be normalized.

12.3.2 Pincer FAI

Pincer-type FAI results from acetabular-sided deformities in which the acetabular deformity leads to impaction-type impingement with contact between the acetabular rim and the femoral head–neck junction. Pincer FAI causes primarily labral damage with progressive degeneration and, in some cases, ossification of the acetabular labrum that further worsens the acetabular overcoverage and premature rim impaction. Chondral damage in pincer-type FAI is generally less significant and limited to the peripheral acetabular rim or a contrecoup lesion in the posteroinferior acetabulum (Fig. 12.4).

Pincer-type FAI may be caused by acetabular retroversion, coxa profunda, or protrusio acetabuli. The definition of a pincer morphology has evolved significantly over the past several years. Through efforts to better define structural features of the acetabular rim that represent abnormalities, hip specialists now have a greater understanding of how these features may influence OA develop-

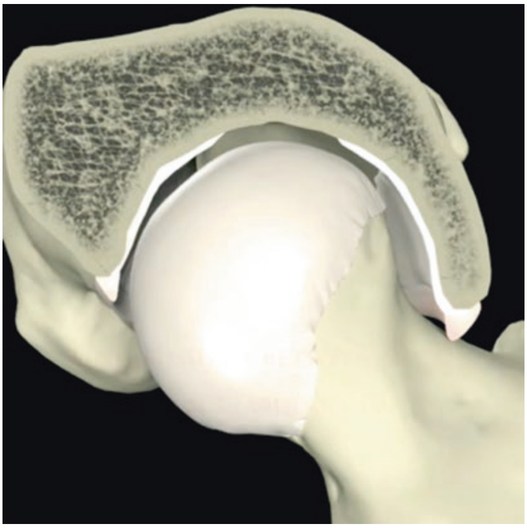

Fig. 12.4 Pincer-type FAI results from acetabular-sided deformities in which acetabular deformity leads to impaction-type impingement with contact between the acetabular rim and the femoral head–neck junction. Pincer FAI causes primarily labral damage with progressive degeneration and, in some cases, ossification of the acetabular labrum that further worsens the acetabular overcoverage and premature rim impaction. Chondral damage in pincer-type FAI is generally less significant and limited to the peripheral acetabular rim or a contrecoup lesion in the posteroinferior acetabulum

ment. One example of improved understanding involves coxa profunda, classically defined as the medial acetabular fossa touching or projecting medial to the ilioischial line on an anteroposterior (AP) pelvis radiograph. Several studies have found that this classic definition poorly describes the "overcovered" hip, as it is present in 70% of females and commonly present (41%) in the setting of acetabular dysplasia [42].

Acetabular retroversion is another type of pincer deformity that has been previously associated with hip OA. Although central acetabular retroversion is relatively uncommon, cranial acetabular retroversion is more common. Presence of a crossover sign on AP pelvis radiographs generally has been viewed as indicative of acetabular retroversion. However, alterations in pelvic tilt on supine or standing AP pelvis radiographs can result in apparent retroversion in the setting of normal acetabular anatomy and potentially influence the development of impingement [43, 44]. Zaltz et al. [45] reported that abnormal morphology of the anterior inferior iliac spine can also lead to the presence of a crossover sign in an otherwise anteverted acetabulum. Nepple et al. [46] recently found that a crossover sign is present in 11% of asymptomatic hips (19% of males) and may be considered a normal variant. A crossover sign can also be present in the setting of posterior acetabular deficiency with normal anterior acetabular coverage. Ultimately, acetabular retroversion might indicate pincer-type FAI or dysplasia, or simply be a normal variant that does not require treatment. Global acetabular overcoverage, including coxa protrusio, may be associated with OA in population-based studies, but is not uniformly demonstrated in all studies [39]. A lateral center edge angle of >40° and a Tönnis angle (acetabular inclination) of <0° are commonly viewed as markers of global overcoverage.

Beck et al. [31] examined 302 cases of FAI and found that 5% had an isolated pincer lesion, 9% had an isolated cam lesion, and 86% had a combination of these two abnormalities. Philippon and Schenker [47] found mixed FAI patterns to be the predominant cause of hip pain among athletes with complaints of decreased hip range of motion as well as impaired athletic performance. Athletes participating in ice hockey, soccer, football, and ballet were most affected.

Therefore, a majority of athletes present with a mixed picture of FAI, including both cam morphology and pincer defect. These factors may act in a synergistic fashion to further limit the hip range of motion and place the knee, and specifically the ACL, at increased risk of injury.

Critical Points

- Cam-type impingement caused by abnormal shear force between an aspherical femoral head and a normal acetabulum during hip flexion and internal rotation.
- Causes separation of labrum from underlying subchondral bone.
- Cam morphology more common among athletes may be a precursor for osteoarthritis.

- Athletes with cam-type FAI and significant deficiency in hip internal rotation may be at greater risk for ACL injury.
- Pincer-type FAI caused by acetabular-sided deformities causes labral damage with progressive degeneration. Chondral damage limited to peripheral acetabular rim.
- Pincer-type FAI caused by acetabular retroversion, coxa profunda, or protrusio acetabuli.
- Majority of athletes have both cam morphology and pincer defect.

12.4 Hip and Core Strength Deficits in Post-ACL Reconstruction State

The majority of secondary ACL injuries are caused by noncontact mechanisms [48], highlighting the alteration of neuromuscular control following primary ACL reconstruction. The risk of secondary ACL injury is approximately seven times the risk of primary ACL injury [49]. One of the major but often overlooked contributors to ACL reinjury is hip and core strength deficiency. An increasing body of literature has suggested that strength within the core and hip muscle groups may be influenced negatively by both an ACL injury and subsequent reconstruction procedure; specifically, weakness of hip flexors and extensors after ACL surgery has been noted. Hiemstra et al. [50] reported hip adductor weakness after hamstring autograft ACL reconstruction, which persisted up to 2 years after surgery in ACL-reconstructed knees compared with uninjured knees. Furthermore, Khayambashi et al. [6] studied isometric hip abduction and external rotation strength in 501 patients for one season and reported that 15 (3%) suffered an ACL tear. Importantly, the authors noted significantly lower hip strength in the ACL-injured patients.

Other lower extremity muscle groups have also been studied in the context of ACL reinjury. Hamstring strength alone has not been shown to have a significant effect on knee function following ACL reconstruction [51, 52]; however, hamstring activation may be important for the neuromuscular control of an ACL-reconstructed knee [51]. Moreover, deficits in hamstring strength may alter the hamstrings–quadriceps torque production ratio, which has been hypothesized to be one potential risk factor for primary ACL injury [1, 53–55].

Rehabilitation following ACL reconstruction is crucial to ensure good outcomes for the patient and to give athletes the best opportunity to return to high-level sport. The importance of rehabilitation comes into focus when considering that muscular deficits are observed following ACL reconstruction up to 2 years after surgery [56]. Much of the observed muscle weakness is centered in the hip and core muscle groups. The core musculature plays an important role in stabilizing the lower extremity, especially during knee movement [57]. The primary core muscles firing during reaction activities like running are the transversus abdominis and internal oblique. Trunk neuromuscular control has been implicated as a risk factor for knee ligament injuries [58, 59]; however, the current evidence for increases in trunk displacement and deficits in proprioception as risk factors for noncontact ACL injuries in female athletes is insufficient.

Because of the relationship between hip strength deficits and ACL injury, a growing body of literature of focused hip rehabilitation after ACL reconstruction has emerged. Stearns et al. [60] evaluated a hip-focused training program on the lower extremity during a drop–jump test and found that training resulted in significantly greater hip extensor strength and knee flexion. These findings lead these authors to conclude that focused hip rehabilitation creates favorable lower extremity kinematics to reduce ACL injuries. Paterno et al. [56] studied postural control and stability in 56 athletes after primary ACL reconstruction. The 13 athletes that suffered a second ACL injury had deficits in transverse plane hip kinematics and frontal plate knee kinematics during landing. These deficits were 92% sensitive for a second ACL injury. Dynamic single-limb tests have also been used to identify post-ACL reconstruction strength deficits. Performance in the single-limb hop test for distance in ACL-deficient patients has been reported to predict self-measured function 1 year after ACL reconstruction, with 71% sensitivity and specificity [61]. These findings indicate that decreasing or eliminating asymmetrical lower extremity movement after ACL reconstruction has the capacity to reduce secondary ACL injury risk and maximize performance.

Identifying and treating hip and core weakness in ACL-reconstructed athletes is crucial in getting the athlete back to competition. In a recent systematic review of return to sport rates following ACL injury, only 44% of athletes returned to sport after an average of 41.5 months after ACL reconstruction [62]. This level of return to sport may be secondary to the deficits in hip and core strength, leading to abnormal lower extremity kinematics during sport. This concept is supported by a recent study that demonstrated that aberrant lower extremity motion is a predictor of secondary ACL injury [56]. Rehabilitation of the ACL-injured patient must be performed in a bilateral fashion, because leg asymmetry has been demonstrated to greatly increase the risk of second ACL injury. Furthermore, attention should be directed toward strengthening the core to create optimal motion symmetry and equal external knee abduction control [63].

Critical Points

- One of the major contributors to ACL reinjury is hip and core strength deficiency.
- Weakness of hip flexors and extensors after ACL reconstruction has been documented.
  - Attention on hip strengthening after ACL reconstruction is critical.
  - Identifying and treating hip and core weakness is crucial for return to competition.
  - Rehabilitation must be done in a bilateral fashion.

12.5 FAI Treatment with ACL Injury

In patients with concomitant knee and hip pathology, it is pertinent for the physician to address both issues. In athletes, an ACL injury should take precedence due to its acuity and the increased stress imparted on secondary stabilizers of the knee, and should be reconstructed in a timely fashion. However, if the ACL-injured patient presents with concomitant, symptomatic FAI that is left untreated, this may increase the risk for reinjury of the reconstructed knee and potentiate chondral and labral pathology within the hip joint [15].

Improvements in hip arthroscopy techniques and instrumentation have led to hip arthroscopy becoming the primary surgical technique for the treatment of most cases of FAI after failure of nonoperative treatments. Hip arthroscopy allows for precise visualization and treatment of labral and chondral disease in the central compartment by traction, as well as complete decompression of bony impingement lesions on the femur and acetabulum in the peripheral compartment. The importance of preserving the acetabular labrum is now well accepted from clinical and biomechanical evidence [64–66]. As in previous studies in surgical hip dislocation, arthroscopic labral repair (vs. debridement) results in improved clinical outcomes [67, 68]. Labral repair techniques currently focus on stable fixation of the labrum while maintaining the normal position of the labrum relative to the femoral head and avoiding labral eversion, which may compromise the hip suction seal (Fig. 12.5).

Open and arthroscopic techniques have shown similar ability to correct the typical mild to moderate cam morphology in FAI [69]. Yet, inadequate femoral bony correction of FAI is the most common cause for revision hip preservation surgery [70]. Inadequate bony resection may be the result of surgical inexperience, poor visualization, or lack of understanding of the underlying bony deformity. Modern osteoplasty techniques focus on gradual bony contour correction that restores the normal concavity–convexity transition of the head–neck junction (Fig. 12.6). Overresection of the cam deformity may not only increase the risk of femoral neck fracture, but also may result in early disruption of the hip fluid seal from loss of contact between the femoral head and the acetabular labrum earlier in the arc of motion. In addition, a high range of motion impingement can be seen in various athletic populations (dance, gymnastics, martial arts, hockey goalies), and the regions of impingement may to be farther away from the classically described impingement [37]. Impingement in these situations occurs at the distal femoral neck and subspine regions, adding a level of complexity and unpredictability from a surgical standpoint. Nevertheless, in a patient with concomitant FAI and knee pathology, accurate and complete resection of the cam deformity is necessary to improve the patient's hip biomechanics and range of motion, and therefore decrease the risk for ACL injury or reinjury in the future.

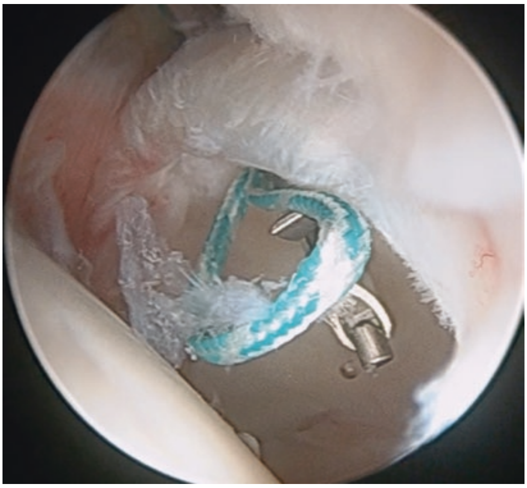

Fig. 12.5 The importance of preserving the acetabular labrum is now well accepted from clinical and biomechanical evidence [2, 36, 47]. As in previous studies in surgical hip dislocation, arthroscopic labral repair (vs. debridement) results in improved clinical outcomes [38, 44]. Labral repair techniques currently focus on stable fixation of the labrum while maintaining the normal position of the labrum relative to the femoral head and avoiding labral eversion, which may compromise the hip suction seal

Similar to the treatment of cam deformities, mild to moderate pincer-type deformities are also commonly treated with hip arthroscopy. As the understanding of pincer-type FAI continues to improve, many surgeons are performing less-aggressive bone resection along the anterior acetabulum. Severe acetabular deformities with global overcoverage or acetabular protrusion are particularly challenging by arthroscopy, even for the most experienced surgeons. Although some improvement in deformity is feasible with arthroscopy, even cases reported in the literature have demonstrated incomplete deformity correction and persistent functional disability. Open surgical hip dislocation may continue to be the ideal treatment technique for severe pincer impingement to improve hip and lower extremity biomechanics.

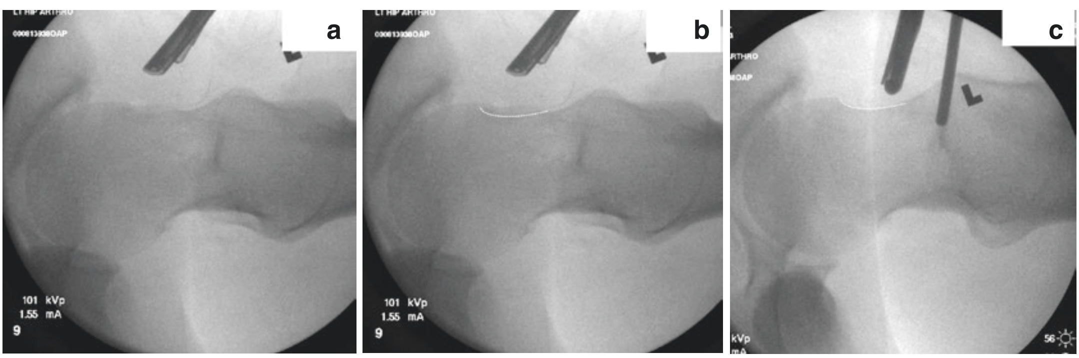

Fig. 12.6 Modern osteoplasty techniques focus on gradual bony contour correction that restores the normal concavity–convexity transition of the head–neck junction. (**a**), a proximal femoral intraoperative frog-leg fluoroscopy view before correction; (**b**), with a marked region of correction; and (**c**), after osteoplasty is complete. Overresection of the cam deformity may not only increase the risk of femoral neck fracture but also may result in early disruption of the hip fluid seal from loss of contact between the femoral head and the acetabular labrum earlier in the arc of motion

Table 12.1 Reduction in noncontact ACL injury incidence with Sportsmetrics program

Sportsmetrics neuromuscular training program: Reduction in ACL injury risk						
Trained athletes		Control athletes		Statistics		
Athletes (*n*)	Noncontact ACL injury rate[a]	Athletes (*n*)	Noncontact ACL injury incidence rate[a]	*P* value	Relative risk reduction (95% CI)	Number needed to treat[b] (95% CI)
700	0.03	1120	0.21	0.03	88 (6–98)	98 (59–302)

[a]Calculated per 1000 exposures
[b]Positive value to benefit, negative value to harm
Reprinted from Noyes FR, Barber-Westin SD: Noyes FR, Barber-Westin SD (2014) Neuromuscular retraining intervention programs: do they reduce noncontact anterior cruciate ligament injury rates in adolescent female athletes? Arthroscopy 30:245–255

Critical Points

- ACL-injured patient with concomitant symptomatic untreated FAI may be at risk for reinjury in the reconstructed knee and chondral and labral pathology in the hip joint.
- Hip arthroscopy primary techniques for FAI.
  - Arthroscopic labral repair improves clinical outcomes.
  - Modern osteoplasty techniques focus on gradual bony contour correction that restores the normal concavity–convexity transition of the head–neck junction.
- Mild to moderate pincer-type deformities commonly treated with hip arthroscopy.

12.6 The Role of the Hip in ACL Injury Prevention Efforts

ACL injury prevention efforts have made an incredible leap forward in recent decades. The first program of this type was Sportsmetrics, a neuromuscular knee ligament injury prevention program developed by Frank Noyes, M.D., and associates [4, 71]. There have since been a variety of ACL injury prevention programs all aimed at decreasing knee ligament injury risk by improving neuromuscular control in the lower extremity and thereby improving dynamic stability. Many investigations regarding the efficacy of this approach have since been conducted and guidelines now exist on their recommended utilization [72].

As demonstrated in the literature, abnormal hip muscle strength is a significant predictor of abnormal knee kinematics and therefore a risk factor for noncontact ACL injury [6]. Athletes with poor motor control of the lower extremities have increased valgus loading and malalignment during jump landing and other athletic endeavors. Because of this link, Sportsmetrics (along with other validated prevention programs) aims to improve neuromuscular control of hip, quadriceps, hamstring, and general lower limb musculature. Studies have demonstrated that athletes undergoing such interventions have improved overall lower limb alignment on the drop–jump test [73], improved hamstring strength, increased knee flexion angles on landing, and reduced deleterious knee abduction and adduction moments and ground reactive forces [71]. From a clinical outcomes standpoint, such interventions have demonstrated efficacy in reducing the risk of noncontact ACL injuries in female athletes participating in soccer and basketball (Table 12.1) [4]. Additionally, Sportsmetrics has been shown to enhance performance in female soccer [74], basketball [75], tennis [76], and volleyball players [73].

Conclusions

Current literature has demonstrated a relationship between hip range of motion and risk of ACL injury and ACL reinjury. An increasing body of literature supports the notion that females are at an increased risk of these injuries in part due to female pelvis anatomy, but also due to muscle weakness throughout the hip. All sports medicine professionals must be aware of the interplay between hip motion and ACL injury. Knowledge of this relationship is crucial so that athletes perform a comprehensive proper return to sport protocol including hip and core strengthening following ACL reconstruction.

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