

FOREWORD

Hip Injuries



Mark D. Miller, MD

Consulting Editor

Orthopedic sports medicine used to be mostly the knee and shoulder. OK, throw in an occasional ankle or elbow to spice things up... but the hip? Interestingly, hip injuries have increased dramatically in recent years—or is it just that our recognition of them has increased dramatically? Hip arthroscopy, treatment of sports hernias, femoroacetabular impingement, hip instability, and a variety of other diagnoses and treatment options did not even exist 10 years ago! So, for those of you who don't know what all the fuss is about—please read this issue carefully!

Drs. Bharam and Philippon have done an excellent job of pulling this issue together and have covered the gamut of hip disorders in the athlete. Most of the topics are arthroscopically related—which is appropriate, because this a new frontier for most of us. This issue is thorough and comprehensive—please enjoy!

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PREFACE

Hip Injuries



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Guest Editors

The recent popularity of hip arthroscopy has led to a new focus on hip injuries in athletes for the sports medicine practitioner. Five to six percent of all adult athletic injuries and 24% of pediatric athletic injuries are hip-related injuries. Hip loading increases up to 50%–80% during athletic activity and may place the athlete at risk of injury during athletic participation.

Hip pain in the recreational to elite athlete in both men and women can result from either acute injury or repetitive hip-demanding activity, affecting athletic participation. These sports-specific injuries are seen in multiple sports, including cutting activities (football, soccer), repetitive rotational activities (golfers, martial artists), dancers, and skaters.

Evaluation of hip pain in the athlete can be challenging to the sports medicine practitioner. This requires a detailed history and hip exam and appropriate imaging studies. Communication with trainers and physical therapists is also essential in the evaluation process.

Recent advancements in hip arthroscopy have expanded our knowledge of the management of athletes with hip injury. Adaptations to arthroscopic instrumentation have been established to overcome the constrained hip joint and dense muscular envelope. Flexible instrumentation has also been developed for improving access to the hip joint in both the central and peripheral compartments.

Refined arthroscopic techniques have improved our ability to manage labral tears, chondral injuries, capsular laxity, impingement, loose bodies, ligamentum teres tears, and snapping hip syndrome. Structural abnormalities predisposing athletes to intra-articular hip injury can also be addressed with arthroscopic intervention.

Managing athletic hip injuries with hip arthroscopy and a well-defined rehabilitation protocol can safely return athletes back to competition.

We would like to thank our authors for their dedication in providing us their expertise and update on this subspecialty field of sports medicine.

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Neuromuscular Hip Biomechanics and Pathology in the Athlete

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Dynamic movement occurs at the hip joint and is characterized and constrained by the anatomy of the region, including osseous, ligamentous, and musculotendinous structures. The majority of patients who require hip arthroscopy are young, active individuals with a history of hip or groin pain. In some athletes, the onset of hip pain may be due to a traumatic event such as a fall, tackle, or collision. However, in many sports, athletes suffer a minor hip injury or perform repetitive motions that exacerbate a chronic pathologic or congenital hip condition that leads to increased capsular laxity and labral tears over time. One of the obvious benefits of arthroscopic hip surgery in this population is that it allows the surgeon to perform procedures within the hip joint with a minimal amount of postoperative morbidity, allowing for a return to sporting activities in a shorter time period. This type of surgery is relatively new, with only a few experts advancing in the field worldwide. However, this surgery is gaining popularity among sports medicine/orthopedic surgeons, and is being performed more and more on all levels of athletes and in the nonarthritic, hip-injured population alike.

Although joint mechanics for total hip joint replacements (THR) are well described, little is known with regard to hip joint mechanics in injuries such as hip labral tears that are observed in younger athletes; and although hip arthroscopic techniques have been developed and evolved over the last 5 years, the mechanisms of these injuries across various sports are not well understood. Moreover, rehabilitation protocols associated with hip arthroscopy remain rooted in THR theories and paradigms. It is evident from the literature that rehabilitation after hip arthroscopic surgery requires a mechanical foundation for its implementation during initial, intermediate, and return to sport/agility protocols. Without such a scientific foundation, the risk of an unsuccessful surgery or reinjury is greatly enhanced.

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The purpose of this article is to review the literature related to the osseous, ligamentous support as well as the neuromuscular control strategies associated with hip joint mechanics. The neuromuscular contributions to hip stability and mobility with respect to gait will be provided because the data related to gait represents the largest body of knowledge regarding hip function. Further, this article will describe the probable mechanisms of injury in sporting activities most often associated with hip injury in the young athlete.

OSSEOUS STRUCTURES CONTRIBUTING TO HIP STABILIZATION

The adult hip is a multiaxial ball-and-socket synovial joint composed of two bony structures: the femur and the acetabulum. This bony architecture provides the hip with inherent stability. Three biomechanical and anatomic geometries of the femur and acetabulum are significant to joint stability and preservation of the labrum and articular cartilage: appropriate femoral head-neck offset, acetabular anteversion, and acetabular coverage of the femoral head. Proper function of the hip joint necessitates that the amount of offset from the femoral head to the femoral neck be enough to allow a full range of motion without impinging upon the acetabular labrum. A lack of offset from the femoral head to the femoral neck has been described as a cause for femoroacetabular impingement [1]. Flexion at the hip may cause the osseous femoral head-neck junction to come into contact with the acetabular labrum, resulting in impingement [1–3]. A large femoral head can compensate for a flat head-neck junction by simulating offset and adding stability to the joint [4].

Large variations exist in the rotational axis that characterizes the relationship between the acetabular and femoral osseous structures. The range of acetabular anteversion to femoral anteversion affects the rotation of the extremity and changes from the time of birth and through mature skeletal development. The transfer of dynamic and static load to the ligamentous and osseous structures is dependent on this relationship. Abnormal distribution of force or pressure in an incongruent joint precipitates chronic or acute injury. Normal adult acetabular positioning intersects the sagittal plane at 40° and the transverse plane at 60°, opening anteriorly and laterally [5]. The acetabulum is positioned approximately 45° caudally and 15° anteriorly [6,7]. Normal anteversion of the acetabulum is essential to maintaining a normal relationship with the femoral head and is critical in avoidance of impingement [8]. Normal range of acetabular anteversion as defined by Tonnis and Heinecke [9] is 15° to 20°, decreased anteversion is 10° to 14°, and increased anteversion is 21° to 25°. An increase in external rotation is commonly found with decreased acetabular anteversion.

In addition to recognizing acetabular anteversion, it is also important to appreciate the degree of femoral head coverage provided by the acetabulum. This can be measured radiographically as the central edge angle of Wiberg, which is defined as the angle between the horizontal line through the center of the femoral head and a line tangent to the superior and inferior acetabular rims. The normal center edge angle is 30° and a decrease in this angle (dysplasia) has been associated with rapid onset of osteoarthritis [10–13]. Center edge angles of less

than 20° correlate with an abnormal orientation of the acetabulum, providing less than satisfactory head coverage and load transfer.

Anteversion of the femur is also important in maintaining proper static and dynamic mechanics in the hip. Anteversion of the femur diminishes with age. A healthy 1 year old has an average anteversion of 31°. This anteversion decreases to 24° at 8 years and to 15° by 15 years [14]. The McKibbin instability index is based on the sum of the angles of the femoral and acetabular anteversion. This ratio will affect range of motion. The sum of the angles of femoral and acetabular anteversion predicts instability for summed angles of 60° or more and predicts low instability for angles of less than 20°. The authors found that, of 290 hips tested, 38% had a low and 6% had a high index.

LIGAMENTOUS STRUCTURES CONTRIBUTING TO HIP STABILIZATION

The hip capsule is comprised of a series of ligaments, which can be subdivided into functional and anatomic components. The five primary ligaments discussed in the hip are the iliofemoral (lateral and medial arms), pubofemoral, ischiofemoral, the ligamentum teres femoris, and the ligamentum obicularis. The collagen structure of the hip as demonstrated by electron microscopy is similar to that of the shoulder and the elbow [15].

The iliofemoral ligament (also referred to as the Y-ligament of Bigelow) is the largest of the ligaments and reinforces the capsule anteriorly. Originating at the anterior superior iliac spine (ASIS) and the acetabular rim, it inserts at the intertrochanteric line and the front of the greater trochanter. The ischiofemoral ligament supports the capsule posteriorly, fastening the ischial portion of the acetabular rim to the neck of the femur, medial to the base of the greater trochanter. The pubofemoral ligament reinforces the capsule inferiorly, extending from the superior pubic ramus and acetabular rim to the lower femoral neck. These ligaments are connected to each other by the circular ligamentum obicularis, which circumvents the femoral neck. The ligamentum teres femoris originates at the acetabular notch from the transverse acetabular ligament, and inserts in the fovea of the femoral head.

The function of these ligaments has been well described in terms of limiting ranges of motion. There is debate in the literature over which ligament might limit what motion. Most authors agree that the iliofemoral ligament limits extension [16], the pubofemoral ligament limits abduction, and the ischiofemoral ligament limits internal rotation. It is thought that with an elongated or surgically resected iliofemoral ligament, the ligamentum teres has a limiting effect on external rotation. There is debate regarding the ligament limitation in other motions and debate as to what role is played by the functional subdivisions of each ligament (such as the lateral and medial iliofemoral ligament) [17]. The ligamentum orbicularis appears to be overlooked as a major key in stability of the hip joint. Traditionally, the ligamentum orbicularis was thought to be relevant only to extension by tightening the posterior capsule [18]. It now appears to play a vital role in stability, particularly in the area where the lateral arm of the

iliofemoral ligament and the orbicularis merge together and continue over the anterosuperior portion of the capsule.

Although studies have described independent motions limited by the ligaments, it is believed that they do not function independently. The ligament complex surrounding the hip acts to stabilize the hip in all ranges of motion. Fuss and Bacher [17] discussed three varieties of interconnections between the ligaments as they form the capsule: parallel fibers either join and become one ligament, join and intermingle though separate ligaments, or join by fusing at the borders (pilema, confluens and conjunction fibrarum, respectively). Fuss and Bacher performed a kinematic study on 10 intact pelves secured to a table mount. The ligaments of the hip were removed except for the iliofemoral ligament (medial and lateral arm). The hip was taken through extension, abduction, adduction and internal/external rotation movements (as guided by a grid) and the motion of the ligament was recorded. In many hips, the iliofemoral ligament appeared to lock when the hip was in pure terminal extension without rotation. The ligament moved to the lateral aspect of the femoral head in abduction or external rotation unlocking the major anterior structure. The pubofemoral ligament contribution to the capsular structures is thought to play a role in controlling this motion.

Certain *in vivo* studies have illustrated the importance of the ligamentous structures in providing stability to the hip joint [19–22]. While standing, the body's center of gravity lies just posterior to the axis of the hip in the sagittal plane, which causes the pelvis to tilt posteriorly on the femoral head [19]. This tilt is opposed by the tensile forces from the stretching of the anterior capsule, implying that the energy required to stand stationary should be compensated by the ligaments without muscular contribution [19]. Gait involves ranges of motion in all three planes. The force for motion is derived from the musculature of the lower limbs, although stability could not be maintained without the ligamentous capsule. Abnormal functioning of the iliofemoral ligament has been identified as a cause for coxa saltans [20]. Owing to the relatively large tensile forces of the ligaments of the capsule, dislocation of the hip requires high impact forces, except in children, due to their relatively shallow acetabulum [21,22].

NEUROMUSCULAR FACTORS CONTRIBUTING TO HIP STABILIZATION

Maintaining an appropriate femoral head position within the joint capsule and labral complex is paramount to normal hip function and failure in this mechanism can lead to debilitating labral and cartilage compression in active individuals. Thus, hip congruency, although affected by, is not solely dependent upon the femoral head–acetabular bony and labral constituents for complete hip stabilization. The ligaments described above and the muscles that cross the hip joint contribute and provide for articular congruency (ie, proper joint rotation of the femoral head within the acetabular–labral complex) and maintain articular stabilization (ie, limit translations of the femoral head within the acetabular–labral complex). To accomplish this, muscles that cross the hip must act as force

regulators across a very wide range of motions by regulating their stiffness. Muscular stiffness is determined by a complex neural feedback control system. A highly regulated hierarchy of neuromuscular control strategies begins with the activation of the single fiber and progresses to the mechanical properties of the whole muscle. Discussing the exact mechanisms that are involved in this neuro-mechanical hierarchy is beyond the scope of this article, but a few of the more pertinent aspects are listed briefly below:

1. Muscle stiffness is regulated by muscle activation frequency (ie, temporal summation) [23].
2. Muscle stiffness is regulated by muscle fiber recruitment (ie, spatial summation) [24].
3. Muscle stiffness is regulated by the sarcomere length–tension relationship [25].
4. Muscle stiffness is regulated by sarcomere force-velocity relationship [26].
5. Muscle stiffness is regulated by passive sarcomere length tension relationships [27].
6. Intrafusal and extrafusal (muscle spindle) fibers feedback mechanisms [28].
7. Muscle force and moment regulation by skeletal muscle architecture [29,30].

The first six points relate a specific muscle's function primarily to its intrinsic properties and are standard across all skeletal muscles. However, point 7, *muscle stiffness regulation by skeletal muscle architecture* (ie, the physical arrangement of the muscle fibers within a specific muscle) is of substantial importance at the hip given the large, “irregular” shaped muscles that cross this joint, and much work has been recently constructed in this area [31,32]. Functionally, the force generated by a muscle is proportional to its physiologic cross-sectional area (PCSA). The total excursion of a muscle is determined by its fiber length. Traditionally, fiber length were determined by dissection methods and histologic analysis; but recently, newer MRI-based technologies have been used with great success and detail [31,33,34]. Thus, from a muscle design perspective, muscle architecture results in muscle function based on unique fiber arrangements. Mechanical properties of many of the larger muscles surrounding the hip have been characterized and are presented in Table 1. Although detailed studies of muscles architecture have been conducted for the lower extremity [34], these studies often omit many of the smaller muscles (eg, piriformis, superior and inferior gemellus and obturator internus and externus) that cross the hip.

Because many of the hip muscles involve very complex geometric architectures, determining their exact mechanical influence on hip function is difficult. Computer modeling techniques enhanced by computer tomography (CT) and MRI are some of the newer techniques of estimating the complex hip muscular actions. These methods have allowed researchers to reconstruct the hip muscle geometry with “lumped parameter muscle models,” where each muscles is represented by a single line of action estimated from a centroid of the muscles taken from the a 3D reconstruction via an MRI image [31,33,34]. These “lumped parameter muscle models,” however, only allow for a one length of muscle fiber and moment arm to be estimated for each muscle path [31,33,34].

Table 1
Muscle–tendon parameters for the hip muscles

Muscle	Physiological cross-sectional Area (cm ²)	Peak muscle force (N)	Optimal fiber length (cm)	Pennation angle (degrees)	Tendon slack length (cm)	Tendon length/fiber length
Gluteus medius 1	22.0	550	5.4	8	7.8	1.4
Gluteus medius 2	15.2	380	8.4	0	5.3	0.6
Gluteus medius 3	17.4	435	6.5	19	5.3	0.8
Gluteus minimus 1	7.2	180	6.8	10	1.6	0.2
Gluteus minimus 2	7.6	190	5.6	0	2.6	0.5
Gluteus minimus 3	8.6	215	3.8	1	5.1	1.3
Gluteus maximus 1	15.2	380	14.2	5	12.5	0.9
Gluteus maximus 2	22.0	550	14.7	0	12.7	0.9
Gluteus maximus 3	14.8	370	14.4	5	14.5	1.0
Adductor magnus 1	13.8	345	8.7	5	6.0	0.7
Adductor magnus 2	12.4	310	12.1	3	13.0	1.0
Adductor magnus 3	17.8	445	13.1	5	26.0	2.0
Adductor longus	16.8	420	13.8	6	11.0	0.8
Adductor brevis	11.4	285	13.3	0	2.0	0.2
Pectineus	7.0	175	13.3	0	0.1	0.1
Iliacus	17.2	430	10.0	7	9.0	0.9
Psoas	14.8	370	10.4	8	13.0	1.3
Quadratus femoris	10.2	255	5.4	0	2.4	0.4
Gemelli	4.4	110	2.4	0	3.9	1.6
Piriformis	11.8	295	2.6	10	11.5	4.4
Rectus femoris	12.8	780	8.4	5	34.6	4.0
Semimembranosus	16.9	1030	8.0	15	35.9	4.5
Semitendinosus	5.4	330	20.1	5	26.2	1.3
Biceps femoris (lh)	11.8	720	10.9	0	34.1	3.1
Gracilis	1.8	110	35.2	3	14.0	0.4
Sartorius	1.7	105	57.9	0	4.0	0.1
Tensor fasciae latae	2.5	155	9.5	3	42.5	4.5

Optimal muscle fiber length is defined as the number of sarcomeres in series, and has been shown to be a major component of maximal velocity of shortening during a contraction [26]. Muscle belly fiber lengths can be determined by methods described by Veeger et al [82], where the distance between the most proximal and most distal musculotendinous conjunctions are measured in situ then removed, macerated, and measured again via calibrated microscopic examination.

Tendon slack length is typically measured in situ prior to dissection and after muscular tissue separation. Tendon slack length represents the noncontractile element of the musculotendinous unit and each bundle's tendon slack length is usually quantified (cm) via calibrated microscopic examination.

Pennation angle of muscle fibers represents the angle or direction of pull between the insertion and origin of the muscles. These angles are noted in situ and prior to dissection and the angle of pull can be measured with a goniometer. Of note, how researchers determine individual muscle bundles within each broad fan shaped muscle is subject to much debate. For instance, most hip anatomic studies have divided the gluteus medius into at least three separate bundles based on the broad anatomic insertion sites across the pelvic–iliac crest. Similarly, some authors have combined the iliacus and psoas; while others separate their functions.

Physiologic cross-sectional area of muscle is defined as the number of sarcomeres in parallel and is reported to be directly related to the amount of tension a muscle can produce [26] (muscle mass + fiber length) / pennation angle).

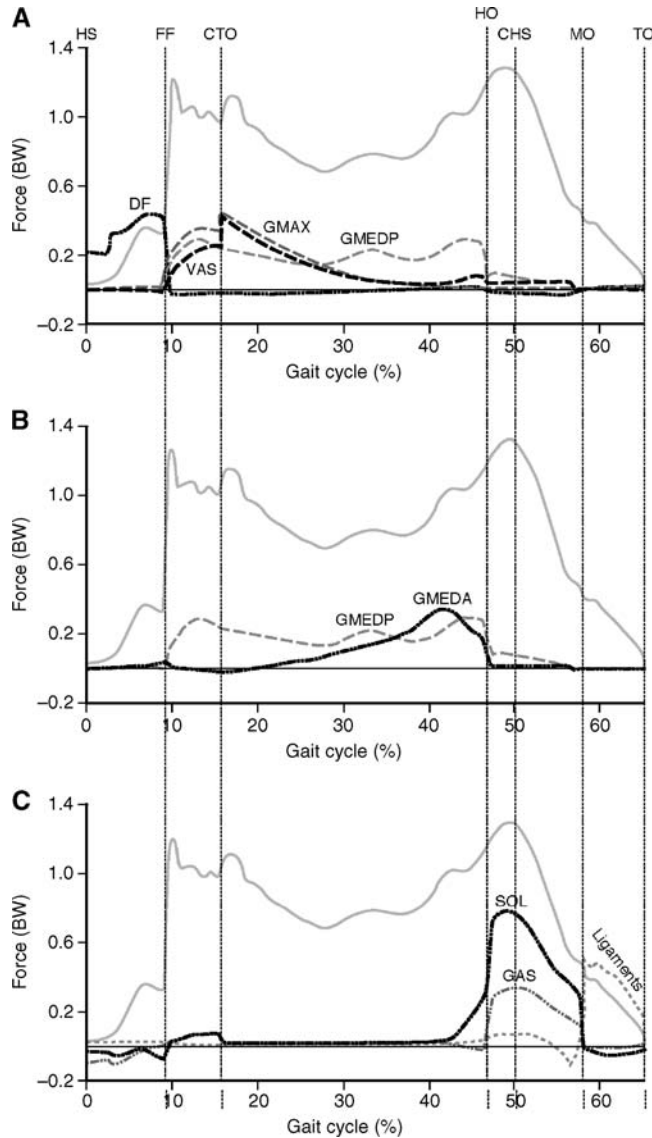
Data from Wickiewicz TL, Roy RR, Powell PL, et al. Muscle architecture of the human lower limb. Clin Orthop 1983;179:275–83; Brand RA, Pedersen DR, Friederich JA. The sensitivity of muscle force predictions to changes in physiologic cross-sectional area. J Biomech 1986;19(8):589–96; Friederich JA, Brand RA. Muscle fiber architecture in the human lower limb. J Biomech 1990;23(1):91–5.

Because muscle moment arms and fiber length may be different within the resting geometry of a muscle, or may change over a given range of motion for a specific muscle, using single lines of action to represent these actions may over- or underestimate each muscle's force generating capacity given a dynamic movement [31,33,34]. Moreover, Herzog and Keurs [36] have shown that lumped parameter models do not accurately predict in vivo force-velocity behaviors for muscles with complex geometries. To illustrate this point further, Blemker and Delp [32] developed a mathematical model of the hip joint in which the complex geometries of the major muscles of the hip over a specified range of hip flexion and extension were estimated from an MRI of a single subject. This technique allowed the researchers to reconstruct and characterize the complex 3D geometries of the hip musculature and to represent each muscle with multiple muscle fibers with varying fiber lengths and with each fiber possessing its own moment arm. This 3D model highlighted the diverse behaviors (please see Figs. 6A–L and 7A–L in Blemker and Delp, *Annals Biomedical Engineering*, 2005, pp. 668–9) among individual muscle fibers within a specific hip muscle as well as illustrated the changing roles specific fibers of a particular hip muscle may have while undergoing flexion and extension [31,33,34]. The considerable change in fiber moment arms within each muscle indicates that the force generating capacity of a muscle may in fact change with different femoral, pelvic, or lumbar motions. This is also evident from the work of Arnold et al [37], who suggested that during upright standing with normal femoral anteversion, the medial hamstrings, adductor brevis, adductor longus, pectineus, and ischiocondylar portion of the adductor magnus produce internal rotation via hip internal rotation moments; the gracilis and proximal portion of the adductor magnus produce external hip rotation moments; and, the middle and distal portions of the adductor magnus have negligible rotation moments. When the hip is rotated more than 20°, or when the knee is flexed more than 30°, the rotational moment arms of the semimembranosus and semitendinosus switch from internal to external [37]. The gracilis also becomes more external with hip internal rotation and knee flexion and the moment arm of the ischiocondylar portion of the adductor magnus becomes less internal with internal hip rotation.

FUNCTIONAL ANALYSIS OF HIP BIOMECHANICS

In vivo estimates of hip mechanics for dynamic activities have been attempted using optical capture, accelerometer, or goniometric methods. Optical methods employ high speed cameras to capture the 3D motion of reflective markers that are placed on pertinent and relative bony landmarks of the subjects. These systems produce 3D trajectories of the markers, which used to estimate internal joint centers and determine segment motions, velocities, and accelerations. These kinematic parameters are then combined with subject's anthropometric inertial data and external forces to yield external reaction forces and moments. These external forces and moments are then used to estimate internal joint reaction forces and internal “muscle” moments. The internal muscles moments must generate equal and opposite forces to the externally measured moments,

and are composed of the muscle contraction, passive soft tissues, and joint reaction forces. However, using the inverse dynamics solution only yields net muscle moments, and these cannot be decomposed into individual muscle contributions to the motion without appropriate assumptions to obtain an equal number of unknowns and equations; or by employing an optimization scheme. Optimization methods assume that the force distribution among the muscles is made by applying an objective function (usually based on a physical property of a muscle). Early hip models [35] were limited in that they assumed muscles



were single bundles represented by straight muscle paths that possess similar fibers lengths with the same moment arms over the cross-section of a large muscle. Today, more sophisticated models [38] have employed more precise muscle paths with better defined “wrapping functions” to deflect muscles path around pertinent anatomic structures and more specific fiber length parameters for individual muscle bundles within the complex geometry of a whole muscle. These advancements have contributed to the understanding of the functional roles for the individual muscles surrounding the hip, as they more closely represent the true functional geometry of those muscles *in vivo*.

Anderson and Pandy [38] developed a muscle model that included select hip musculature to analyze a complete gait cycle. This model contained 54 independent muscles, and the results estimated each muscle’s contribution to the support phase of gait. A muscle’s potential for generating support was described by its contribution to the vertical ground reaction force per unit of muscle force. Of the hip muscles, the gluteus medius, maximus, and minimus provided the majority of the support in first 0% to 30% of stance (Fig. 1A). From foot flat to just after contralateral toe-off (eg, 10–50% of stance), the gluteus maximus and posterior medius/minimus contributed significantly to the vertical ground reaction force. With assistance from joints and bones to gravity, the anterior and posterior gluteus medius/minimus generated nearly all the support evident in midstance. Posterior gluteus medius/minimus provided support throughout midstance, while the anterior gluteus medius/minimus contributed only toward the end of midstance (Fig. 1B). Interestingly, the iliopsoas developed substantial forces during late stance, but this muscle did not make substantial contributions to support [38].

The study of Anderson and Pandy [38] has shown that the muscular actions of the gluteus medius and minimus depend strongly on body positions. Anterior gluteus medius/minimus developed forces as large as the posterior gluteus

Fig. 1. (A–C) Individual muscles contributions to support during gait from heel strike (HS) to toe-off (TO). Here, support is represented by the shaded gray area, which is the vertical ground reaction force. Symbols used to represent muscles in the figure are: DF, ankle dorsiflexors; GAS, gastrocnemius; GMEDP, posterior gluteus medius/minimus; GMAX, medial and lateral portions of the gluteus maximus; GMEDA, anterior gluteus medius/minimus; SOL, soleus; VAS, vasti. In this figure the gluteus maximus contributes the most muscle force to support in early stance; The posterior gluteus medius/minimus contributes notable force throughout the stance phase. In later stance, the anterior gluteus medius/minimus is most effective at maintaining support during gait. The passive resistance of the skeleton to the force of gravity was less than 50% of body weight through out stance, suggesting that muscles are the most important parameter to support the body during gait. Of these muscles, the hip gluteus maximus contributed the most force to support, followed by the vasti, gluteus medius/minimus, and soleus/gastrocnemius of the body compared with all other muscles during gait. Unfortunately, the mechanical roles of the smaller hip muscles such as the pectineus, piriformis, superior and inferior gemellus, and obturator internus and externus were not included in this model. (From Anderson FC, Pandy MG. Individual muscle contributions to support in normal walking. *Gait Posture* 2003;17(2):159–69; with permission.)

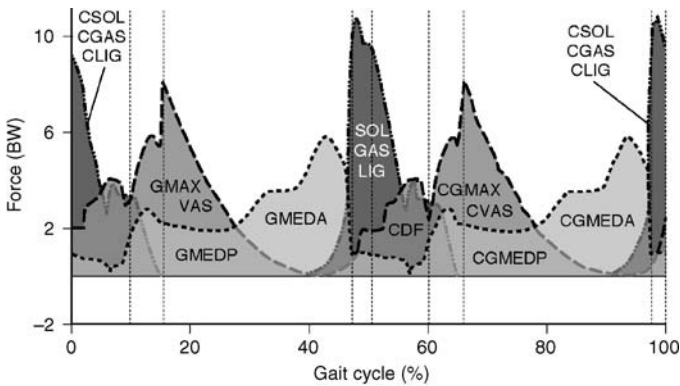


Fig. 2. Contributions of individual muscle groups to the net vertical acceleration of the center of mass of the walking model. Muscle symbols used are: CDF, dorsiflexors of the contralateral limb; CGAS, contralateral gastrocnemius; CGMAX, contralateral gluteus maximus; CGMEDA, contralateral anterior gluteus medius/minimus; CGMEDP, contralateral posterior gluteus medius/minimus; CLIG, ligaments of contralateral limb; CSOL, soleus of contralateral limb; GAS, gastrocnemius; GMAX, medial and lateral portions of the gluteus maximus; GMEDA, anterior gluteus medius/minimus; GMEDP, posterior gluteus medius/minimus; SOL, soleus; VAS, vasti. Only muscles that on the limb in contact with the ground contributed to the vertical acceleration of the center of mass. (From Anderson FC, Pandy MG. Individual muscle contributions to support in normal walking. *Gait Posture* 2003;17(2):159–69; with permission.)

medius, yet the anterior gluteus medius contributed very little to support during early stance. The reason for this is that the anterior gluteus medius possesses a moment arm at the hip that acts to flex the hip as well as abduct it. These two actions oppose one another and prevent the anterior gluteus medius from generating support in early stance no matter how large its force. As the hip extends during mid and late stance phase, the anterior gluteus medius moment arm falls close to zero. The muscle becomes more of a pure abductor and its action more closely resembles the actions of the posterior gluteus medius. The value of the study by Anderson and Pandy [38] is that this study estimated true muscles forces (N) for each muscle (Fig. 2), offering considerably more information than one can derive from electromyography (EMG) alone or from inverse dynamic analysis techniques.

HIP JOINT REACTION FORCES

Studies have been published that examine the specific forces encountered in walking, climbing stairs, skiing, and in routine daily activities [39–42]. Variance of forces rises from incongruence of the femoral head to the acetabulum and the hip muscles that control these motions. It is estimated that the hip endures forces ranging from one-third of the body weight with double leg support to five times the body weight during running [43,44]. The asymmetry between the femoral head and the acetabulum allocates weight to multiple areas. This incongruence is inherent to the hip and necessary for sustaining normal function [45].

During gait, a stride will take the hip through an average of 40° to 50° of motion (30°–40° of flexion and 5°–10° of extension) [19,46]. The force from weight bearing in the acetabulum during gait is biphasic with peaks in force occurring at heel strike and toe off. Areas of contact form two columns of force on the anterior and posterior rims, joining together in the superior aspect of the fossa [47]. As more force is applied to the hip, the areas enlarge as the femoral head settles deeper in the acetabulum. The areas of most frequent weight bearing are also associated with the stiffest and thickest articular cartilage [47].

The result of the forces transferred across the hip can be visualized radiographically in the femoral neck as Ward's triangle [48]. This triangle is outlined by cortical and tensile trabecular osseous formations in the femoral neck. Tensile forces are generated in the medial subtrochanteric cortex and applied into the weightbearing portion of the femoral head [48]. Cortical forces span from the foveal area of the femoral head through the superior femoral neck to the subtrochanteric cortex [48]. In hips with a neck shaft angle of greater than 125° (coxa valga), compressive trabeculae are more prominent due to the increased compressive forces accounted for by the deformity of the femur. In hips with a neck shaft angle of less than 125° (coxa varus), tensile trabeculae are more prominent due to the increased tensile stresses [49].

ELECTROMYOGRAPHY OF HIP MUSCULATURE

EMG is a technique used to measure the electrical input (excitation) of a specific muscle. Considerable literature regarding EMG of the hip musculature for walking, climbing stairs, and various sporting motions has been reported. Due to space limitations and the completeness of data content, only the EMG of hip muscles during gait are presented below. Although EMG studies are valuable in determining *which* and *when* individual muscles are active, it is important to note that EMG cannot provide information regarding the amount of force a specific muscle is producing. This limitation of EMG underscores the importance of computer modeling techniques in understanding hip mechanics during functional activities and in understanding the basic mechanics associated with hip stabilization and the interaction of bony geometries and the actual muscle forces that stabilize the hip joint.

Pectineus, Piriformis, Superior and Inferior Gemellus, and Obturator Internus and Externus Muscles

Studies on the muscles of the hip joint have typically neglected the roles of the deep musculature (Pectineus, Piriformis, Superior and Inferior Gemellus and Obturator Internus and Externus) because of their inaccessibility and their proximity to femoral vessels. Thus, the functional roles of these muscles have been debated [50–52] with little direct evidence to support opposing views. These muscles are often thought to be the “rotator cuff” muscles for the hip, and many studies in the canine models have supported their roles in “fine tuning” hip motions [53]. However, unlike the glenohumeral joint, the human hip is considered a more stable joint via its bony articulations requiring less muscular

stabilization. To this end, many authors have suggested that the small PCSA of these deep muscles combined with their small moment arms (eg, pectineus moment arms during gait has been estimated at less than 9 mm for stance phase of gait) are negligible in providing any “meaningful” forces for maintaining hip stability. Nevertheless, clinical views of the function of the pectineus make this muscle’s role in hip function more important than one would ascertain from its small size and moment arm. Lamb and Pollock [54] suggested that pectineus overactivity is the major cause of flexion deformity of the hip in children with cerebral palsy. Arnold and Delp [37] have shown that the pectineus possesses an internal moment arm during the upright standing position; but this muscle can possess a small external hip rotation moment when walking with an exaggerated internal thigh rotation (as noted in Fig. 7 of Arnold and Delp [37]). These computational results correspond well with EMG profiles during gait in healthy persons. The pectineus is moderately active at mid-heel strike to mid toe-off, functioning to limit femoral abduction and contributing to femoral medial rotation. Some minor activity is also present during the swing phase [55].

Assessing the functional EMG of the piriformis, superior and inferior gemellus, and obturator internus and externus) has proven difficult given their anatomic locations and relative inaccessibility and their proximity to femoral vessels. However, new technologies such as dynamic MRI combined with computer modeling and simulation may offer some exciting advancements in understanding the functional roles of these muscles in the years to come.

Iliopsoas

Based on the anatomic insertion and origins of the iliopsoas, it is the only muscle that has the anatomic prerequisites to simultaneously and directly contribute to stability and movement of the trunk, pelvis, and leg. This muscle has two major portions (the iliacus and the psoas). These two portions have separate innervations, which makes selective activation of each portion feasible for any given movement. However, only a few studies have attempted to define and differentiate the function roles of the iliacus and psoas independently and simultaneously [56,57].

When one begins to search the literature for precise information about the actions and functions of the iliopsoas (or psoas and the iliacus independently), the only point that is agreed upon is that this muscle is a flexor of the hip and probably has some influence on the lumbar vertebrae and pelvis in maintaining appropriate postures. Thus, there is some disagreement in the EMG information of this muscle, partly resulting from different techniques and the difficulty in measuring EMG in this muscle due to its location and pennation. Andersson et al [57] found both muscles are inactive during ipsilateral leg extension; whereas, contralateral leg extension resulted in selective recruitment of the iliacus alone. Andersson et al also noted that both muscles are active during maximal thigh abduction, but no postural activity is noted for either psoas or iliacus during standing at ease or with the whole trunk flexed 30° forward at the hip [57]. These postural positions also did not recruit the psoas or iliacus after

loads up to 34 kg were added. In summary, Andersson et al concluded that the iliacus primarily stabilizes the motions between the hip and pelvis, whereas the psoas assists in stabilizing the lumbar spine in the frontal when a heavy load is applied to the contralateral side.

Iliacus

Attempts to measure EMG of the iliacus alone have shown notable activity throughout flexion of the hip during the “sit-up in the supine position” [56]. LaBan et al [58], however, found that there was little or no activity in the iliacus during the first 30° of hip flexion, but these authors noted activity during a sit-up from the “hook-lying” position. Greenlaw and Basmajian [56] further reported both medial and lateral rotation of the hip joint may produce some slight iliacus activity, whether the hip joint is passively or actively held in any of the extended, semiflexed, or flexed positions.

Psoas Major

Direct recordings from the psoas muscle are generally similar to those measured from the iliacus with a few noted exceptions. There is slight activity during relaxed standing and strong activity during flexion in many postures [57]. Also, slight to moderate activity in abduction and lateral rotation (depending on the degree of accompanying hip flexion) [57] is present, with no activity during most medial rotations and little activity during most other conditions involving the thigh [56,57]. Nachemson [59] concluded that the psoas has a significant role in maintaining upright postures.

Gluteus Maximus

Karlsson and Jonsson [60] concluded that the gluteus maximus was active during extension of the thigh at the hip joint, lateral rotation, abduction against heavy resistance when the thigh is flexed to 90°, and adduction against resistance that holds the thigh abducted. The studies of Joseph and Williams [61] show that the gluteus maximus is not an important postural muscle but it exhibited moderate activity when bending forward and when straightening up from the toe-touching position [61]. In positions in which one leg sustains most of the weight, the ipsilateral gluteus maximus is active. Joseph and Williams [61] also found that, during standing, rotation of the trunk activates the muscle that is contralateral to the direction of rotation (ie, corresponding to lateral rotation of the thigh).

Gluteus Medius and Minimus

The finding of Joseph and Williams [61] that the gluteus medius and minimus are quiescent during relaxed standing serve to confirm that these abductors prevent the Trendelenburg sign, during abduction of the thigh and in medial rotation. The Gluteus medius' and minimus' role(s) in medial rotation was confirmed by Greenlaw [62], who reported triphasic activity for gluteus medius and biphasic activity for gluteus minimus during each cycle of walking. Houtz and Fischer [63] concluded that the activity in all the glutei was minimal in bicycle pedaling (Fig. 14.5). During elevation (flexion) of the thigh in erect

posture, Goto et al [64] found that the anterior part of the gluteus medius was also active in the initial stage only.

Tensor Fasciae Latae

Wheatley and Jahnke [65], Carlsoo and Fohlin [66], Goto et al [64], and Carvalho et al [67] found moderate activity in this muscle during flexion, medial rotation, and abduction of the hip joint. Duchenne [68] reported that the power of tensor fasciae latae as a rotator in response to faradic stimulation is weak. Carlsoo and Fohlin [66] argued the rotary influence of tensor fasciae latae affect at the knee, finding no activity. Greenlaw [62] found the muscle was active biphasically during each stride of the gait cycle. Unlike the glutei, tensor fasciae latae was active during bicycling, showing their greatest activity during the hip flexion phases [63].

Adductors of the Hip Joint

Janda and Vele [69], and Janda and Stara [70] investigated the role(s) of the hip adductors in children and adults during flexion and extension of both the hip and the knee, with and without resistance. They showed that the adductors were activated during flexion or extension of the knee, and became more active with resistance in children. Similarly, adults exhibited activity during flexion of the knee, but only a minority was active during extension compared with children. Janda and Stara [70] stated that this response of the adductors is related to postural control, and suggested that these muscles are facilitated through reflexes of the gait pattern rather than being called upon as prime movers.

De Sousa and Vitti [71] investigated the adductor longus and magnus during movements of the hip joint. During adduction, the longus was always active while the magnus is was almost always silent unless acting against resistance. Both muscles were shown to be active during medial thigh rotation but not during lateral rotation of the hip with the upper fibers of the adductor magnus showing the greatest activity.

Greenlaw [62] examined subjects during both fast test movements and various postures and locomotions. When standing on one foot, the adductors on that side remained silent. Medial thigh rotation recruited all the adductors. During walking, these adductors showed different types of phasic activity. There is marked difference between the two parts of the adductors magnus: the upper, possessing a pure adductor role and was active throughout the whole gait cycle, while adductor brevis and longus showed triphasic periods with the main peaks occurring at toe-off [62].

SPORT-SPECIFIC MECHANISMS OF HIP INJURIES IN THE ATHLETE

As arthroscopic treatments of the hip continue to evolve, there is an increasing need to understand the basic performance biomechanics of the hip joint. This information is important, as it can provide the foundation by which joint function, pathology, and therapeutic modalities can be evaluated. There are a number of recent studies that have applied different approaches to study the hip biomechanics, particularly in THR. However, there is clearly a void in the

amount of literature related to the function, and pathology of the normal or injured, nonarthritic hip. Thus, the remainder of this article will offer our understanding as to how these injuries result in athletes. It is important to keep in mind that a majority of athletes undergoing hip arthroscopy have a complex injury pattern, with damage to the acetabular labrum, capsular structure, and cartilage surfaces. To ascertain the specific injury sequence and pattern(s) of cause and effect, significant research still needs to be performed.

Golf

During the downswing of a right-handed golfer, the right hip is forced into external rotation during axial loading. This movement tends to push the femoral head anteriorly, and over time may lead to focal anterior capsular laxity and stretching of the iliofemoral ligament [72,73]. Subsequent joint instability may result leading to increased translation of the ball in the socket. Labral tears, particularly in the anterosuperior weight-bearing region of the acetabulum, may follow. The labrum has been shown to function as a physiologic seal, stabilizing the femoral head in the acetabulum [74,75]. In a further propagation of the injury, labral tear leads to reduction in seal function; increased translation of the femoral head may result. In addition, an unpublished report by Bharam et al (70th Annual Meeting of the American Academy of Orthopaedic Surgeons) showed that chondral delamination in the area adjacent to the labral tear is a frequent finding in golfers.

Taekwondo

In martial arts, particularly taekwondo, a good kick can be performed well above an athlete's head. The proper positioning for a taekwondo side kick places the stance leg in 90° of external rotation. The stance leg must then sustain significant loads while the opposite leg performs the kick. Similar to the mechanism in golfers, the forced external rotation and axial loading in the stance leg (not the kicking leg) may cause anterior capsular laxity and elongation of the iliofemoral ligament. As a result of the increased translation of the femoral head with respect to the acetabulum, labral and chondral injuries may follow.

Ballet/Figure Skating

Elite ballet dancers and figure skaters perform the extremes of rotational movement during their routines. Flexibility of the lower extremities is crucial for success. Some athletes excel at these sports due to their generalized ligamentous laxity; yet, despite this apparent advantage, they may also suffer from symptoms of hip instability. Other ballet dancers and figure skaters may suffer from instability secondary to repeated hip rotation and focal capsular laxity. Hip laxity has been reported in a ballet dancer to be the cause of atraumatic dislocation of the hip [76]. A very common finding in ballet dancers and figure skaters undergoing hip arthroscopic surgery is capsular laxity with associated labral tear [72,73].

Injuries to the ligamentum teres are also common in ballet dancers and figure skaters. This ligament connects the margins of the acetabular notch and

transverse ligament to the fovea capitus on the femoral head. It is thought to function as a secondary stabilizer to external hip rotation [77]. In athletes with hip instability, the ligamentum teres is under increased stress to help stabilize the joint. Tears to the ligament often result.

Ice Hockey

Hockey players may suffer from traumatic hip injuries after direct blows to the greater trochanter. Isolated labral tears and chondral injuries from simple mechanical shearing are commonly found in these patients [78]. In addition to trauma, hockey players can suffer from overuse-type hip injuries. While skating, significant flexion, abduction, and slight external rotation forces are present at the hip. As a goalie, the hip sustains significant flexion and internal rotation forces. In flexion and abduction or flexion and internal rotation, any morphologic abnormality at the femoral head-neck junction would hit the antero-superior labrum and the acetabular rim. This abnormality is found in patients with cam-type femoroacetabular impingement [1,2,79] and is a very common finding in elite hockey players undergoing hip arthroscopy. Whether this is a subtle developmental deformity exacerbated by sport or whether there is a unique mechanism for the development of cam-type impingement in athletes is still not known.

Running

Although most cases of hip instability are present in athletes whose sports demand excessive rotational movements, runners may also present with subtle anterior hip instability [80]. In the stride phase of high-level extensive running, repeated hip hyperextension may stretch the anterior capsule and iliofemoral ligament. The resulting microinstability may subtly increase femoral head translation, and with repeated insults, cause labral tear and chondral injury.

During running, when the foot contacts the ground the femur is in an abducted position in relation to the pelvis. Thus, the gluteus medius and tensor fascia latae are eccentrically loaded. As the running support phase progresses, these muscles must then contract as abduction occurs at the hip. Thus, it is believed that gluteus medius weakness may lead to decreased thigh control manifesting in increased thigh adduction and internal femoral rotation. These changes may predispose the runner to several pathologic conditions including iliotibial band syndrome at the knee [81].

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Clinical Examination of the Athletic Hip

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The hip assumes an essential role in most sports-related activities. The hip is not only responsible for distributing weight between the appendicular and axial skeleton, but it is also the joint from which motion is initiated and executed. It is known that the forces through the hip joint can reach three to five times the body's weight during running and jumping [1,2]. Considering the amount of demand athletes place on their hips, orthopedic surgeons will evaluate them as patients having hip pain.

Ten percent to 24% of athletic injuries in children are hip related, and 5% to 6% of adult sports injuries originate in the hip and pelvis [3]. Ballet dancers are most likely to have a hip-related injury, and runners, hockey players, and soccer players are also prone to hip injuries [3]. Athletes participating in rugby and martial arts have also been reported as having increased incidence of degenerative hip disease [4–10]. Hip pain often stems from some type of sports-related injury [11–14]. In patients presenting with hip pathology, the hip is not recognized as the source of pain in 60% of all cases [15].

Hip pain has been documented in three categories: anterior-, lateral-, and posterior-based hip pain [16], with multiple etiologies. A short physical examination, complete with a history and evaluation of present illness, is fundamental and necessary in determining the source and cause of the presenting complaint. The results of these two assessment techniques will direct which radiological examination to consider. The history of present illness and physical assessment should be adequate if the physician suspects a specific diagnosis, and radiographic examination should be enough for a conclusive diagnosis to be made [1,4].

Diagnosing hip pain in athletes has been difficult for physicians in the past because of the parallel presenting symptoms shared with back pain, which may exist concomitantly or independently of hip problems [17]. Radiating pain below the knee, palpable pains in the hip and back, and weakness or sensory limitations

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blur the lines in appropriately differentiating between the hip and back [17–22]. Low back pathology involving the paravertebral muscles can lead to an abnormal soft tissue balance, causing an irregular tension absorbed by the hip joint, which leads to knee pain, groin pain, leg length discrepancies, and limited ranges of motion in the hip [23]. Muscle contractures of the hip flexors or extensors as well as leg length discrepancy have also been identified as factors that can cause hip and low back pain to present together [24–28]. Brown and colleagues [17] proposed that limited internal rotation associated with a limp and groin pain were the physical signs to make the distinction of hip-related pathology. The biggest problem facing physicians treating hip-related pathologies is the absence of a valid diagnosis [29].

The physical examination of the hip is evolving as the ability to understand normal and pathological conditions of the hip progresses. The physical examination of the hip is designed to detect a wide variety of pathologies, and has been developed by many generations of surgeons, therapists, and physicians [30–32]. The examination of the hip is optimally performed in a systematic and reproducible fashion in order to facilitate accurate diagnoses and treatment recommendation. The benefit of understanding the osseous, ligamentous, and musculotendonous contribution to the underlying pathology cannot be overestimated. Surgical and nonsurgical treatment outcomes will depend on a consistent method of evaluation to understand which treatments produce the optimal results for a particular type of patient. Conditions related to genitourinary, gastrointestinal, neurologic, and vascular systems, though unlikely in a sports-related injury, can compound the complexity of the assessment. This complexity also emphasizes the importance of a thorough examination.

An 11-point physical evaluation is a tool presented here to help organize the structure of the physical examination of athletes in a simple, reproducible manner, in order to differentiate between hip and back pathology and categorize the hip pain presented. The evaluation aids in the diagnosis of anterior, lateral, and posterior etiologies of the hip in regards to the osseous, ligamentous, and musculotendonous structures. An organized approach, with a systematic structure as used in evaluating other joints, will benefit both the patient and the physician.

The 11-point examination is described below in five parts: the standing, seated, supine, lateral, and prone examinations. The technique of the physical examination is discussed, along with the diagnostic tools that may further the investigation of suspected pathology.

A verbal history including mechanism, time of injury, location, and severity of pain should be obtained. The focus of this article is to describe the physical element of the examination. It should be noted that with any clinical examination the reproduction of pain or limited movement constitutes a positive test sign.

ELEVEN-STEP EXAMINATION

Standing Examination

The initial element in the structured evaluation (Table 1) should be the general body habitus, principally gait and alignment. Because of the hip's role in

Table 1
Standing examination

Examination	Assessment/association
Body habitus	
1. Spinal alignment	Shoulder/iliac crest heights, lordosis, scoliosis, leg length
2. Gait	
a. Trendelenburg	Abductor strength, proprioception mechanism
b. Antalgic	Trauma, fracture, synovial inflammation
c. Pelvic rotational wink	Intra-articular pathology, hip flexion contracture
d. Excessive external rotation	Femoral retroversion, increased acetabular anteversion, torsional abnormalities, effusion
e. Excessive internal rotation	Increased femoral anteversion or acetabular retroversion, torsional abnormalities, effusion
f. Short leg limp	iliotibial band pathology, true/false leg length discrepancy

supporting body weight, hip pathology can often be identified in gait abnormalities [1]. An antalgic gait (one that involves a self-protecting limp caused by pain, characterized by a shortened stance phase on the painful side so as to minimize the duration of weight bearing) is an indication of hip, pelvis, or low back pain [33,34]. The gait should be observed so that the full stride length can be assessed from the front and side [30]. Common key points of evaluation should include stride length, stance phase, foot rotation (internal/external progression angle), and the pelvic rotation in the X and Y axes [1,30,32]. It is recommended that the patient walk down the hall if the room is not big enough to give the physician a chance to observe six to eight full strides.

A Trendelenburg gait is indicative of hip abductor weakness, and is often referred to as an abductor lurch. The pelvic wink displays excessive rotation in the axial plane (greater than the normal 40°) toward the affected hip to obtain terminal hip extension. This gait pattern is associated with internal hip pathology or with hip flexion contractures, especially when combined with increased lumbar lordosis or a forward-stooping posture. Special attention should be given to a limp, noting that a limp with an external foot progression could indicate effusion or traumatic condition. Consideration should also be given to any snapping or clicking the patient or physician hears, noting location as internal or external to the hip joint or derived from within the joint itself. This audible sign could be indicative of psoas contracture (coxa sultans interna), tightness of the iliotibial band (coxa sultans externa) or intra-articular pathology. Coxa sultans interna/externa can be distinguished by the patient actively demonstrating the pop by recreating the sound as he rotates the hip.

The second aspect in observing general body habitus is alignment. Compare the patient's shoulder heights with the heights of the iliac crests to further any leg length discrepancy issues. Other palpable bony structures for pelvic alignment assessment include the anterior superior iliac spine and posterior superior iliac spine. A tilted pelvis can indicate a leg length discrepancy, which can be further investigated by measuring leg lengths manually from the anterior superior iliac spine (ASIS) to the ipsilateral medial malleolous in order to differentiate between

Table 2
Seated examination

Examination	Assessment/association
Neurocirculatory evaluation	Pulse, sensation, motor strength, deep tendon reflexes
Straight leg raise	Radicular neuropathy
Ranges of motion	Internal and external rotation

true and functional leg length discrepancies [32]. A true leg length issue is present when the bony structures are of different proportions. Functional leg length issues arise when muscle spasms, scoliosis, or deformities of the pelvis cause the truly identical leg lengths to function as if they were disproportionate.

Lateral inspection of the lumbar spine is effective for detecting postural or kinetic abnormalities such as excessive lordosis or paravertebral muscle spasm. Increased lumbar lordosis is a common finding in patients who have hip flexor contractures involving the psoas muscle. The spine is initially evaluated with forward bending, recording the range of motion. This assessment will allow inspection of the spine from behind for the purpose of detecting types of scoliosis.

In addition to body habitus, the second point of examination in the standing position involves Trendelenburg’s sign. The Trendelenburg’s test should be performed on both legs, and the nonaffected leg should be examined first. This test helps to establish a baseline for the patient’s neuroproprioceptive function. As with the indications of the Trendelenburg’s gait abnormality, this assessment evaluates the proper mechanics of the hip abductor musculature and neural loop of proprioception. When the right foot is lifted, the left abductor muscles are being tested. If the musculature is weak, the pelvis will tilt toward the unsupported side. The shift of the pelvis should not be more than 2 cm at the midaxis in either the ipsilateral or contralateral direction. A shift of greater than 2 cm constitutes a positive Trendelenburg’s sign.

Seated Examination

The sitting examination (Table 2) is composed primarily of the basic evaluation points of extremity assessment, the neurocirculatory evaluation, and the rotational ranges of motion. Even in the healthy individual, standard basic assessment should be followed.

Table 3
Assessment of motor function

Score	Motor function
0	No muscle function
1	Some visible movement
2	Full range of motion, not against gravity
3	Movement against gravity, but not resistance
4	Movement against resistance, less than normal
5	Normal strength

Table 4
Deep tendon reflexes

Score	Description
0	No reflex
1+	Hypoactive (less than normal)
2+	Normal
3+	Hyperactive (more than normal)
4+	Hyperactive with clonus (like a muscle spasm)

The neurocirculatory evaluation consists of the motor function, perceived sensation, and circulation appraisal. The motor portion includes assessing muscles supplied by the obturator, superior gluteal, sciatic, and femoral nerves. The function is assessed and graded on a 0 to 4/4 scale (Table 3). The sensory assessment includes evaluation of the sensory nerves originating from the L2 through S1 levels, and the sensory function should be compared (left to right) to assess uniformity. Neurologic function can be further evaluated by the deep tendon reflexes (Table 4). Reflexes at the patella (knee-jerk) test the L2–L4 spinal nerves and femoral nerve. Reflexes at the Achilles (ankle-jerk) test the L5–S1 sacral nerves. A straight leg raise is helpful in detecting radicular neurological symptoms, such as the stretching of a centrally entrapped nerve root [35].

The vascular examination includes evaluating the pulses of the dorsalis pedis and posterior tibial arteries. These should be recorded as present or absent on a 0 to 4/4 scale (Table 5). Sensation is assessed by lightly touching both sides of the patient’s thigh and lower leg and asking the patient to compare these subjective findings with the other leg. A common neuralgia occurs on the anterior thigh, deriving from the anterior femoral cutaneous nerve compressed within the femoral nerve, as it passes near the psoas muscle through the pelvic brim [31,36–38]. The skin and lymphatics are also quickly inspected for swelling, scarring, or side-to-side asymmetry.

The second part of the seated examination involves examining internal and external rotational ranges of motion of the hip. The internal and external rotation measurements of the hip are recorded in the sitting position, because it provides sufficient stability and a fixed angle of 90° at the hip joint [16]. Differences may exist in the degree of internal and external rotation in extension and flexion, and assessment of these measurements is subject to substantial variability. The normal range of motion is 20° to 35° for internal rotation and

Table 5
Grading of pulses

Traditional		Basic	
4+	Normal	2+	Normal
3+	Slightly reduced	1+	Diminished
2+	Markedly reduced	0	Absent
1+	Barely palpable		
0	Absent		

30° to 45° for external rotation. Adequate internal rotation is important for normal hip function, and there should be at least 10° of internal rotation at terminal hip extension. The loss of internal rotation is an important physical finding, because it is one of the first signs of internal hip pathology [29]. The loss of internal rotation at the hip joint can be related to diagnoses such as arthritis, effusion, internal derangements, slipped capital femoral epiphysis, and muscular contracture [29,32]. Pathology related to osteocartilaginous impingement (femoroacetabular impingement) or to rotational constraint from increased or decreased femoral acetabular anteversion can result in significant side-to-side measurement differences [17]. An increased internal rotation combined with a decreased external rotation may indicate excessive femoral anteversion [32]. Further ranges of motion are assessed in the supine examination, below.

Supine Examination

An important examination position to address the multifactorial presentation of complex hip pathology is the supine position (Table 6). The battery of tests, conducted with the patient in the supine position, helps to further distinguish internal from extra-articular sources of hip symptoms. There are four initial examination s of the athletic hip in the supine position.

The first examination completes the hip ranges of motion initiated in the seated position, focusing now upon flexion, adduction, and abduction. With the patient supine, abduct the affected leg by holding the ankle, and note the degree between the body’s center line and the shaft of the femur. A normal abduction is 45°. To adduct, the leg must cross over the nonaffected leg. Note the degree again between the center line and femoral shaft. Normal adduction is 20° to 30°. During this evaluation, place one hand on the ASIS to assess any

Table 6
Supine examination

Examination	Assessment/association
Ranges of motion	Abduction, adduction, flexion
Thomas test	Hip flexor contracture (psoas), femoral neuropathy, intra-articular pathology, abdominal etiology
McCarthy’s	
1. Internal	Anterior femoroacetabular impingement, torn labrum
2. External	Superior femoroacetabular impingement, torn labrum
Patrick FABER	Distinguish between back and hip pathology, specifically sacroiliac joint pathology
Palpation	
1. Abdomen	Fascial hernia or associated gastrointestinal/genitourinary pathology
2. Pubic symphosis	Osteitis pubis, calcification, fracture, trauma
3. Adductor tubercle	Adductor tendonitis
Trauma assessment	
1. Log roll	Effusion, synovitis
2. Heel strike	Femoral fracture, trauma

compensatory motion in the pelvis. Limited adduction/abduction could result from a contracture of the respective musculature. Flexion is recorded by having the patient flex both thighs into the chest, flattening the lumbar spine and keeping the knee flexed to oppose any hamstring tightness. Normal flexion is 120°. Difficulties in flexion result in limited active daily living [1].

The Thomas test is performed to assess any hip flexor contracture that may be present. With the patient holding the nonaffected leg in the flexed position, lower the affected leg to the table. If the thigh cannot reach the table, this represents a positive Thomas test, and is a sign of the hip flexor contraction. Note the angle between the femoral shaft and the table [32]. If a clicking is audible during this test, it may be an indication of a labral tear [16], or coxa saltans externus. Clicking is most indicative of a tear and a louder, more audible pop, is snapping of the psoas tendon.

The McCarthy test is performed in an attempt to re-establish the discomfort felt by the patient in order to discover the underlying etiology. The cause of pain reconstructed from this test is likely a tear of the acetabular labrum. This test is relevant in that most tears occur in the anterior acetabulum, compounded in athletes who have acetabular dysplasia [39–44]. By rolling the hip in a wide arc of internal and external rotation through flexion to extension, the goal is to find a site of bony impingement that may have caused a tear [45]. A positive McCarthy sign is noted by recreation of the patients pain in a specific position.

The Patrick FABER (Flexion ABduction External Rotation) test is the classical physical examination test for the characterization of hip pain in the abducted position. The test is performed by laying the ankle of the affected leg across the thigh of the nonaffected leg proximal to the knee joint, creating a figure 4 position. This position displaces the anterior superior rim of the femoral neck to the twelve o'clock position of the acetabular rim. Pressure is applied to the knee of the affected leg, causing stress in the ipsilateral sacroiliac (SI) joint. Pain in the posterior hip should cause consideration of SI joint pathology. Pain in the groin can be caused by pathology of the iliopsoas muscle, resulting in an iliopsoas sign [32]. Pain in the lateral aspect of the hip can also be associated with lateral femoroacetabular impingement (FAI).

Because of the demands placed on the hip in sports-related activities, it is necessary to assess the hip for trauma. This assessment is made through the log roll test and the heel strike test. Rolling the leg in the Z axis on the table will reproduce pain in femoral fractures. Striking the heel of the foot will reproduce pain if the fracture has occurred in the femoral neck. Positive signs in either of these two tests should warrant radiographic investigation.

Finalizing the supine examination, bony and soft tissue structures around the pelvis should be palpated for tenderness. The abdominal examination should include inspection and palpation for fascial hernias. Fascial hernias may be difficult to detect by palpation, and the isometric contraction of the rectus abdominus and obliques can facilitate their detection. The region of the ilio-inguinal ligament should be inspected and the presence or absence of a Tinel's sign (tingling sensation in the distribution of the femoral nerve) at the level of

the ilioinguinal ligament indicating femoral nerve pathology should be noted [32]. Palpation of the adductor tubercle as the patient adducts the extended leg may help identify adductor tendonitis, because point tenderness will be present in this location. Pain with palpation of the pubic symphosis is a cause for further examination of the area. Additional palpation should be continued in the lateral position.

Lateral Position

The lateral hip examination (Table 7) is performed with the patient in the lateral recumbent position lying on the unaffected hip with his shoulders perpendicular to the table. The physical examination tests in the lateral position are useful in the determination of lateral-based hip pain, and can further confirm the presence of intra-articular pathology.

Palpation for tenderness is continued, with special attention given to the SI joint, gluteus maximus origin, piriformis, sciatic nerve, iliotibial band (ITB), greater trochanteric bursae, tensor fascial lata and ischial tuberosity [1,16,31,32,46,47]. Tenderness in one of these regions warrants further examination.

Ober's test is used to assess the tightness of the ITB and fascia lata. Three positions are examined in this test: extension, neutral, and flexion. These refer to the positions of the affected leg in respect to the nonaffected leg. In extension, the affected leg is abducted with the knee flexed. When the force abducting the leg is removed, the affected leg should adduct due to gravity. If the leg remains abducted, this is a positive Ober's sign. The neutral position is performed similar to extension with the knee flexed, and is a test of the gluteus medius tension. In flexion, the ipsilateral shoulder should be rotated posteriorly (making both shoulders come into contact with the table) and the knee extended to assess the gluteus maximus origin in cases with gluteus maximus contractures. The ITB tension may be released by flexing the knee, and this technique can

Table 7
Lateral examination

Examination	Assessment/association
Palpation	
1. Greater trochanter	Greater trochanteric bursitis, iliotibial band contracture
2. Sacroiliac joint	Distinguish between hip and back pathology, gluteus maximus assessment
3. Ischium	Biceps femoris contracture, avulsion fracture, bursitis
FAI assessment	
1. Flexion, abduction, internal rotation	Anterior FAI, torn labrum
2. Lateral rim impingement	Lateral FAI, torn labrum
Ober's	
1. Extension	Tensor fascia lata contracture
2. Neutral	Gluteus medius contracture/tear
3. Flexion	Gluteus maximus contracture, contribution to iliotibial band

Table 8 Prone examination	
Examination	Assessment/association
Ely Test	Hip flexor contracture, rectus contracture

be helpful in isolating and assessing the gluteus medius, specifically for musculo-tendinous tears. If the affected leg in any position cannot adduct to the table, this constitutes a positive Ober’s sign.

The last examination in the lateral position assesses the degree of FAI present. This series of examinations includes the FADDIR (flexion adduction internal rotation) test. When examining the hip with the patient in the lateral recumbent position, the examiner stands behind the patient with the examiner’s arm beneath the patient’s lower leg. The examiner holds the knee with the supporting hand while the opposite hand monitors the hip. The hand monitoring the hip should grasp the joint with the index finger anteriorly and the thumb posteriorly. Position the leg in FADDIR to assess impingement from the femoral neck, which may have caused an acetabular labral tear. Reproduction of the patient’s pain with this maneuver is suggestive for anterior FAI. A lateral rim impingement can also be assessed by taking the leg from flexion to extension in continuous abduction, trying to reproduce the pain in order to identify impingement. The emphasis in lateral examination should be toward the primary area of complaint, and additional examinations should be performed as necessary.

Prone Examination

The prone position is optimal for identifying the precise location of pain related to the SI joint region (Table 8). The SI joints and surrounding region should be palpated in three areas: the infra SI region adjacent to the origin of the gluteus maximus, the supra SI location adjacent to the spinous process of L4–L5, and the SI joint location itself.

Table 9 Eleven-step examination of the adult athletic hip	
Standing	1. Body habitus
Seated	2. Trendelenburg’s test
	3. Neurocirculatory evaluation
Supine	4. Ranges of motion
	4. Ranges of motion (continued)
	5. Thomas test
	6. McCarthy test
Lateral	7. Trauma assessment
	8. Palpation
	8. Palpation (continued)
	9. FAI assessment
Prone	10. Ober’s test
	11. Ely’s test

Table 10

Auxiliary clinical examinations of the hip

Examination	Assessment/association
Scours	Intra-articular pathology, internal pop/click
Foveal distraction	Torn labrum
Extension, abduction, external rotation	Hyperlaxity, high instability index
Craig's test	Femoral anteversion

The physical examination test recommended for assessing any contracture of the rectus femoris muscle is Ely's test. This assessment is performed by flexing the knee and drawing the lower leg into the thigh. A negative test demonstrates full flexion of the knee to the thigh with no movement in the pelvis. A positive Ely's sign demonstrates that with flexion at the knee, the pelvis will tilt, raising the buttocks from the table.

SUMMARY

The 11-point athletic hip examination can be effective in screening and evaluating patients who have hip pain, and can be helpful to direct further diagnostic studies (Table 9). A maraine injection test may be necessary to distinguish between hip and back pathology. This and other auxiliary clinical tests may be helpful in further evaluation of the hip (Table 10). The majority of examinations that compose the 11-point athletic hip examination were developed over many years, before the pathomechanics were fully understood. Individuals using these tests and the tests that have been more recently developed could benefit from validation to determine their accuracy in the detection of the various types of hip pathology. A thorough systematic physical examination coupled with history is the best method to determine subsequent radiologic or diagnostic testing recommendations. As with any examination, practice and repetition are essential to gain an appreciation of what constitutes a normal as well as an abnormal exam. When used consistently and with practice, the 11-point athletic hip examination will help the examiner to formulate an accurate list of diagnostic possibilities and to determine what other diagnostic examinations or techniques may benefit the patient.

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Radiographic and MR Imaging of the Athletic Hip

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Magnetic resonance imaging (MRI) and radiography are the imaging essentials needed to evaluate intra-articular pathology and extra-articular sources of hip pain. Over the past decade MR imaging has highlighted the detection of labral tears as a source of hip pain, but it is also critical for detecting cartilage defects, capsular/iliofemoral ligament injury, ligamentum teres tears, and bony findings associated with femoroacetabular impingement (FAI). Despite the central role of MR arthrography for evaluating intra-articular abnormalities, radiography remains essential for the radiologic work up of the athlete with hip pain. A normal hip radiograph has been re-defined over the past several years, as relatively normal appearing radiographs may have evidence of subtle acetabular dysplasia (ie, retroversion) or a femoral neck bump that may provide a clue to the presence of intra-articular labral or cartilage injury. One recent study showed that 87% of patients that underwent surgery for labral tears had a structural hip abnormality identified on conventional radiographs [1]. In addition, periacetabular ossicles and synovial herniation pits were once considered normal variants, but we now view them as markers for underlying FAI or labral pathology. A generalized MR of the entire pelvis may be useful for the evaluation of surrounding muscle, tendon, and bone marrow abnormalities; but it is insufficient for evaluating internal derangements of the hips. This article first describes the general approach for the radiologic work up for the athletic hip, followed by MR appearances of labral and nonlabral abnormalities.

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RADIOLOGIC EVALUATION AND MODALITY OVERVIEW

Radiography

Plain film radiography remains the primary screening tool because it is widely available, simple, and relatively inexpensive; but it must be done properly. In the past, a typical screening radiographic series for hip pain often included a nonweight-bearing anteroposterior (AP) and frogleg lateral view of the affected hip with or without a supine AP view of the pelvis. The goal of the screening test was to detect obvious sources of pathology such as advanced arthrosis, tumor, fracture, and advanced dysplasia. In addition to an AP and frogleg lateral view of the hip, we currently prefer an AP standing pelvis instead of nonweight-bearing view and add a crosstable lateral view in cases where FAI is suspected. We prefer reviewing film by electronic softcopy using a PACS system, which allows for optimal window and leveling and facilitates measuring.

When screening radiographs are negative, the next useful imaging modality is generally magnetic resonance imaging using unilateral direct MR arthrography of the hip for the evaluation of intra-articular pathology or screening MR of the pelvis for extra-articular sources of pain. However, radiographs or MRI of the lumbar spine, sacroiliac joints, femur/thigh, or knee may be needed to evaluate for referred pain.

Magnetic Resonance Imaging

Not all MRIs are equivalent, and it is important to differentiate between the types of MRI available and whether they are enhanced with contrast. The quality of MR images depends not only upon field strength (>1.5 Tesla considered high), but also coil selection, contrast administration, imaging plane and sequence parameters, and ultimately interpreter experience and familiarity with pathologic processes and surgical interventions. For optimum care, it is important to develop a relationship with your imaging facility to ensure quality and consistency, both technically and interpretively.

We use a generalized screening protocol of the pelvis to evaluate for nonfocal hip pain or suspicion of nonlabral pathology such as avascular necrosis (AVN), stress fracture, tendon avulsion, sports hernia, tumor, pubalgia, and marrow edema syndromes (Fig. 1). This type of MR study uses larger coils (ie, torso or body) and a wider field of view that includes both hips. Consequently, resolution is decreased and this protocol cannot be used to evaluate for labral tears and subtle chondral pathology. This protocol consists of coronal T1 and inversion recovery images; axial T1-weighted and T2-weighted with fat saturation, and sagittal T1-weighted images in the anatomic plane of the patient. Occasionally a large paralabral cyst can be seen, and a labral tear or advanced bone edema may indicate significant chondrosis.

In general, when one thinks of MR for evaluation of intra-articular hip pathology one refers to high-resolution unilateral direct MR arthrography. Direct MR arthrography involves fluoroscopic guided injection of the hip before MR imaging, and should not be confused with indirect MR arthrography, which relies on intravenous injection of gadolinium contrast with synovial uptake and

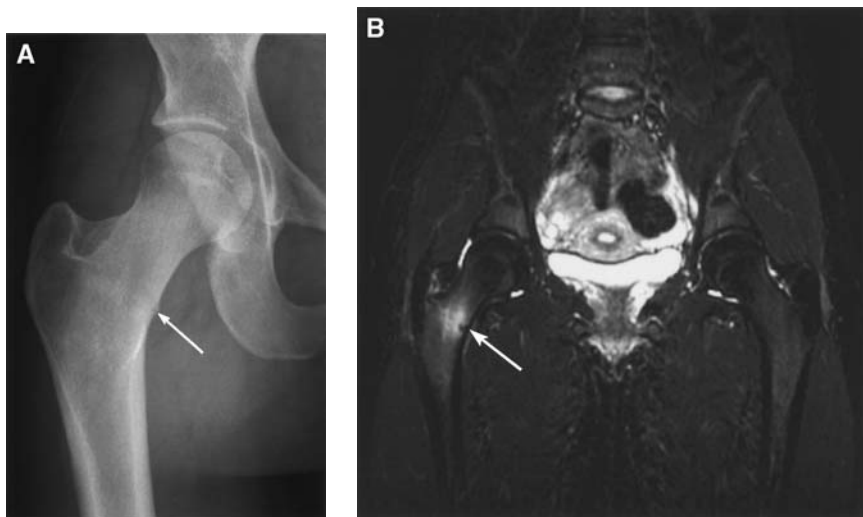


Fig. 1. Stress fracture of the medial cortex of the proximal femur (A) confirmed on MRI (B) using general screening MR protocol of the pelvis. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. *Oper Tech Orthop* 2005;15(3):182–90, with permission.)

diffusion into the joint, for which supportive widespread literature does not exist, but it can be useful. A prescription for “MRI hip/pelvis with/without contrast” will often get you neither study, and is reserved for detecting enhancement generally for cases of tumor or infection.

The use of direct MR arthrography is critical not only for preoperative assessment and confirming clinical suspicions, but it also provides information regarding surgical planning (ie, reparability of labral tears) and prognosis (as surgical outcomes are associated with degree of chondrosis) [2]. One study has shown that the clinical assessment is useful for detecting intra-articular pathology but not the type or extent of the pathologic process [3]. This same study also showed improved detection of intra-articular pathology with MR arthrography versus nonarthrogram MR. Other researchers show a high positive predictive value of MR arthrography, but suggested a negative study does not obviate the need for arthroscopy to detect pathology [4]. Due to its generalized acceptance and higher sensitivity and accuracy (90% and 91% versus 30% and 36%, respectively) compared with nonarthrogram MR images, we use unilateral direct MR arthrography to evaluate for labral pathology [5]. In our experience MR arthrography may, however, underestimate extent of injury as unpublished data regarding MR hip evaluation in professional golfers that underwent arthroscopic surgery revealed underestimation of average labral tear size (1.5 versus 2.0 cm) and degree of cartilage injury. Dissenting opinion on the use of MR arthrography from one study suggested nonarthrogram unilateral hip MR may accurately detect labral tears and cartilage defects using an “opti-

mized protocol”; however, one must consider whether this can widely reproduced in the average setting [6].

Nonetheless, we continue to prefer direct MR arthrography as part of our routine evaluation as other advantages exist. We are more confidently able to predict the morphologic appearance of labral tears (ie, degenerated, intrasubstance, or detached), which guides surgical planning (ie, debridement, intrasubstance suture banding, or suture anchor reattachment, respectively). We have also shown (unpublished data) MR arthrography helps predict the presence of capsular laxity and partial tears of the ligamentum teres, treatable entities often overlooked. The ability to detect these latter findings is likely influenced by the joint distention that occurs with MR arthrography.

Another advantage of direct MR arthrography is that the incorporation of anesthetic in the injection mixture can provide diagnostic information regarding intra-articular causes of pain. Intra-articular anesthetic has shown to be 90% accurate for detection of intra-articular pathology [3]. Others have shown that lack of response to lidocaine during MR arthrography does not exclude intra-articular pathology [7]. We routinely incorporate anesthetic (lidocaine) in our arthrogram injection mixture.

Although patient anxiety may exist regarding direct MR arthrography, the injection procedure is routine and fairly simple. Interestingly, one study evaluated patient perception of MR arthrography (all joints, not just hip) and found that patients described less pain than anticipated, and were generally willing to undergo the procedure to obtain more useful information [8].

Direct MR Arthrography Technique

Under fluoroscopic guidance, sterile conditions, and local anesthetic, we advance a 22-gauge spinal needle via an anterior or anterolateral approach targeting the mid- to proximal aspect of the femoral neck (Fig. 2). The femoral artery is palpated before injection to avoid injury, but at this level the vessels are usually located more medial. The patient is positioned with the hip internally rotated and knee mildly flexed and supported with a foam pad to expose the femoral neck and increase laxity to the anterior capsule. Sterile extension tubing is used to connect the needle to the syringe to avoid self-exposure of radiation to the operator's hand. Intra-articular positioning is confirmed with small 1- to 2-mL injection of nonionic iodine-based contrast followed by a dilute gadolinium contrast solution ($0.2 \text{ mmol/L} = 0.1 \text{ mL}$ of gadolinium contrast in 20 mL solution), which contains lidocaine (5–10 mL) and normal saline for a total injected volume of 10 to 20 mL, depending on the patient. Overdistention is avoided, as a recent study showed blood flow to the femoral head can be diminished with increased intracapsular pressure [9]. Care is taken to avoid leakage of air bubbles into the joint, which can create artifact on the MR images that mimics debris in the nondependent portions of the joint. Alternatively, one can incorporate the nonionic contrast into the total mixture. If the patient is allergic to iodine-based contrast, rather than premedicating with steroids we avoid using the iodine-based contrast. We typically inject dilute gadolinium solution using fluoroscopic



Fig. 2. Fluoroscopic spot film shows normal appearance of intra-articular injection of nonionic iodine-based contrast and dilute gadolinium solution containing lidocaine from an anterior approach. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. *Oper Tech Orthop* 2005;15(3):182–90, with permission.)

guidance and the tactile loss of resistance as the indicator of being intra-articular with good success. Allergic reactions to gadolinium contrasts are far more rare than iodine-based contrast agents allergies [10,11]. Complications of contrast injection including bleeding, infection, soft tissue injury, and allergic reaction are very low. Anecdotally, <1% of patients may experience severe postprocedural pain thought to be related to reactive synovitis. This is often treated with rest, ice, nonsteroidal anti-inflammatory drugs, and antihistamine agents. Rarely, patients may notice transient numbness in the leg/thigh likely related to extravasations of dilute gadolinium solution containing lidocaine outside the capsule, which may be iatrogenic but most often related to underlying pathologic capsular perforation. We have not experienced any cases of infection or long-term complication of direct MR arthrography in over 500 cases.

After injection, patients are transferred on a stretcher to the MR unit within 30 minutes to minimize chance of extravasation from the joint. All hips are imaged on 1.5 Tesla field strength MRI or higher to allow for sufficient signal and resolution. We use a phased array surface coil centered over the hip [12]. Scout images are checked to ensure proper coverage and signal output. We prefer a smaller field of view (14–16 mm) to enhance resolution and visualization of the labrum. We also use a combination of T1- and T2-weighted sequences with and without fat saturation in the true coronal and sagittal planes, as well as the oblique axial plane, that is directly perpendicular to the anterior acetabulum (ie, parallel to femoral neck) (Fig. 3). Our diagnostic checklist includes not only evaluation of the labrum, but a search for cartilage defects, ligamentum teres tears, anterior and posterior capsular injuries, joint debris, iliopsoas and rectus femoris insertional injuries, marrow signal changes, and muscle injury.

Specifics of our pulse sequences for unilateral MR arthrogram is as follows: true coronal T1 fat saturated (repetition time [TR] 600, echo time [TE] min, echo

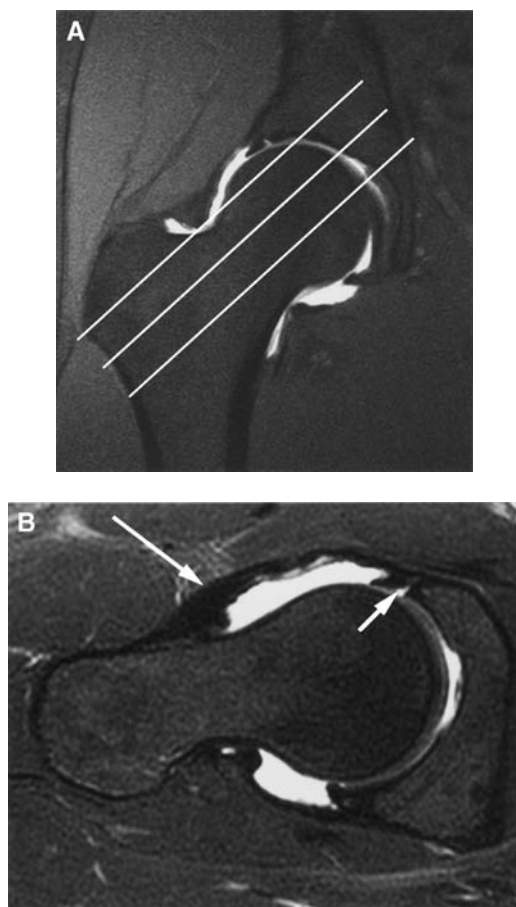


Fig. 3. (A) Coronal T1 fat-saturated image with 16-cm field of view demonstrating plane orientation of oblique axial images. (B) Oblique axial T1-weighted image with anterosuperior detached labral tear (*short arrow*) eventually reattached with suture anchors. Also note tapered appearance of anterior capsule from lateral to mid-portion (*long arrow*), which correlates with surgical and clinical findings of iliofemoral ligament/capsular laxity. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182–90, with permission.)

train length 8, frequency and phase matrix 320×256 , slice thickness 4 mm with 1-mm interslice gap, number of excitations [NEX]=2), true coronal T2 weighted with fat saturation (TR >4000, TE=68, echo train length 3, frequency and phase matrix 256×224 , slice thickness 4 mm with 1-mm interslice gap, NEX=2), oblique axial T1 (TR 600, TE min, echo train length 8, frequency and phase matrix 256×224 , slice thickness 4 mm with 1-mm interslice gap, NEX=2), oblique axial T2 with fat saturation perpendicular to the plane of the acetabulum TR >4000, TE=68, echo train length 3, frequency and phase matrix 256×224 , slice thickness 4 mm with 1-mm interslice gap, NEX=2)

and oblique sagittal T1-weighted images (TR 600, TE min, echo train length 8, frequency and phase matrix 256×224 , slice thickness 4 mm with 1-mm interslice gap, NEX=2).

Use of Other Modalities

Fluoroscopy, aside from providing localization for direct arthrography as described above, is not routinely used, but may be used to assess joint laxity by demonstrating translation or presence of vacuum phenomena with mild traction [13]. Fluoroscopy is also used to guide injections of steroid or viscoelastic supplementation.

Computed tomography (CT) has a limited role as well, and is used primarily for evaluation of small joint bodies, traumatic fracture, bony alignment, and osteoid osteoma. Occasionally, with good success we use multidetector CT arthrography of the hip to evaluate labral pathology in patients that cannot undergo MRI procedures (positive metal screening or significant claustrophobia). In general, with CT, radiation doses to the pelvic organs may be substantial, a concern primarily in the pediatric population. The technique should minimize radiation dose, whenever possible [14]. Recently, multidetector/multislice CT arthrography of the hip was found useful for evaluating the degree of chondrosis in dysplastic hips. There may be a role for CT arthrography in the future (Fig. 4).

Nuclear medicine bone scintigraphy often provides sensitive but nonspecific information with poor spatial resolution, and is not routinely used at our institution for hip pain in the athlete. One study described increase uptake at

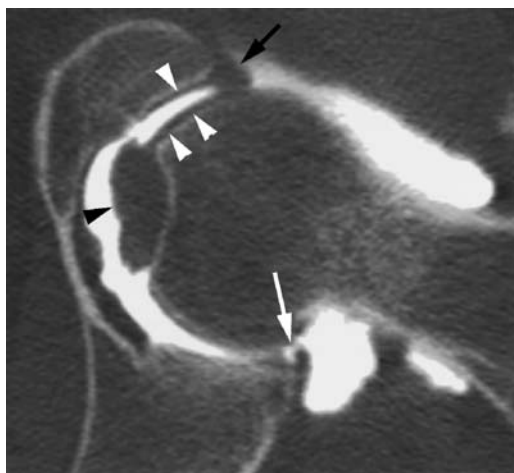


Fig. 4. Axial image from multidetector CT arthrogram of the hip in a patient with severe claustrophobia showing normal contour of the anterior labrum (*black arrow*) and a normal variant posterior labral cleft (*white arrow*). Note the mild diffuse cartilage thinning with this technology involving both sides of the joint (*white arrowheads*) as well as a hypertrophied and frayed ligamentum teres (*black arrowhead*).

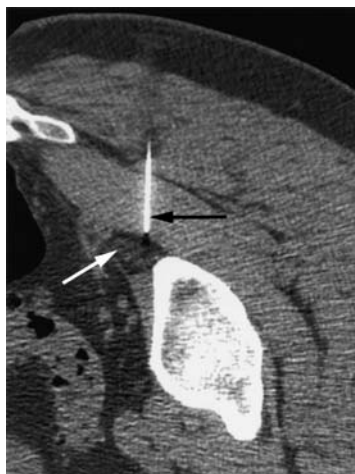


Fig. 5. Twenty-two-year-old college runner with piriformis syndrome received good relief with a CT-guided intramuscular lidocaine injection of the piriformis muscle and perineural injection of sciatic nerve with anesthetic and steroid. In this image the needle is within the piriformis muscle (*black arrow*), but was subsequently advanced for additional perineural injection of the sciatic nerve at the site of potential impingement (*white arrow*). (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182–90, with permission.)

the anterosuperior rim in cases of FAI. Absence of this finding had a high negative predictive value [15]. However, even for stress fractures of the hip, MRI has supplanted scintigraphy as well [16].

Ultrasound of the hip is widely used in the pediatric population to assess for congenital hip disorders and joint effusions, but is infrequently used in the adult populations to assess intra-articular abnormalities. Due to its ability for real-time dynamic imaging, it does offer potential to detect internal snapping hip syndrome [17]. In general, the role of ultrasound for evaluating labral tears is limited. One study showed poor detection of labral tears, as only one eighth were visualized with ultrasonography [18]. However, one abstract presentation of 20 patients described good visualization of anterior labral tears during ultrasound guided injections of a steroid mixture [19].

Therapeutic injections of the hip and pelvis may provide diagnostic information and possible therapeutic relief. We routinely use CT guidance for accurate injection for sacroiliac (SI) joint pain, osteitis pubis, piriformis syndrome, iliopsoas bursitis or insertional tendonitis, and peritendinous injections of the gluteus medius/minimus and hamstring insertions (Fig. 5). Based on operator preference, fluoroscopic and ultrasound guidance can be used as well.

RADIOGRAPHIC EVALUATION AND MEASUREMENTS OF THE HIP

To identify more recently described findings of FAI, our radiographic hip protocol deviates from common past screening hip radiographs. The AP weight-bearing view of the pelvis and AP view of the hip provides multiple measure-

ments to assess acetabular coverage and orientation [1,20,21]. Radiographic measurements should be performed after a thorough assessment for subtle fractures or tumors, soft tissue, and intrapelvic anomalies, as well as sacroiliac, pubic symphyseal, and lower lumbar pathologies.

A commonly used measurement to assess for readily apparent acetabular dysplasia is the lateral center edge angle (of Wiberg), which is obtained by drawing a line from the center of the femoral head to the lateral margin of the acetabulum (as its name implies) referenced to a vertical perpendicular line originating from the center of the femoral head (Fig. 6A). Normal values vary, but generally, values less than 20° to 25° are considered abnormal. The anterior lateral edge angle (or false profile view) has also been used, particularly when the center edge angle is abnormal. The horizontal toit externe (THE) angle, also known as acetabular index of the weight-bearing surface, is measured from a line parallel to the weight-bearing surface of acetabulum referenced to a horizontal line (Fig. 6B). Values greater than 10° are considered abnormal. Other measurements such as femoral head extrusion index (with normal values of less than 25%) and acetabular index of depth may also be useful.

However, to evaluate for FAI it is essential to detect more subtle abnormalities of the femoral head–neck junction and acetabulum that are associated with labral tears. Femoroacetabular impingement has been categorized into two basic types [22]. Type 1 is loss of femoral head neck offset, also known as cam-type or pistol-grip deformity, and is best identified on crosstable lateral view (or CT or MRI), but can be appreciated on some AP and frogleg lateral views depending on the severity. On the AP view the femoral head may appear nonspherical [23].

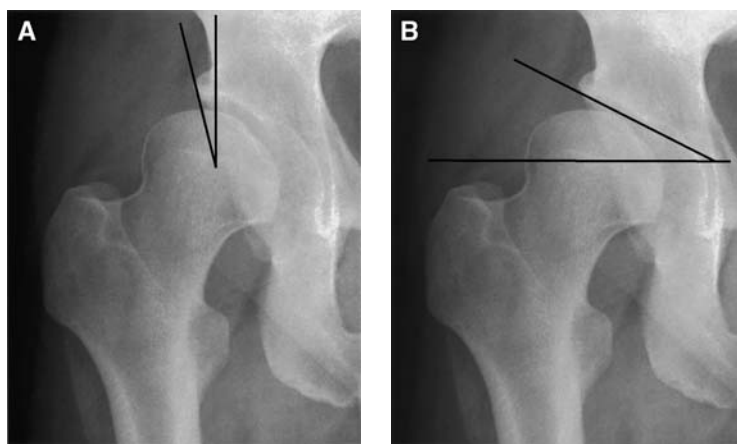
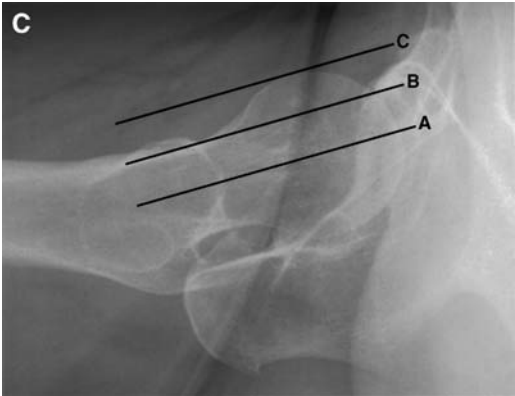
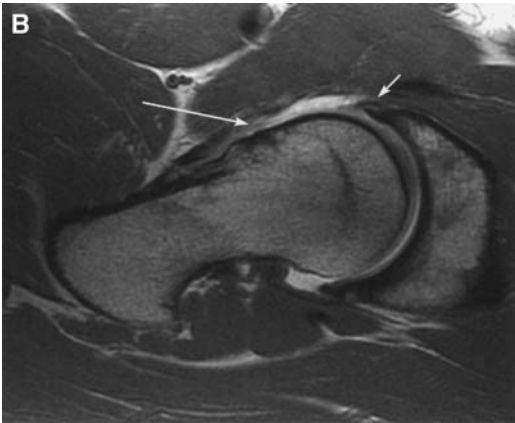
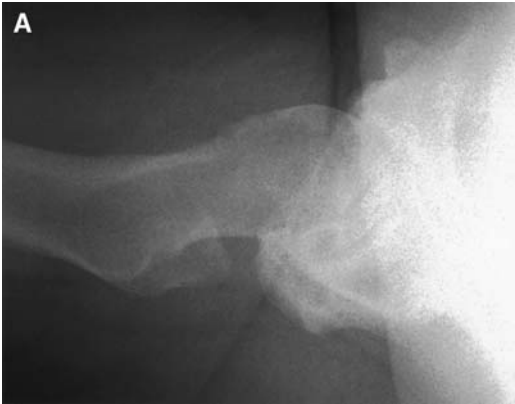


Fig. 6. AP view of the pelvis in a patient with hip dysplasia shows that the lateral center edge angle is markedly decreased less than 20° (A) and the acetabular index of the weight-bearing surface is increased above 10° (B). Note also substantial lack of coverage of the femoral head, also indicative of a dysplastic hip. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182–90, with permission.)



Type 2, or pincer-type impingement, is associated with acetabular retroversion. A combination of cam and pincer types has been described, as well as impingement associated with a deep acetabular socket and morphologic changes of the proximal femur such as coxa vara [22,24,25].

Femoral head-neck offset can be assessed on plain films using the crosstable lateral view with the leg in neutral position (Fig. 7) [26,27]. This image is obtained by placing the film cassette adjacent to the hip of concern with the patient in the supine position while the opposite knee is bent to allow passage of the X-ray beam. Offset is measured by creating a line along the longitudinal axis of the femoral neck (which may or may not intersect the center of the femoral head). Two other parallel lines are placed at the level of the anterior femoral neck cortex and the most anterior margin of the femoral head. Distance or offset between the two most anterior lines has been shown to be less than 7.2 mm (SD 2.6) in abnormal cases and 11.5 mm (SD 2.2) in asymptomatic normal patients. A ratio can also be determined by dividing by the diameter of the femoral head. The cause of cam-type impingement is unclear but thought to result from physeal injury and extension of physeal scar [26]. However, it is possible that repeated abutment of the femoral head-neck junction may cause bony bump formation [27]. Also, the finding could be related to underlying initial soft tissue injuries such as labral tear or capsular instability, causing altered mechanics and bone remodeling, reminiscent of Fairbank's type changes in the knee. One immunohistologic analysis of perilesional capsular tissue suggested progenitor cells were recruited to this region of the bony bump, which would support the latter hypotheses [28]. The cause however, is likely multifactorial.

Pincer-type FAI is associated with acetabular retroversion. Although acetabular dysplasia is often associated with anteversion, several recent studies estimate that acetabular retroversion can be seen in one sixth to one third cases of acetabular dysplasia, a finding that may influence surgical techniques and approaches (ie, adjustment of acetabular realignment procedures) [20,29]. When the anterior rim abnormally crosses over the posterior rim (usually superiorly) on plain film radiographs, this finding has been termed the crossover sign, and represents a marker of acetabular retroversion (Fig. 8) [30]. The posterior acetabular rim should also lie medial to the center of the femoral head as well (posterior wall sign). These findings must be measured on a well-centered AP view of the pelvis with the distance between the sacrococcygeal joint and pubic

Fig. 7. (A) Thirty-two-year-old professional football player with femoroacetabular impingement seen on crosstable lateral view. (B) There is loss of normal femoral head-neck offset, which is confirmed with an MR arthrogram. MRI also shows a complex intrasubstance predominant anterior labral tear (arrow) treated arthroscopically with intrasubstance suture banding. A normal crosstable lateral view shows good offset between lines B and C. Line A is drawn along the femoral shaft, lines B and C are drawn parallel to line A along the anterior femoral neck cortex and anterior femoral head respectively (C). (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182-90, with permission.)

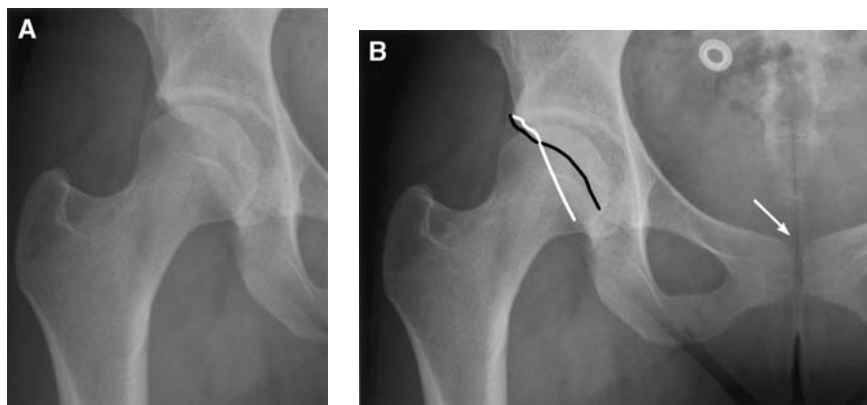


Fig. 8. (A) Acetabular retroversion with positive crossover sign. (B) The same patient with annotations marking crossover sign of the anterior rim (*black line*) of the acetabulum superiorly over the posterior rim (*white line*). Note relationship of coccyx with pubic symphysis. This radiograph shows the pelvis is slightly reclined, which can minimize appearance of retroversion. One must account for reclination, inclination, and rotation to properly assess the degree of acetabular retroversion. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182–90, with permission.)

symphysis measuring about 3 cm to 5 cm (3.2 cm male, 4.7 cm female) [31]. Others consider the radiograph well centered when the coccyx is about 1 cm from the pubic symphysis [29]. Reclination of the pelvis can underestimate the appearance of retroversion (crossover sign), and inclination can overestimate the finding. One must also account for rotation of the film as well (ie, rotation of the pelvis to the right increases appearance of retroversion on right and decreases on left).

Normal Variants or Pathologic Process?

Periacetabular ossicles are often anecdotally considered normal variants of secondary ossification centers of the acetabulum. However, when we see small superolateral periacetabular ossicles we raise suspicion for underlying labral pathology (Fig. 9). “Os acetabuli” have also been described in dysplastic hips with anterior rim syndrome where the labrum was detached along with an avulsed a piece of the acetabular rim [32].

Radiographic findings of the synovial herniation pit of the hip were first described in 1982, and have a characteristic appearance [33]. Despite past considerations as a normal anatomic variant in about 5% of the population, the original description hypothesized that the finding could be a pathologic abnormality in the setting of a painful hip. Subsequent reports suggesting a pathologic nature as well, described soft tissue impingement, enlargement over time, and increased uptake on bone scan [34,35]. Currently when seen, we report herniation pits as compatible with femoroacetabular impingement (Fig. 9).

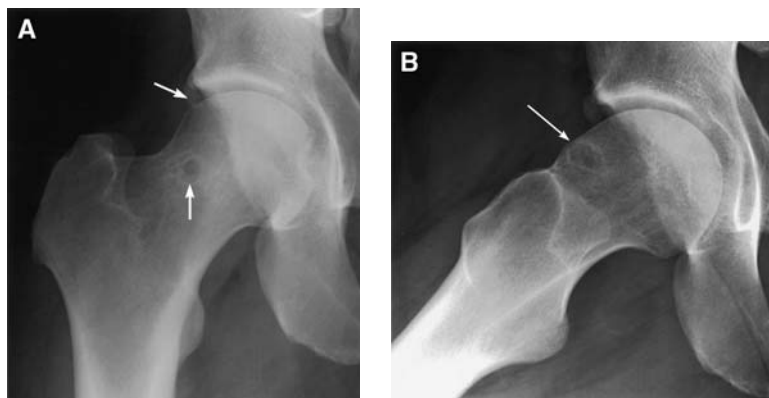


Fig. 9. Synovial herniation pit with periacetabular ossicle in the setting of cam type 1 FAI on AP view (A) and frogleg lateral view rather than crosstable lateral view (B). Note loss of sphericity of the femoral head on both views. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182–90, with permission.)

A recent publication retrospectively reviewed 117 hips with femoroacetabular impingement and found fibrocystic changes (ie, synovial herniation pit) on AP radiographs in one third of the cases. Dynamic MR and intraoperative observations of the same patients demonstrated close proximity of the fibrocystic lesion with area of impingement suggesting a causal relationship [36]. One recent presentation of radiographic analysis of 54 patients with findings suggestive of FAI on frogleg lateral view reported 15% had synovial herniation pits and 30% had periacetabular ossicles [37].

MR EVALUATION OF THE HIP

Labrum

Acetabular labral tears have become a commonly recognized source of intra-articular hip pain that affects athletes and nonathletes alike. Although strongly associated with athletes performing twisting pelvic motions and rotations of the hip that occur in sports like soccer, golf, football, ballet, and hockey; athletes in all major sports (and even minor ones such as skateboarding and Olympic yachting) have been affected [38]. Many tour-level professional golfers have undergone successful hip surgery for labral pathology with return to previous level of play and sometimes beyond prior performances (Marc J. Philippon, personal communication). As stated earlier, direct MR arthrography is the best imaging modality for evaluation of underlying intra-articular disorders. Interpretation should not only include labral evaluation, but also evaluation of chondral, capsular, bony, ligamentum teres, and adjacent extra-articular (iliopsoas, rectus femoris, pubic symphysis) abnormalities (Fig. 10). However, it is important to also realize that the clinical situation ultimately dictates the need for surgical intervention, as a negative MR arthrogram does not currently obviate arthroscopic evaluation [4].

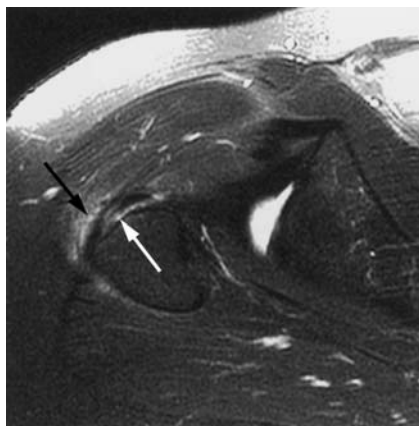


Fig. 10. Oblique axial T2 fat-saturated image of an intact labrum, but there is a partial tear of the undersurface of gluteus minimus tendon insertion (*white arrow*) with surrounding lateral edema and inflammation (*black arrow*). It is essential to search for surrounding extra-articular abnormalities.

The labrum is generally considered a triangular-shaped structure with its medial base firmly anchored to the rim of the acetabulum with the apex extending laterally. It extends nearly circumferentially around the horseshoe-shaped acetabulum but blends with the transverse acetabular ligament inferiorly (Fig. 11).

On the articular side, the labrum merges with the acetabular cartilage over a 1- to 2-mm transition zone [39]. On the capsular side, this transition does not exist. The labrum (like the meniscus) has been shown to contain nerve endings (presumably related to nociceptive and proprioceptive function), and is thought to have low intrinsic healing ability due to low vascularity primarily obtained from the capsule [40,41]. Biomechanically, the labrum increases the depth of the acetabular socket and helps maintain negative intra-articular pressure that increases static stability [42,43]. When the labrum is torn, forces on adjacent cartilage increase, suggesting a role in the development of cartilage injury and arthritis [44].

The labrum demonstrates typical MR imaging features of organized collagen elsewhere in the body with decreased low signal intensity on T1- and T2-weighted images. However morphologic (rounded or irregular) and increased intrasubstance signal intensity changes have been seen in asymptomatic individuals with increasing age based on nonarthrogram MR imaging and likely represent areas of degeneration [45–47]. However, in the young athlete undergoing evaluation for labral tear these findings are considered abnormal.

Several confusing issues regarding the MR appearance of the labrum should be addressed and understood (Fig. 12). First, on MR arthrography there is a normal perilabral recess between the capsule of the hip (particularly superiorly on coronal images) and the capsular side of the labrum (Fig. 11B). This recess may not be seen in a nonarthrogram MRI due to lack of capsular distention,

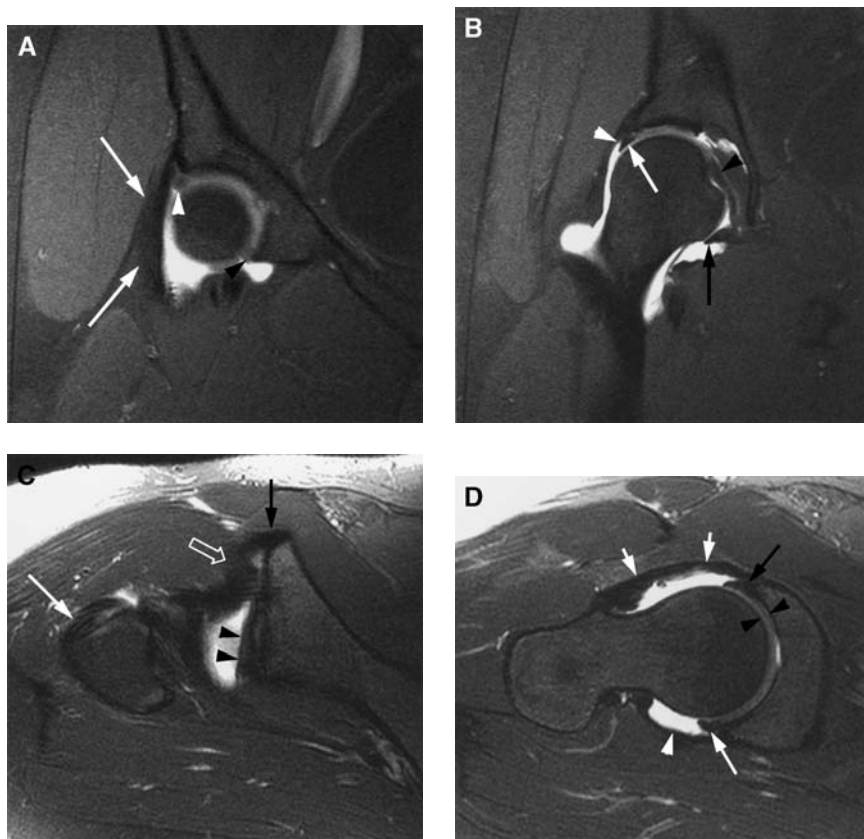
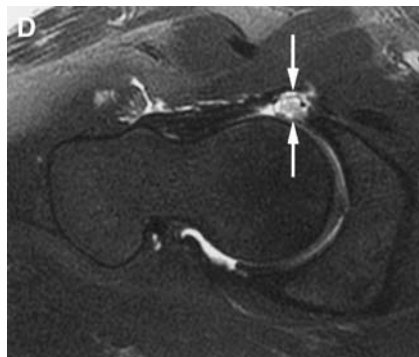
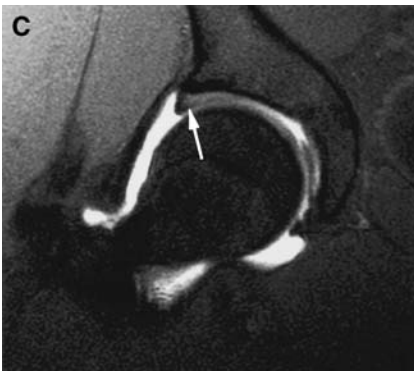
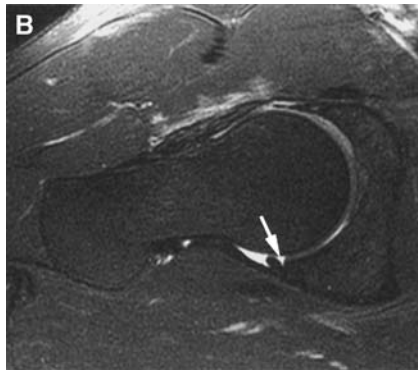
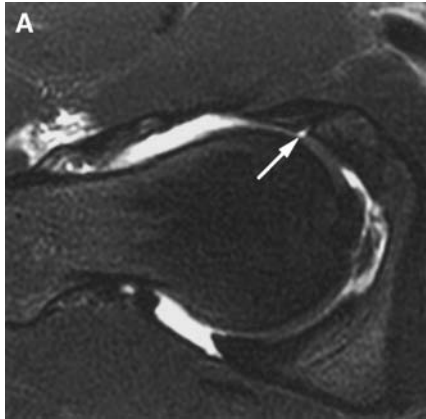


Fig. 11. Normal MR anatomy. (A) Coronal T1 fat-saturated images of anterior aspect of the hip demonstrating iliofemoral ligament (arrows) and free edges of the anterior labrum superiorly (white arrowhead) and inferiorly (black arrowhead). The anterior labrum is better assessed on axial images. (B) Coronal T1 fat-saturated image of mid-hip with a normal triangular-shaped labrum (white arrow) firmly attached to the acetabular rim. Inferomedially lies the transverse acetabular ligament (black arrow), which should not be confused with a labral abnormality. Medially, a normal appearing ligamentum teres (black arrowhead) arises from the transverse acetabular ligament and extends to the fovea. Note normal perilabral capsular recess is adjacent to the labrum (white arrowhead). (C) Oblique axial T2 fat-saturated images of the superior aspect of the hip demonstrating the free edge of the superior labrum (black arrowhead), which is better evaluated on coronal images. Note the appearance of the rectus femoris direct (black arrow) and reflected heads (open arrow) and the normal gluteus minimus insertion on anterior aspect of greater trochanter (white arrow). (D) Oblique axial T2 fat-saturated images of mid aspect of hip demonstrating normal dark triangular appearance of well-attached anterior (black arrow) and posterior labrum (white arrow). Curvilinear gray signal of the femoral head and acetabular cartilage blend together (black arrowheads). The anterior capsule and iliofemoral ligament (short arrows) are seen as well as the posterior capsule (white arrowhead).

which can make evaluation of the labrum more difficult. Lack of this recess may also be seen in dysplastic hips with a hypertrophied labrum [32]. Second, a sublabral sulcus or recess under the labrum in the anterior superior quadrant has been described by some, yet others with surgical and anatomic studies have not identified this finding [48]. In our experience, the presence of a small defect



in the anterosuperior labroacetabular junction is usually considered a small partial detachment, because when probed arthroscopically, it appears unstable. Third, there is, however, a small sublabral sulcus in the posterior inferior aspect of the labrum seen in many individuals that has been reported as normal findings, which our own clinical experience confirms [49]. Fourth, the labrum cartilage interface and zone of transition may have mild increased signal on nearly all sequences and should not be confused for a tear. This “cartilage undercutting” phenomenon is seen in the shoulder involving the glenoid labrum-cartilage interface as well [49,50]. Finally, nonarthrogram imaging in asymptomatic volunteers described the absence of the anterosuperior labrum, particularly in older adults. In our experience in young adult athletes, this finding is markedly abnormal and indicative of a macerated torn labrum.

Classifications for labral tears exists that are based on MR signal intensity, tear morphology, or arthroscopic findings [5,51,52]. The utility of an MR classification scheme has been questioned due to the general acceptance of arthroscopic debridement as the definitive treatment for symptomatic tears. Although debridement produces good to excellent results for 85% to 90% of patients, long-term studies are forthcoming [38]. However, there is a strong relationship between acetabular labral tears and arthritis [53]. In the knee and shoulder it is well known that meniscal and glenoid labral resection can cause significant increase in joint contact pressures [54,55]. One should also keep in mind that several decades passed after Fairbank’s classic 1948 description of post-meniscectomy arthritis was published before meniscal repair became the standard of care [56]. Therefore, although not proven in the hip, based on past history of injury to fibrocartilage bearing joints, it is reasonable to surgically attempt to restore biomechanical function of the hip using techniques similar to those used to repair menisci and the glenoid labrum to reduce the possibility of late onset arthritis. Consequently, emerging arthroscopic techniques emphasizing tissue preservation and biomechanical function are being developed to repair the labrum [38]. Therefore, to help guide surgical intervention, our MR assessment of tears has progressed from a yes or no evaluation for the presence of a labral tear to a descriptive evaluation emphasizing the amount of residual intact labral tissue, orientation of intrasubstance tears, and the presence of labro-

Fig. 12. Normal MR variants. (A) Oblique axial T2 fat-saturated image showing small cleft or recess (*white arrow*) under the anterior labroacetabular junction arthroscopically confirmed to be a partially detached unstable tear. (B) Oblique axial T2 fat-saturated image with small cleft between the posteroinferior labrum and acetabulum, which should not be confused with a detached tear (*white arrow*). (C) Coronal T1 fat-saturated image of mid-hip with normal appearing superior labrum and normal labral–cartilage interface with a mild increased signal that should not be confused with a labral tear (*white arrow*). (D) Oblique axial T2 fat-saturated images with near complete loss of the anterosuperior labrum (*white arrow*) consistent with a macerated tear rather than a normal variant.

acetabular detachment. Currently, we categorize tears into three major groups: detached, intrasubstance, and degenerated with combinations thereof.

Detached tears demonstrate separation of the labrum from its acetabular base, which can be complete or partial, and may be nondisplaced. Detached tears with displacement on MR arthrography demonstrate linear fluid or contrast signal gap interposed between the base of the labrum and bony acetabular rim, and are best seen on coronal images for superior predominant tears and oblique axial images for anterior predominant tears (Fig. 13). These tears may exist without displacement, in which case diagnosis can be difficult with the tear manifesting as only a thin line of fluid signal at the labroacetabular junction. Detachment injuries can be treated with suture anchor reattachment much like glenoid labral repair techniques in the shoulder.

Intrasubstance labral tears demonstrate intrasubstance fluid or contrast signal, usually extending to the articular side of the labrum (sometimes capsular side), which is often oblique or curvilinear in shape. However, signal may also be complex extending in multiple directions in the long and short axis of the labrum. These tears can be treated with intrasubstance suture bandings and thermal treatment to restore shape (Fig. 14).

A labrum with abnormal irregular contours and a thin morphology, with or without intrasubstance fluid or contrast signal extending to the free margin, is considered a degenerative type tear. These tears will likely undergo debridement or thermal treatment when necessary. In young athletes, it is not uncommon to have a combination of detached tears or intrasubstance tears with superimposed degenerative components. Treatments include a combina-

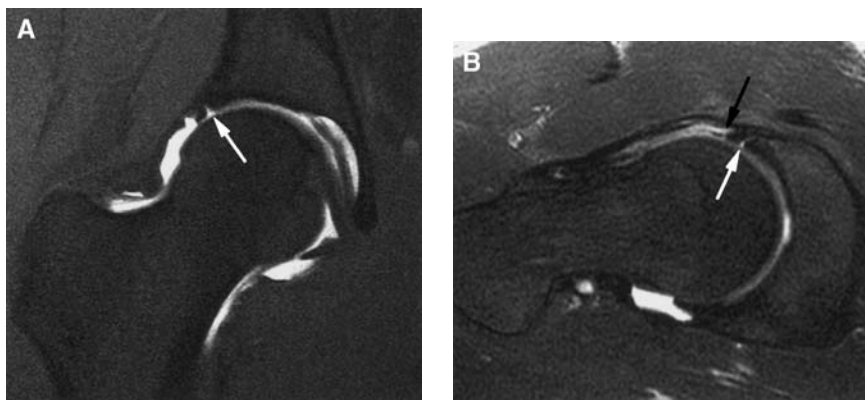


Fig. 13. (A) Coronal T1 fat-saturated image with typical finding of minimally displaced detached labral tear (*white arrow*) from the acetabular margin without an intrasubstance or degenerated component. (B) Axial image of a complex tear of anterosuperior labrum with more subtle detachment. Note the fraying and thinning of the free edge with small vertical intrasubstance tear (*black arrow*).

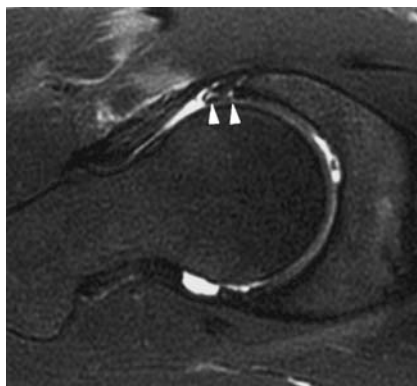


Fig. 14. Oblique axial T2 fatsaturated images of an intrasubstance tear of the anterosuperior labrum extending transversely from the acetabular base to the apex of the free edge (*white arrowheads*).

tion of reattachment, suture banding, debridement, and thermal contouring (Fig. 15).

We also note the estimated length of tears as well as location (anterior, anterosuperior, superior, posterosuperior, posterior). We include an additional clock face modifier to help convey beginning and endpoints of the tear based on arthroscopic appearance to aid the surgeon (Fig. 16). For example, a professional golfer may have a left hip 3 cm-long labral tear with an intrasubstance oblique articular sided tear extending from the 10 to 11 o'clock position, a detached component extending from the 11 to 1 o'clock position, and margins of the anterosuperior labrum demonstrating thin and frayed morphology consistent with acute on chronic injury.

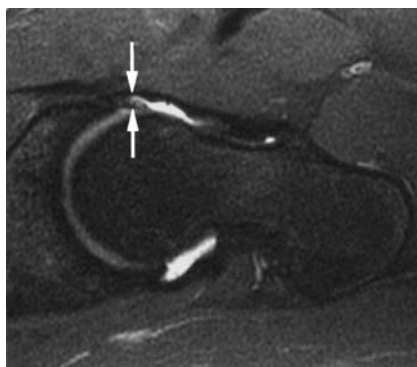


Fig. 15. Oblique axial T2 fatsaturated image with degenerated labral tear. Note loss of sharp triangular appearance and normal dark signal (*white arrows*). This finding is more commonly seen in older individuals, but one must also search for superimposed acute detachments and intrasubstance tears.

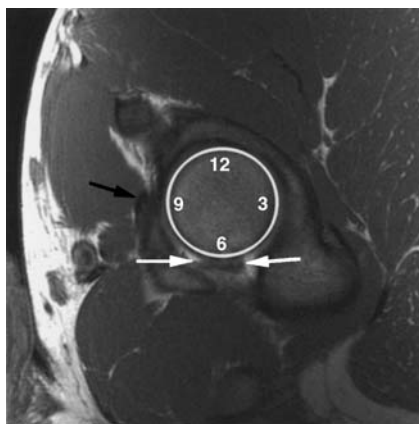


Fig. 16. Oblique sagittal T1-weighted image of the left hip showing clock face descriptors as seen if viewed lateral to medially. The acetabulum is horseshoe shaped with the iliopsoas tendon anteriorly at the 9 o'clock position (*black arrow*). There is partial visualization of ligamentum teres merging with transverse acetabular ligament at the 6 o'clock position (*white arrows*). It is important to avoid confusion when describing tears and include the name of the quadrant (ie, anterosuperior) along with clock face description, as some may switch the orientation of the clock face depending if it is a left or a right hip.

Femoroacetabular Impingement

Plain film findings of FAI have been well described. The MR appearance of FAI has been recently described, and corroborates surgical and radiographic findings [25]. A recent study described a triad of MR findings of FAI included loss of femoral head–neck junction offset, anterosuperior labral tears, and adjacent chondrosis [57]. The alpha angle measurement is used to quantify cam type impingement on MR images (Fig. 17) [58]. MRI quantification of pincer type impingement has not been described to our knowledge, but cross-sectional analysis of axial CT findings of acetabular retroversion have been described and emphasize the importance of evaluating the superior aspect of the acetabulum rather than mid-portion to accurately measure version and avoid a false negative finding [20].

Cartilage Injury

Cartilage injury is often associated with labral tears and femoroacetabular impingement. Accurate assessment of articular cartilage of the hip can be difficult due to its thinness and spherical contours unlike the knee [59]. Principles of cartilage evaluation in other parts of the body are applied to the hip and include assessment of size, location, defect thickness, subchondral bone interface, and subjacent marrow signal (Fig. 18). Although difficult, cartilage assessment is critical, as arthroscopic labral debridement outcomes are linked to the degree of underlying cartilage abnormality [2]. Plain film findings of cartilage injury due to labral tears and type 1 FAI involving the anterosuperior rim likely does not result in joint space narrowing on AP radiographs. One

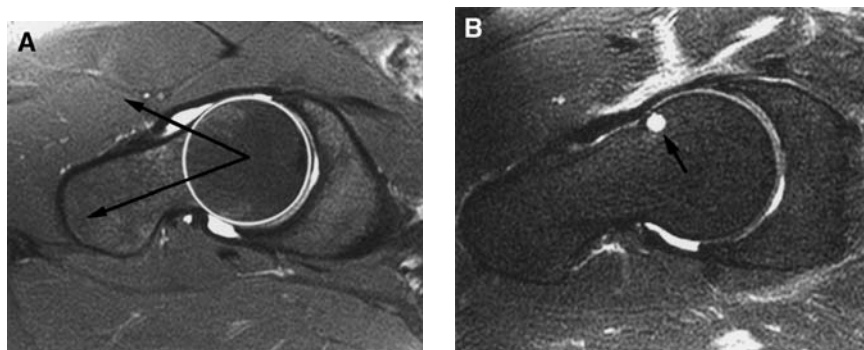


Fig. 17. (A) Oblique axial T2 fat-saturated images in the plane with the femoral neck demonstrating normal head-neck offset with an alpha angle measuring about 45° (normal less than 50° – 55°). This angle arises from two rays originating at the center of a best-fit circle of the femoral head. The first is along the axis of the femoral neck, and the other intersects the point where the cortex of the anterior femoral head-neck junction separates from the best-fit circle. (B) Comparison image shows MR appearance of FAI in a professional golfer. Note mild loss of normal head-neck offset measuring 60° along with a focal fibrocystic change at the area of impingement consistent with radiographic finding of a synovial herniation pit (*black arrow*).

recent study describes different cartilage pattern losses with different types of impingement. Specifically type 2 or pincer type results in diffuse circumferential cartilage injury, whereas type 1 had anterior superior injury primarily [60]. Acetabular delamination injuries have been reported in cases of type 1 FAI that were identified with direct MR arthrography [61].

Therefore, from an imaging standpoint, cross-sectional imaging is needed to evaluate cartilage unless plain film findings are advanced. MR arthrography has been found to offer moderate sensitivities and specificities between 47% to 79%

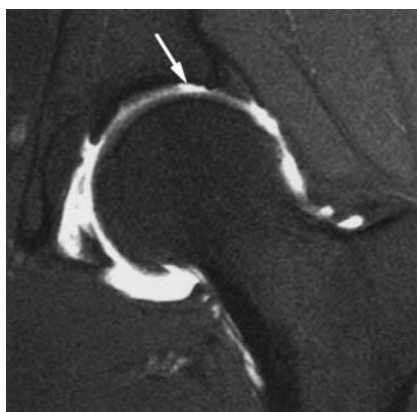


Fig. 18. Coronal T1 fat-saturated image of focal grade 3 cartilage defect of superior acetabulum (*white arrow*).

and 77% to 89% for cartilage injury detection, respectively [4,62]. One of these studies showed an overreliance on secondary signs of osteoarthritis and chondrosis (ie, increased signal intensity of subchondral marrow and osteophytes) resulted in false positive interpretation. These authors also had more difficulty assessing acetabular sided cartilage lesions. However, a more recent study using unilateral noncontrast MR described sensitivities from 86% to 93% and specificities from 72% to 88% [6]. Unpublished data from our institution evaluating MRI in professional golfers found that MRI underestimated the degree of articular cartilage injury when compared with arthroscopic findings. Traumatic lateral impact injuries associated with falls onto the ground with axial loading of femoral head can be associated with hip pain and chondral impaction injury. Subchondral marrow edema may be present, but MR findings can be minimal in these cases [63].

Capsular Laxity/Injury

The glenohumeral joint of the shoulder is the archetypal unstable joint, which relies on secondary soft tissues to confer static and dynamic stability because of the relative small bony contact of the humeral head and glenoid fossa. Unlike the shoulder, the hip is generally considered a statically stable joint due to large bony contact areas of the femoral head and acetabulum. Consequently, the concept of soft tissues to confer additional static and dynamic stability to the hip, particularly during rotation and extremes of motions associated with sporting activities, is relatively new [13]. Clinically, some patients without generalized laxity disorders (ie, Marfan or Ehler-Danlos syndromes) have exam findings of rotational instability of the hip thought to be related to laxity or dysfunction of the anterior capsule and iliofemoral ligament, which is amenable to surgical intervention via suture plication or thermal capsulorrhaphy [13,38]. Therefore, we thoroughly assess the joint capsule and iliofemoral ligament during MR arthrography. With MR arthrography, we have noticed a thick lateral margin of the anterior capsule (which corresponds to the iliofemoral ligament), along with irregularity of the undersurface on oblique axial images, correlates highly with clinical findings of capsular laxity, whereas a capsule with uniform thickness and a smooth undersurface was found in patients without capsular laxity (unpublished data) (Fig. 19). Anecdotally we have also noted an association of capsular laxity in patients with ligamentum teres hypertrophy suggesting recruitment of this ligament. Traumatic rupture to the iliofemoral ligament have been described in American football players in the setting of traumatic posterior hip subluxation, posterior acetabular rim fracture, and hemarthrosis [64]. Although much less commonly involved, posterior capsule injury may also occur.

Ligamentum Teres

Tears of the ligamentum teres have recently been associated with intra-articular hip pain and represented the third most common intra-articular problem in athletes. These injuries are usually diagnosed arthroscopically as either complete, partial, or degenerated tears [65,66]. In the past, preoperative imaging

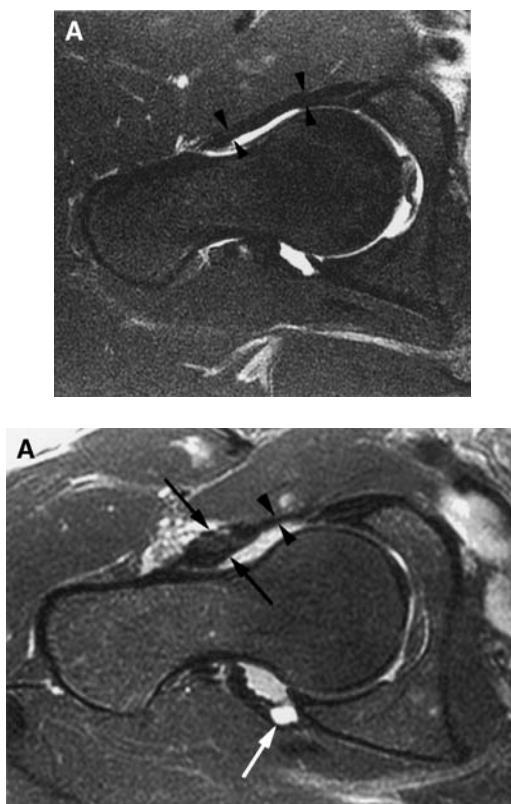


Fig. 19. (A) Oblique axial T2 fatsaturated images with normal uniform thickness (from lateral to medial) of the anterior capsule/iliofemoral ligament with smooth undersurface (*black arrowheads*). (B) Lack of uniform thickness of the capsule with thickening of lateral aspect (*black arrows*) and relative thinning medially (*black arrowheads*). This latter finding correlated with clinical and surgical findings of capsular laxity. Also note cystic changes of the posterior capsule insertion medially indicative of prior injury (*white arrow*).

studies of were of little value for detecting tears of the ligamentum teres. Bony avulsion of the femoral head has been associated with tears of ligamentum teres, but this is a very unusual finding [67]. There is almost no literature regarding the MR appearance of tears of the ligamentum teres [68].

Anatomically, the ligamentum teres arises inferiorly predominantly from the transverse ligament where it is trapezoid in shape and becomes progressively round or oval in shape (and somewhat banded or bilobed in appearance) [65]. It inserts in the fovea of the femoral head. In our MR experience, the normal ligamentum teres generally appears homogenous with dark signal intensity on T1- and T2-weighted images. At its inflection where it crosses 55°, magic angle phenomena can be noted on short TE sequences. We rely heavily on oblique axial images during MR arthrography for assessment, as there is too much

partial volume averaging with sagittal and coronal images for consistent evaluation. We look for discontinuity, fraying, and intrinsic signal changes to assess for injury (Fig. 20). Adjacent inflammation and edema of the cotyloid fossa may also be present and contribute to symptoms. A recent unpublished retrospective review from our institution found that MR arthrography offered good correlation with arthroscopic evaluation for partial tears of the ligamentum teres, which can aid preoperative planning and treatment. Our definition of a tear in this study included abnormal T2 signal and morphology of the ligament when the cross-sectional thickness was determined to be normal. The criteria were less stringent in cases of a hypertrophied ligamentum teres (defined as extending more than 2 mm beyond foveal insertion on oblique axial images) where only abnormal T2 signal or morphologic irregularity was considered a partial tear.

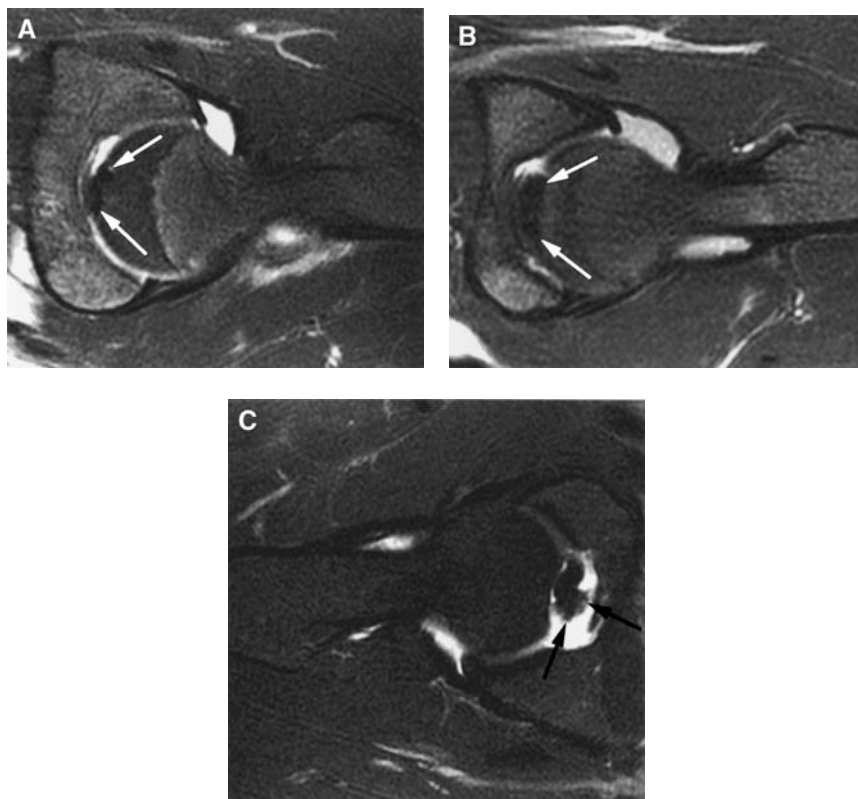


Fig. 20. (A) Oblique axial T2 fat-saturated image with normal size and signal of proximal aspect of ligamentum teres (*white arrows*). (B) A different patient with a hypertrophic ligamentum teres with normal signal and contour without a superimposed tear (*white arrows*). (C) Demonstrates a hypertrophic ligamentum teres with abnormal contour and bright T2 signal indicating a partial tear posteriorly that was arthroscopically debrided (*black arrows*).

The significance of a hypertrophied ligamentum teres is unclear, but may represent a chronic process with reactionary changes of the ligament from overloading (ie, rotational instability) and could be an abnormal finding by itself. Interestingly, a recent study of high level runners noted a hypertrophic change of the ligamentum teres during arthroscopy, and suggested a relationship with chronic instability [69].

POSTOPERATIVE EVALUATION OF THE HIP

Initial radiographs should assess for overall anatomic alignment, bony contours, and mineralization with comparison to preoperative studies. Postoperative changes involving arthroscopic osteochondroplasty, open resection osteoplasty, or acetabular realignment should assess for any residual FAI. Plain films may detect postoperative myositis ossificans, which can be a rare postoperative complication. However, when clinically indicated, symptomatic postoperative evaluation primarily involves analysis of the labrum searching for recurrent labral tears or detachments (Fig. 21). Although no published data exists, evaluation of the postoperative labrum can be difficult. It is essential that the interpreting physician is familiar with the original surgical technique to properly diagnosis recurrent problems. Intrasubstance suture or granulation tissue may mimic tear, much like postoperative MR appearance of meniscal repair. In our experience, if bioabsorbable suture anchors are used they are rarely seen postoperatively. Postoperative scarring or fibrosis can occur and symptomatic labral adhesions have been seen (Fig. 22). Anecdotally, pre- and postoperative synovitis may be occult with MR arthrography, and there may be a role for intravenous contrast in this scenario to better assess for synovitis. It is not uncommon to see enlargement of the iliofemoral ligament/anterior

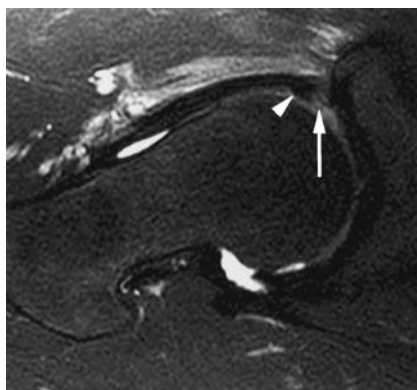


Fig. 21. Division 1 college running back with two prior labral debridement surgeries with persistent pain. Axial T2 fat-saturated image showed attenuated anterosuperior labrum (white arrow-head), which on close scrutiny was detached from the acetabular rim (white arrow) causing entrapment that was confirmed arthroscopically.

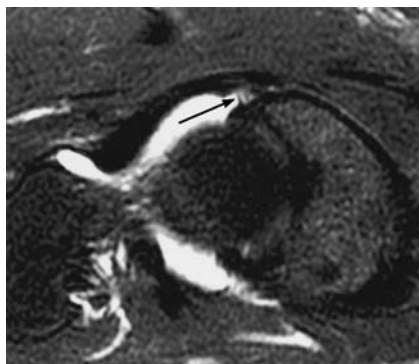


Fig. 22. Oblique axial T2 MR arthrogram image demonstrating surgically proven postoperative labral adhesions (*black arrow*) between the anterior capsule and capsular side of the anterior labrum. (From Armfield DR. Clinical evaluation of the hip: radiologic evaluation. Oper Tech Orthop 2005;15(3):182–90, with permission.)

capsule after surgery when suture plication or thermal capsulorrhaphy has been performed.

FUTURE DIRECTIONS

Future evaluation of intra-articular hip pathology will be largely influence by stronger MR magnetic fields (3T and greater), improved coil technology, and expanding knowledge base. The ultimate goal will be to create an easily reproducible noninvasive test with conspicuity of abnormal findings. We are currently evaluating the role of stress positioning and kinematic imaging to assess for biomechanical soft tissue dysfunction of the capsule, labrum, and ligamentum teres. We are evaluating computer-generated bone collision detection to help predict and visualize femoroacetabular impingement to aid surgical planning.

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Pediatric Athlete Hip Disorders

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Injuries of the hip and pelvis in pediatric athletes are receiving increased attention. The majority of injuries are soft tissue injuries or apophyseal injuries that heal with nonoperative supportive treatment. Unique injury patterns can be seen in patients who have underlying pediatric hip disorders such as slipped capital femoral epiphysis, and Legg-Perthes disease. With the advent of hip arthroscopy and the development of more advanced imaging of the hip through MR arthrography, internal derangements of the hip such as labral tears, loose bodies, and chondral injuries are being diagnosed and treated with increased frequency. This article reviews the more common injuries of the hip and pelvis in pediatric athletes.

APOPHYSEAL INJURIES

Avulsion injuries are common among skeletally immature athletes because of the inherent weakness across the open apophysis [1]. The incidence of avulsion fractures is increasing, especially among 14 to 17 year olds, as a result of the growth in competitive sports participation.

Avulsion fractures results from indirect trauma caused by sudden, violent, or unbalanced muscle contraction, and are most commonly associated with sports such as soccer, rugby, ice hockey, gymnastics, and sprinting, that involve kicking, rapid acceleration and deceleration, and jumping. Whereas in adults this mechanism of injury typically causes a muscle or tendon strain, in skeletally immature athletes the consequences are more serious, because of the inherent biomechanical weakness and subsequent separation of the apophyseal region. Intensive training exposes the epiphyseal plate to repetitive tensile stress while simultaneously enhancing muscle contractility and power. The inherent weakness at the epiphyseal plate, combined with the increased functional demands placed on the musculature, may predispose athletes to subsequent avulsion injury. Once the injury has occurred, the degree of bony displacement is restricted by the periosteum and surrounding fascia.

Although avulsion fractures can occur at any major muscle attachment, the three most common sites of avulsion injuries include the anterior superior iliac

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Fig. 1. Anterior superior iliac spine (ASIS) avulsion fracture in an adolescent athlete.

spine (ASIS) (Fig. 1), the anterior inferior iliac spine (AIIS) and the ischial tuberosity (Fig. 2), because of violent contraction of the sartorius, rectus femoris, and hamstring muscles, respectively. In addition, avulsion fractures of the lesser trochanter can also occur (Fig. 3).

Clinical presentation typically follows a traumatic incident or strenuous exercise, and is characterized by acute onset of localized pain and swelling that is exacerbated on palpation and by passive stretching of the involved muscle. Patients will characteristically assume a position that places the least amount of tension on the involved muscle. Although clinical presentation is often diagnostic, radiological imaging is useful in determining the size of the avulsed fragment and degree of bony displacement.



Fig. 2. Ischial tuberosity avulsion fracture in an adolescent athlete.



Fig. 3. Lesser trochanteric avulsion fracture in an adolescent athlete.

Controversy exists regarding the optimal management of avulsion fractures, particularly those involving the ischial tuberosity [1]. Typically, initial management will be conservative, including rest and ice, followed by protected weight-bearing with crutches until symptoms resolve. Thereafter, progression to light isometric stretching and full weight bearing is indicated, and return to full sports participation can occur once full strength and a pain-free range of motion is achieved. The need for surgical intervention is rare, and is typically based on ongoing symptoms and the degree of bony displacement. As a general rule, large displaced fragments greater than 2 cm may require surgical fixation; however, the optimal timing of surgical intervention remains unclear.

SLIPPED CAPITAL FEMORAL EPIPHYSIS

Slipped capital femoral epiphysis (SCFE) involves the posterior slippage of the proximal femoral epiphysis caused by mechanical shearing forces, with concomitant extension and external rotation of the femoral neck and shaft (Fig. 4). It is regarded as the most common hip disorder of adolescence, with an increased prevalence among males, and with peak onset around 11 years of age [1]. Increased body mass index (BMI) is a significant risk factor for the development of slipped capital femoral epiphysis, with both biomechanical and endocrinological factors implicated.

Classification of slipped capital femoral epiphysis has traditionally been based on acuity of symptoms and severity of the slip; however, a greater emphasis is now being placed on mechanical stability because of its greater prognostic value. A mechanically stable slip will allow weight-bearing, whereas a patient who has an unstable SCFE typically represents an acute physeal fracture, with concomitant microscopic instability resulting in pain and an inability to bear weight.



Fig. 4. Anteroposterior pelvis radiograph demonstrating a left mild stable slipped capital femoral epiphysis.

Accurate, early diagnosis of SCFE is important in preventing both short-term complications, including chondrolysis and avascular necrosis of the femoral head, and longer-term problems such as hip dysfunction and osteoarthritis. The insidious and often ambiguous onset of symptoms, combined with the absence of radiological changes early in the condition, are common causes of delayed diagnosis. Symptoms associated with a stable slip typically involve a dull ache that is exacerbated by exercise, but can be localized anywhere from the groin to the medial aspect of the knee. The delayed onset of significant pain and dysfunction may allow for the progression from a stable to unstable slip, with major implications for long-term prognosis.

Management of SCFE is fraught with challenges, especially for severe slips caused by significant deformity of the femoral head, and there is inherent risk of iatrogenic avascular necrosis and subsequent osteoarthritis. A number of potential risks factors of avascular necrosis have been reported, including the use of multiple pins, pin position and penetration, complete or partial reduction, and the stability and severity of slip. Unfortunately, at present there is little in the literature regarding the optimal management of acute, unstable SCFE. A recent survey of Pediatric Orthopaedic Society of North America (POSNA) members found that 57% reported using a single threaded screw for fixation for unstable SCFE, whereas 40.3% recommended three threaded screws [1].

There is a clear relationship between the stability and severity of the slip and subsequent postoperative risk of osteonecrosis. Patients who had stable lesions showed no increase in risk of osteonecrosis, whereas those who had unstable lesions demonstrated an increased level of risk that was proportional to the grade or severity of the slip. In situ pinning without reduction using a single cannulated screw was associated with the lowest risk of iatrogenic osteonecrosis of the femoral head, irrespective of stability or severity of slip [1].

Bilateral SCFEs have been reported to occur in 20% to 50% of cases, though simultaneous presentation is unusual [1]. Despite this high incidence, the optimal

management of the contralateral hip when presented with a unilateral SCFE remains controversial [1].

LEGG-PERTHES DISEASE

Legg-Calve-Perthes disease, also known as Legg-Perthes or Perthes disease, is an idiopathic, self-limiting condition involving avascular necrosis of the femoral head (Fig. 5) [1]. It typically presents in the first decade of life, and for unknown reasons predominates among males aged 4 to 8 years, with a gender ratio of 5:15 [1]. In the past 95 years, since it was first described by Legg, Calve, and Perthes, we have gained little insight into the etiology and pathophysiology of this complex condition.

Pathogenesis appears complex, and involves avascular necrosis, followed by resorption, collapse, and subsequent repair of the capital femoral epiphysis, resulting in impaired growth and development of the hip joint. The natural history of the disease is variable, and is largely dependant on the age of onset and the degree of femoral head involvement, but is also greatly influenced by intervention [1]. The younger a child is at the onset of the disease, the greater the time he has for subsequent growth and remodeling [1]. Moreover, in the long term, 50% of those who had childhood Perthes disease who did not receive treatment developed subsequent osteoarthritis in the fifth decade of life [1].

Femoral head biopsies from patients who had the disease have demonstrated lesions with varying degrees of necrosis and repair, indicating that repetitive injury to the circumflex arteries rather than a single traumatic event may be responsible for the pathological findings in Perthes disease [1]. Several hypotheses have been formulated to explain this hypovascularity. Two thrombophilic risk factors, factor-V Leiden mutation and anticardiolipin antibodies, which enhance intravascular clotting and increase blood viscosity, are significantly associated with the disease [1]. Also postulated is intermittent increases in intra-



Fig. 5. Frog pelvis radiograph demonstrating left hip Perthes disease.

capsular hip pressure, causing a tamponade effect and subsequent compression of the retinacular vessels as they course through the restricted intracapsular space [1]. Unfortunately, the literature remains conflicting, and there is a lack of evidence to support either of these hypotheses at present [1].

Perthes disease is specific to the hip joint, and typically presents as an insidious, unilateral, painless limp [1]. If pain is present, it is usually mild, is exacerbated by exercise, and is frequently referred to the knee. The most consistent examination findings include reduced internal rotation and abduction of the hip, and these are important prognostic indicators. In the early stages of the disease, this is attributable to muscle spasm and synovitis, whereas later on in the disease, bony impingement of the femoral head on the acetabulum results in restricted hip motion. The prevalence of bilateral cases reported in the literature ranges from 8% to 24%, and interestingly they are more common in girls [1]. Development and outcome of the disease in each hip appears to be an independent event, with endocrinological etiologies such as hypoparathyroidism or skeletal dysplasias playing a role [1].

A large number of radiological classification systems have been developed that attempt to stratify patients according to the severity of their disease, predict prognosis, and provide parameters for instituting treatment [1]. The two most commonly used classification systems include the Catterall classification, which defines four groups based on the involvement of the epiphysis (25%, 50%, 75%, or 100% involvement), and the Herring classification, which defines three groups according to the degree of collapse in the lateral epiphyseal pillar during the fragmentation stage. The Herring classification system is a more accurate predictor of long-term outcome.

The treatment of Perthes Disease remains highly controversial regarding conservative versus surgical intervention [1]. The primary goals of intervention include maintenance of hip motion, pain relief, and containment. At present there is a lack of conclusive data in the literature regarding the indications for and the benefits of specific treatment modalities, and as a result surgical intervention largely reflects the physician's personal preference. For patients who have severe disease, surgical intervention appears preferable to nonoperative treatment, because it improves the sphericity of the femoral head and provides greater acetabular coverage [1]. The two most common surgical methods for containment include the femoral varus osteotomy and the Salter innominate osteotomy.

Herring and colleagues, who devised the Herring lateral pillar classification system, conducted one of the largest studies on the topic to date, and concluded that patients over the age of 8 years at the time of onset that have a Herring classification of B or B/C border have a better outcome with surgical treatment (femoral osteotomy or innominate osteotomy) than they do with nonoperative treatment (brace treatment or range of motion exercises) [1]. Children that fit into group B and were less than 8 years old at the time of onset were shown to have favorable outcomes irrespective of treatment, whereas group C children of all ages frequently had poor outcomes regardless of treatment modality [1].

HIP ARTHROSCOPY IN CHILDREN AND ADOLESCENTS

Described originally by Burman in 1931 [2], arthroscopy of the hip has more recently become an established procedure [3–7]. Arthroscopic surgery of the hip may offer potential advantages over traditional open arthrotomy and surgical dislocation in terms of limited invasiveness and diminished morbidity. The most recognized indications for hip arthroscopy are for the management of labral tears [8–13] and loose bodies [9,14]; however, hip arthroscopy has been described for a variety of other hip disorders, including osteoarthritis [9], osteonecrosis [9], osteochondral fracture [15], chondral injury [9], hip dysplasia [16], septic arthritis [17–19], inflammatory arthritis [9,20], synovial chondromatosis [21,22], foreign bodies [23], ligamentum teres tears [24–26], and complications after total joint arthroplasty [27–30].

Most of the experience in hip arthroscopy has been with hip disorders in adults. The indications and results of hip arthroscopy in children and adolescents have been less well-characterized [15,20,31–36]. Pediatric hip conditions include Legg-Perthes disease, slipped capital femoral epiphysis, developmental dysplasia of the hip, septic arthritis, coxa vara, juvenile rheumatoid arthritis, and chondrolysis [1,37]. Gross [33] described his early experience with hip arthroscopy in patients who had congenital dislocation of the hip, Legg-Perthes disease, slipped capital femoral epiphysis, and neuropathic subluxation. Bowen and coworkers [15,34] described arthroscopic chondroplasty of unstable osteochondral lesions of the femoral head as sequelae after skeletal maturity in patients who had Legg-Perthes disease as children. Other indications in the pediatric population have included labral tears, loose bodies, chondral lesions, juvenile rheumatoid arthritis, and septic arthritis [20,31,32]. In a review of 24 hip arthroscopies performed in 21 patients ages 11 to 21 years old, Schindler and colleagues [35] concluded that hip arthroscopy was effective for synovial biopsy and loose body removal; however, as a diagnostic procedure, the arthroscopy failed to correlate with the presumptive cause of symptoms in 11 hips (46%).

The authors recently reviewed our results of hip arthroscopy in children and adolescents [37,38]. From January 2001 to March 2004, 164 hip arthroscopies in 129 patients were performed by the first author in the adolescent and young adult hip unit of Children's Hospital in Boston. Of these 164 procedures, 91 procedures were performed in 72 patients who were 18 years old and younger. Of these 91 procedures, 56 procedures in 44 patients had minimum 1-year follow-up. Two of these patients were lost to follow-up (follow-up rate: 95.5%). Thus, the study population included 54 hip arthroscopies in 42 patients.

Data collected included patients' demographics, indications for surgery, complications, and outcomes. Outcome was assessed preoperatively and postoperatively using the modified Harris hip score. The modified Harris hip score is a condition-specific outcome instrument that has been widely used after hip arthroscopy. The score assesses both pain (44 points) and function (47 points). Function is divided into domains of limp (11 points), support (11 points), distance walked (11 points), stairs (4 points), socks/shoes (4 points), sitting (5 points), and public transportation (1 point). The Harris hip score was modi-

fied from the original by the elimination of the 9 points for range of motion and deformity, because hip arthroscopy is principally indicated for pain and function. Thus, the modified Harris hip score is multiplied by 1.1 to give a total possible score of 100.

Mean patient age was 15.2 years old (range: 5.9–18.9 years old). Twenty eight patients were female (67%) and 14 patients were male (33%). Minimum follow-up was 1 year, with mean 17.4 month follow-up (range: 12.0–26.2 months).

Chief complaints were pain in 48 hips and catching or locking in 6 hips. All patients reported diminished hip function. Fifteen patients had undergone 17 previous operations, including pelvic osteotomy ($n=11$), femoral osteotomy ($n=5$), and in situ pinning ($n=1$). Indications for the 54 hip arthroscopies included isolated labral tears ($n=30$), Perthes disease ($n=8$), developmental dysplasia of the hip following prior periacetabular osteotomy ($n=8$) (Fig. 6), inflammatory arthritis ($n=3$), spondyloepiphyseal dysplasia ($n=2$), avascular necrosis ($n=1$), slipped capital femoral epiphysis ($n=1$), and osteochondral fracture ($n=1$). Specific procedures included debridement of labral tear ($n=41$), chondroplasty of acetabulum or femoral head ($n=10$), removal of loose bodies ($n=8$), synovectomy ($n=3$), and general debridement for degenerative changes ($n=2$). Some hip arthroscopies included multiple specific components. Staged bilateral procedures were performed in 9 patients. Revision procedures were performed in 3 patients who had recurrent labral tears. Concurrent procedures included iliotibial band release at the greater trochanter for snapping ($n=4$) and proximal femoral blade plate removal ($n=1$).

Overall, there was significant improvement in modified Harris hip score (preoperative: 53.1; postoperative: 82.9; $P<0.001$) (Table 1). For patients who had isolated labral tears ($n=30$), there was significant improvement in modified Harris hip score (preoperative: 57.6; postoperative: 89.2; $P<0.001$), and scores were improved in 26 of 30 procedures (see Table 1). For patients who had Perthes disease ($n=8$), there was significant improvement in modified Harris hip



Fig. 6. Full thickness cartilage loss (arrow) of the anterosuperior acetabulum in a patient with hip dysplasia after prior periacetabular osteotomy.

Table 1
Modified Harris hip score results by diagnosis

Diagnosis	n	Preoperative	Postoperative	P value
Overall	54	53.1 (7.3)	82.9 (8.1)	<0.001
Isolated labral tear	30	57.6 (7.2)	89.2 (8.5)	<0.001
Perthes disease	8	49.5 (7.7)	80.1 (7.9)	<0.001
Developmental dysplasia of the hip (after prior periacetabular osteotomy)	8	51.8 (8.1)	79.8 (8.9)	<0.001
Inflammatory arthritis	3	54.8 (7.0)	81.3 (8.2)	<0.001
Spondyloepiphyseal dysplasia	2	47.5	82.5	
Avascular necrosis	1	55	55	
Slipped capital femoral epiphysis	1	62	85	
Osteochondral fracture	1	29	96	

Values represent mean (standard deviation).

score (preoperative: 49.5; postoperative: 80.1; $P<0.001$), and scores were improved in all eight procedures (see Table 1). For patients who had labral tears with developmental dysplasia of the hip following prior periacetabular osteotomy ($n=8$), there was significant improvement in modified Harris hip score (preoperative: 51.8; postoperative: 79.8; $P<0.001$) and scores were improved in six of eight procedures (see Table 1). For the 2 patients who had Outerbridge grade 4 degenerative changes (full-thickness chondral loss), scores were not improved. For patients who had inflammatory arthritis ($n=3$), there was significant improvement in modified Harris hip score (preoperative: 54.8; postoperative: 81.3; $P<0.001$) and scores were improved in all three procedures (see Table 1). Preoperative and postoperative modified Harris hip scores for patients who had spondyloepiphyseal dysplasia ($n=2$), avascular necrosis ($n=1$), slipped femoral capital epiphysis ($n=1$), and osteochondral fracture ($n=1$) are shown in Table 1.

Complications included transient pudendal nerve palsy ($n=3$), instrument breakage ($n=1$), and recurrent labral tear ($n=3$). All three patients who had pudendal nerve palsies had paresthesia in the groin and scrotal/labial region that resolved spontaneously by 3 months postoperative. The case of instrument breakage involved shearing off of a flexible guide wire by a cannulated obturator upon insertion. The broken guide wire was retrieved arthroscopically. Two patients who had isolated labral tears and one patient who had developmental dysplasia of the hip following prior periacetabular osteotomy who had undergone arthroscopic debridement had recurrent labral tears (recurrent labral tear rate: $3/41=7.3\%$). All three patients had demonstrated improvement after their initial arthroscopic debridement, with recurrent symptoms developing 3 to 21 months after their index procedure. All three patients improved after repeat arthroscopy and labral tear debridement.

Thus, in reviewing the authors' results of hip arthroscopy in children and adolescents for a variety of diagnoses, it appears that hip arthroscopy was a safe procedure with few complications, and that it was efficacious in the short term for certain indications.

SPECIFIC INDICATIONS FOR HIP ARTHROSCOPY IN CHILDREN AND ADOLESCENTS

Developmental Dysplasia of the Hip

Intra-articular pathology is often associated with developmental dysplasia of the hip [1,37,39]. Hip dysplasia may present in adolescence or young adulthood as hip pain from a degenerative labral tear or chondral lesion (Fig. 7). Anterior labral tears may also occur as a result of anterior impingement from a post-slipped capital femoral epiphysis deformity or pistol-grip deformity [36,40–45]. Although favorable results have been reported from the arthroscopic management of intra-articular pathology in dysplastic hips [10], the authors' preferred approach is to address the underlying dysplasia with periacetabular osteotomy, with or without proximal femoral osteotomy [1,37]. After periacetabular osteotomy, some patients may present with increasing hip pain and mechanical symptoms caused by a degenerative labral tear. In the authors' series, we found improvement in symptoms with arthroscopic debridement in six of eight patients; however, the two patients who had full-thickness degenerative joint disease did not improve after arthroscopic debridement, questioning its efficacy in patients who have advanced degenerative joint disease.

Loose Bodies

Loose bodies of the hip may occur from traumatic injury or as a sequelae of hip disorders such as Legg-Perthes disease, spondyloepiphyseal dysplasia (see Fig. 7), chondrocalcinosis, or avascular necrosis. In patients who have Legg-Perthes disease, an unstable osteochondral fragment in the central portion of the femoral head may persist after the healing phase, particularly in patients who have a flattened, aspherical head. Patients may present with pain and mechanical symptoms such as catching or locking. The loose osteochondral lesions may be visible on radiographs, CT scan, or MRI. Arthroscopic excision has yielded

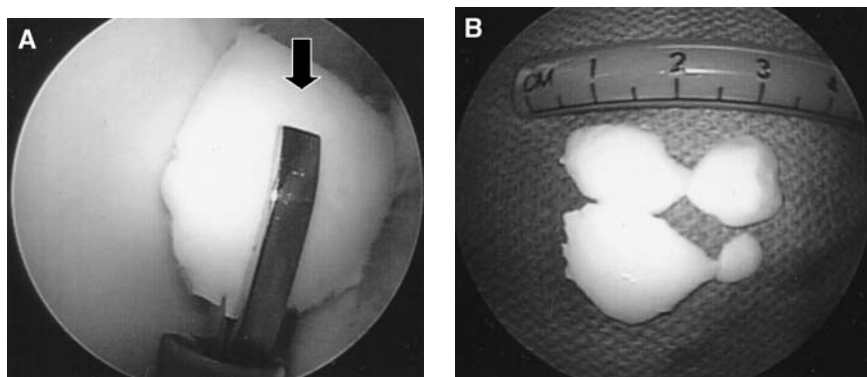


Fig. 7. Loose bodies associated with spondyloepiphyseal dysplasia. (A) Arthroscopic image of intra-articular loose body (arrow) held by grasper. (B) Multiple loose bodies after removal.

excellent results with minimal morbidity [9,14]. In the authors' series, loose bodies were associated with Legg-Perthes disease, spondyloepiphyseal dysplasia, and traumatic osteochondral fracture, and excision typically resulted in resolution of pain and mechanical symptoms during this period of follow-up; however, the longer-term prognosis in patients who have Legg-Perthes disease remains guarded if there is substantial asphericity of the femoral head [1,37].

Inflammatory Arthritis/Septic Arthritis

Arthroscopic synovectomy of the hip in cases of inflammatory arthritis has been suggested to improve pain and function [20]. In the cited series, three patients who had inflammatory arthritis underwent arthroscopic synovectomy for hip pain and dysfunction that was recalcitrant to medical therapy, and all three patients demonstrated improvement.

Arthroscopic irrigation and debridement of septic arthritis of the hip in children has been reported [17–19]. The authors' preference is for open arthrotomy through a limited anterior approach to the hip, because this allows for capsulectomy, drilling of the femoral neck to rule out associated osteomyelitis, thorough debridement of infected tissue, and placement of a drain.

Other Indications

Femoracetabular impingement is a condition that is being further developed and understood. Cam-type and pincer-type impingement can result in degenerative joint disease. Arthroscopic management of femoracetabular impingement has recently received attention.

Arthroscopy may potentially be used as an adjunct during closed reduction for hip dysplasia in infants. Arthroscopy may allow for the visualization of impediments to reduction, transection of the transverse acetabular ligament, and assessment of reduction.

SUMMARY

Hip arthroscopy offers potential advantages over traditional open arthrotomy and surgical dislocation in terms of limited invasiveness and diminished morbidity. Most of the experience in hip arthroscopy has been with hip disorders in adults. The indications and results of hip arthroscopy in children and adolescents have been less well-characterized. The pediatric hip has unique conditions, including Legg-Perthes disease, slipped capital femoral epiphysis, developmental dysplasia of the hip, septic arthritis, coxa vara, juvenile rheumatoid arthritis, and chondrolysis. Hip arthroscopy in children and adolescents may be efficacious for certain indications, including isolated labral tears, loose bodies and chondral flaps associated with Legg-Perthes diseases or spondyloepiphyseal dysplasia, labral tears associated with hip dysplasia after prior periacetabular osteotomy, and inflammatory arthritis. Further development of hip arthroscopy in children and adolescents is necessary to refine indications, evaluate longer-term results, and develop pediatric-specific instrumentation.

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The Role of Hip Arthroscopy in the Athletic Hip

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The arthroscope has been instrumental in the growing understanding of hip joint injuries in athletes. Until recently, sports-related hip injuries have received little attention. There are three reasons for this. First, perhaps hip injuries are less common than other joints. Second, investigative skills for the hip have been less sophisticated, including clinical assessment and imaging studies. Third, there have been fewer interventional methods available to treat the hip including both surgical techniques and conservative modalities. Thus, there has been little incentive to pursue this area when there were few treatment options available. Operative arthroscopy has revolutionized the management of athletic hip injuries. Numerous intraarticular disorders have been identified that previously went unrecognized and untreated. In the past, athletes were simply resigned to living within the constraints of their symptoms, often ending their competitive careers. This is a work in progress. Clinical assessment skills are improving; understanding of hip joint pathology and associated pathomechanics is evolving; and the interventional methods available continue to expand.

PATIENT SELECTION

In a study of athletes undergoing arthroscopy, 60% were treated for an average of 7 months before it was recognized that the joint was the source of their problems [1]. Most were initially diagnosed as various types of musculotendinous strains. Thus, it is prudent to include intraarticular pathology in the differential diagnosis when managing problems around the hip area. Extraarticular disorders may also coexist with intraarticular lesions.

Hip symptoms are most commonly referred to the anterior groin, and may radiate to the medial thigh. However, a very characteristic clinical feature that has been described is the “C-sign” [2]. A patient describing deep interior hip pain will often grip their hand above the greater trochanter with their thumb lying posteriorly and the fingers cupped within the anterior groin. Casually viewed, it may appear that they are describing lateral pain such as the iliotibial band or trochanteric bursa, but characteristically, they are reflecting pain within the hip joint.

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On examination, log rolling the leg back and forth is the most specific maneuver for hip pathology because this rotates only the femoral head in relation to the acetabulum and capsule, not stressing any of the surrounding neurovascular or musculotendinous structures. More sensitive examination maneuvers include forced flexion combined with internal rotation or abduction combined with external rotation. Flexion with internal rotation is sometimes referred to as the impingement test [3]. However, a joint irritated by a variety of conditions will typically be painful with this maneuver, and thus it is not specific for impingement alone. It is postulated that abduction with external rotation translates the femoral head anteriorly, exacerbating symptoms associated with the anterior labral pathology or subtle instability. These maneuvers may normally be uncomfortable, so it is important to compare the asymptomatic to the symptomatic side. Most important is not simply whether the maneuver is uncomfortable, but whether it recreates the type of pain that the athlete experiences with activities. Sometimes there may be an accompanying click or pop. These may be indicative of pathology, but often occur in normal hips.

Radiographs are an integral part of the assessment process. Subtle findings may be indicative of significant intraarticular pathology, and the bony morphology can be evaluated for variants such as dysplasia and impingement implicated in hip joint pathology. Conventional MRI is improving, but even high-resolution studies have up to a 42% false negative interpretation [4]. Also, even with imaging evidence of pathology, the clinician must determine whether these findings explain the athlete's symptoms. Gadolinium arthrography combined with MRI has a greater sensitivity. Along with the contrast, bupivacaine should always (!) be used as the injection diluent. Whether or not the athlete experiences significant pain relief from the anesthetic effect of the injection is the most reliable indicator of the presence of joint pathology.

TECHNIQUE

The hip joint has both an intraarticular and a peripheral compartment. Most hip pathology is found within the intraarticular region; therefore, distraction is necessary to achieve arthroscopic access. The patient can be placed supine or in the lateral decubitus position for performing the procedure [5,6]. Both techniques are equally effective; therefore, the choice is simply dependent on the surgeon's preference. An advantage of the supine approach is its simplicity in patient positioning, while the lateral approach may be preferable for severely obese patients.

Performing hip arthroscopy without traction has not been popular because it does not allow access to the intraarticular region [7]. However, it is now recognized that this method can be a useful adjunct to the traction technique [8]. Hip flexion relaxes the capsule and allows access to the peripheral compartment, which is intracapsular, but extraarticular. Numerous lesions are encountered in this area that are overlooked with traction alone, such as synovial disease and free-floating loose bodies. Femoral sided impingement



Fig. 1. The patient is positioned on the fracture table so that the perineal post is placed as far laterally as possible toward the surgical hip resting against the medial thigh. (From Byrd JWT. The supine approach. In: Byrd JWT, editor. *Operative hip arthroscopy*. 2nd edition. New York: Springer; 2005. p. 145–69; with permission.)

lesions (cam impingement) are best addressed from the peripheral compartment. Hip flexion also allows generous access to the capsule for plication or thermal modulation.

The technique illustrated is one with the patient in a supine position (Fig. 1). The important principles for performing safe, effective, reproducible arthroscopy are the same whether the patient is in the lateral decubitus or supine orientation. Portal placements, relationship of the extraarticular structures, and arthroscopic anatomy are also the same, regardless of positioning.

A standard fracture table or custom distraction device is needed to achieve effective joint space separation. A tensiometer can be helpful to monitor the traction forces intraoperatively. The C-arm is important for precise placement of the instrumentation within the joint.

The procedure is commonly performed under general anesthesia. It can be performed under epidural anesthesia but requires an adequate motor block to ensure optimal distractibility of the joint.

INTRAARTICULAR (CENTRAL) COMPARTMENT

The perineal post is heavily padded and lateralized against the medial thigh of the surgical hip. This aids in achieving the optimal traction vector (Fig. 2) and reduces direct pressure on the perineum, lessening the risk of neuropraxia of the pudendal nerve. Neutral rotation achieves a constant rela-

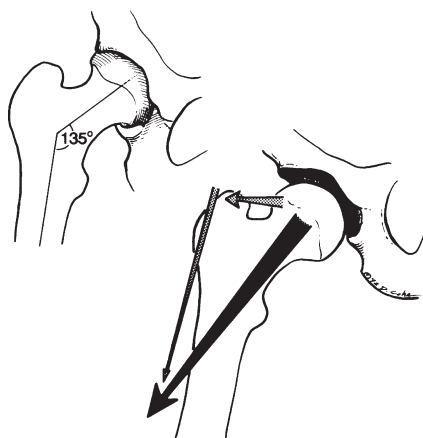


Fig. 2. The optimal vector for distraction is oblique relative to the axis of the body, and more closely coincides with the axis of the femoral neck than the femoral shaft. This oblique vector is partially created by abduction of the hip and partially accentuated by a small transverse component to the vector created by lateralizing the perineal post. (From Byrd JWT. The supine approach. In: Byrd JWT, editor. *Operative hip arthroscopy*. 2nd edition. New York: Springer; 2005. p. 145–69; with permission.)

tionship between topographic landmarks and the joint. Slight flexion may relax the capsule, but excessive flexion should be avoided, as this places undue tension on the sciatic nerve and may block access for the anterior portal. Approximately 50 pounds of force is typically needed to distract the joint. In general, the goal is to use the minimal force necessary to achieve adequate

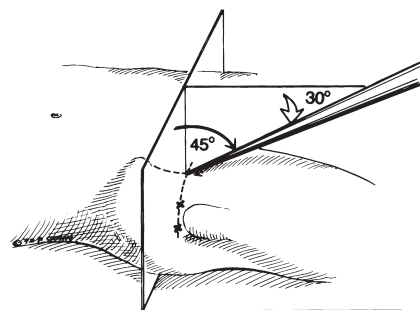


Fig. 3. The site of the anterior portal coincides with the intersection of a sagittal line drawn distally from the anterior superior iliac spine and a transverse line across the superior margin of the greater trochanter. The direction of this portal courses approximately 45° cephalad and 30° toward the midline. The anterolateral and posterolateral portals are positioned directly over the superior aspect of the trochanter at its anterior and posterior borders. (From Byrd JWT. *Hip arthroscopy using the supine position*. *Arthroscopy* 1994;10(3):275–80; with permission.)

distraction and keep traction time as brief as possible. (Less than 2 hours is usually considered optimal.)

PORTALS

Three standard portals are used for this portion of the procedure (Fig. 3). Two of these (anterolateral and posterolateral) are placed laterally over the superior margin of the greater trochanter at its anterior and posterior borders. The anterior portal is placed at the site of intersection of a sagittal line drawn distally from the anterior superior iliac spine and a transverse line across the tip of the greater trochanter. With careful orientation to the landmarks in relation to the joint, these portals are placed at a safe distance from the surrounding major neurovascular structures [9] (Fig. 4 and Table 1).

DIAGNOSTIC PROCEDURE

After applying traction, a spinal needle is placed from the anterolateral position, and the joint is distended with fluid. The anterolateral portal is then established under fluoroscopic control for introduction of the arthroscope (Fig. 5). Careful attention is necessary to avoid perforating the labrum or scuffing the articular surface [10]. Using the 70° scope, the anterior and posterolateral portals are then placed under direct arthroscopic view, as well as under fluoroscopy for precise

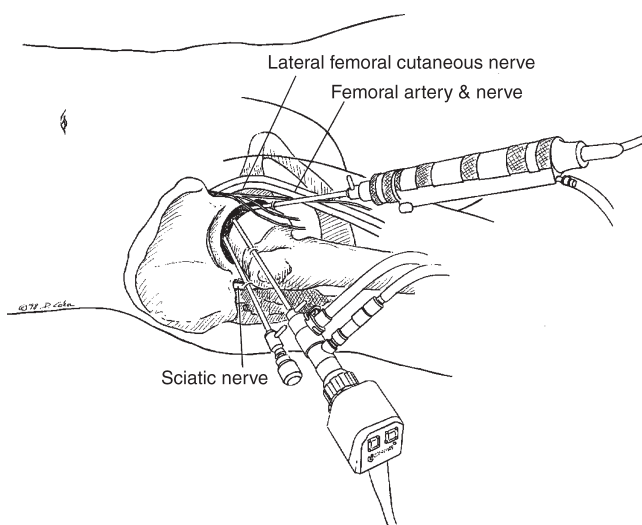


Fig. 4. The relationship of the major neurovascular structures to the three standard portals is demonstrated. The femoral artery and nerve lie well medial to the anterior portal. The sciatic nerve lies posterior to the posterolateral portal. Small branches of the lateral femoral cutaneous nerve lie close to the anterior portal. Injury to these is avoided by using proper technique in portal placement. The anterolateral portal is established first, as it lies most centrally in the safe zone for arthroscopy. (Courtesy of J.W. Thomas Byrd, MD.)

Table 1

Distance from portal to anatomic structures (based on an anatomic dissection of portal placements in eight fresh cadaver specimens)

Portals	Anatomic structure	Average (cm)	Range (cm)
Anterior	Anterior superior iliac spine	6.3	6.0–7.0
	^a Lateral femoral cutaneous nerve	0.3	0.2–1.0
	^b Femoral nerve (level of sartorius)	4.3	3.8–5.0
	(level of rectus femoris)	3.8	2.7–5.0
	(level of capsule)	3.7	2.9–5.0
	Ascending branch of lateral circumflex femoral artery	3.7	1.0–6.0
	^c Terminal branch	0.3	0.2–0.4
Anterolateral	Superior gluteal nerve	4.4	3.2–5.5
Posterolateral	Sciatic nerve	2.9	2.0–4.3

^a Nerve had divided into three or more branches and measurement was made to the closest branch.

^b Measurement made at superficial branch of sartorius, rectus femoris, and capsule.

^c Small terminal branch of ascending branch of lateral circumflex femoral artery identified in three specimens.

From Byrd JWT, Pappas JN, Pedley MJ. Hip arthroscopy: an anatomic study of portal placement and relationship to the extraarticular structures. *Arthroscopy* 1995;11:418–23; with permission.

entry into the joint. Diagnostic and surgical arthroscopy is then achieved by interchanging the arthroscope and instruments between the three established portals. Use of both the 70° and 30° scopes provides optimal viewing, despite limited maneuverability within the joint (Fig. 6).

PERIPHERAL COMPARTMENT

After completing arthroscopy of the intraarticular compartment, the instruments are removed, the traction released, and the hip flexed approximately 45° (Fig. 7). This relaxes the capsule, providing access to the peripheral compartment.

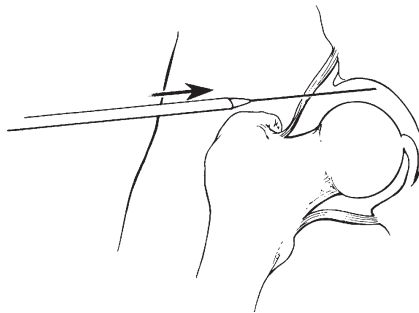


Fig. 5. The arthroscope cannula is passed over a guide wire that was inserted through a prepositioned spinal needle. Fluoroscopy aids in avoiding contact with the femoral head or perforating the acetabular labrum. (From Smith & Nephew Endoscopy, Andover, MA. Copyright Smith & Nephew, Inc. 2003–2004; with permission.)

Two portals are routinely used to access the peripheral compartment. These include the anterolateral portal and an ancillary portal established approximately 5 cm distally. The anterolateral portal is redirected onto the anterior neck of the femur (Fig. 8). The ancillary portal is then established distally under direct arthroscopic and fluoroscopic guidance (Fig. 9). The arthroscope and

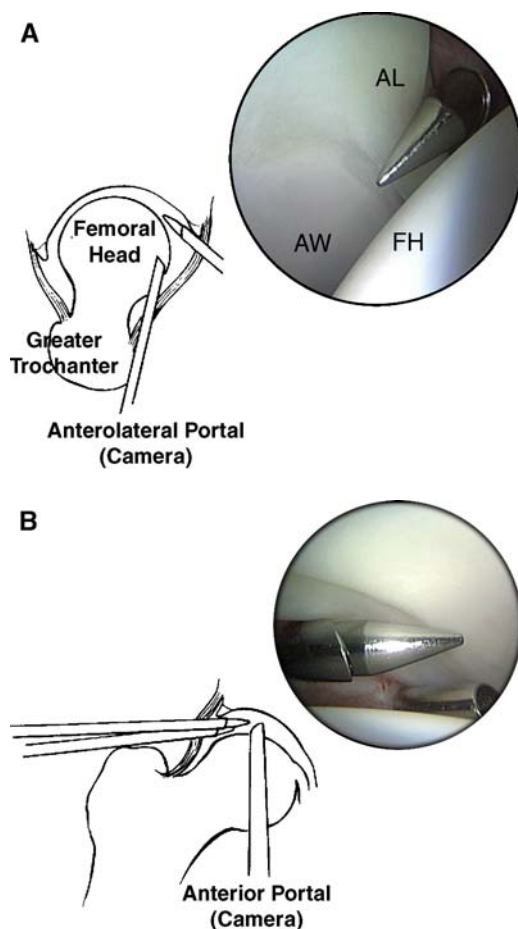


Fig. 6. (A) Arthroscopic view of a right hip from the anterolateral portal demonstrates the anterior acetabular wall (AW), anterior labrum (AL), and femoral head (FH). The anterior cannula is seen entering underneath the labrum. (B) Arthroscopic view from the anterior portal demonstrates the lateral aspect of the labrum (L) and its relationship to the lateral two portals. (C) Arthroscopic view from the posterolateral portal demonstrates the posterior acetabular wall (PW), posterior labrum (PL), and the femoral head (FH). (D) The acetabular fossa can be inspected from all three portals to view the ligamentum teres (LT) with its accompanying vessels traversing in a serpentine fashion from its more posteriorly placed acetabular attachment. (Line art from Smith & Nephew Endoscopy, Andover, MA. Copyright Smith & Nephew, Inc. 2003–2004; with permission. Arthroscopic images courtesy of J.W. Thomas Byrd, MD.)

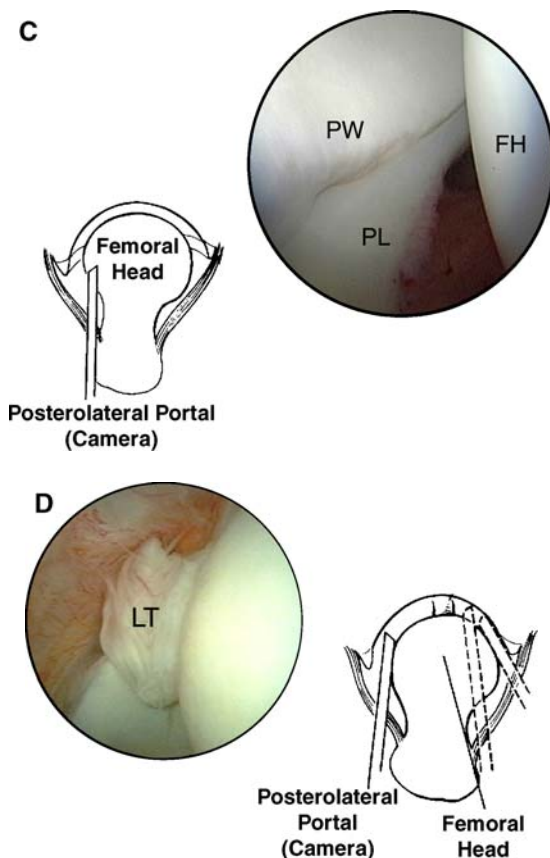


Fig. 6 (continued).

instruments are interchanged, and both the 30° and 70° scopes are used for inspection (Fig. 10).

ILIOPSOAS BURSOSCOPY

Flexion is slightly less (15° to 20°) than that used to view the peripheral compartment. The hip is also externally rotated, which moves the lesser trochanter more anterior and accessible to the portals.

Two portals are needed for viewing and instrumentation within the bursa (Fig. 11). These portals are distal to those used for the peripheral compartment and require fluoroscopy for precise positioning. These portals may be slightly more anterior to completely access the area of the lesser trochanter.

ILIOPSOAS RELEASE

The spinal needle is placed directly on the lesser trochanter under fluoroscopy. With the arthroscope introduced, a second portal is then established. Adhesions or



Fig. 7. The surgical area remains covered in sterile drapes while the traction is then released and the hip flexed 45°. (*Inset*) Illustrates position of the hip without the overlying drape. (Courtesy of J.W. Thomas Byrd, MD.)

fibrinous debris within the bursa may need to be debrided to achieve clear visualization (**Fig. 11**). Staying next to the bone avoids straying into the medial soft tissues. As the iliopsoas is identified, the tendinous portion can be released (**Fig. 12**).

TREATMENT

Loose bodies represent the clearest indication for hip arthroscopy (**Fig. 13**) [11–13]. Most problematic loose bodies reside in the intraarticular compartment

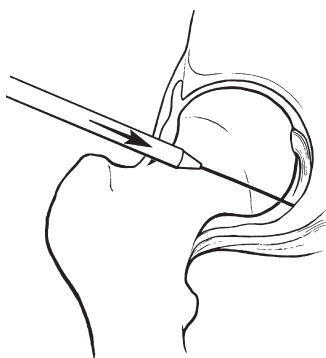


Fig. 8. From the anterolateral entry site, the arthroscope cannula is redirected over the guide wire through the anterior capsule, onto the neck of the femur. (From Smith & Nephew Endoscopy, Andover, MA, reprinted with permission. Copyright Smith & Nephew, Inc. 2003–2004; with permission.)

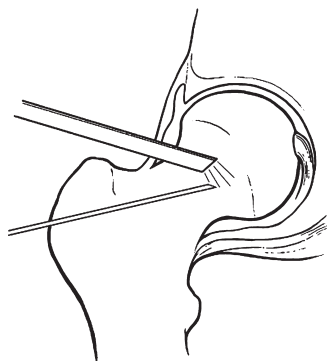


Fig. 9. With the arthroscope in place, prepositioning is performed with a spinal needle for placement of an ancillary portal distally. (From Smith & Nephew Endoscopy, Andover, MA. Copyright Smith & Nephew, Inc. 2003–2004; with permission.)

and are addressed with standard arthroscopic methods. However, many may remain hidden in the peripheral compartment and later become troublesome. Thus, arthroscopy to address symptomatic fragments must include both the intraarticular and peripheral joint [8]. Many can be debrided with shavers or flushed through large diameter cannulas. Large ones can sometimes be morselized and removed piecemeal. However, often fragments may be too large to be removed through a cannula system and must be removed free-hand with sturdy graspers. Once a portal tract has been developed, these larger graspers can be passed along the remaining tract into the joint in a free-hand fashion. Make sure to enlarge the capsular incision with an arthroscopic knife and the skin incision so that, as the fragment is retrieved, it will not be lost in the tissues either at the capsule or subcutaneous level.

Tearing of the acetabular labrum represents the most common pathology encountered among athletes undergoing hip arthroscopy [1]. MRI and magnetic resonance arthrogram (MRA) are improving at detecting these lesions. However, care is necessary in interpreting these studies. Labrum degeneration occurs naturally as part of the aging process [14,15]. Studies have shown evidence of labral pathology even among asymptomatic volunteers, and some tears among athletes have been noted to become clinically asymptomatic without surgery [16–18].

Traumatic labral tears may respond remarkably well to arthroscopic debridement (Fig. 14) [19–23]. However, at arthroscopy be especially cognizant of any underlying degeneration that may have predisposed to the acute tear. There will often be accompanying articular damage, and the extent of this may be a significant determinant on the eventual response to debridement (Fig. 15). Femoroacetabular impingement has been recognized as a distinct entity that can result in labral tearing, articular breakdown, and osteoarthritis [3]. Pincer impingement occurs from an overhanging lip of bone from the anterior ace-

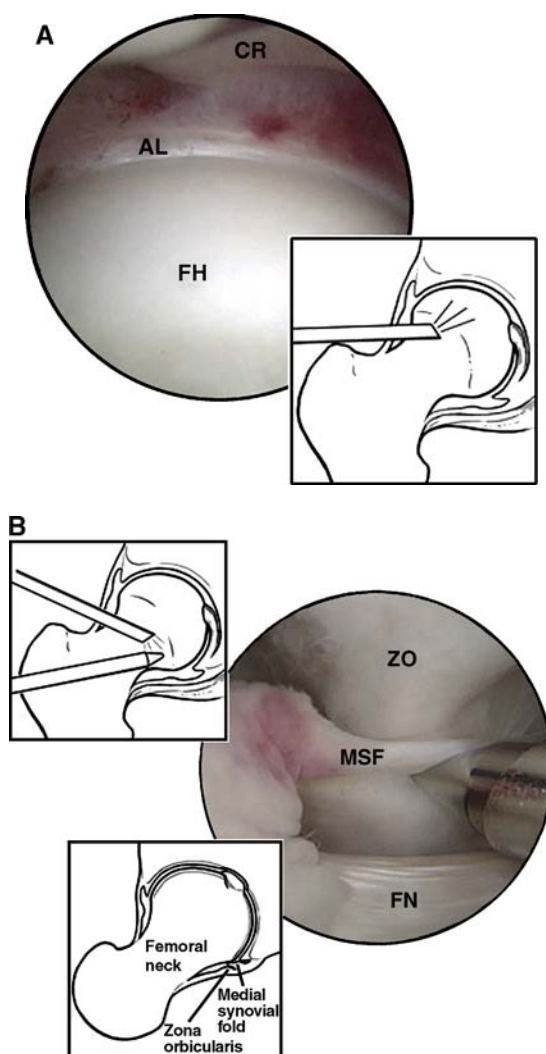


Fig. 10. (A) Peripheral compartment viewing superiorly demonstrates the anterior portion of the joint including the articular surface of the femoral head (FH), anterior labrum (AL), and the capsular reflection (CR). (B) Peripheral compartment viewing medially demonstrates the femoral neck (FN), medial synovial fold (MSF), and zona orbicularis (ZO). (Line art from Smith & Nephew Endoscopy, Andover, MA. Copyright Smith & Nephew, Inc. 2003–2004; with permission. Arthroscopic images courtesy of J.W. Thomas Byrd, MD.)

tabulum, and cam impingement occurs from a bony prominence of the anterior femoral head/neck junction. Traditionally, these have been resected with open surgical dislocation. These lesions can now be addressed arthroscopically in a much less invasive fashion [24,25]. This requires competent arthroscopic skills for the technically challenging aspects of this procedure (Fig. 16).

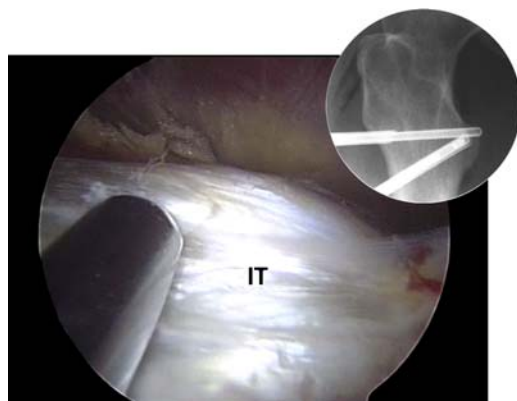


Fig. 11. The arthroscope and shaver are positioned within the iliopsoas bursa directly over the lesser trochanter, identifying the fibers of the iliopsoas tendon (IT) at its insertion site. (Courtesy of J.W. Thomas Byrd, MD.)

Labral tears can be adequately accessed through the three standard portals. Similar to a meniscus in the knee, the task is to remove unstable and diseased labrum creating a stable transition to retained healthy tissue. The most difficult aspect is creating the stable transition zone. Thermal devices have been quite useful at ablating unstable tissue adjacent to the healthy portion of the labrum. Caution is necessary because of the concerns regarding depth of heat penetration, but with judicious use, these devices have been exceptionally useful for precise labral debridement despite the constraints created by the architecture of the joint.

The natural evolution in arthroscopic management of labral pathology is from debridement to repair. Current methods of acetabular labral repair are in their infancy. A few have been attempted with mixed results. Reliable techniques exist



Fig. 12. An electrocautery device is used to transect the tendinous portion of the iliopsoas (black asterisks) revealing the underlying muscular portion (white asterisk) which is preserved. (Courtesy of J.W. Thomas Byrd, MD.)

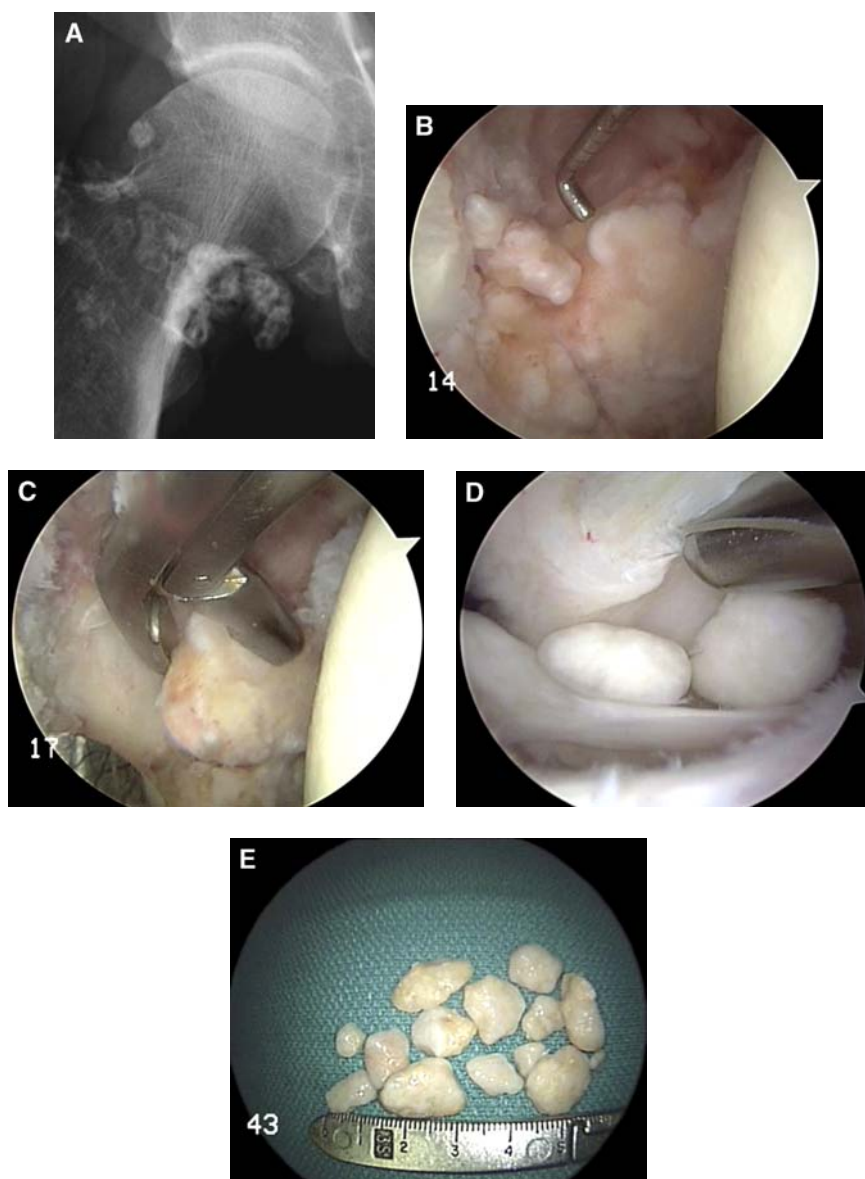


Fig. 13. A 54-year-old Hall of Fame baseball player with a several year history of insidious onset, progressively worsening mechanical right hip pain. (A) An AP radiograph shows evidence of synovial chondromatosis as well as secondary degenerative changes. (B) Arthroscopic view of the intraarticular compartment demonstrates numerous lesions obliterating the acetabular fossa. (C) These are morselized and excised. (D) The peripheral compartment reveals more free-floating loose bodies. (E) Whole fragments removed from the peripheral compartment. (Courtesy of J.W. Thomas Byrd, MD.)

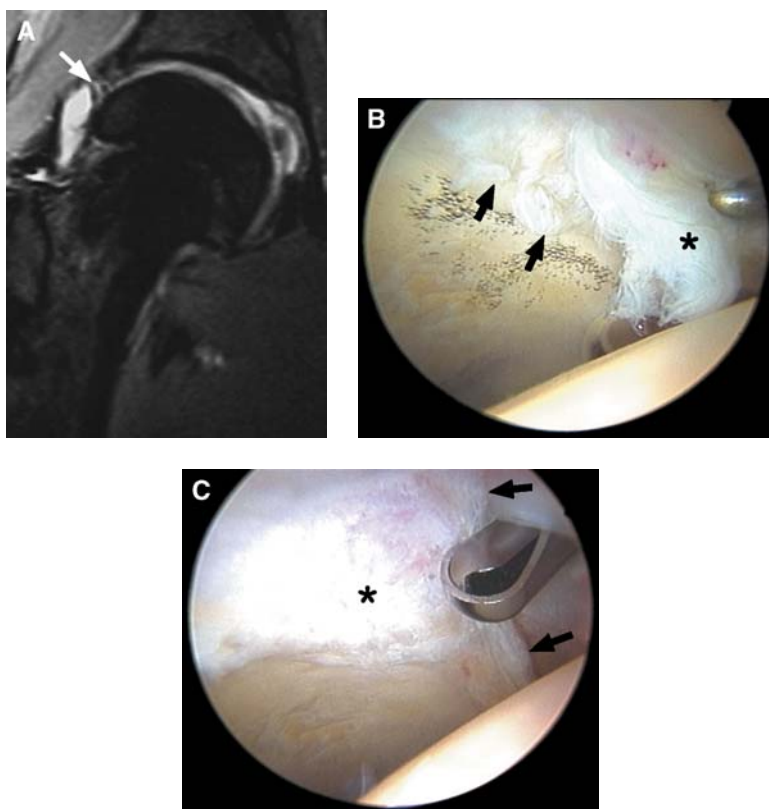


Fig. 14. A 25-year-old top-ranked professional tennis player sustained a twisting injury to his right hip. (A) Coronal MRI demonstrates evidence of labral pathology (*arrow*). (B) Arthroscopy reveals extensive tearing of the anterior labrum (*asterisk*) as well as an adjoining area of grade III articular fragmentation (*arrows*). (C) The labral tear has been resected to a stable rim (*arrows*) and chondroplasty of the grade III articular damage (*asterisk*) is being performed. (Courtesy of J.W. Thomas Byrd, MD.)

for repair, but much remains to be elucidated regarding our understanding of labral morphology and pathophysiology. There is considerable variation in the normal appearance of the labrum including a labral cleft at the articular labral junction, which can be quite large [19]. It is important to distinguish this from a traumatic detachment, which can also occur. Additionally, many labral tears, even in the presence of a significant history of injury, seem to occur due to some underlying predisposition or degeneration. Under these circumstances, even with reliable techniques, repair of a degenerated or morphologically vulnerable labrum would unlikely be successful.

A propensity for acute articular fracture has been identified in athletes due to lateral impact injury (Fig. 17 A–C) [26]. Subchondral edema of the femoral head may provide indirect evidence of this injury. Mechanical symptoms can be significantly improved with excision of the fragment. Articular delamination

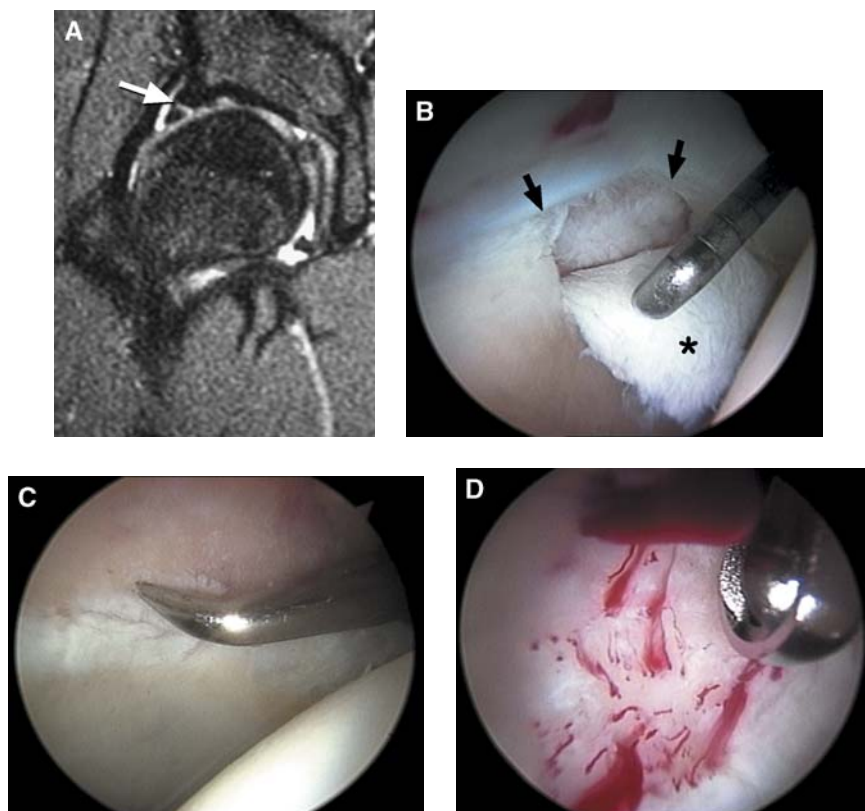


Fig. 15. A 23-year-old elite professional tennis player sustained an injury to his right hip. (A) Coronal MRI demonstrates evidence of labral pathology (arrow). (B) Arthroscopy reveals the labral tear (arrows), but also an area of adjoining grade IV articular loss (asterisk). (C) Microfracture of the exposed subchondral bone is performed. (D) Occluding the inflow of fluid confirms vascular access through the areas of perforation. The athlete was maintained on a protected weight-bearing status emphasizing range of motion for 10 weeks with return to competition at three and a half months. (Courtesy of J.W. Thomas Byrd, MD.)

of the anterior acetabulum is a characteristic arthroscopic finding associated with cam impingement, and should alert the surgeon to this condition (Fig. 18 A–G). Chondroplasty can be effectively performed for lesions of both the acetabular and femoral surfaces. Curved shaver blades are helpful for negotiating the constraints created by the convex surface of the femoral head. Due to limitations of maneuverability, thermal devices have again been especially helpful in ablating unstable fragments. However, cautious and judicious use around articular surface is even more important because of potential injury to surviving chondrocytes.

Microfracture of select grade IV articular lesions has been beneficial (Fig. 15) [23]. As with other joints, it is best indicated for focal lesions with healthy surrounding articular surface. The lesion most amenable to this process is encoun-

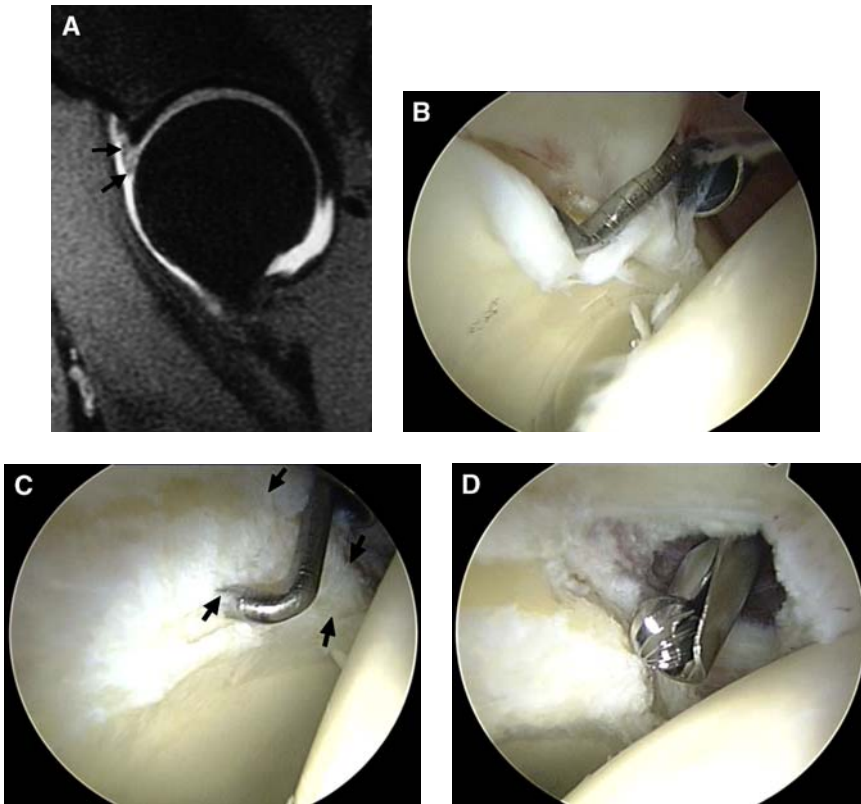


Fig. 16. A 16-year-old high school football player develops acute onset of right hip pain doing squats. (A) Sagittal image MR arthrogram demonstrates a macerated anterior labrum (arrows). (B) Viewing from the anterolateral portal, a macerated tear of the anterior labrum is probed along with articular delamination at its junction with the labrum. (C) The damaged anterior labrum has been excised, revealing an overhanging lip of impinging bone from the anterior acetabulum. (D) Excision of the impinging portion of the acetabulum (acetabuloplasty) is performed with a burr. (Courtesy of J.W. Thomas Byrd, MD.)

tered in the lateral aspect of the acetabulum. This is followed by 8 to 10 weeks of protected weight bearing to neutralize the forces across the hip joint while emphasizing range of motion. Using this protocol, among a cohort of 24 patients, 86% demonstrated a successful outcome at a 2- to 5-year follow-up [27].

Injury to the ligamentum teres is increasingly recognized as a source of hip pain in athletes (Fig. 19) [1]. The disrupted fibers catch within the joint and can be quite symptomatic. This disruption may be the result of trauma, degeneration, or a combination of both [28]. The tear may be partial or complete, with the goal of treatment being to debride the entrapping, disrupted fibers. A recent report by these authors documented excellent success in the arthroscopic management of traumatic lesions of the ligamentum teres. The average improvement

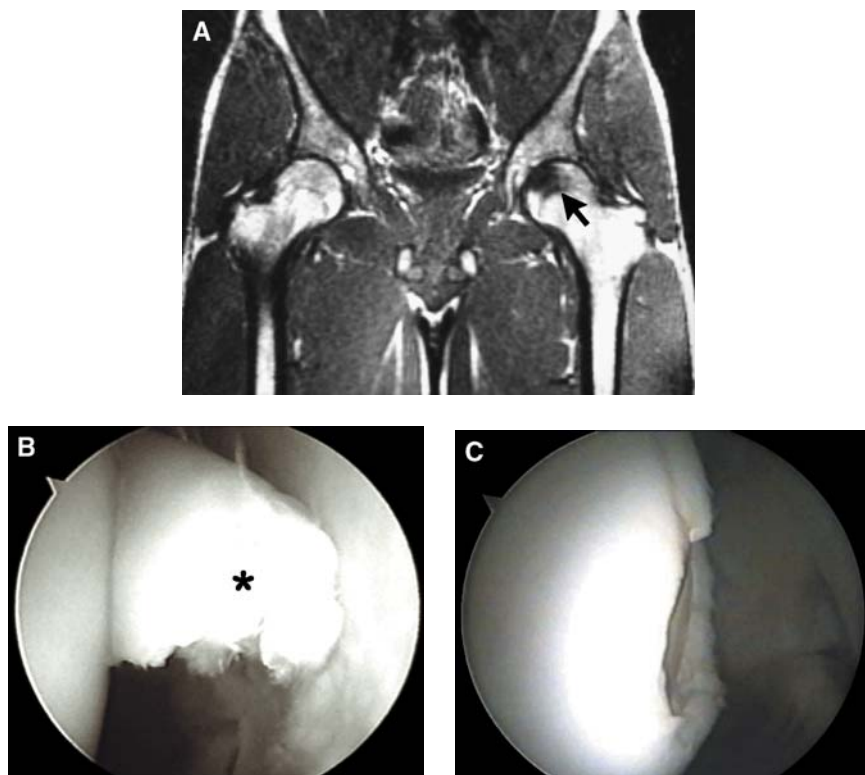


Fig. 17. A 20-year-old male collegiate basketball player with painful catching of the left hip following a fall with lateral impaction of the joint. (A) MRI revealed extensive signal changes in the medial aspect of the femoral head characterizing the subchondral injury associated with his fall. (B) A full-thickness chondral flap lesion (*) associated with the injury is identified. (C) The unstable portion has been excised. (From Byrd JWT. Hip arthroscopy in athletes. In: Byrd JWT, editor. Operative hip arthroscopy. 2nd edition. New York: Springer; 2005. p. 195–203; with permission.)

was 47 points (100-point modified Harris Hip score system) with 93% showing marked (>20 points) improvement [29].

The acetabular attachment of the ligamentum teres is situated posteriorly at the inferior margin of the acetabular fossa and attaches on the femoral head at the fovea capitis. The disrupted portion of the ligament is avascular, but the fat pad and synovium contained in the superior portion of the fossa can be quite vascular. Debridement is facilitated by a complement of curved shaver blades and a thermal device. The disrupted portion of the ligament is unstable and delivered by suction into the shaver. A thermal device can also ablate tissue while maintaining hemostasis within the vascular pulvinar.

Access to this inferomedial portion of the joint is best accomplished from the anterior portal. External rotation of the hip also helps in delivering the ligament

to the shaver brought in anteriorly. The most posterior portion of the fossa and the acetabular attachment of the ligament may be best accessed from the posterolateral portal. Indiscriminate debridement of the ligamentum teres should be avoided because of its potential contribution to the vascularity of the femoral head.

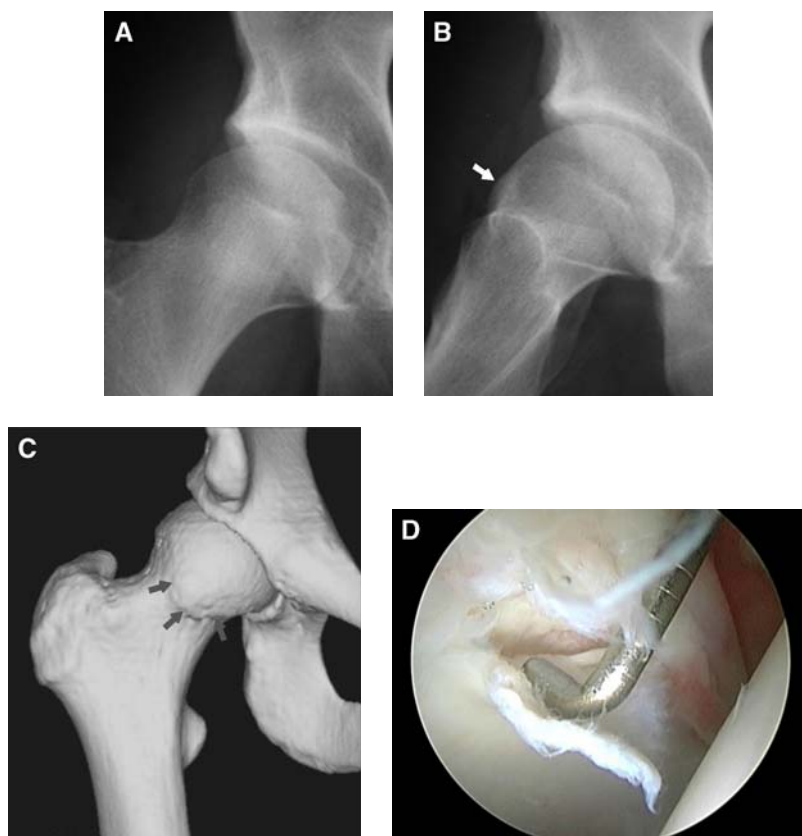


Fig. 18. A 20-year-old hockey player with a 4-year history of right hip pain. (A) AP radiograph is unremarkable. (B) Frog lateral radiograph demonstrates a morphological variant with bony buildup at the anterior femoral head/neck junction (arrow) characteristic of cam impingement. (C) A 3D CT scan further defines the extent of the bony lesion (arrows). (D) Viewing from the anterolateral portal, the probe introduced anteriorly displaces an area of articular delamination from the anterolateral acetabulum characteristic of the peel-back phenomenon created by the bony lesion shearing the articular surface during hip flexion. (E) Viewing from the peripheral compartment the bony lesion is identified (*) immediately below the free edge of the acetabular labrum (L). (F) The lesion has been excised, recreating the normal concave relationship of the femoral head/neck junction immediately adjacent to the articular surface (arrows). Posteriorly, resection is limited to the mid portion of the lateral neck to avoid compromising blood supply to the femoral head from the lateral retinacular vessels. (G) Postoperative 3D CT scan illustrates the extent of bony resection. (Courtesy of J.W. Thomas Byrd, MD.)

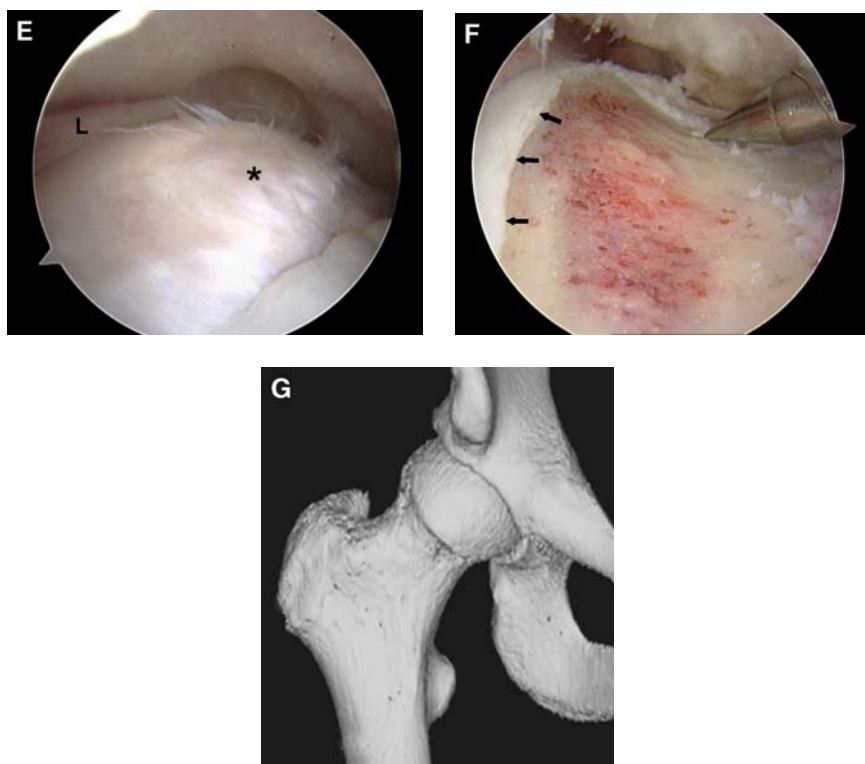


Fig. 18 (continued).

Primary synovial disease may be encountered in athletes, but more often synovial proliferation occurs in response to other intraarticular pathology. Synovitis may be diffuse, encompassing the lining of the joint capsule or be focal, emanating from the pulvinar of the acetabular fossa. Focal lesions within the fossa may be dense and fibrotic or exhibit proliferative villous characteristics. Presumably, because of entrapment within the joint, these lesions can be quite painful, and respond remarkably well to simple debridement. Although a complete synovectomy cannot be performed, a generous subtotal synovectomy can be performed. Enlarging the capsular incisions with an arthroscopic knife improves maneuverability within the intraarticular portion of the joint. For most synovial disease, arthroscopy of the peripheral compartment is necessary to adequately resect the diseased tissue [8,24].

In the presence of clinical evidence of arthritis, there will be arthroscopic evidence of various pathology including free fragments, labral tearing, articular damage, and synovial disease. With a meticulous systematic approach, each component can be addressed arthroscopically. Ultimately, with a well-performed procedure, the response to treatment will be mostly dictated by the extent of pathology, much of which cannot be reversed [30–33].

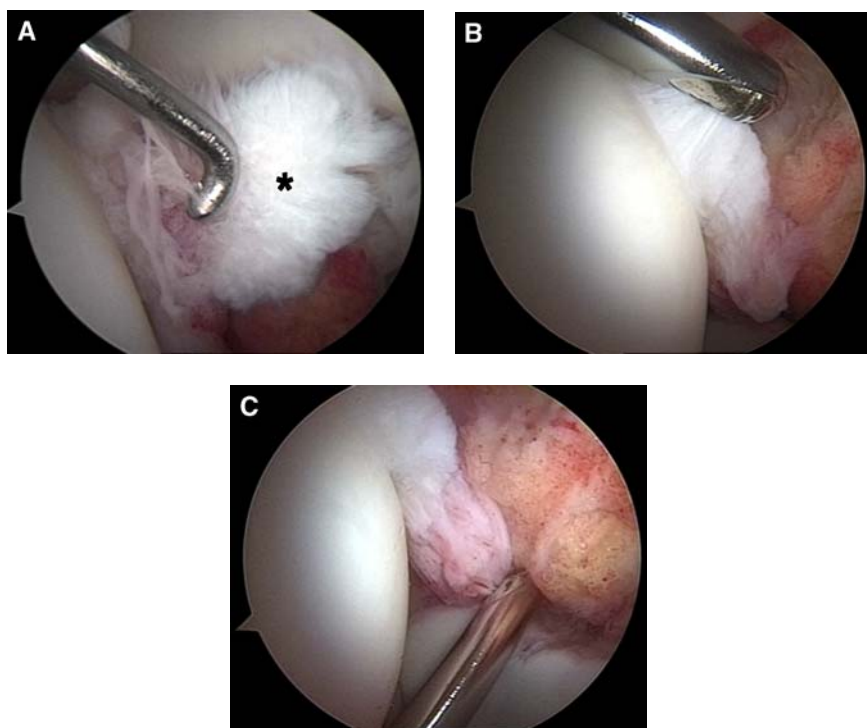


Fig. 19. A 16-year-old cheerleader has a 2-year history of catching and locking of the left hip following a twisting injury. (A) Arthroscopic view from the anterolateral portal reveals disruption of the ligamentum teres (*asterisk*). (B) Debridement is begun with a synovial resector introduced from the anterior portal. (C) The acetabular attachment of the ligamentum teres in the posterior aspect of the fossa is addressed from the posterolateral portal. (From Byrd JWT, Jones KS. Traumatic rupture of the ligamentum teres as a source of hip pain. *Arthroscopy* 2004;20(4):385–91; with permission.)

Posttraumatic impinging bone fragments, occasionally encountered in an active athletic population, may respond well to arthroscopic excision [34,35]. Degenerative osteophytes rarely benefit from arthroscopic excision as the symptoms are usually more associated with the extent of joint deterioration and not simply the radiographically evident osteophytes that secondarily form. However, the posttraumatic type may impinge on the joint, causing pain and blocking motion. These fragments are often extracapsular and require a capsulotomy extending the dissection outside the joint for excision (Fig. 20). This necessitates thorough knowledge and careful orientation of the extraarticular anatomy and excellent visualization at all times during the procedure. In general, the dissection should stay directly on the bone fragments and avoid straying into the surrounding soft tissues. Various techniques aid in maintaining optimal visualization. A high flow pump is especially helpful, maintaining a high flow rate without excessive pressure, which would worsen extravasation.

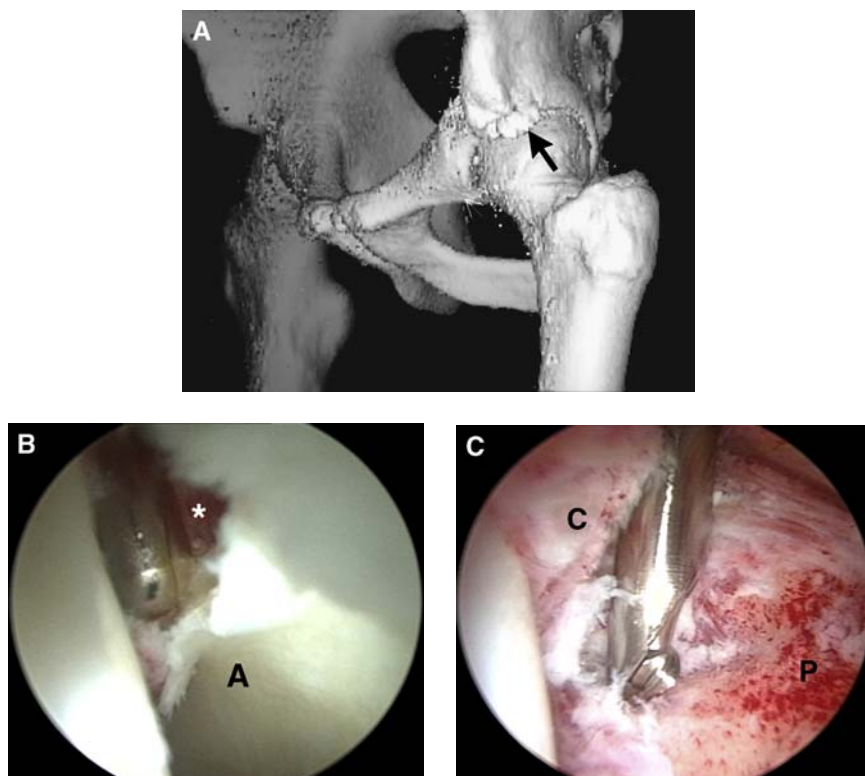


Fig. 20. An 18-year-old high school football player sustained an avulsion fracture of the left anterior inferior iliac spine. (A) A 3D CT scan illustrates the avulsed fragment (arrow) which ossified, creating an impinging painful block to flexion and internal rotation. (B) Viewing from the anterolateral portal, a capsular window is created, exposing the osteophyte (asterisk) anterior to the acetabulum (A). (C) The anterior capsule (C) has been completely released allowing resection of the fragment along the anterior column of the pelvis (P). Postoperatively, the patient regained full range of motion with resolution of his pain. (Courtesy of J.W. Thomas Byrd, MD.)

Hypotensive anesthesia, placing epinephrine in the arthroscopic fluid and electrocautery or other thermal device for hemostasis all aid in visualization for effectively performing the excision.

Hip instability can occur, but is much less common than seen in the shoulder. There are several reasons but, most principally, this is due to the inherent stability provided by the constrained ball-and-socket bony architecture of the joint. Also, the labrum is not as critical to stability of the hip as it is in the shoulder as there is no true capsulolabral complex. On the acetabular side, the capsule attaches directly to the bone, separate from the acetabular labrum [14]. An entrapped labrum has been reported as a cause of an irreducible posterior dislocation, and a Bankart type detachment of the posterior labrum has been identified as the cause of recurrent posterior instability [36,37]. These cir-

cumstances have only rarely been reported, but may be recognized with increasing frequency as our understanding and intervention of hip injuries evolves.

Instability may occur simply due to an incompetent capsule. This is seen in hyperlaxity states and less often encountered in athletics. The most common cause is a collagen vascular disorder such as Ehlers-Danlos syndrome. With normal joint geometry, thermal capsular shrinkage has continued to meet with successful results (Fig. 21). If subluxation or symptomatic instability is due to a

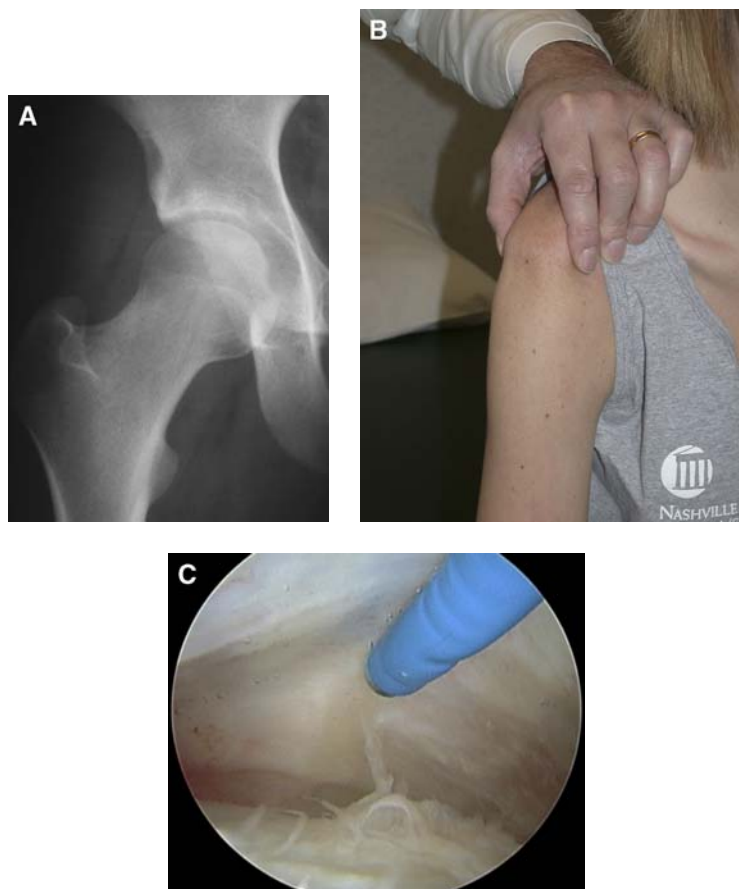


Fig. 21. A 19-year-old female had undergone two previous arthroscopic procedures on her right hip for reported lesions of the ligamentum teres. Following each procedure, she developed recurrent symptoms of “giving way.” (A) Radiographs revealed normal joint geometry. (B) She was noted to have severe diffuse physiologic laxity best characterized by a markedly positive sulcus sign. (C) With objective evidence of laxity and subjective symptoms of instability, an arthroscopic thermal capsulorrhaphy was performed, accessing the redundant anterior capsule from the peripheral compartment. Modulation of the capsular response was controlled by a hip spica brace for 8 weeks postoperatively with a successful outcome. (Courtesy of J.W. Thomas Byrd, MD.)

dysplastic joint, it is likely that bony correction for containment is necessary to achieve stability.

Based on this author's observations, we have found that posterior instability is associated with macrotrauma. This is due to the characteristic mechanisms of injury, including dashboard injuries and axial loading of the flexed hip encountered in collision sports. Atraumatic instability, or instability due to repetitive microtrauma, is anterior and develops when the normally occurring anterior translation of the femoral head exceeds the physiologic threshold and becomes pathologic. Symptoms may be due to primary instability or secondary intra-articular damage, or a combination of both.

SUMMARY

Hip joint problems in the athlete can be disabling, yet remain elusive to investigation. The arthroscope has proved essential in both the detection and treatment of many of these disorders. Less invasive methods with quicker return to safe competition has been a *sine qua non* of sports medicine. The incentive to return motivated athletes to a sport has proven fertile ground for advancement of arthroscopic techniques. This has been especially exemplified in the rapidly evolving field of hip arthroscopy, and has allowed these methodologies to find application in the management of patients of all levels of activity. As has been stated, the athletic field of competition represents one of the most fertile clinical laboratories in the world.

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Labral Tears, Extra-articular Injuries, and Hip Arthroscopy in the Athlete

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The incidence of labral tears in high-demand athletes is increasing as awareness and knowledge of these injuries expands. Hip injuries can be divided into intra-articular and extra-articular injuries. These injuries can also coexist. The question of whether an injury is of intra-articular versus extra-articular etiology after insidious onset of hip pain can be challenging to the sports medicine practitioner.

Extra-articular hip injuries are usually the result of overuse activity leading to inflammation, tendonitis, and bursitis. Extra-articular hip disorders may also arise from secondary compensation to intra-articular hip pathology.

Athletic hip injuries leading to disabling intra-articular hip pain most commonly involve labral tears [1,2]. Labral tears in the athletic population can occur from an isolated traumatic event or from repetitive trauma [2]. Structural abnormalities of the hip joint may also place athletes at higher risk for labral pathology. It is uncommon to have isolated labral tears, and they are usually associated with other intra-articular injuries [3]. In this article, identifying labral tears and associated lesions in the hip, arthroscopic management of these injuries, and return to sport are highlighted. Arthroscopic intervention for extra-articular hip injuries is also discussed.

LABRUM ANATOMY

The hip joint is a ball and socket joint enveloped in dense capsular tissue. The Y-shaped triradiate cartilage acetabulum covers 170° of the femoral head [3]. The acetabular labrum is a fibrocartilaginous structure that outlines the acetabular socket. Labral attachment occurs at the periphery of the labrum to the capsule, and is anchored anteriorly and posteriorly at the acetabular transverse ligament. The posterior labrum has a sulcus that can be mistaken for pathology (Fig. 1). Its free margin articulates with the articular surface. The thickness of the labrum and its morphology may slightly vary, but it is from 2 to 3 mm thick, and extends 2 to 3 mm past the acetabular socket. Neuroreceptors have been identified and may provide proprioception to the hip joint [4]. This may explain

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Fig. 1. Arthroscopic view of posterior labrum and a normal sulcus.

the decrease in proprioception and pain with labral tears. Kelly and colleagues [5] have shown a limited blood supply to the periphery of the labrum (Fig. 2), demonstrating the healing potential for detached labral tears with arthroscopic labral repair. The labrum has been shown to provide secondary stability to the bony constrained hip joint. The intact labrum has been shown to have a sealant effect on the hip joint that maintains fluid for articular cartilage [6–8].

Ferguson and coworkers [6–8] have shown increased cartilage surface consolidation with deficient labral tissue, and demonstrated the role of the labrum in resisting lateral and vertical motion of the femoral head within the acetabulum.

LABRAL TEARS

The etiology for labral tears can be from traumatic and degenerative causes, structural abnormalities from femoroacetabular impingement (cam and pincer

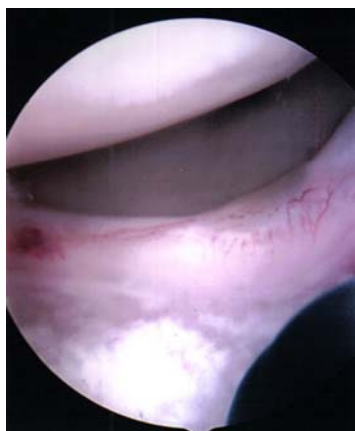


Fig. 2. Limited blood supply to the labrum at the labrocapsular junction. Arthroscopic view of a hyperemic labrum.



Fig. 3. Arthroscopic view showing degenerative changes within the labrum.

type lesions) [9], developmental abnormalities from dysplasia, old slip epiphysis and Perthes disease [9], and hip instability [10].

Traumatic tears in athletes can occur from an isolated event, or more commonly from repetitive trauma [2]. Traumatic hip dislocations are also susceptible to labral tears. Acetabular fractures that occurred from football injuries have also been associated with labral tears [2,11]. Acetabular labral tearing from repetitive trauma during sport-specific activity has been demonstrated [11,12]. Hip injuries in golfers from repetitive golf swing show anterior labral tears with delamination of the adjacent cartilage [12].

Degenerative labral tears (Fig. 3) in the athletic population can be the result of wear-and-tear injuries, and may be associated with degenerative changes of the hip joint. These types of tears can cause mechanical symptoms during athletic participation.

Labral tears can also be caused by structural abnormalities of the hip joint, leading to abnormal loading of and irritation to the labrum and adjacent

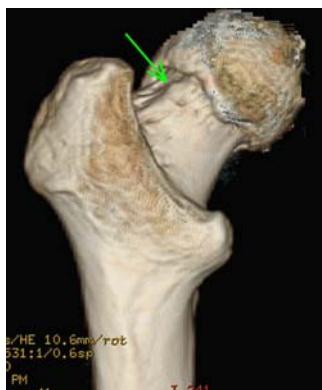


Fig. 4. Three-dimensional CT scan image of the femoral head and neck junction. The arrow points to the bump deformity.

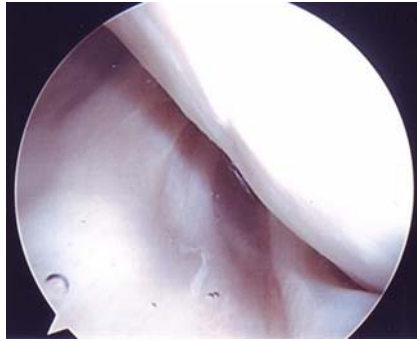


Fig. 5. 27-year-old female marathon runner with displaced anterior labral tear. Assessing head-neck junction in peripheral compartment.

cartilage. Sport activity and injury can enhance this irritation and lead to eventual tearing of the acetabular labrum and thinning of the adjacent cartilage [9]. The concept of femoroacetabular impingement has been developed to describe this phenomenon [13]. Cam-type impingement occurs from loss of femoral neck offset (Fig. 4), leading to abnormal contact during flexion and internal rotation. Pincer-type impingement is the result of a retroverted acetabulum creating an anterior wall overhang [13]. Both types of impingement can occur in combination [13]. The labrum is encountered first during contact with both types of impingement (Fig. 5). Continued insult to the labrum, initially in the anterolateral zone, can lead to bruising (Fig. 6) and give the labrum a short, round appearance [9]. Eventually tearing can occur with detachment from the acetabular rim and direct chondral injury. Repetitive activity, as seen in golfers [12] and martial arts practitioners, can lead to bruising and tearing of the labrum. Articular lesions on the posteromedial load zone of the acetabulum



Fig. 6. 19-year-old male hockey player with femoroacetabular impingement, with arthroscopic view showing bruised anterior labrum.

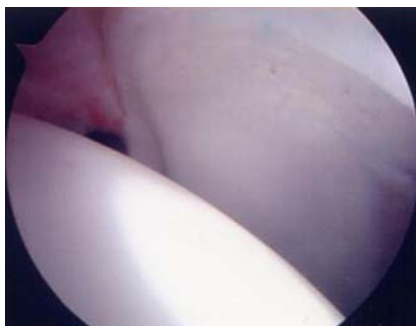


Fig. 7. Hypertrophied anterior labrum in a patient with mild hip dysplasia.

result from anterior impingement and leverage of the head posteromedial into the acetabulum [9]. This process may lead to arthrosis of the hip joint.

Developmental abnormalities such as developmental dysplasia, Perthes, and old slipped capital femoral epiphysis (SCFE) can lead to abnormal contact of the labrum [9]. Mild hip dysplasia has been identified in athletes who have labral tears [2,11]. A hypertrophied labrum (Fig. 7) may also be seen during arthroscopic evaluation of the dysplastic hip.

Hip instability in athletes has been attributed to capsular laxity from either acquired or traumatic etiology. Capsular elongation, particularly at the level of iliofemoral ligament (capsular ligament), can create increased stress and pathology to the labrum [10]. Labral tears can also cause capsular redundancy and affect hip stability.

CLASSIFICATION OF LABRAL TEARS

Labral tears in athletes have been demonstrated to occur mainly anterior-superior, but can also occur in conjunction with posterior tears [11]. Labral tears are characterized by their location and by their morphology. Labral tears

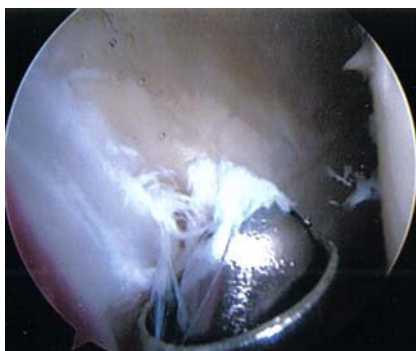


Fig. 8. Fibrillations of posterior labral tear.

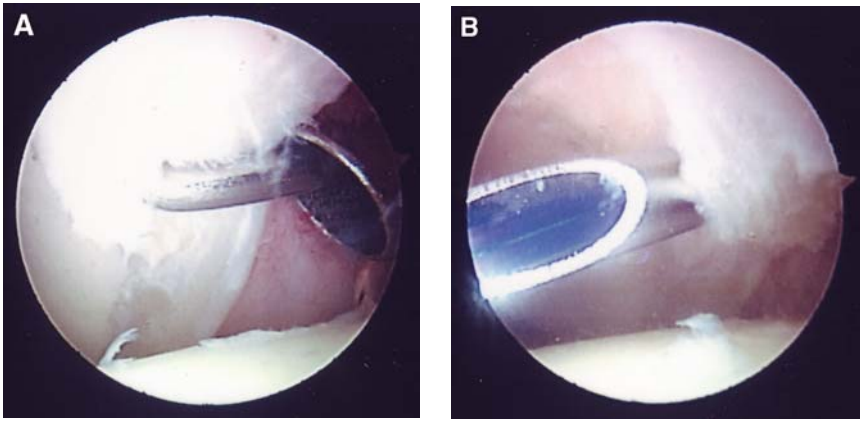


Fig. 9. (A) Probing the displaced anterior labral tear. (B) Reattaching displaced labral tear to the acetabular rim with bioabsorbable suture anchor.

have been classified morphologically as: radial flap, radial fibrillated, and longitudinal peripheral and unstable tears (Fig. 8) [14]. Labral tears have also been classified based on histologic analysis of cadaveric specimens [15]. Type 1 labral tear is a detached labrum with displacement from the fibrocartilaginous labrum-cartilage junction (Fig. 9) [15]. Type 2 labral tear involves intrasubstance tears with variable depth [15].

ASSOCIATED INTRA-ARTICULAR INJURIES

The most common associated lesions with labral tears in athletes are chondral injuries [2]. These injuries are usually adjacent to the labral pathology [2,11,12]. Chondral changes include chondromalacia, thinning of the cartilage, delamination of the cartilage, chondral flap tears (Fig. 10), and full-thickness chondral



Fig. 10. Posterior acetabular chondral flap tear.

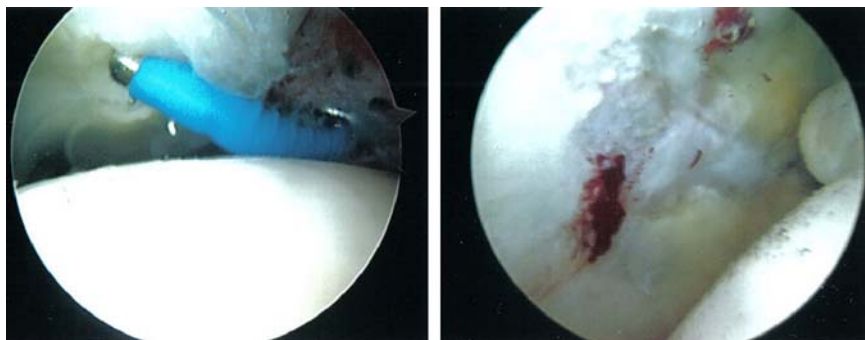


Fig. 11. Grade IV chondral lesion adjacent to anterior labral tear.

injury with exposed bone (Fig. 11). Lateral impaction injuries seen with football injuries have been reported [16].

Ligamentum teres in conjunction with labral tears has been reported [11]. The ligamentum teres is attached from the acetabular fossa to the fovea capitis and has both anterior and posterior bundles. Partial ligamentum teres tears (Fig. 12) have been described by Rao and colleagues [17]. This ligament tightens in external rotation, and may have a secondary stabilizer role with labral deficiency [17]. Displaced ligamentum teres tears can cause impingement with hip flexion (Fig. 13).

Synovitis can occur with labral tears in athletes. Capsular inflammation can be visualized adjacent to the labral tear (Fig. 14).

Potential loose bodies, particularly in known traumatic injuries, should be evaluated in both the central and peripheral compartments (Fig. 15) [11,18]. The

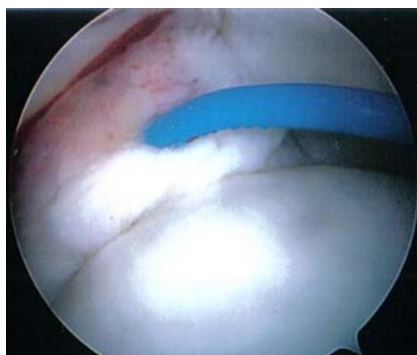


Fig. 12. Ligamentum teres tear being debrided with an RF probe.



Fig. 13. Ligamentum teres tear causing anterior impingement.

presence of multiple loose bodies, however, should be considered for synovial chondromatosis [19].

EXAMINATION FINDINGS

A detailed history of the onset of symptoms—traumatic event or insidious onset of symptoms—and the level of athletic participation before and after injury should be elicited from the athlete. An assessment of possible referred hip pain from low back pain or abdominal or gynecologic disorders should also be considered. Risk factors for avascular necrosis (AVN) and stress fractures should be obtained in the history as well. Mechanical symptoms of the hip related to a single traumatic event or from repetitive trauma from athletic activity may be exacerbated by athletic participation and daily activities. Physical findings of a labral tear may include an abnormal gait with shortened stance phase; reproducible groin pain elicited with forced flexion/adduction and internal rotation (impingement test) [9] or flexion/abduction and external rotation test, and limitations of terminal motion of the hip. Plain radiographs that include

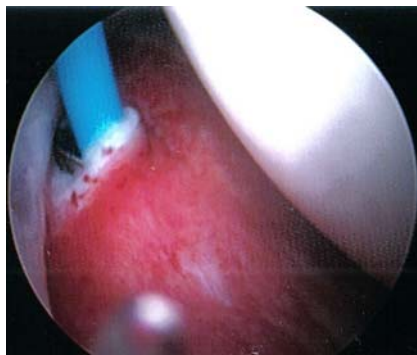


Fig. 14. Synovitis with capsular laxity after traumatic posterior hip dislocation.

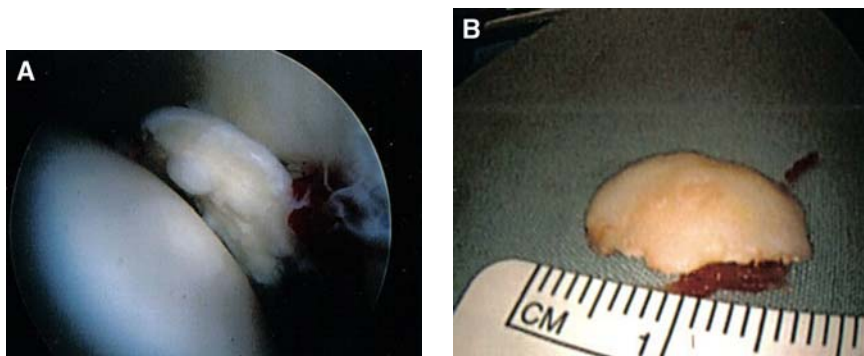


Fig. 15. (A) Osteochondral loose body in the fovea, and (B) removal.

anterior-posterior (AP) pelvis and AP and lateral views of the involved hip should be used to assess for structural/developmental abnormalities or arthritic conditions, and to rule out stress fractures and avulsion fractures. High clinical suspicion for labral tears should further be evaluated with an MR arthrogram. MR arthrography is highly sensitive to detect labral pathology. MRI findings consistent with AVN should also be considered, although chondral injuries can also mimic AVN changes on the MRI. Criteria for tears on an MR arthrogram include contrast extending into the labrum or acetabular/labral interface, blunted appearance, and displacement.

Athletes who have symptomatic labral tears should consider a course of activity modification, anti-inflammatory medication, and possible physical therapy. If symptoms persist past 4 weeks, hip arthroscopy should be considered.

Snapping ilioaspoas tendonitis can be disabling to the athlete. These symptoms can be seen in ballet dancers and skaters, including hockey players. Loud audible popping or clicking can be reproduced by the patient and the examiner [20]. If painful, these symptoms can be mistaken for a labral tear. The patient should be examined in a supine position and opposite hip flexed (Thomas test). The hip should then be actively flexed and extended and the examiner's hand placed on the anterior portion of the hip to assess for snapping. Dynamic fluoroscopy may also confirm the diagnosis [21].

Iliotibial band syndrome and trochanteric bursitis in the athlete can cause pain at the level of the greater trochanter with activity. This syndrome is common in runners. On examination, point tenderness over the greater trochanter is reproduced; excessive adduction and abduction also reproduce the symptoms. The iliotibial band in these patients can also snap over the greater trochanter, and may give the patient the sensation of hip subluxation and dislocation. MRI may show signs of bursitis and gluteus medius tendonitis, but generally is limited for diagnosing this condition.

Isolated extra-articular disorders of the hip do respond to conservative management, which includes physical therapy, a course of anti-inflammatories, and

activity modification. Steroid injections can also help to reduce the inflammation. If symptoms do not improve, arthroscopic intervention may be beneficial.

ARTHROSCOPIC MANAGEMENT

Hip arthroscopy can be performed in either the supine approach, as popularized by Byrd [22], or the lateral approach [23], popularized by Glick and McCarthy. This procedure is generally performed on a fracture table to apply gentle hip distraction and allow for fluoroscopy. Philippon [2] has developed a modified supine position (see Fig. 16) in which the table is tilted 10° to keep the femoral neck parallel to the floor, the hip is slightly flexed 10° and internally rotated, and the lower extremity is in neutral abduction. General anesthesia or a spinal anesthetic is given for optimal muscle relaxation. An oversized peroneal padded post is used to minimize pudendal nerve injury, and the feet are also well-padded. Fluoroscopy is used to obtain hip joint distraction of approximately 1 cm, and can help to access the hip joint. Modified arthroscopic flexible radiofrequency (RF) probes [24] and extended shavers have been developed to improve access to the hip joint.

Proper operating room setup and portal placement are crucial for this procedure. Portal placement consists of two main working portals—anterior and anterolateral portals in the paratrochanteric region. Additional portals can made



Fig. 16. Modified supine position for hip arthroscopy.

posteriorly, but care is used to avoid the sciatic nerve. Distal accessory portals can be used for accessing the peripheral compartment to perform femoral neck osteoplasty (see Fig. 5) and to perform trochanteric bursectomy [25,26]. Access of the hip joint can be achieved using long spinal needles and introducing cannulas over a flexible guide wire. This can be done under fluoroscopic guidance, allowing the anterior portal to be placed under direct visualization and avoiding iatrogenic chondral and labral injury [27,28]. Seventy and thirty-degree scopes can be used interchangeably to maximize visualization. A diagnostic arthroscopic examination of the central compartment can be done systematically to evaluate the labrum from anterior to posterior, to locate possible cartilage lesions on both the acetabular and femoral side and potential ligamentum teres tear and loose bodies in the fovea, and to assess capsular abnormalities (eg, capsular laxity). The labrum and labrocapsular junction are closely evaluated for structural integrity and probed to rule out detachment to the acetabular rim and acetabular rim lesions. This is best achieved by moving the arthroscope to different portals.

Synovitis may be present, particularly in athletes who continue to participate in sports despite hip injury. A partial synovectomy should then be performed first to improve visualization with a motorized shaver. Radio frequency probes can also be useful to minimize bleeding.

In managing labral tears, the surgeon should focus on preserving healthy labral tissue in order to maintain its role as a secondary joint stabilizer and to minimize potential arthrosis [9]. Fraying from labral tears should be debrided to stability with motorized shavers and RF probes. Intrasubstance labral tears can be stabilized by placing an absorbable suture through the defect and retrieving the suture through the capsule. Detachment of labral tears off the acetabular rim is best managed with arthroscopic labral repair using bioabsorbable suture anchors. The peripheral limited blood supply may give a potential healing response for labral repairs and maximize labral function.

Adjacent cartilage lesions should be debrided and stabilized with the use of shavers and RF probes to minimize further propagation. Grade IV chondral lesions can be managed with microfracture techniques to stimulate fibrocartilage.

Partial ligamentum teres tears can cause impingement and be a source of disabling pain. Arthroscopic debridement can be difficult secondary to sphericity of the femoral head. Flexible RF probes and curved shavers can overcome this challenge, and the ligamentum teres can be debrided to a stable remnant.

Global capsular laxity can be addressed with capsular plication at the level of the iliofemoral ligament, as described by Philippon [2]. Localized capsular elongation adjacent to the labral tear can be managed with capsulorrhaphy created by a focal contracture of the capsule with the use of RF probes [10].

Loose bodies, most commonly found in the fovea region, are essentially removed with arthroscopic graspers and shavers [18].

After addressing labral tears and their associated lesions in the central compartment, the peripheral compartment is evaluated to assess cam-type impingement and abnormalities in the head and neck junction and potential loose bodies.

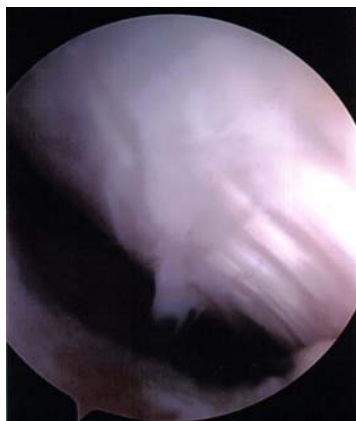


Fig. 17. Intra-articular arthroscopic view of the iliospoas tendon as described by Philippon.

The peripheral compartment is entered by placing the arthroscope in the anterior portal and releasing traction with the extremity in neutral, and then the hip is flexed at 45° [26]. Bump deformities and osteophytes at the femoral head and neck junction are usually anterolateral and adjacent to the labral tear [9]. Femoral neck osteoplasty can be achieved arthroscopically with the use of motorized burrs and shavers [26].

Painful snapping iliospoas tendonitis can be relieved through partial releases performed arthroscopically. Glick [29] has described an endoscopic extra-articular release of the iliospoas tendon through the use of two portals at the level of the lesser trochanter and fluoroscopic guidance. Philippon [2] has performed intra-articular partial iliopoas releases in athletes at level of the anterior capsule (see Fig. 17). There is a potential concern of hip flexor weakness, but muscle strength is regained with strengthening exercises. The potential risk of fluid extravasation is also increased with this procedure.

Athletes, particularly runners, are at risk of iliotibial band syndrome and trochanteric bursitis [30]. Endoscopic releases can be performed with Z lengthening of the iliotibial band and endoscopic bursectomy. This procedure can be performed by making a distal accessory portal approximately 4 cm from the anterolateral portal [25]. Endoscopic bursectomy can be achieved with an RF ablator [24].

Removal of calcific tendonitis of the gluteus medius tendon has been reported with endoscopic techniques [31]. After removal and debridement of the tendon, abductor strength was markedly improved with the aid of physical therapy.

RETURN TO SPORT

Return to competition after hip arthroscopy in a motivated athlete with the aid of athletic trainers and physical therapists can be successful. The author's

series of professional athletes who had labral tears from seven different sports demonstrated successful return to preinjury athletic activity after hip arthroscopy [11]. The earliest return to sport was seen with the golfers (average 6 weeks), followed by hockey players and skaters. Baseball and soccer players averaged twelve weeks. Addressing bony abnormalities during arthroscopic intervention for labral tears may require extended protected weight bearing, however, which may potentially prolong return to sport.

SUMMARY

Labral tears in athletes can lead to disabling hip pain and affect their athletic performance. Isolated athletic injury or repetitive traumatic activity can lead to labral tears; however, underlying structural (femoroacetabular impingement) and developmental abnormalities predisposing athletes to labral pathology must also be addressed. Recent studies [11,12] have demonstrated lesions associated with acetabular labral tears, and that labral tears uncommonly occur as isolated injuries. Return to sport is favorable in athletes who have labral tears if they are properly treated with arthroscopic intervention [11,32].

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A New Method for Acetabular Rim Trimming and Labral Repair

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Our previously reported technique of labral repair has shown promising clinical outcomes [1,2]. However, the surgical technique is technically demanding and provides less than optimal visualization for anchor placement. As a result, the senior author (M.J.P.) has developed a new technique using the lateral portal. This technique permits better visualization and arthroscopic access to the entire anterior and posterosuperior acetabular rim. The suture anchor can be placed higher on the acetabular rim and at a more precise location and angle (closer to 90°) under direct visualization to avoid anchor penetration into the articulating surface.

Using the previously reported modified supine position for hip arthroscopy [1,2], the patient is placed on a standard fracture table with the operative hip in 10° of flexion, 15° of internal rotation, 10° of lateral tilt, and neutral abduction. To provide for instrument clearance and to avoid iatrogenic damage to the labrum or chondral surfaces, approximately 8 to 10 mm of joint distraction is required. Three arthroscopic portals (anterolateral, anterior, distal lateral accessory) are used and have been previously described [1,2].

Upon joint entry, a systematic examination should be performed of the entire acetabular labrum. The fibrocartilaginous labrum is normally adherent to the acetabular rim and transitions to the hyaline articular cartilage in a zone of approximately 1 to 2 mm [3] (Fig. 1). The labrum is widest anteriorly and thickest superiorly, corresponding to the weight-bearing region of the acetabulum [4]. The labrum has been shown to provide approximately 5 mm of additional femoral head coverage [4], and primarily function as a physiologic joint seal [5,6]. A torn labrum is thought to alter load transmission in the joint and increase articular cartilage consolidation [6,7].

In our practice, we observe five types of labral tears: detached, midsubstance longitudinal, flap, frayed, and degenerative. Seldes et al [3] have described the histology of these tears in cadaveric specimens. The authors defined a separation

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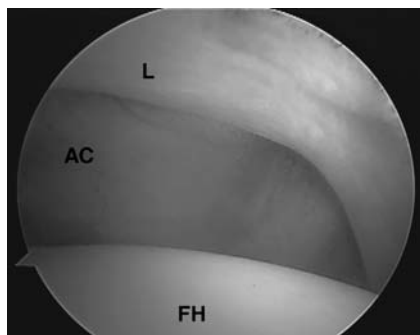


Fig. 1. Arthroscopic view of the normal anterior triangle. L, labrum; AC, anterior capsule; FH, femoral head.

between the labrum and the hyaline cartilage as a detached tear and a cleavage plane within the substance of the fibrocartilage as a midsubstance tear. The authors of this study observed a high incidence of labral tears in the aging hip and concluded that they may be an early precursor to hip osteoarthritis [3]. Given what is currently understood about the vascular pattern and function of the labrum, we believe that, in patients with labral tears, preservation of any healthy labral tissue may improve the overall integrity of the hip joint. Thus, it is thought that repair of detached and certain healthy midsubstance labral tears (in the capsular one third section of fibrocartilage) may effectively delay or prevent the onset of hip osteoarthritis. Recently, an *in vivo* ovine model has been established, to compare labral repair versus labral resection. At 12 weeks post-labral repair, the labrum has shown early evidence of healing (Philippon MJ. Unpublished data, 73rd Annual Meeting of the American Academy of Orthopaedic Surgeons, 2006).

The first steps to addressing labral tears are to assess the type(s) of tear present and to define the borders of the tear with a flexible instrument. Controlled application of monopolar radiofrequency energy to the margins of the tear will contract the fibrocartilage and better define the tear. The goal of arthroscopic debridement of a torn labrum should be to remove the impinging tissue that causes pain and mechanical symptoms. A flexible ligament chisel detaches the torn portion of the labrum from the intact healthy labrum, and a motorized angled shaver helps define the appropriate plane and removes the debrided tissue from the joint (Fig. 2). As previously mentioned, we believe it is important to avoid overresection and preserve as much of the healthy fibrocartilage as possible.

We are currently proposing a new technique for the repair of a detached labrum. Based on our surgical experience and the reports of Ganz et al [8], detached labra are common findings in patients with cam-type femoroacetabular impingement. In this condition, a bony abnormality at the junction of the femoral head and neck abuts the acetabular rim, particularly during flexion, internal rotation, and abduction. As a result of the shear forces generated by this impingement,

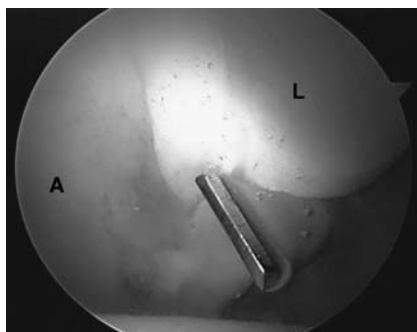


Fig. 2. Debridement of a flap tear of the labrum. L, labrum; A, acetabulum.

a separation is thought to be created between the fibrocartilaginous labrum and the articular cartilage at the transition zone. Additionally, in patients with large pincer-type femoroacetabular impingement, it may be necessary to surgically detach the labrum in a “rim trimming” procedure for full resection of the bony overhang. In these cases, an arthroscopic osteotome placed through the lateral portal removes small sections of the anterosuperior acetabular rim. A motorized burr through the lateral portal then removes the remaining overhang and contours normal acetabular rim morphology. Following the rim trimming procedure, reattachment of the labrum to the acetabular rim is necessary, and may now also be performed through the lateral portal.

For the repair of a detached labrum, at least one bioabsorbable suture is needed to stabilize the fibrocartilage back to the acetabular rim. After appropriately defining the margins of the tear, the arthroscope is placed in the anterior portal, providing a view of the anterosuperior acetabular rim. A clear 8.25-mm cannula is then introduced through the lateral portal. A sleeve for the anchor is used to establish the appropriate angle for the anchor (Fig. 3A). Fluoroscopy may be used during the procedure to ensure optimal placement. We recommend tapping the sleeve slightly into the acetabular rim and then manually driving the anchor into place using tactile sensation as guidance. While tapping the path of the anchor, it is critical to visualize the articular surface of the acetabulum to assure that the articular surface is not being compromised. If bulging of the articular surface is noticed, the angle of the anchor must be redirected. To avoid penetration into the articular surface, the anchor is typically driven at an approximate angle of 15° to the vertical (Fig. 4). Once the anchor is in place, the articular surface should again be visualized to verify that it has not been penetrated.

The next step is to deliver a limb of suture between the labrum and the acetabular rim with a suture passer (Fig. 3B). Using an arthropiercer (bird beak), the suture is retrieved over the labrum (Fig. 3C). As the suture is pulled out through the clear cannula, it is important to visualize the anchor to assure that the correct suture limb is being retrieved. A disadvantage to this labral repair

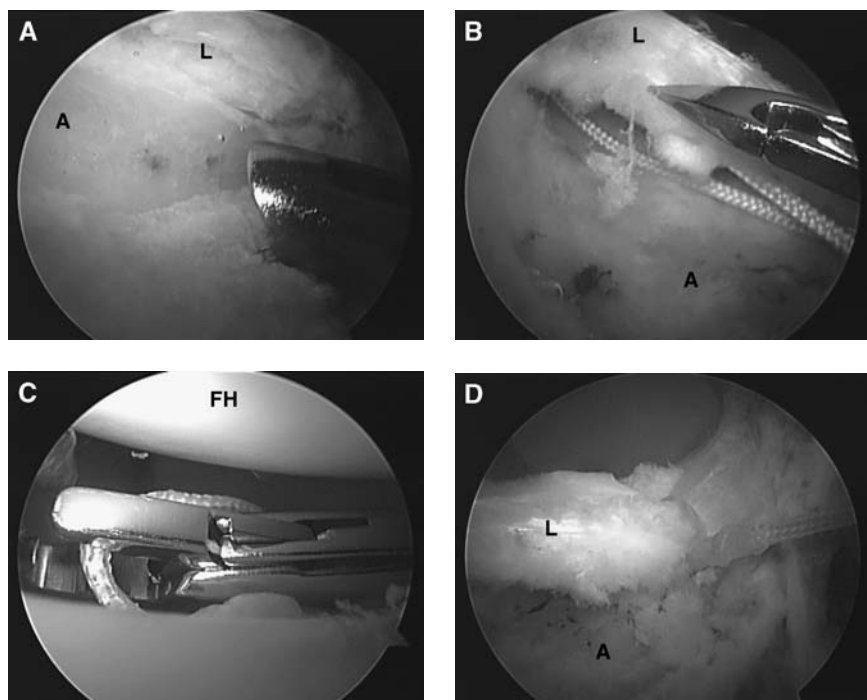


Fig. 3. Sequence of repair for a detached acetabular labrum. (A) A sleeve is placed on the anterosuperior acetabular rim. L, labrum; A, acetabulum. (B) An arthropiercer passes the suture between the acetabular rim and the detached labral tissue. (C) An arthropiercer grabs the suture to pull back around the labral tissue. FH, femoral head. (D) Arthroscopic view of completed repair of a detached labrum. L, labrum; A, acetabulum.

approach is that the suture cannot be easily visualized with the arthroscope in the anterior portal. The cannula must then be pulled back slightly for improved visualization, and the suture is tied down using standard arthroscopic knot-tying techniques (Fig. 3D).

Depending on the size of the labral detachment, a second or third anchor may be necessary. The camera should then be returned to the lateral portal to visualize the labral repair. A flexible radiofrequency probe may then be used to contour the edges of the labrum. At the conclusion of the labral repair, traction should be released and dynamic testing of the labral repair should be performed to confirm adequate repair.

Following repair of the detached labrum, it may be necessary to address pathologies commonly associated with detached labra. Osteoplasty of cam-type femoroacetabular impingement or microfracture of acetabular or femoral chondral defects may be performed as needed.

In conclusion, a novel technique for the suture anchor repair of a detached labrum has been described. Detachment of the labrum can result from cam-type femoroacetabular impingement or may be necessitated for full resection of the



Fig. 4. To avoid penetration into the articulating surface, the anchor should be driven at an approximate angle of 15° to the vertical.

pincer-type acetabular overhang. The senior author has performed this new technique in over 140 patients and has noticed a few key advantages over the previously described technique. This approach allows direct visualization of the anterosuperior acetabular rim. The suture anchor may then be placed higher and at a more precise location and angle through the lateral portal. This technique appears to be easier to master and more reproducible when compared to the former technique [1,2].

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Arthroscopy for the Treatment of Femoroacetabular Impingement in the Athlete

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Femoroacetabular impingement (FAI) has been recently revealed as a significant cause of hip pain in the athlete [1] and as a predictor of early onset hip osteoarthritis [2–4]. The hip is highly reliant on its bony structure for stability and support during substantial loading in weight bearing and sport. As a result, any abnormality in bony morphology may alter the force distribution in the joint, and can potentially cause injury to the capsulolabral structure or articular cartilage.

Ganz et al [5–7] have described two distinct types of FAI: cam and pincer. Cam impingement occurs when an abnormally shaped femoral head contacts a normal acetabulum, particularly during flexion and internal rotation. Pincer impingement involves a normal femoral head contacting an abnormally shaped, deep, or retroverted acetabulum. The patterns of labral and chondral injury resulting from the impingement appear to be unique to the distinct type of impingement [6]. In cam impingement, the “bump” at the femoral head–neck junction produces a shearing force, displacing the labrum toward the capsule and the adjacent articular cartilage into the joint. Softening of the articular cartilage can be observed as a “wave sign” when arthroscopically probed before frank chondral delamination (Fig. 1). With repeated insults, the labrum may completely detach from the acetabular rim, and the cartilage may fully delaminate. In pincer impingement, the labrum is essentially trapped between the bony structures, thus it often bruises and flattens. With persistent pincer impingement, the labrum may degenerate, with cyst formation or ossification of the fibrocartilage. Persistent pincer impingement may lead to a chondral defect (a “contre-coup” lesion) at the posteroinferior acetabulum or posteromedial femoral head [6]. The chondral injuries resulting from a pincer impingement are typically less severe than those resulting from a cam impingement.

Several mechanisms, particularly subtle developmental deformities, have been proposed for FAI. Subacute slipped capital femoral epiphysis has been shown to

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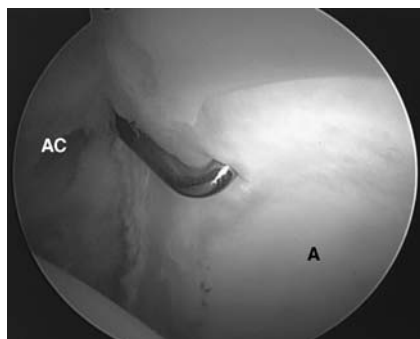


Fig. 1. Softening of the articular cartilage on the acetabulum can be observed as a “wave sign” when arthroscopically probed. This appears to be a precursor of chondral delamination. A, acetabulum; AC, anterior capsule.

induce cam-type impingement, causing injury to the labrum and adjacent articular cartilage [8–10]. Insufficient reduction of femoral neck fractures and decreased anteversion of the femoral neck have also been shown to cause cam impingement [11,12]. Pincer impingement may be caused by general acetabular overcoverage (coxa profunda) or acetabular retroversion [13,14], and has been shown to be associated with osteoarthritis of the hip [15]. Demographically, cam impingement seems to be more common in young males and pincer impingement in female athletes.

In the athlete, FAI is a major cause of hip pain, reduced range of motion, and decreased performance. In fact, 36% (57 of 157) of professional and Olympic-level athletes who have undergone hip arthroscopic surgery between September 2000 and April 2005 have required decompression of FAI. Included in this group are professional hockey players, of whom 27 of 33 (81%) had FAI [1]. No known studies have looked at possible mechanisms for overuse-type impingement in athletes. It is possible that each of these athletes with FAI suffers from a subtle developmental deformity due to a mild slip of the epiphysis during growth in adolescence. Subsequent damage to the labrum and articular cartilage could be worsened by their frequent sport activity. However, it is also possible that repetitive movement, particularly deep flexion, abduction, and internal rotation, may cause the abutment of the femoral neck with the acetabular rim. A reactive osteophyte may form at the head–neck junction, causing a cam-type impingement.

As described above, it has been shown that FAI can cause labral injury and early osteoarthritis. Therefore, surgery has proven necessary to increase joint clearance, particularly in flexion and internal rotation, in hopes of delaying the onset of osteoarthritis. Historically, only open osteoplasty for FAI decompression has been reported. Ganz and colleagues have supported this approach for its ability to provide an unobstructed 360° view of the femoral head and acetabulum [6,16]. It is our belief, however, that almost all areas of the head–neck junction and acetabular rim can be safely accessed through the arthroscope.

With the use of long and flexible arthroscopic instrumentation and controlled and precise intra-operative maneuvering of the lower extremity, we believe that arthroscopy can allow equivalent decompression of FAI when compared to the open technique. In addition, the arthroscopic approach seems to reduce post-operative morbidity, and provide a shorter rehabilitation time and quicker return to play for athletes.

CLINICAL PRESENTATION

The most common complaint in the clinical history of a patient with FAI is anterior groin pain exacerbated by hip flexion. Patients complain of pain with prolonged sitting and with putting on shoes and socks, and also difficulty with getting into and out of a car. During physical examination, sharp groin pain is classically elicited when the hip is flexed to 90° and internally rotated. This “impingement sign” is thought to be triggered when the bony prominence at the junction of the femoral head and neck hits into the acetabulum and labral tissue. Nerve endings present in the labrum may trigger pain sensation with this examination [17]. Another test for FAI places the patient supine and the hip in a figure-four or flexed-abducted externally rotated (FABER) position. The clinician should measure or visually observe the distance between the lateral genicular line and the examination table. Typically, this distance is increased in patients with FAI, and lateral pain may be reported during the test. A thorough hip examination should be performed in addition to these provocative maneuvers. A complete history, gait analysis, motor strength testing, and range-of-motion testing should be performed in all patients [18].

A complete radiologic workup of a patient with FAI includes two plain film views (supine anterior–posterior [AP] pelvis and crosstable lateral) and magnetic resonance (MR) arthrography enhanced with gadolinium contrast. The AP radiograph should be evaluated for a crossover sign, which may be indicative of a retroverted acetabulum, and a posterior wall sign, which may be indicative of coxa profunda [13,19]. The crosstable lateral radiograph offers a good view for assessing femoral head–neck offset, and degree of femoral neck anteversion

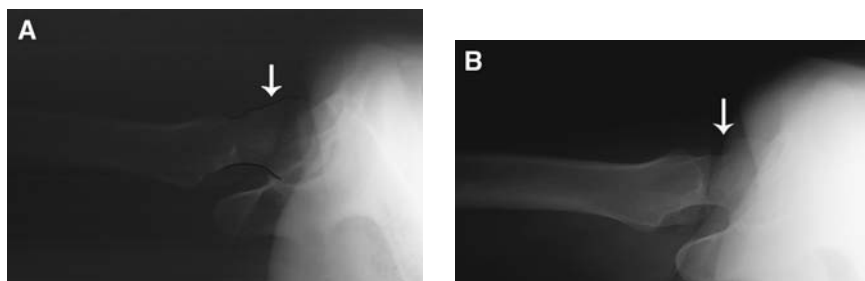


Fig. 2. Crosstable lateral X-ray. (A) A preoperative bump at the anterior femoral head–neck junction (arrow). (B) Postosteoplasty of the anterior femoral head–neck junction showing improved femoral head–neck offset (arrow).

[20] (Fig. 2). A recent study has found that a classic triad of MR arthrography findings, including anterosuperior labral tear, anterosuperior cartilage defect, and abnormal alpha angle, is present in 88% of patients with cam impingement [21].

SURGICAL TECHNIQUE

Patient Positioning

In a previously reported method [18,22,23], the patient is placed in the modified supine position with the operative hip in 10° of flexion, 15° of internal rotation, 10° of lateral tilt, and 30° of abduction. An extra wide peroneal post is used to minimize the risk of pudendal nerve injury. Traction is first applied to break the joint's vacuum seal. The leg is then slightly adducted over the post, thereby venting the capsule and laterally displacing the femoral head. Additional traction, typically requiring 25 to 50 pounds of force, is then required to create approximately 10 mm of joint distraction for safe surgical instrument clearance. Minimal countertraction is also applied to the contralateral leg to reduce the amount of traction necessary on the operative leg.

Portal Placement

Two portals (anterolateral and anterior) are recommended for safe and adequate decompression of FAI and treatment of associated intraarticular pathologies. We have previously described a method of establishing the portals [22,23]. Using the 70° arthroscope, the anterolateral portal provides a view of the anterior triangle (anterior capsule, labrum, and anterior chondral surface of the femoral head), iliofemoral ligament, iliopsoas tendon, cotyloid fossa, ligamentum teres, transverse ligament, and most of the acetabulum. The posterosuperior labrum, posterior capsule, posterior recess, and ligamentum teres may be visualized through the anterior portal. Additionally, the anterior portal provides a good view of the anterior femoral neck, head-neck junction, zona orbicularis, and distal insertion of the capsular ligaments [22].

Cam Procedure

The first step in treating cam impingement is to address the associated intraarticular pathology. This may include labral repair or debridement, and microfracture chondroplasty of femoral or acetabular chondral defects. The next step occurs after the impinging lesion has been visualized with the scope in the anterior portal (Fig. 3A). A long motorized shaver is introduced through the lateral portal to debride any capsular tissue that may be obstructing a complete view of the femoral head-neck junction. Osteoplasty of the impinging lesion is then performed with a long motorized burr through the lateral portal (Fig. 3B). Throughout the procedure, the hip may be flexed and extended, abducted and adducted, and internally and externally rotated to dynamically assess the impinging lesion. In these hip positions, the motorized burr may be used to resect any impinging bone. Caution should be taken when approaching the anterolateral and posterolateral aspects of the head-neck junction because branches of the medial circumflex artery (lateral retinacular vessels) perforate the joint

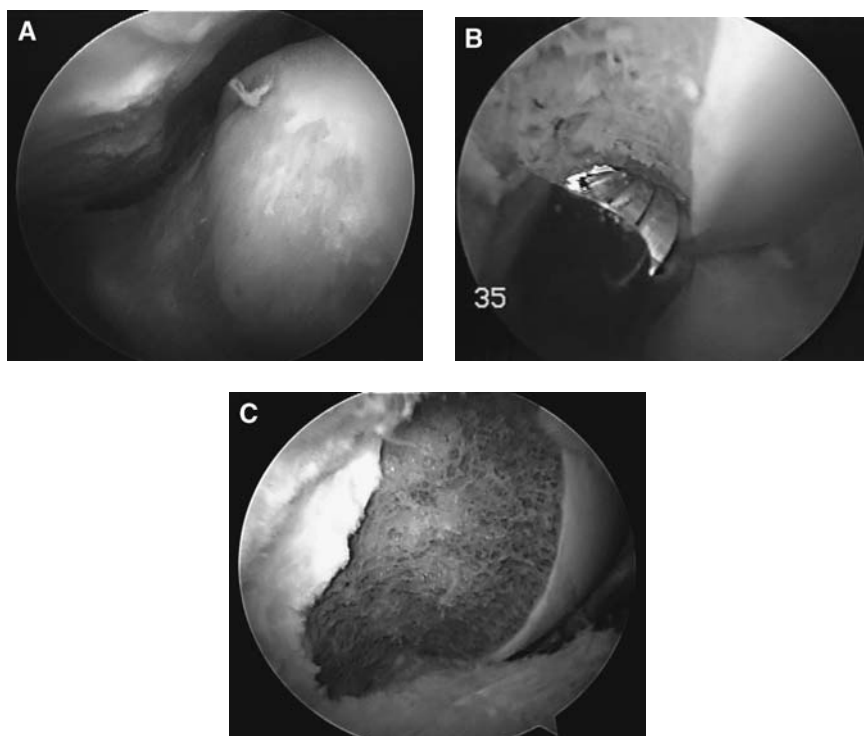


Fig. 3. Sequence for treatment of cam-type impingement (A) A sclerotic bony bump is observed arthroscopically in the region of the anterior femoral head-neck junction. (B) A long motorized burr resects the region of sclerotic bone to a depth of approximately 5 to 8 mm and as far circumferentially as needed, carefully avoiding the anterolateral and posterolateral regions of the head-neck junction. (C) Joint clearance is assessed arthroscopically postosteoplasty with the operative hip flexed beyond 90° and internally rotated.

capsule and run along these regions of the femoral neck [24,25]. Understanding the anatomy of the vasculature is critical to avoid avascular necrosis following osteoplasty.

The goal of cam debridement is to eliminate the bony prominence that impinges the labrum and acetabular rim, and restore the anatomic offset between the femoral head and neck. An obvious concern that has been raised in FAI decompression is how much bone can be removed without increasing the risk of femoral neck fracture. A recent study in cadavers demonstrated that resection of up to 30% of the anterolateral head-neck junction of a morphologically normal femur did not alter the load-bearing capacity [26]. A resection larger than 30%, however, did result in structural compromise of the femoral neck. Although this study should be used as a guideline for maximal resection, it is difficult to interpret the results with regards to morphologically abnormal head-neck junctions. In our experience, burring to a depth of approximately 5 to 8 mm has been clinically observed to be a safe and effective procedure.



Fig. 4. Placement of the third arthroscopic portal approximately 1 cm anterior to the antero-lateral portal and 4 cm distal with the operative hip flexed to 45°.

To assess joint clearance following osteoplasty, the operative hip should be flexed beyond 90° and internally rotated under direct visualization through the anterior portal (Fig. 3C). Furthermore, the leg should be brought into full abduction and again flexed to 90°, and internally and externally rotated. This “butterfly” test simulates the hockey goalie stance, a position frequently found to trigger impingement signs in athletes. If impingement is visualized in this position, further resection of the lesion is needed. Successful decompression is concluded when no further impingement between the femoral head-neck, the labrum, and the acetabular rim is observed during the dynamic testing.

Although the senior author (M.J.P.) prefers a two-portal approach to decompressing FAI, an additional distal lateral accessory portal may be used, if necessary, to access the site of the lesion (Fig. 4). This portal is typically the last to be placed, as the traction needs to be slowly released and the operative leg flexed to 45°. The arthroscope should be placed in the anterior portal to visualize the anterior femoral head and neck. Upward pressure on the scope will reduce the risk of chondral injury to the femoral head as the hip is flexed. The arthroscope can then easily slide anteriorly and distally over the femoral head, in a position peripheral to the labrum. With the hip flexed to 45° and in neutral rotation, the anterior capsule will distend and provide excellent visualization of

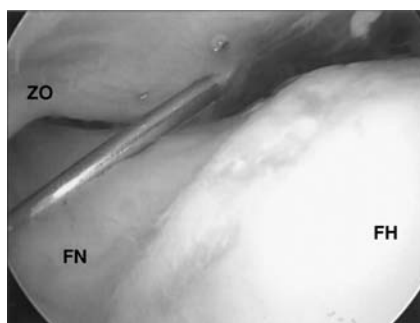


Fig. 5. A spinal needle is directed through the capsule in the region of the zona orbicularis (ZO) for the placement of the third arthroscopic portal. FH, femoral head; FN, femoral neck.

the head–neck junction and any impinging lesion. Once the scope is in position, a skin incision is made approximately 1 cm anterior to the anterolateral portal and 4 cm distal. Under direct visualization, a spinal needle is directed through the capsule in the region of the zona orbicularis (Fig. 5). A guide wire is then inserted through the spinal needle, and a cannulated blunt trochar is used to safely establish the portal.

Postoperative complications following cam debridement include capsular adhesions and the slight risk of femoral neck fracture, avascular necrosis, and myositis ossificans.

Pincer Procedure

Pincer impingement in the hip occurs when the acetabulum provides anterior overcoverage of the femoral head. The first step to resecting a pincer lesion is defining the margins by probing with a flexible instrument (Fig. 6A). As mentioned above, other clues to recognizing pincer impingement may include observing a bruised, flattened, degenerative, or cystic labrum [6]. After assess-

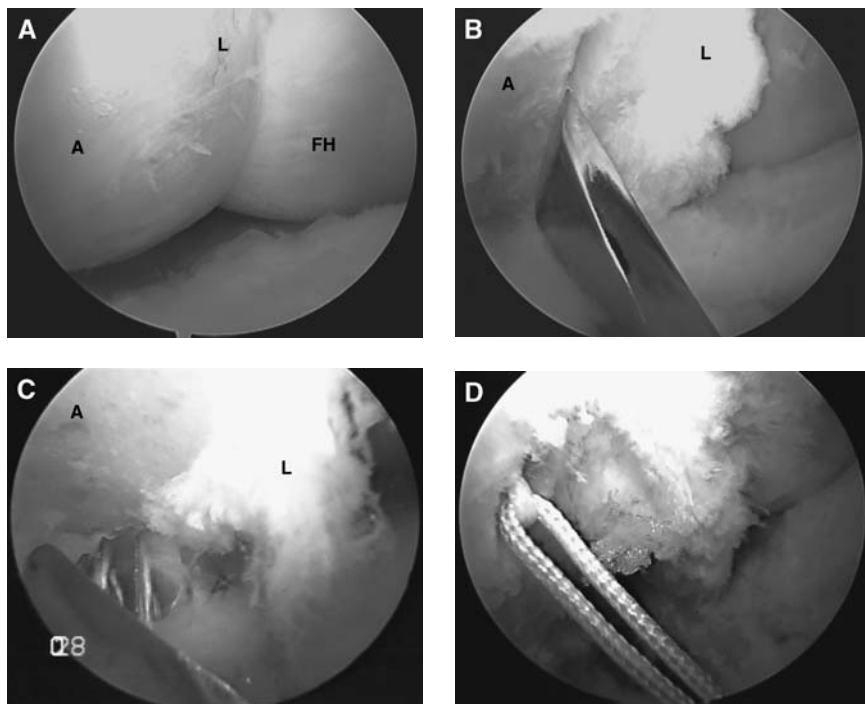


Fig. 6. Sequence for treatment of pincer-type impingement (A) A sclerotic bony overhang is observed arthroscopically in the region of the anterosuperior acetabular rim (A). L, labrum; FH, femoral head. (B) An arthroscopic osteotome resects small portions of the anterosuperior acetabular rim (A) until a majority of the lesion is removed. L, labrum. (C) A motorized burr completes the resection by reshaping the acetabulum (A) into its normal contour. L, labrum. (D) The labrum is reattached to the anterosuperior acetabular rim using suture anchor repair.

ing the lesion, three different surgical options may be pursued depending on the size of the lesion. If the overhang is slight and the labral attachment is intact, it may be possible to perform a cam-type procedure to create more clearance on the femoral side. However, medium to large pincer lesions require resection of the acetabulum to avoid excessive bony resection at the distal femoral neck and potential injury to the lateral epiphyseal vessels.

After the margins of a pincer lesion have been recognized, a motorized shaver is used to clear all soft tissue from the overhanging acetabulum and to define the plane between the labrum and the acetabular rim. If the lesion is moderately sized, a motorized burr is inserted into the anterior portal and the overhang is carefully resected in a “rim trimming” procedure. If the lesion is large, an arthroscopic osteotome may be used through the anterior portal to carefully separate the anterosuperior labrum from its insertion on the pincer lesion. The osteotome is then placed on the anterosuperior acetabulum and small portions of the rim are resected until a majority of the lesion has been removed (Fig. 6B). The motorized burr then completes the resection by reshaping the acetabulum (Fig. 6C). A maximum of approximately 5 mm of acetabular rim should be removed. It is critical to avoid overresection of the rim to prevent future instability in the patient. In all resections of the acetabular rim, microfracture of the subchondral bone should be performed until punctate bleeding is achieved. If detached during the pincer procedure, the labrum should be reattached to the superior acetabular rim with suture anchors [22,23] (Fig. 6D).

Following resection of the pincer impingement, it is important to slide the arthroscope into the peripheral compartment through the anterior portal to visualize the head–neck junction. Mixed cam–pincer impingement disorders are a very common finding [2] and for best postoperative outcomes, it may be necessary to surgically address both pathologies.

POSTOPERATIVE MANAGEMENT

After resection of the cam or pincer impingement, autologous-derived platelet gel is injected directly onto the femoral neck to reduce bleeding and promote early tissue healing. Early range-of-motion exercises are performed within 4 postoperative hours to reduce the risk of developing tissue adhesions. Twenty pounds of flat-foot weight bearing is then recommended for 4 weeks in patients undergoing a standard arthroscopy for cam or pincer impingement. If microfracture or other chondral work is performed, this may be extended to 6 to 8 weeks. Special foot boots are worn at night for 10 days to limit hip internal and external rotation. If thermal capsulorrhaphy or capsular plication is performed, rotation precautions are extended to 21 postoperative days. A modified brace is used for 10 postoperative days to protect the hip and limit abduction movement. A continuous passive motion machine is used for 4 to 8 postoperative weeks, for 8 hours each day.

DISCUSSION

FAI has recently been recognized as a major source of hip pain, labral tears, reduced range of motion, and decreased performance in the athlete. In the past,

labral tears were regarded as isolated pathologies, and proposed treatment involved simple resection of the tears [27]. Although labral debridement may yield immediate postoperative pain relief, long-term outcomes of this procedure can be improved [27]. As a result, Ganz et al [5,6] have sought a cause for labral tears; they have proposed FAI as an underlying mechanism in a significant proportion of labral tears. Further, FAI has been shown to be a significant cause of early osteoarthritis in the hip [2–4,8,9]. As a result, treatment of the impingement as well as the associated pathology is thought to improve patient outcome following hip arthroscopy.

Historically, an open surgical dislocation procedure for FAI decompression has been advocated to provide an unobstructed 360° view of both the femoral head and acetabulum [6,16]. Although a study has shown good midterm results with this technique [28], the surgical trauma sustained during the open dislocation may make it difficult for high-level athletes to return to play. Proponents of the open technique have argued that the “constrained hip renders [arthroscopic] access to the underlying cause of impingement technically challenging, if not impossible” [6]. However, with the combined use of long and flexible arthroscopic instrumentation, and controlled intra-operative manipulation of the lower extremity, we believe that 360° access to the femoral head–neck junction is definitely possible with arthroscopy. The senior author has performed over 516 hip arthroscopies for decompression of FAI between September 2000 and April 2005. In a review, 45 of these patients were professional athletes who each experienced symptomatic improvement and all returned to play (Philippon MJ, unpublished data, 73rd Annual Meeting of the American Academy of Orthopaedic Surgeons, 2006).

In conclusion, athletes presenting with hip pain should be evaluated for the signs and symptoms of FAI in addition to those of labral and chondral injuries. The increasing popularity of hip arthroscopy has led to the development of this new technique. Advantages to the arthroscopic approach seem to be a reduction in postoperative morbidity and a more prompt postoperative return to play for athletes. By treating FAI in athletes at an early stage, it is hopeful that osteoarthritis progression in the years following competition will be delayed or completely prevented.

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Diagnosis and Management of Traumatic and Atraumatic Hip Instability in the Athletic Patient

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Although hip stability relies primarily on its osseous anatomy, its unique soft tissue anatomy also plays a critical role. As in the shoulder, hip instability does occur. The consequences of both acute bony and soft tissue injuries must be considered. The etiology of hip instability can be either traumatic or atraumatic in nature. Although hip instability is relatively uncommon, it is a potential source of great disability, because it is a commonly unrecognized injury.

Hip instability can be considered either traumatic or atraumatic in origin. Traumatic instability has defined acute events. The spectrum of traumatic hip instability ranges from subluxation to dislocation with or without concomitant injuries. Atraumatic instability, on the other hand, is a more subtle and less well-defined entity. It can be a consequence of chronic overuse secondary to rotational instability or microinstability such as in elite golfers or gymnasts. The spectrum may also include patients with hip pain secondary to more generalized ligamentous laxity or, in the extreme form, in patients with connective tissue disorders such as Marfan syndrome or Ehlers-Danlos syndrome [1]. In addition to this spectrum of atraumatic instability, we would consider patients with underlying mild to moderate dysplasia as a separate category. These patients have instability secondary to abnormal bony architecture and therefore have increased stresses applied to their soft tissue structures. Each of these entities has unique diagnostic and management dilemmas.

Recently, hip arthroscopy has gained considerable interest as both a diagnostic and therapeutic tool for both acute and chronic hip pain. It has the potential to effectively treat many of the associated injury patterns of hip instability; however, many of its indications are still undefined. In this article, we will outline the basic anatomy, physiology, and management principles of the spectrum of hip instability in the athletic patient.

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ANATOMY

The hip is a diarthrodial joint and is an articulation between the head of the femur and the acetabulum. The acetabulum is formed by the union of the ilium, ischium, and the pubis. The tri-radiate cartilage usually fuses by 15 to 16 years of age, and is oriented approximately 45° caudally and has 15° of anteversion. A variety of normal radiographic indices have been described to differentiate normal from abnormal bony anatomy and play an important role in understanding why some patients develop instability. The Tönnis angle is determined by marking a horizontal line along the inferior aspect of the ischial tuberosities (line 1), and another line parallel to the first line but through the center of the femoral head (line 2). Finally, a third line (line 3) is drawn from the medial and lateral aspects of the weight-bearing portion of the superior acetabulum (the “Sourcil”). Where this intersects with line 2 is the Tönnis angle, which normally measures $<10^\circ$ [2,3] (Fig. 1). Increased Tönnis angles are associated with lateral subluxation of the femoral head in the acetabulum and increased forces directed across the weight-bearing zone of the socket.

The center-edge angle of Wiberg is determined by again drawing a horizontal line along the inferior aspect of the ischial tuberosities (line 1) and then a line parallel to line 1 that passes through the center of the femoral head (line 2). Another line is drawn perpendicular to the second line and passes through the center of the femoral head (line 3). A fourth line (line 4) is then drawn from the center of the femoral head to the lateral aspect of the acetabulum and is normally $>25^\circ$ with 20° to 25° considered borderline [3,4] (Fig. 2).

The acetabular version can also be estimated based on an anteroposterior (AP) radiograph of the pelvis. The posterior rim is identified by extending a line from the ischial tuberosity superiorly and laterally along the posterior wall to the

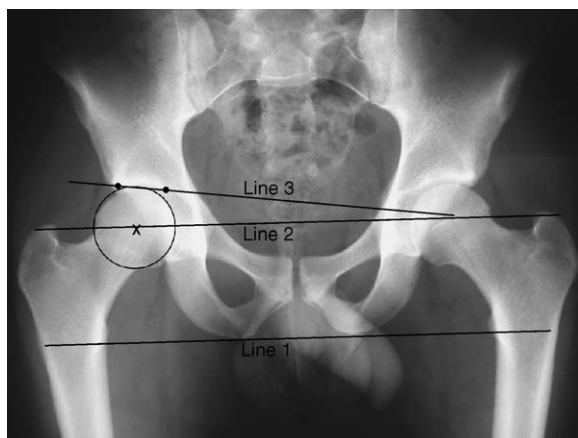


Fig. 1. An AP radiograph demonstrating the method for measuring the Tönnis angle of the hip. A normal Tönnis angle is $<10^\circ$. Increased Tönnis angles are associated with lateral subluxation of the hip and increased contact pressures of the femoral head on the anterosuperior weight-bearing zone of the acetabulum.

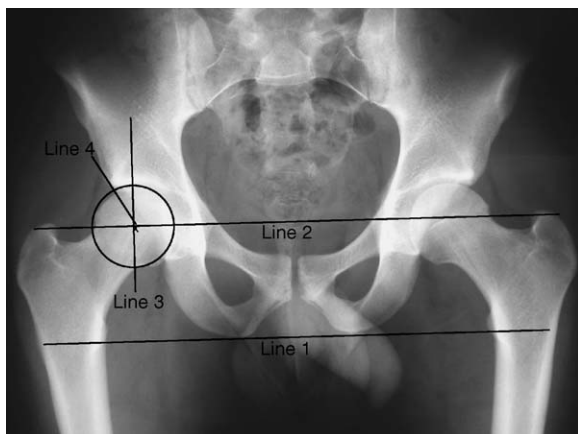


Fig. 2. An AP radiograph demonstrating the method for measuring the center-edge angle of Wiberg. The center-edge angle is normally $>25^\circ$, with 20° to 25° considered borderline (From Delaunay S, Dussault RG, Kaplan PA, et al. Radiographic measurements of dysplastic adult hips. *Skeletal Radiol* 1997;26(2):75–81.)

roof of the acetabulum. A second line is then drawn along the anterior acetabular rim by extending a line from the acetabular teardrop superolaterally along the margin of the rim to the roof. If the lines do not cross, the acetabulum is anteverted with normal values ranging between 15° to 20° . A “crossover” sign is present if the lines cross, which represents a retroverted acetabulum [2,4,5] (Fig. 3). The degree of retroversion can be estimated by the height of the crossover, with lower crosses suggestive of increased retroversion. Although important in understanding the complete bony anatomy of the hip joint, femoral anteversion



Fig. 3. An AP radiograph of the pelvis demonstrates the crossover sign indicative of a retroverted acetabulum. In a retroverted acetabulum, the anterior acetabular rims (solid lines) crosses over the posterior acetabular rim (dashed lines) on the AP radiograph of the pelvis.

is difficult to determine on standard plain radiographs. For complete evaluation of femoral anteversion, either a CT scan or MRI of the hip joint with a spot view of the distal femoral epicondyles is necessary for an accurate calculation.

The hip joint is an intrinsically stable joint. Its deep acetabulum allows the hip to withstand joint reactive forces that may be in excess of five times body weight during athletic activities [6]. The femoral head normally forms two-thirds of a sphere and is flattened in the area where the acetabulum applies the greatest load. In the neutral, anatomic position, the anterior part of the femoral head is not engaged in the acetabulum, and the labrum augments the femoral head coverage by its extension from the bony acetabulum [7]. In other situations, there is natural variation in the acetabular depth and femoral head geometry. The soft tissue anatomy of the hip consists primarily of the capsuloligamentous structures, ligamentum teres, labrum, transverse acetabular ligament, pulvinar, and the articular surfaces of the femoral head and acetabulum. Inclination and version of the weight-bearing surface may affect the joint capsule and ligaments of the hip, the labrum, the ligamentum teres, as well as the suction effect of the hip [7]. In cases where there is deficiency of the bony acetabulum (dysplasia) there is more reliance on these surrounding soft tissue structures. More specifically, McKibbin has observed an association between femoral and acetabular version that leads to increased stress to the anterior capsulolabral structures. He defined the McKibbin index as the sum of the angles of femoral and acetabular anteversion with a total of >60 denoting severe instability [2,8].

The fibrous hip capsule has three discrete thickenings which form the main capsular ligaments: the iliofemoral (Y-Ligament of Bigelow), the pubofemoral, and the ischiofemoral (Fig. 4). The Y-ligament of Bigelow is the strongest of the three ligaments and prevents anterior translation of the hip during extension and external rotation. The terminal fibers of this ligament form a deep circular orientation surrounding the femoral neck in a leash-like fashion and are termed the zona orbicularis. These fibers tighten during extension but unwind or loosen during hip flexion which leads to a “screw home” effect in full extension.

Labral tissue, unlike capsular tissue, is made predominantly of fibrocartilage. The labrum runs circumferentially around the acetabular perimeter and becomes attached to the transverse acetabular ligament posteriorly and anteriorly. The labrum plays a role to help contain the femoral head in extremes of range of motion, especially flexion. The labrum is also involved with limiting fluid expression from the joint space, which has an important sealing function. The absence of the labrum causes increases contact pressure of the femoral head against the acetabulum [9–11]. The labrum appears to enhance joint stability and preserve joint congruity; thus, there is a significant concern about the potential for rotational instability or hypermobility in patients with a labral deficient hip [1]. This instability may lead to redundant capsular tissue, which can create a potential abnormal load distribution due to a transient incongruous joint resulting from subtle subluxation.

The ligamentum teres runs from the fovea capitis, a small depressed bare spot located at the medial aspect of the femoral head, and inserts adjacent to the

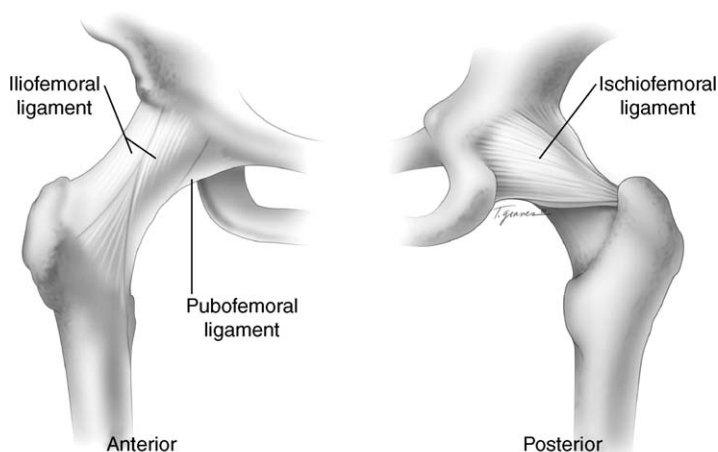


Fig. 4. Anatomical constraints of the hip. The anterior ligamentous constraints of the hip are seen in the anterior view and include the iliofemoral and pubofemoral ligaments. The ischiofemoral ligament is the primary posterior restraint. (From Kelly BT, Williams 3rd RJ, Philippon MJ. Hip arthroscopy: current indications, treatment options, and management issues. *Am J Sports Med* 2003 Nov-Dec;316:1020–37, with permission. © 2003 American Orthopaedic Society for Sports Medicine.)

transverse acetabular ligament in the acetabular fossa. In the presence of a deficient labrum or a dysplastic hip, it may have a secondary stabilizing effect on the hip joint [12]. It is routinely observed clinically that tension on the ligamentum teres occurs as the hip is brought into external rotation (Fig. 5A and B). The transverse acetabular ligament runs from the base of the anterior and posterior labrum and acts as a conduit to the obturator foramen.

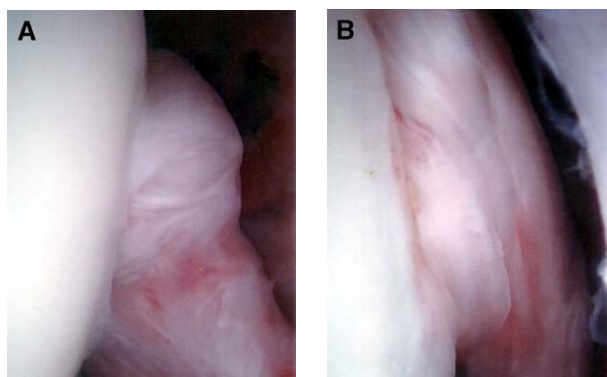


Fig. 5. (A, B) Dynamic hip arthroscopy demonstrates significant tightening of the ligamentum teres during external rotation (B) compared with internal rotation of the hip (A). These findings support the biomechanical role of the ligamentum teres in the stabilization of the hip.

The psoas major muscle originates from the vertebral bodies of T12 through L5 and the transverse processes of L1 through L5 and crosses anterior to the hip capsule as it inserts onto the lesser trochanter. As it crosses the anterior-medial aspect of the hip joint, it helps protect the anterior intermediate portion of the capsule. The tendon may be subjected to increased load during athletic activities, which can be further exacerbated in athletes with associated intra-articular pathology [13]. The psoas tendon may also become shortened and inflamed in patients with underlying instability as it attempts to provide dynamic stabilizing effects to the anterior aspect of the hip joint in the presence of static ligament deficiency. The coexistence of hip instability and secondary internal coxa saltans is not unusual to encounter [14].

TRAUMATIC HIP INSTABILITY

The diagnosis of a traumatic hip injury is obvious in severe cases of dislocation. However, more subtle traumatic subluxation of the hip can occur with seemingly minimal trauma. The clinician should have a high index of suspicion for intraarticular injury even after minor trauma. A careful physical examination should be performed to differentiate intraarticular versus extraarticular pathology. Patients may also have concomitant soft tissue injuries such as chondral injuries, labral tears, and capsular injuries. Injury patterns depend upon the age of the patient and the competency of the surrounding soft tissue. The most common mechanism for hip dislocations is a dashboard motor vehicle injury (high energy). However, in athletic competition, a forward fall on the knee with a flexed hip or a blow from behind while down on all four limbs can also produce these patterns (more low energy) [15].

Patients with traumatic hip instability caused by hip dislocations or fracture dislocations present in severe discomfort and are unable to move their lower extremity. Hip dislocations have been reported in American football, skiing, rugby, gymnastics, jogging, basketball, biking, and soccer [16–19]. On physical examination, patients will classically present with the hip fixed in a position of flexion, internal rotation, and adduction. A complete neurovascular examination should be performed, and care must be taken to check for the presence of a partial or complete sciatic nerve palsy before any closed or open manipulation of the hip. Although rare, team physicians need to be aware of this injury due to the potentially serious long-term sequelae and associated loss of playing time.

The radiologic workup after a presumed traumatic hip injury begins with plain radiographs including an AP view of the pelvis and AP and frog-lateral views of the affected hip. In many cases, this will provide a relatively definitive diagnosis such as an acute traumatic fracture, avulsion fractures, dislocation, subluxation, osteitis pubis, or degenerative joint disease. Additional views that are typically required include a crosstable lateral radiograph and Judet oblique films to further assess acetabular fractures that are noted on the AP pelvis. Once the diagnosis of a hip dislocation is made, a careful evaluation of the femoral neck must be performed to rule out the presence of a femoral neck fracture before any manipulative procedures are performed.

Management of a hip dislocation is divided into an initial phase of achieving a rapid reduction of the dislocation followed by a secondary phase, which focuses on performing definitive care [20]. The initial urgency of reducing a dislocated hip is to minimize long-term complications such as avascular necrosis (AVN). Closed reduction performed under 6 hours has been shown to reduce AVN rate [21]. Estimates of AVN following hip dislocation varies in the literature from 1% to 17% [21–23]. At times, to achieve a safe reduction, the resources of the operating room may be necessary such as adequate anesthesia and fluoroscopy. After closed reduction is performed, additional films usually include an AP view of the hip and a CT scan with fine (3 mm) cuts through the hips. The value of CT scanning is its ability to assess the femoral head and to demonstrate the presence of small intraarticular fragments. In addition, CT can better visualize the size, location, and displacement of any associated acetabular wall fractures. In the acute setting of traumatic hip dislocations, numerous studies have demonstrated that MRI may aid in the diagnosis of labral disruptions, femoral head contusions and microfractures, sciatic nerve injury, and intraarticular fragments [24,25].

Most hip dislocations sustained during athletic activities are pure dislocations with either no associated fractures or small acetabular rim fractures due to the relative low-energy mechanism. Thus, surgical stabilization is often not indicated. Active and passive range of motion (ROM) can begin as soon as comfort permits. Flexion greater than 90° and internal rotation greater than 10° is not permitted for 6 weeks [26].

Surgical management is warranted for most displaced acetabular fractures that involve the weight-bearing portion to allow early ambulation and to produce a stable and congruent joint and allow early motion/ambulation [27]. Giza et al [16] recently reported two hip fracture dislocations sustained during soccer that involved 20% to 40% of the weight-bearing portion of the posterior wall of the acetabulum that required open reduction and internal fixation. Examination under anesthesia with stress testing of the hip is warranted if there is any question regarding the size and significance of posterior wall injuries.

Recently, hip arthroscopy has become a new adjuvant to open surgery to address femoral head pathology, chondral injuries, loose bodies, and labral pathology. Its role is not well defined and the optimal timing of the procedure is debatable given the concern of placing a hip in traction too soon after a dislocation. We feel that hip arthroscopy should be delayed for at least 6 to 12 weeks so that a repeat MRI can be performed to rule out the presence of early AVN before placing the patient into traction.

Traumatic posterior hip subluxation has recently received increased attention because it is a potentially devastating injury that may be misdiagnosed as a simple hip sprain or strain. Similar to hip dislocations, the mechanism is most often a fall on a flexed hip and knee with a posteriorly directed force being transmitted through the hip joint [28]. Due to less energy, the hip subluxates rather than dislocates. Physical examination usually reveals painful limitation of hip motion [28]. Unlike dislocation, hip subluxation has a more subtle

presentation, and a high index of suspicion is necessary to avoid missing the diagnosis.

Patients who have sustained a hip subluxation often have normal radiographs or they demonstrate nonspecific changes. Moorman et al [28] performed Judet radiographs, which demonstrated posterior acetabular lip fractures in seven patients who sustained a posterior hip subluxation during American football. They have recommended that the radiographic workup of a patient who has a suspected hip subluxation should include radiographs of the hip, including oblique radiographs to evaluate for a “posterior lip fracture.” The role of MRI is growing increasingly more important in the evaluation of traumatic instability. Moorman et al [28] performed MRIs on seven American football players suspected of having traumatic posterior hip subluxation, and defined a characteristic triad of findings including a posterior acetabular lip fracture, an iliofemoral ligament disruption, and a hemarthrosis. Patients typically will have an effusion in the hip joint as well as bone marrow edema in the region of the acetabular lip fracture. The presence of a significant hemarthrosis may push the treating physician toward fluoroscopic aspiration to decrease intra-capsular pressure (Fig. 6). Commonly, nondisplaced posterior wall injuries are present, analogous to a bony Bankart lesion in the shoulder. MRIs will typically demonstrate disruption of the iliofemoral ligament, confirming that the anterior structures are torn as they are placed on tension during the posterior subluxation episode. In our experience, the entire anterior capsulolabral complex may be injured involving both the iliofemoral ligament as well as the anterior labrum. Chondral shear injuries to the femoral head may also be seen, and an MRI can help to identify the presence of large cartilaginous loose bodies floating in the central and peripheral compartments, potentially pushing the treating physician toward arthroscopic removal (Fig. 7A–D).



Fig. 6. MRI of collegiate football player who sustained a posterior hip subluxation event resulting in significant hemarthrosis. This patient was taken for urgent aspiration under fluoroscopic guidance.

MRI is also a useful tool to detect AVN. Although MRI is not an accurate predictor of AVN in the acute setting, a repeat scan usually should be performed at 6 weeks. If patients have no evidence of osteonecrosis at 6 to 12 weeks, they may return safely to sports activity. Those with evidence of osteonecrosis are at increased risk for subsequent collapse and joint degeneration, and the treating physician should caution the athlete about the risks associated with return to contact sports [28,29]. A general treatment algorithm for the management of athletic hip subluxation or dislocation is outlined in Fig. 8.

The last question that remains is what happens to athletes with untreated hip dislocations or subluxations? Athletes that sustain acute hip dislocations or

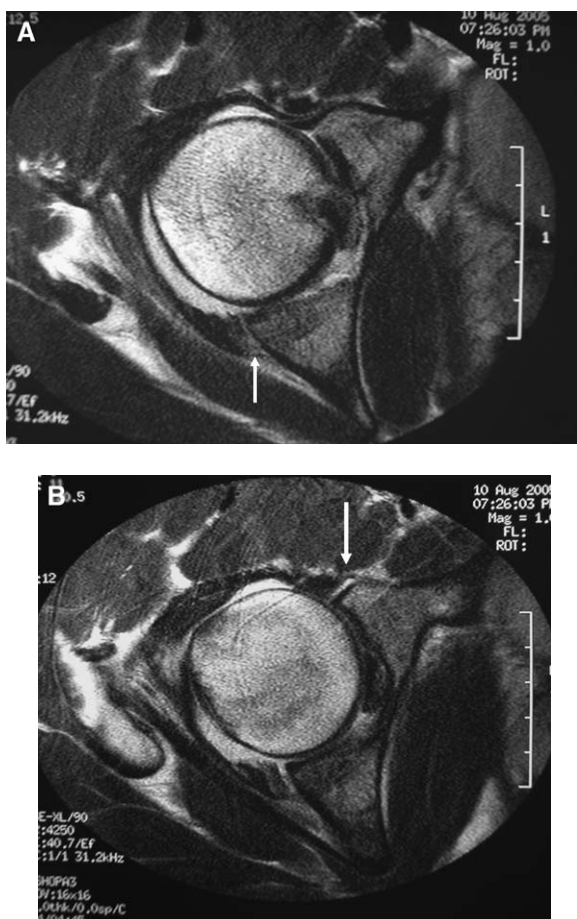


Fig. 7. MRI of a recent posterior subluxation event demonstrating posterior rim injury (A), anterior capsulolabral injury (B), chondral shear injury to the femoral head (C), and chondral loose bodies in the peripheral compartment (D).

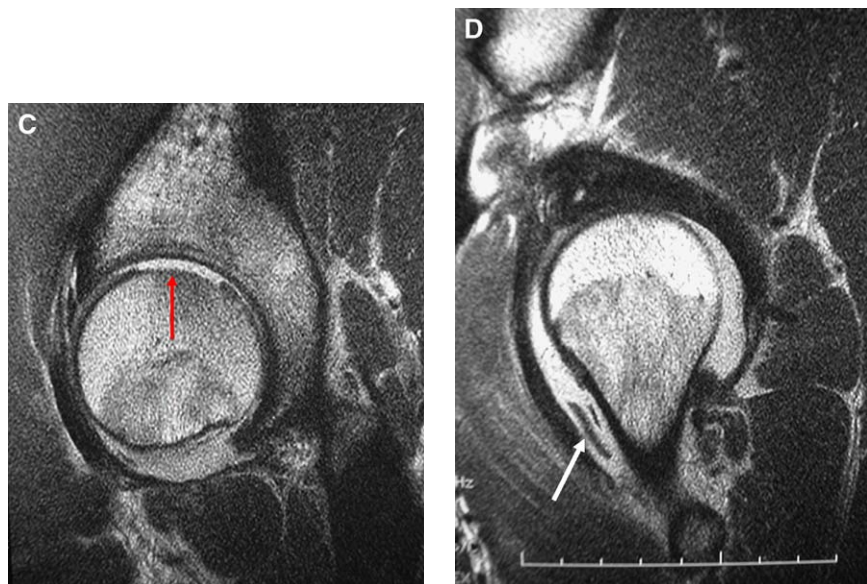


Fig. 7 (continued).

subluxations may develop chronic instability. Several papers have cited hip capsular laxity associated with previous hip dislocations [30–32]. Liebenberg [33] described two cases of recurrent posttraumatic hip dislocations that both had initial posterior dislocations sustained during football. The first patient had his first dislocation occur on the football field when he was 16 years old, which was followed by two subsequent hip dislocations with minor trauma. Arthrography after the third dislocation revealed a posterior capsular lesion, and thus, the patient underwent surgery before the introduction of hip arthroscopy. During this open procedure, the labrum was identified and found to be retained at its attachment to the acetabular margin. However, there was attenuation of the capsular fibers, which allowed abnormal mobility of the labrum in a proximal to distal direction. Repair of the capsular defect was performed by excising the synovial pouch and by a “double-breast” repair of the lower part of the capsule over the upper with silk sutures. The second patient also sustained the first dislocation during football and then dislocated four subsequent times with minimal trauma. This patient also underwent open surgery and, again, the labrum was still attached firmly to the acetabular rim and the capsule was repaired with silk sutures. The authors concluded that a broad defect in the posterior capsule allowed the femoral head to dislocate and that obliteration of the pseudocavity by capsular repair appeared to be an adequate solution to the problem.

Other reports have also associated the presence of excessive hip capsular laxity and labral injury associated with previous hip dislocations or subluxation

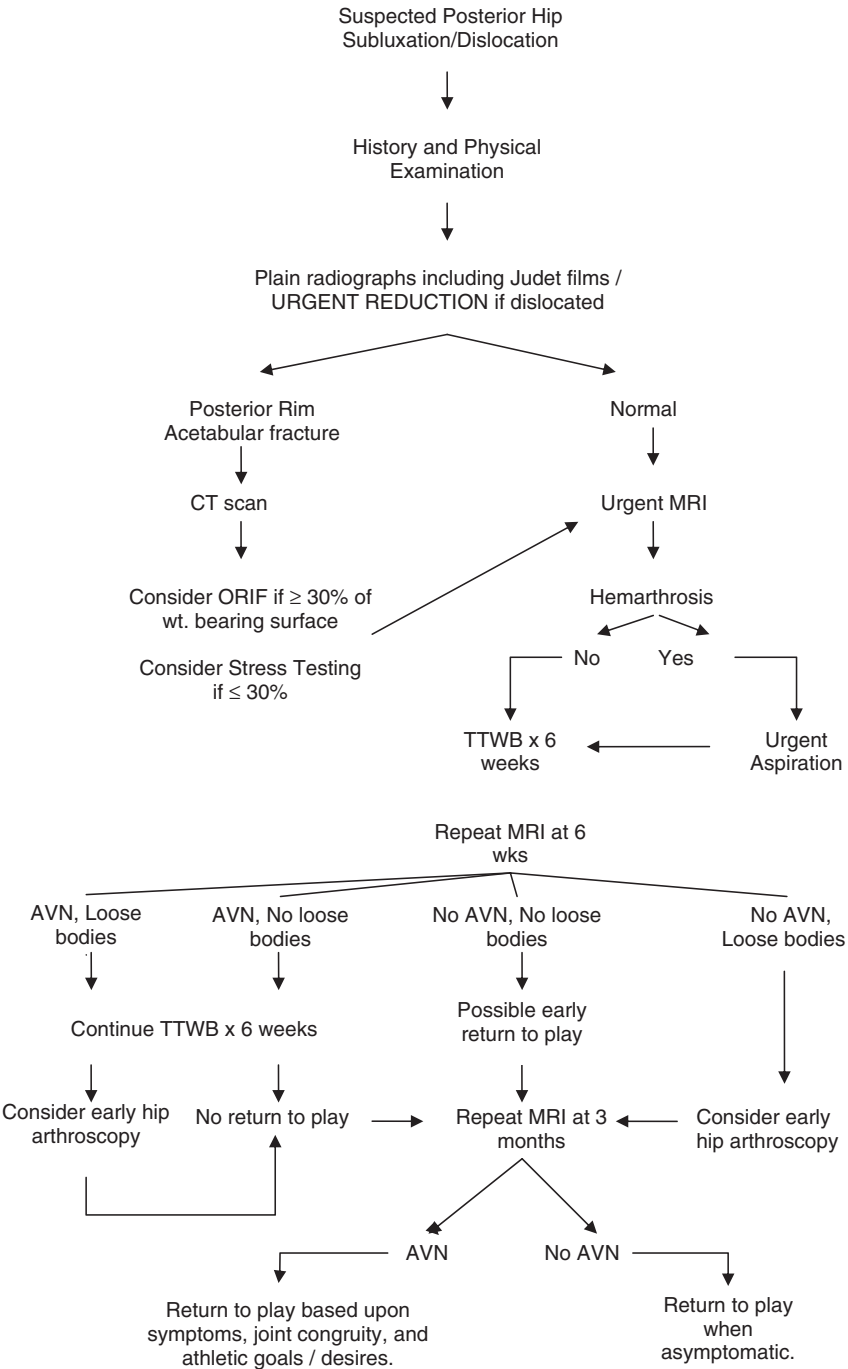


Fig. 8. Treatment algorithm for athletic hip subluxation or dislocation.

[30,31,34,35]. Nelson et al [32] also reported a case of a 21-year-old male who sustained his first hip dislocation at 13 years of age when he was playing football. Subsequently, he had two more dislocations with minor trauma, and arthrography revealed a posterior capsular lesion. Due to this finding, he was taken to the operating room for an open repair, and a tear of the capsule was identified, which included the labrum. The capsule was sutured and the detached labrum was firmly attached more medially to the acetabular rim. The patient tolerated the procedure well and was asymptomatic 18 months after the surgery. The authors concluded that recurrent dislocations of the hip were due to either erosion of the fibrocartilaginous labrum, or attenuation and tearing of the capsule [32].

ATRAUMATIC INSTABILITY

Due to a lack of a discrete acute event, the etiology of hip pain in the absence of trauma may be more difficult to determine. Furthermore, the differential diagnosis of hip pain is quite broad (Table 1). Based on the history and physical examination, various categories can be eliminated and the differential diagnosis further narrowed. The history should assess the timing of the onset of symptoms, the qualitative nature of the discomfort (pain, clicking catching, instability, stiffness, weakness), the specific location of the discomfort, and the precipitating cause of the symptoms [1,7].

Atraumatic instability can occur due to overuse or repetitive motion. This is a common complaint in athletes who participate in sports involving repetitive hip rotation with axial loading (ie, figure skating, golf, football, baseball, martial arts, ballet, gymnastics, and so forth). The history provides the greatest clues to the diagnosis because patients can usually describe the motion that causes the pain such as swinging a golf club during a drive or throwing a football toward the sideline. These repetitive stresses may directly injure the iliofemoral ligament or labrum and alter the balance of forces in the hip. These abnormal forces cause increased tension in the joint capsule, which can lead to capsular redundancy, painful labral injury, and subsequent microinstability. On physical examination, patients will usually experience anterior hip pain while in the prone position with passive hip extension and external rotation [1,7].

Once the static stabilizers of the hip including the iliofemoral ligament and labrum are injured, the hip must rely more on the dynamic stabilizers for stability. It is hypothesized that when capsular laxity is present, the psoas major, a dynamic stabilizer of the hip, contracts to provide hip stability. Over time, this condition can lead to stiffness, coxa saltans, or flexion contractures of the hip [14]. In addition, due to the origin of this muscle from the lumbar spine, a chronically contracted or tightened psoas major may be a major contributor to low back pain. Thus, hip instability or capsular laxity can trigger a whole spectrum of disorders that the physician must take into consideration when considering various treatment options.

In addition to screening plain radiographs, an MRI is critical for the further workup of unexplained hip pain. An MRI allows for high-resolution imaging

Table 1

Differential diagnosis of hip pain

Primary labral pathology	Non-musculoskeletal causes
Femoroacetabular impingement	Genitourinary
Laxity	Spine
Trauma	Psoas muscle abscess
Dysplasia	Hernia
Degenerative	Endometriosis
	Ovarian cyst
	Peripheral vascular disease
Primary chondral	Unknown etiology
Lateral impact	Transient osteoporosis of the hip
Subluxation/dislocation	Bone marrow edema syndrome
AVN	
Loose bodies	
Degeneration	
Primary capsule	Synovial proliferative disorders
Laxity	Pigmented villonodular synovitis
Adhesive capsulitis	Synovial chondromatosis
Synovitis/inflammation	Chondrocalcinosis
Extra-articular	Infectious/tumor/metabolic
Snapping hip (internal/external)	Septic arthritis
Trochanteric bursitis	Osteomyelitis
Ischial bursitis	Benign bone and soft tissue
Psoas bursitis	Neoplasms
Osteitis pubis	Malignant bone and soft tissue
Sports hernia	Neoplasms
Piriformis syndrome	Paget's disease
SI joint	Primary hyperparathyroidism
Tendonitis	Metastatic bone disease
Hip flexor	
Adductor	
Abductor	
Gluteus medius tear	
Inflammatory	Systemic
Rheumatoid arthritis	Polyarticular
Reiter's syndrome	RSD
Psoriatic arthritis	Regional pain sx
Bursitis	Hormonal

of not only the osseous structures of the hip, but more importantly, the soft tissue structures, including muscle, synovium, and acetabular labrum in multiple orthogonal planes. For evaluation of the capsulolabral structures in the hip, magnetic resonance (MR) arthrography increases the sensitivity and accuracy when compared with a conventional MRI [36]. Byrd et al [37] recently demonstrated that MR arthrography was much more sensitive than conventional MRI for detecting various lesions, but leads to twice as many false-positive interpretations. In addition, this study showed that a response to an intra-articular injection of bupivacaine was a 90% reliable indicator of intraarticular

abnormality. More recently, however, Mintz et al [38] demonstrated that a noncontrast MRI of the hip, using an optimized protocol, can noninvasively identify labral and chondral pathology with a high degree of accuracy.

The management of atraumatic instability is still quite unclear. With the advent of better diagnostic and therapeutic capabilities, it is becoming increasingly more recognized as a real entity. If a patient has a physical examination and history consistent with capsulolabral injury and instability, and appropriate imaging studies corroborate the clinical suspicion, then a trial of physical therapy and anti-inflammatories may be appropriately administered in an attempt to break the cycle of painful capsulolabral pathology. If this fails and the patient has pain relief after an intraarticular anesthetic injection, then hip arthroscopy may be appropriate.

Recently, success has been reported with anatomic restoration of the labrum and a reduction in capsular laxity [34]. To reduce the volume of the capsule, thermal capsulorrhaphy and/or capsular plication may be performed (Fig. 9). Although controversial, the use of thermal energy has been used as a means of shrinking redundant or lax connective tissues using the mechanism of collagen denaturation [39–41]. Arthroscopic thermal modification of collagen in the hip capsular tissue combined with labral debridement appears to be an effective treatment option for patients with chronic hip instability. During this procedure, the capsule is probed and if excessive laxity is present, a focal thermal capsulorrhaphy is performed with a flexible probe at a temperature of 67°C and 40 watts. Phillipon [42] uses three passes performed in a cornfield pattern. No charring should be seen, and capsular contraction should be visualized. If capsular redundancy is still present after this procedure, plication may also be performed by passing and tying a nonabsorbable No. 2 braided suture through the capsule (Fig. 10). One limb of the suture is passed through the medial limb of the Y-ligament (iliofemoral ligament) and the other limb is passed through



Fig. 9. Arthroscopic image demonstrating thermal capsulorrhaphy.



Fig. 10. Arthroscopic image demonstrating capsular plication.

the lateral limb. Additional sutures can be passed through the posterior capsule. If further tension is required, sutures can be passed through the more superior capsule under direct visualization within the peripheral compartment. These steps are repeated until excellent capsule tension is observed and there is stability to the capsule upon rotational testing.

Philippon [1] reported on 10 patients who had intractable hip pain with subtle signs of instability on examination combined with visualization of redundant capsular tissue during arthroscopy and underwent labral tear debridement with thermal capsulorrhaphy. The patients were allowed to weight bear as tolerated, and had rotation and extension precautions for 18 days. Preliminary results showed excellent outcomes with the first eight patients resuming their preinjury athletic activities with minimal or no pain.

On the extreme end of the atraumatic instability spectrum are patients with generalized ligamentous laxity or collagen disorders. The clinician should be aware of the subtle variants of generalized joint laxity (hyperextension of the elbows, hypermobility of the shoulders, and increased finger and wrist laxity) [1]. Patients may also have an underlying connective tissue disorder such as Ehlers-Danlos syndrome or Marfan syndrome, and may be able to voluntarily or habitually dislocate their hips [2]. The diagnosis is usually quite clear based upon the generalized findings as well as genetic testing in these patients.

Another category of atraumatic instability exists and consists of patients with anatomic deficiencies. When deviation occurs from “normal” bony anatomy, the hip must rely more on the soft tissue structures including the capsule and labrum for stability. Tonnis et al [2] evaluated the radiographs and CT scans of 356 hips in 181 patients and calculated the McKibbin instability index. They demonstrated that patients with a normal McKibbin instability index had the lowest rates of pain and osteoarthritis and had balanced ranges of rotation of the hip. As the McKibbin instability index approached the upper and lower extremes, patients had significantly more pain, osteoarthritis and altered degrees of hip rotation. They concluded that a McKibbin instability index of less than

20 is a major cause of osteoarthritis, pain and altered rotation of the hip. Due to a small sample size, patients with an increased McKibbin instability index had a tendency toward increased pain and osteoarthritis but definite conclusions were not possible [2,8].

If a patient has significant dysplasia, the role of hip arthroscopy is less well defined because addressing soft tissue pathology without addressing the underlying bony deformity may increase the failure rate of the surgical procedure. Nonetheless, several reports in the literature have reported good and excellent results in the management of labral pathology in patients with dysplasia [43,44]. These reports have discussed the role of labral debridement in patients with dysplastic hips and new mechanical symptoms associated with labral injury. In our experience, there is a significant role for labral repair in these patients, as preservation of the soft tissue anatomy will likely provide improved outcome in patients with overall bony deficiency. In cases of severe dysplasia the role of reorientation osteotomy should be examined [3,45].

It is important to differentiate whether the bony deformities are primary or secondary in nature. Bellabarba et al [14] described a cohort of patients that had longstanding painful snapping in the groin with no history of trauma. Using manual longitudinal traction under fluoroscopy, these patients were diagnosed with idiopathic hip instability and had evidence of mild acetabular dysplasia on plain radiographs. They postulated that the main pathologic process in these patients was capsular laxity, which resulted in clinically insignificant, yet radiographically detectable acetabular dysplasia. One of these patients was treated with a posterior imbrication capsulorrhaphy and her symptoms of pain, coxa saltans, and gait disturbances disappeared. Thus, in some patients the bony deformity may be secondary to soft tissue abnormalities.

SUMMARY

Hip instability may be of traumatic or atraumatic origin. We define here the treatment algorithm for traumatic instability. The algorithm for atraumatic instability is less well defined. Hip arthroscopy is now becoming a more common orthopaedic procedure and potentially has a role for the treatment for traumatic and atraumatic instability. Further studies are warranted to understand the clinical course of this disease entity and to test the effectiveness of these procedures to treat them.

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Microfracture of the Hip in Athletes

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Technologic advance and refinement of technique have together revolutionized the modern field of hip arthroscopy. These advances have enabled surgeons to address subtle pathology in and around the hip joint that previously was either misdiagnosed or poorly understood. As both the indications and the applications of this surgical technique have expanded, one area of significant interest in the hip joint is articular cartilage injury. Previous authors have shown that articular cartilage defects rarely heal spontaneously regardless of whether acute, chronic, or degenerative [1]. The vast majority of studies addressing the treatment of articular cartilage lesions have involved the knee. Various techniques have been employed in an attempt to treat this difficult problem including abrasion chondroplasty, osteochondral drilling, the use of osteoarticular autograft or allograft plugs, bulk allograft techniques, autologous chondrocyte implantation, and microfracture [2–6]. Microfracture of the knee has become increasingly popular among orthopedic surgeons as the preferred treatment for chondral defects. Several studies have shown good clinical results following microfracture of chondral defects [3,7–10].

Microfracture falls into the category of marrow-stimulating procedures. When microfracture is properly performed, subchondral perforation brings undifferentiated stem cells into the defect from the marrow. A marrow clot is established within the microfractured area. This clot provides an environment for both pluripotential marrow cells and mesenchymal stem cells to differentiate into stable tissue within the base of the lesion. Histologic evaluation indicates that fibrocartilaginous tissue is the final product covering the previous lesion [11].

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CHONDRAL INJURIES OF THE HIP

Chondral injuries of the hip may be seen in conjunction with a variety of hip disorders, and may result from an atraumatic or traumatic etiology. These disorders include labral tears, loose bodies, hip instability or dislocation, osteonecrosis of the femoral head, slipped capital femoral epiphysis, hip dysplasia, and degenerative joint disease [12–17]. Chondral injuries can be acute, chronic, or degenerative, and may be partial thickness or full thickness lesions.

In their report after arthroscopy of 457 hips over a 6-year period, McCarthy et al [17] found that most chondral injuries were associated with a torn acetabular labrum. The anterior acetabulum was affected in the majority of hips. Chondral injury was noted in the superior acetabulum in 24%, and the posterior acetabulum in 25% of the patients in this series. Seventy percent of anterior acetabular chondral lesions were Outerbridge grade III or IV, whereas only 36% of all posterior and 27% of all superior acetabular defects were graded III or IV.

Another common injury pattern is the cartilage defects in the presence of cam or pincer impingement. Cam impingement results from pathologic contact between an abnormally shaped femoral head and neck with a normal acetabulum. As the hip flexes, this abnormal region of the femoral head contacts the acetabulum. This contact results in force, which can produce chondral injury. Pincer impingement is the result of contact between an abnormal acetabular rim and, typically, a normal femoral head–neck junction. This results in decreased joint clearance and repetitive contact between the femoral neck and acetabulum. This repetitive contact can cause injury to the chondral surface of the femur or a “contre-coup” injury of the acetabulum.

As the experience with hip arthroscopy expands, so, too, will the ability to recognize the various injury patterns to the chondral surfaces of the hip. As our understanding of the pathologic processes contributing to chondral injury of the hip joint improves, perhaps we will be able to intervene preventing the progression to osteoarthritis.

INDICATIONS AND CONTRAINDICATIONS

The indications for microfracture of the hip include focal and contained lesions, typically less than 2 to 4 cm in size. Some authors have noted that lesions less than 400 mm² tend to respond better to microfracture than lesions 400 mm² or greater [9]. Other indications include full thickness loss of articular cartilage in weight-bearing areas and unstable cartilage flaps overlying intact subchondral bone. Patients with degenerative joint disease of the hip may also be candidates for this procedure, especially if the changes are focal and not extensive enough to warrant total hip arthroplasty. Other considerations for performing the procedure include patient age, activity level, and the ability to comply with the postoperative rehabilitation protocol.

Contraindications to microfracture include partial thickness defects and those chondral lesions associated with a bony defect. Those patients who are unwilling to follow the postoperative protocol should not have this procedure. Patients may not be able to effectively comply with the postoperative rehabilitation

protocol if they are unable to bear weight on the contralateral leg. Some patients over the age of 60 may have difficulty using crutches to protect the treated limb. This age limit should be a relative contraindication because there are many people over the age 60 that are healthy and active and meet the preoperative criteria. Other specific contraindications include systemic processes such as immune-mediated disease and systemic disease induced arthritis or cartilage injury [8,9,13].

HISTORY AND PHYSICAL EXAMINATION

A thorough history is the most useful clinical tool to diagnose and treat hip disease. The clinician should inquire about the location, frequency, pattern, and radiation of symptoms. Clicking, locking, and other mechanical symptoms are common with labral injuries, whereas pain, stiffness, and decreased hip range of motion may suggest an inflammatory process. The clinician should establish which factors exacerbate or relieve the symptoms, and whether the complaints are of an acute or chronic nature. Intraarticular hip pain usually presents as groin discomfort and may radiate to the anterior thigh. Pain which emanates from the thigh or buttock with radiation to the knee or below can often be attributed to a neurogenic disorder [12,13].

A history of coagulopathy, collagen disorder, vascular or inflammatory disorder, any history of malignancy, alcohol abuse, steroid therapy, or use of nonsteroidal anti-inflammatory drugs may help to guide the clinician's evaluation. Patients with a history of developmental dysplasia of the hip or brace use as a child, may have an arthritic process resulting from dysplastic changes. A history of trauma and any subsequent treatment should also be sought. A history of sports participation often yields helpful information. Athletes competing at a higher level of sport have a greater propensity to develop both labral tears and chondral injuries. Any history of prior hip surgery should also be elicited [12,13].

The physical examination should be thorough. The position of the hip at rest should be noted, as it may indicate the underlying pathology. For example, a hip that is abducted, flexed, and externally rotated achieves the greatest capsular volume, suggesting an effusion or synovitis. The patient's gait should be noted. Examination of the lumbar spine including motor function, sensation, range of motion, reflexes, and straight-leg raises must be performed to rule out lumbar spine pathology as the cause of symptoms. Leg-length discrepancies should be assessed [12,13].

The hip examination begins with palpation of bony prominences about the hip and assessment of range of motion. Side-to-side differences should be noted as they may indicate areas of pathology. Clicking, catching, or other mechanical symptoms during the examination are common findings associated with the diagnosis of a labral tear. Although chondral injuries may be associated with mechanical symptoms, there is no specific examination maneuver to assess for them. The impingement test should be performed in the supine position.

Guarding and decreased range of motion is also evaluated in the prone and lateral decubitus positions.

IMAGING

Plain radiographs are the most useful imaging tool for the initial evaluation of hip complaints. Radiographs can reveal degenerative disease, bony lesions, dysplastic changes, the presence of loose bodies, and impingement. An MRI allows improved visualization of the soft tissues, early degenerative changes, and osteonecrosis [12,13,18]. Plain MRI does not accurately identify labral or chondral defects primarily because the lack of joint distension makes it more difficult to assess the cartilage surface. Sekiya et al found that plain MRI is not adequate for measuring the articular cartilage of the hip joint in avascular necrosis (AVN) when compared with hip arthroscopy [19]. They suggested that either direct visualization by arthrotomy or arthroscopy of the hip joint is required for accurate evaluation and staging of cartilage, especially in Marcus-Enneking stage IV AVN [19].

MRI arthrogram allows improved visualization of intraarticular structures. Dilute gadolinium is injected into the joint of interest, which distends the capsule and allows better visualization of the articular cartilage. Labral tears can be identified by an abnormal linear extension of contrast solution into the labrum. Chondral lesions are better visualized when the cartilage defect is outlined by gadolinium. Keeney compared MRI arthrogram with arthroscopy of the hip and showed that the MRI arthrogram detected 76% of the acetabular labral tears [20]. Articular cartilage findings on the MRI arthrogram were confirmed using arthroscopy only 62.7% of the time. In Keeney's study [20], the MRI arthrogram had a sensitivity of 47%, specificity of 89%, a positive predictive value of 84%, and negative predictive value of 59%. Although MRI arthrogram offers improved evaluation of the chondral surface, this technique has been shown to have a high false-negative rate, thus limiting its usefulness in identifying true articular surface damage [18,20].

OPERATIVE TECHNIQUE

We perform hip arthroscopy using a standard fracture table with the patient in the modified supine position in which the hip is placed in a position of 10° flexion, 15° internal rotation, 10° lateral tilt, and neutral abduction [21]. Traction is placed on the affected limb using a foot stirrup. Adequate traction typically requires between 25 and 50 pounds of force [22]. Usually 7 mm to 15 mm of joint distraction is adequate for evaluation and instrumentation. The C-arm is used to confirm the amount of traction and to facilitate portal placement. Portal placement includes anterior, anterolateral, and peripheral portals [23–26].

A complete diagnostic examination of the hip joint should be performed. Once the chondral defect is identified, the extent of the lesion is noted (Fig. 1). Debridement of all remaining unstable cartilage from the exposed bone is completed using a full radius resector and curettes. Debridement of the rim

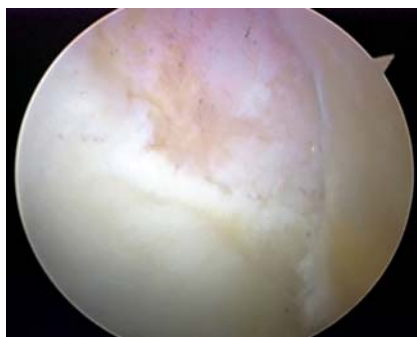


Fig. 1. Chondral lesion of the hip visualized at arthroscopically.

surrounding the defect should be careful and meticulous. A ring curette is particularly useful for preparation of the defect and creating a smooth, perpendicular border (Fig. 2). Debridement should remove the calcified cartilage layer; however, the integrity of the subchondral plate should be maintained [6,7]. The edges of the lesion should be perpendicular to the adjacent, unaffected cartilage to allow for the marrow clot to form more effectively. For lesions of the femoral head, where the cartilage is thinner, an adequate border must be prepared to maintain the clot. After preparation of the bed, arthroscopic awls (Fig. 3) with an angle that allows the tip of the awl to be perpendicular to the subchondral bone surface, are used to make multiple holes (“microfractures”) in the exposed subchondral bone plate. Microfracture holes are made around the periphery of the bed first immediately adjacent to the healthy cartilage rim. As many holes as possible are created, leaving about 3 to 4 mm between each (Fig. 4). A depth of approximately 2 to 4 mm is usually sufficient to access marrow elements. With the irrigation pressure decreased, the release of fat droplets and blood from the microfracture holes can be observed (Fig. 5). Once microfracture is complete, the instruments are removed and the intraarticular fluid is drained from the hip.



Fig. 2. A curette is used to prepare the defect, including a perpendicular border.



Fig. 3. Microfracture awls used in the hip.

The portals or incisions are closed in standard fashion, and sterile dressings placed over the wounds. The patient usually is discharged the same day but may stay overnight to allow for optimal pain control and to initiate physical therapy contact [6,9,13].

Postoperative management parallels that of knee microfracture. Great care is taken to maintain the marrow clot, and thus the ideal environment for appropriate healing. Use of a continuous passive motion (CPM) machine is used throughout the 8-week period. Crutch-assisted touchdown weight bearing is allowed for 6 to 8 weeks, with advancement to full weight bearing after 8 weeks. Initial physical therapy consists of passive motion progressing to active-assisted motion and eventually active motion with particular emphasis on regaining hip internal rotation. The early phase of physical therapy should focus primarily on achieving range of motion. This phase is followed by an emphasis on muscular endurance. The last phase of therapy focuses on the return of power and strength. Stationary bicycle exercises without resistance are begun in the immediate postoperative period. Cryotherapy is also used in the immediate postoperative period to provide pain relief and to decrease the inflammatory response. Impact sports are delayed until at least 4 to 6 months postoperatively,



Fig. 4. Microfracture of the hip with holes approximately 3 to 4 mm apart.



Fig. 5. Clot formation following microfracture.

and only after range of motion, strength, and functional agility have returned to normal [9,13].

DISCUSSION

There are very few published series following arthroscopic microfracture for full-thickness chondral defects of the hip. In 2002, Byrd et al [27] reported on nine patients with an inverted acetabular labrum. Three of these patients were treated using a microfracture technique. At a minimum 2-year follow-up, those patients that underwent microfracture were the only patients to return to a level of activity higher than simple activities of daily living. These three patients' activities included martial arts, horseback riding, and fitness activities.

In a group of 28 professional athletes, 19 cartilage lesions were treated in addition to other pathologies. All athletes had pain relief and returned to competition by 12 weeks postoperatively (Bharam S, et al. Unpublished data, Meeting of the American Orthopaedic Society for Sports Medicine, Orlando, FL, 2002) Recently, Byrd et al reported on 21 patients who underwent microfracture of the hip. The average size of the lesion was 12.2 mm², and the average age of the patient was 35 years. At the 2-year follow-up, 86% of the patient had improved and no complications were reported (Byrd T, et al. Unpublished data. Meeting of 2005 ISAKOS Meeting, Miami, FL).

McCarthy et al [28] described a cohort of 10 elite athletes that underwent hip arthroscopy for a variety of diagnoses. Of these, four patients had chondral injury on the acetabular side of the joint that underwent an unspecified treatment. All 10 athletes returned to compete in their sport. Fargo et al [29] evaluated 28 hips that underwent arthroscopy for acetabular labral tears with a minimum follow-up of 13 months. They found that patients with degenerative changes noted either radiographically or arthroscopically, whether on the femoral or acetabular chondral surface, had a significantly worse outcome ($P=0.008$, $P=0.0004$, and $P=0.003$, respectively).

In 2003, the first long-term outcomes paper was published on the microfracture technique in the knee [10]. This study reported on 72 patients an average of

11 years following microfracture of the knee, with the longest follow-up at 17 years. With a 95% follow-up rate, the results showed overall improvement in symptoms and function. Patient reported decreased pain and swelling at postoperative year 1, continued decrease at year 2, and those clinical improvements were maintained over the study period. The study identified age as the only independent predictor of Lysholm improvement. Patients over 35 years of age improved less than patient under 35; however, both groups showed improvement [10].

Recently microfracture has been compared with autologous chondrocyte transplantation in the knee [10]. In a randomized study, 40 patients were treated with microfracture and 40 patients were treated with autologous chondrocyte transplantation. Both groups showed improvement in functional outcome and reduced pain. No differences in the repair tissue were noted histologically. Microfracture had a lower rate of failure and repeat debridement.

SUMMARY

Based on our experience, microfracture is a safe and effective method to treat chondral defects of the hip. Early results have shown microfracture significantly improves functional outcomes and decreases pain in the majority of patients treated. The repair tissue created by microfracture appears tough and durable, yet it is smooth enough to function similarly to the patient's normal articular cartilage.

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Rehabilitation Following Hip Arthroscopy

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The management of hip injuries has evolved significantly in recent years with the advancement of arthroscopic techniques. The application of minimally invasive surgical techniques has facilitated relatively rapid returns to sporting activity in both recreational and elite athletes [1]. These recent surgical advances require establishment of rehabilitation guidelines that consider the constraints of soft tissue healing while advancing patients as rapidly and safely as possible.

Although rehabilitation guidelines following hip arthroscopy continue to evolve, the overall goal remains to return the patient to a preinjury level of activity. This involves restoration of normal range of motion, gait, and strength to allow return to functional activity. In the athlete, the rehabilitation program must also focus on restoration of power, speed, and agility for optimal return to competition.

Repaired tissue must be properly protected to allow healing and to prevent excessive stress on tissue. However, prolonged immobilization is not desired because of the numerous deleterious effects, including muscle atrophy, articular cartilage degeneration, ligament strength loss, and excessive adverse collagen formation [2–9]. Rehabilitation protocols need to follow several basic principles: (1) consideration of soft tissue healing constraints, (2) control of swelling and pain to limit muscular inhibition and atrophy, (3) early range of motion (ROM), (4) limitations on weight bearing, (5) early initiation of muscle activity and neuromuscular control, (6) progressive lower extremity strengthening and proprioceptive retraining, (7) cardiovascular training, and (8) sport specific training.

We have divided postoperative hip rehabilitation protocols into four phases. Progression through each phase is based on clinical criteria and time frames as appropriate.

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PHASE I—IMMEDIATE REHABILITATION

Goals

- Protect integrity of repaired tissue
- Restore ROM within restrictions
- Diminish pain and inflammation
- Prevent muscular inhibition

Precautions

- Do not push through hip flexor pain
- Specific ROM restrictions (surgery dependent)
- Weight-bearing restrictions

Criteria for Progression to Phase II

- Minimal pain with all phase I exercise
- ROM $\geq 75\%$ of the uninvolved side
- Proper muscle firing patterns for initial exercises
- Do not progress to phase II until full weight bearing is allowed

Rehabilitation

The initial phase of rehabilitation is started immediately following surgery. The goals during this phase are to protect the integrity of repaired tissue, diminish pain, and inflammation, restore ROM within restrictions, and prevent muscular inhibition. During the initial phase, a brace is used to maintain motion restrictions and protect the joint for 10 days. Swelling and pain are controlled through the use of ice and nonaspirin nonsteroidal anti-inflammatory drugs.

Early ROM is initiated to restore joint motion and decrease tissue scarring in the joint. ROM is started the day of surgery using a continuous passive motion (CPM) machine, passive ROM exercises, and stationary bicycling. The CPM is typically used 8 to 12 hours per day for 4 to 6 weeks. With early PROM, emphasis is placed on internal rotation and flexion of the hip to prevent formation of adhesions between the joint capsule and the labrum. Progressive stretching of the piriformis and iliopsoas muscles is beneficial in preventing muscle contractures. Early stretching of the posterior hip capsule is achieved through quadruped rocking (Fig. 1). Stationary bicycling with minimal resistance is done for 20 minutes daily, starting the day of surgery.

The prevention of muscular inhibition is achieved through early strength exercises that limit joint stress while providing the appropriate load through the hip and lower extremity muscles. Aquatic walking with the use of a waterproof dressing in chest deep water can be initiated postoperative day 1. Early ambulation in the pool allows patients to work on gait symmetry and low load strengthening in an unweighted environment. Isometric strengthening is initiated as early as day 1 for the gluteals, quadriceps, hamstrings, and transverse abdominals. Hip adduction and abduction isometrics, prone internal and exter-



Fig. 1. Quadrupedal rocking.



Fig. 2. Prone internal and external rotation isometrics.



Fig. 3. Double leg bridges.

nal rotation isometrics (Fig. 2), and three-way leg raises (abduction, adduction, and hip extension) are started as early as week 2. Patients also start double leg bridges (Fig. 3), leg press with limited weight, and short lever hip flexion (Fig. 4) during the initial exercise phase. Once the goals for phase I have been met and full weight bearing is allowed, patients are progressed to the intermediate phase of rehabilitation.



Fig. 4. Short lever hip flexion.

PHASE II—INTERMEDIATE REHABILITATION

Goals

- Protect integrity of repaired tissue
- Restore full ROM
- Restore normal gait pattern
- Progressively increase muscle strength

Precautions

- No ballistic or forced stretching
- No treadmill use
- Avoid hip flexor/joint inflammation

Criteria for Progression to Phase III

- Full range of motion
- Pain-free/normal gait pattern
- Hip flexion strength >60% of the uninvolved side
- Hip add, abd, ext, IR, ER strength >70% of the uninvolved side



Fig. 5. Double one third knee bends.

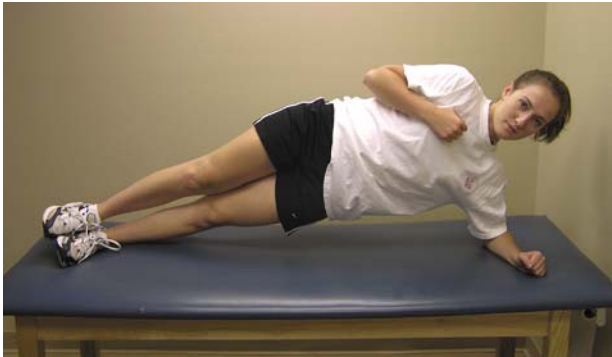


Fig. 6. Side supports.



Fig. 7. Single leg stance on Dyna-disc (Exertools Novato, California).



Fig. 8. Advanced bridging.

Rehabilitation

The intermediate phase of rehabilitation is typically started between 4 and 6 weeks postoperatively, dependent upon the surgical procedure and weight-bearing restrictions. The second phase of rehabilitation includes a progression of ROM/stretching, gait training, and strengthening. PROM and stretching exer-



Fig. 9. Single leg cord rotations.



Fig. 10. Sidestepping with resistance.

cises should be continued as needed to achieve full ROM. Gait training should take place both in the pool and on land as the patient is progressed off of crutches. Intermediate strength exercises include double one third knee bends (Fig. 5), side supports (Fig. 6), stationary biking with resistance, swimming with fins, single leg stance on a Dyna Disc (Exertools, Novato, California) (Fig. 7), advanced bridging (Fig. 8), single leg cord rotations (Fig. 9), Pilates skaters, sidestepping with resistance (Fig. 10), and single knee bends (Fig. 11). Cardiovascular training is achieved with the use of an elliptic machine or stairclimber during this phase. Once the goals of phase II have been met, patients are progressed to the advanced phase of rehabilitation.

PHASE III—ADVANCED

Goals

- Restoration of muscular endurance/strength
- Restoration of cardiovascular endurance
- Optimize neuromuscular control/balance/proprioception



Fig. 11. Single knee bends.

Precautions

- Avoid hip flexor/joint inflammation
- No ballistic or forced stretching/strengthening
- No treadmill use
- No contact activities

Criteria for Progression to Phase IV

- Hip flexion strength >70% of the uninvolved side
- Hip add, abd, ext, IR, ER strength >80% of the uninvolved side
- Cardiovascular fitness equal to preinjury level
- Demonstration of initial agility drills with proper body mechanics

Rehabilitation

The advanced phase of rehabilitation is typically started between 6 and 8 weeks postoperatively. During this phase, patients focus on restoration of muscular strength and endurance, restoration of cardiovascular endurance, and neuromuscular control. Advanced strength and neuromuscular control exercises include lunges, water bounding and plyometrics, side to side lateral agilities



Fig. 12. Side to side lateral agilities.

(Fig. 12), forward and backward running with a cord, initiation of a running progression, and initial agility drills. Cardiovascular training should continue with progressive biking, elliptic trainer, stairclimber, and swimming. Once the goals of phase III have been met, patients are allowed to begin sport specific training.

PHASE IV—SPORT-SPECIFIC TRAINING

Criteria for Full Return to Competition

- Full pain-free ROM
- Hip strength >85% of the uninvolved side
- Ability to perform sport-specific drills at full speed without pain
- Completion of functional sports test

Rehabilitation

Sport-specific training is initiated between 8 and 16 weeks postoperatively. The goals of this phase are full return to competition following assessment of ROM, strength, power, and agility. Advanced agility drills and sport specific training are initiated during this phase of rehabilitation. Any deficits in ROM,

strength, balance, and proprioception are addressed during this phase as well. Contact activities should be limited until the patient is cleared for competition by the physician.

All patients should progress through the above phases of rehabilitation. Specifics of each phase are modified based upon the surgical procedure performed.

LABRAL REPAIR

Specific rehabilitation guidelines following labral repair must take into consideration the location and size of the repair. Because the majority of labral tears occurring in the North American population are located on the anterior superior region of the labrum, the following rehabilitation guidelines are specific to these repairs (Table 1) [1,10–12]. Intraoperative analysis reveals that the following ranges of motion do not stress the anterior superior labrum are; 0° to 90° flexion, 0° to 25° abduction, and 0° to 25° external rotation (Philippon MJ, personal communication, June 2005). Postoperatively, patients are instructed to limit ROM as follows: 25° of abduction for 3 weeks, gentle external rotation and extension for 3 weeks, and 90° of flexion for 10 days. Weight bearing is limited to foot-flat weight bearing (20 lbs.) for 2 weeks. A continuous passive motion machine is used for 4 weeks. Patients typically initiate phase I immediately following surgery, phase II at week 4, phase III at week 7, and phase IV at week 9.

OSTEOPLASTY

The focus of rehabilitation following osteoplasty is to avoid impingement of the hip and inflammation of the iliopsoas while restoring full ROM and strength. In cases that involve significant shaving of the femoral neck, caution must also be taken to limit impact activities that may increase risk of femoral neck fracture during the first 8 weeks (Table 2).

Following osteoplasty, flexion is limited to 90° for 10 days to protect the joint from impingement. Weight bearing is limited to foot-flat weight bearing (20 lbs.) for 4 weeks. A continuous passive motion machine is used for 4 weeks. Patients typically initiate phase I immediately following surgery, phase II at week 5, phase III at week 9, and phase IV at week 13.

MICROFRACTURE

The rehabilitation program after microfracture for treatment of chondral defects is crucial to optimal recovery after surgery [13–16]. Rehabilitation is designed to promote the ideal physical environment in which newly recruited mesenchymal stem cells from the marrow can differentiate into the appropriate articular cartilage-like cell lines [17]. The size and anatomic location of the chondral lesion will determine the specific progression of rehabilitation (Table 3) [13–16].

Postoperatively, flexion ROM is limited to 90° to protect the joint from postoperative impingement for 10 days. Passive ROM should focus on all planes of motion, progressing flexion as tolerated after 10 days. Weight bearing is

Table 1
Labral repair

	Week												
	1	2	3	4	5	6	7	9	13	17	21	25	
Phase I: initial exercise													
Ankle pumps	•	•											
Gluteal, quad, HS, Tab isometrics	•	•											
Stationary biking with minimal resistance	•	•	•										
Passive ROM (emphasize IR)	•	•	•	•									
Piriformis stretch	•	•											
Passive supine hip roll (IR)	•	•											
Water walking	•	•											
Quadruped rocking		•	•										
Standing hip IR (stool)		•	•										
Heel sides		•	•										
Hip abd/add isometrics		•	•										
Uninvolved knee to chest		•	•										
Prone IR/ER (resisted)		•	•	•	•								
Sidelying clams			•	•									
3-way leg raises (abd, add, ext)			•	•	•								
Water jogging			•	•									
Dbl leg bridges w/tubing			•	•									
Kneeling hip flexer stretch			•	•									
Leg press (limited weight)			•	•									
Short lever hip flexion/straight leg raises			•	•	•								
Phase II: intermediate exercises													
Double 1/3 knee bends				•	•								
Side supports				•	•								

Table 2
Osteoplasty

	Week											
	1	2	3	4	5	6	7	9	13	17	21	25
Phase I: initial exercise												
Ankle pumps	•	•										
Gluteal, quad, HS, Tab isometrics	•	•										
Stationary biking with minimal resistance	•	•	•	•								
Passive ROM (emphasize IR)	•	•	•	•								
Piriformis stretch	•	•										
Passive supine hip roll (IR)	•	•										
Water walking	•	•	•	•								
Quadruped rocking		•	•									
Standing hip IR (stool)		•	•									
Heel sides		•	•									
Hip abd/add isometrics		•	•									
Uninvolved knee to chest		•	•									
Prone IR/ER (resisted)		•	•	•	•							
Sidelying clams			•	•								
3-way leg raises (abd, add, ext)			•	•								
Water jogging			•	•								
Dbl leg bridges w/tubing				•	•							
Kneeling hip flexer stretch				•	•							
Leg press (limited weight)				•	•							
Short lever hip flexion/straight leg raises				•	•							
Phase II: intermediate exercises												
Double 1/3 knee bends					•	•						
Side supports					•	•						

[illegible]

Table 3
Microfracture

	Week												
	1	2	3	4	5	6	7	9	13	17	21	25	
Phase I: initial exercise													
Ankle pumps	•	•											
Gluteal, quad, HS, Tab isometrics	•	•											
Stationary biking with minimal resistance	•	•	•	•	•	•							
Passive ROM (emphasize IR)	•	•	•	•	•	•							
Piriformis stretch	•	•											
Passive supine hip roll (IR)	•	•											
Water walking	•	•	•	•	•	•							
Quadruped rocking		•	•										
Standing hip IR (stool)		•	•										
Heel sides		•	•										
Hip abd/add isometrics		•	•										
Uninvolved knee to chest		•	•										
Prone IR/ER (resisted)		•	•	•	•								
Sidelying clams			•	•	•								
3-way leg raises (abd, add, ext)			•	•	•	•							
Water jogging			•	•	•	•							
Dbl leg bridges w/tubing				•	•	•	•	•	•	•	•	•	
Kneeling hip flexer stretch				•	•	•	•	•	•	•	•	•	
Leg press (limited weight)				•	•	•	•	•	•	•	•	•	
Short lever hip flexion/straight leg raises				•									
Phase II: intermediate exercises													
Double 1/3 knee bends							•	•					
Side supports							•	•					

[illegible]

Table 4
Capsular Repair

	Week												
	1	2	3	4	5	6	7	9	13	17	21	25	
Phase I: initial exercise													
Ankle pumps	•	•											
Gluteal, quad, HS, Tab isometrics	•	•											
Stationary biking with minimal resistance	•	•	•	•									
Passive ROM (emphasize IR)	•	•	•	•									
Piriformis stretch	•	•											
Passive supine hip roll (IR)	•	•											
Water walking	•	•	•	•									
Quadruped rocking		•	•										
Standing hip IR (stool)		•	•										
Heel sides		•	•										
Hip abd/add isometrics		•	•										
Uninvolved knee to chest		•	•										
Prone IR/ER (resisted)		•	•	•	•								
Sidelying clams			•	•									
3-way leg raises (abd, add, ext)				•									
Water jogging			•	•									
Dbl leg bridges w/tubing				•	•								
Kneeling hip flexer stretch				•									
Leg press (limited weight)				•	•								
Short lever hip flexion/straight leg raises				•	•								
Phase II: intermediate exercises													
Double 1/3 knee bends					•	•							
Side supports					•	•							

Stationary biking with resistance																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
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limited to foot-flat weight bearing (20 lbs.) for 6 to 8 weeks. A continuous passive motion machine is used for 6 to 8 weeks. Care should be taken during strengthening to avoiding compressive or sheering forces at the site of the microfracture. Impact activities should be added cautiously while the hip is monitored for swelling or pain. Patients typically initiate phase I immediately following surgery, phase II at week 7, phase III at week 9, and phase IV at week 17. All high impact activities such as running should be discussed with the physician before initiation.

CAPSULE REPAIR (PLICATION/CAPSULORRAPHY)

The focus of rehabilitation following a capsular procedure is to protect the integrity of the repair following surgery. Exercise progression must limit capsule stress throughout the rehabilitation program. Motion restrictions are determined by the location of the repair (anterior versus posterior). The majority of capsule repairs seen by the authors involve the anterior capsule. The following rehabilitation guidelines are specific to these repairs (Table 4).

Following an anterior capsule repair, extension and external rotation are limited to neutral for 3 weeks, followed by 3 weeks of gentle motion. At 4 weeks, it is felt that the cicatrix in the hip is formed and will not be subject to significant elongation [18–21]. Foot wraps are used for 3 weeks to maintain neutral hip rotation while the patient is in a supine position and not in the CPM. Flexion ROM is limited to 90° to protect the joint from impingement for 10 days. Weight bearing is limited to foot-flat weight bearing (20 lbs.) for 4 weeks. To avoid capsular stretch, neutral rotation during ambulation is emphasized. A continuous passive motion machine is used for 4 weeks. Care should be taken to avoid capsule stresses with rotational activities. Achieving a balance of joint stability and mobility is essential for successful return to competition. Patients typically initiate phase I immediately following surgery, phase II at week 5, phase III at week 9, and phase IV at week 13.

SUMMARY

Rehabilitation following hip arthroscopy has not been well understood in the past. Although surgical procedures continue to advance, athletes are already pushing the limits to return to competition as quickly as possible. As post-operative protocols evolve, it is essential to follow the basic guidelines of rehabilitation. Initially, soft tissue healing constraints must be considered while focusing on controlling swelling and pain, restoring ROM, and preventing muscle atrophy. As physiologic healing occurs, rehabilitation must address progressive lower extremity strengthening, proprioceptive retraining, and sports specific training.

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Sports after Total Hip Replacement

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The overlying purpose of total hip replacement (THR) is to relieve hip pain. The indications for THR involve a combination of objective and subjective criteria. Although the objective factors related to examination and radiographic factors remain largely unchanged, the subjective criteria continue to evolve.

The effect on a patient's quality of life determines when to proceed with THR. It is this determination of quality of life that is currently changing. Formerly, quality of life, or lack thereof, reflected the persistence of pain with walking, rest, and sleep. Even the analysis of clinical success based on the Harris hip score measured only limited functional criteria of limp, stair climbing, need for a cane, and ability to put on shoes and socks. This relative success of THR seen in the elderly, lower-demand population has now expanded the indications to a younger, more active individual.

Today these patients expect much more than pain relief; their goals of hip replacement now extend to function. This subgroup often hopes and expects to return to an active, even athletic, lifestyle. Although most will have already self-restricted their activity before hip replacement [1], some make seek a return to sports that is unrealistic or unsafe. It is the surgeon's responsibility to preoperatively guide these patients to distinguish between reasonable and unreasonable athletic expectations.

Few validated guidelines exist for a return to sports after THR, however. Current recommendations are based on a consensus of opinion and practice patterns. Surgeons at the Mayo Clinic in 1995 listed activities as recommended, intermediate, and not recommended based on a similar survey [2]. Members of the 1999 Hip Society who were polled to differentiate activities that were allowed, allowed with experience, or not allowed, developed a modestly conflicting list [3]. Other anecdotal reports describe a return to running, professional golf and tennis, and ballet [4]. Given recent advances in materials, fixation, and technique, each of these activities may deserve re-examination.

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PATIENT- AND ACTIVITY-RELATED FACTORS

Patients can return to an active lifestyle after successful THR, and these benefits extend beyond recreational pursuit. In one study [5], many patients who were not previously active presurgically developed a healthy habit postoperatively of walking, cycling, swimming, or cross-country skiing. Ries and colleagues [6] noted an improvement in cardiovascular fitness 2 years after surgery, with an increase in maximum workload and oxygen metabolism. Macnicol and co-workers [7] reported improved gait characteristics and oxygen consumption.

Firm rules to summarily limit or allow athletic participation may be too general. A safe return to sports is dependent on patient- and activity-specific risk factors. It is these issues that require careful exploration preoperatively.

Although impact and load from athletics are risk factors for failure, the degree of influence of these factors varies widely. Just as chronological age is related less to wear than activity level [8], how aggressively a patient participates in a sport is as critical as the specific sport he participates in. Patients participate at vastly different levels of intensity, from highly competitive to weekend athlete. Load and risk will likewise be reduced in those pursuing occasional recreation rather than peak fitness [9]. More extreme athletic patients may be encouraged to modify their expectations and levels of participation (Fig. 1). Preoperative expertise is also a factor in minimizing risk. Accomplished athletes can often return to a sport with a lower risk of injury. For example, the expert water skier or surfer engaged in moderate activity after THR is at less risk than a novice attempting to learn the sport.

Sports-specific demands are also important considerations. Factors to evaluate include required flexibility, the amount of repetitive load, and the potential for high impact and contact. Although yoga and Pilates raise a surgeon's concern for hip dislocation, these activities may not be contraindicated (Fig. 2). Although



Fig. 1. THR in 48-year-old patient who returned to tournament-level beach volleyball. Procedure was performed with cementless implants, a large head, and highly crosslinked polyethylene.



Fig. 2. THR in 43-year-old patient who returned to work as a Pilates instructor. Procedure was performed using a Smith-Petersen anterior approach to minimize the risk of dislocation, and a metal-on-metal bearing surface.

some yoga positions extend beyond the limitations of traditional posterior hip precautions, participants can often substitute an alternative position with the instructor's guidance. Regarding martial arts, patients should avoid sparring and high kicks, but may return to technical forms. Surgical technique, approach to the hip, and implant choice may also increase the relative safety of returning to these exercises.

The duration and extent of repetitive load raise wear-related concerns after THR. These discussions involve questioning whether a patient can or should do an activity. A common concern centers on running after THR. A patient is able to run in times of need, and is not limited from running short distances infrequently, as in softball or tennis; however, the repetitive joint reactive forces resulting from jogging raise appropriate concern for the durability of the prosthesis. The bearing surface is prematurely stressed, with repetitive loading up to five times body weight caused by each heel strike [9]. Cardiovascular fitness can be maintained instead with alternative low-impact, closed-chain exercises. Because the joint loads are reduced, patients are encouraged to achieve an aerobic workout with power walking, biking, swimming, the stair climber, and elliptical machines.

The surgeon should also evaluate a return to sports based on the potential for contact. High-contact sports place the joint and bone at risk. One can differentiate, however, between the safety of ice skating versus the heavy contact in hockey. Similar contact-intensive sports such as football and rugby are also best avoided. High impact may also result from uncontrolled falls. Although skiing and surfing are not discouraged for experienced athletes, the intensity of the activities should be modified based on preoperative proficiency [10].

Finally, all patients will require an appropriate period of rehabilitation after surgery to return to sports. Any activity with increased cyclical loading should

be avoided until solid ingrowth is achieved in cementless THR. Muscle mass, coordination, balance, and reflexes need to be redeveloped before returning to competitive play. Golfers are advised to resume chipping and putting initially, to work with a golf professional, and to ride the cart for the first 6 months. Tennis players are similarly advised to work on strokes with an instructor, and to advance gradually from doubles to singles play. Although all patients require follow-up, active athletes deserve closer observation with routine radiographs.

TECHNICAL FACTORS

Despite clear benefits to health and mobility, the hesitancy to allow patients to return to sports remains strong. To what extent and just how safely patients can test the limits of their THR remains unclear. Studies demonstrate that many patients will return to a sport even against the doctor's recommendation [11]. The concern is multifactorial, and based in a desire to minimize a patient's risk and potential complications. Four main risks of sports participation after THR are dislocation, bearing wear, aseptic loosening, and periprosthetic fracture.

Instability

Postoperative hip dislocation is directly related to soft tissue integrity, approach, component position, and implant choice. The need to achieve a stable, impingement-free range of motion is even more crucial in the potential athlete. Maintenance of the soft tissue envelope decreases the risk of dislocation. Preserving the integrity of the posterior soft tissue provides the most stability, and is achieved either by maintaining tendinous attachments through an anterior or lateral approach [12], or by repairing capsular tissues and the short external rotators [13].

Intraoperatively, surgeons should ensure that hip does not demonstrate prosthetic or bony impingement. Prosthetic impingement in athletes can be minimized with larger head sizes, and even eliminated with head sizes greater than 36 mm [14]. Larger head sizes also increase the "drop distance" before potential dislocation, and the use of modified neck tapers maximizes head-to-neck ratios. Bony impingement is minimized with restoration of leg length and offset and the debridement of osteophytes. Optimal component position in the position of safety may also be enhanced with image guidance or computer navigation [15].

Wear

Bearing wear leads to osteolysis, aseptic loosening, and potential catastrophic failure, and the active athletic patient is at the greatest risk. Further, in the Swedish Registry a subgroup of active patients who were young heavy males had the highest historic incidence of THR failure [16]. Many of these concerns, however, arose because of the limitations of previously available bearing surfaces. Elevated levels of wear beyond 0.2 mm per year were a recognized problem with standard metal on polyethylene [17]. Enhanced alternative bearing

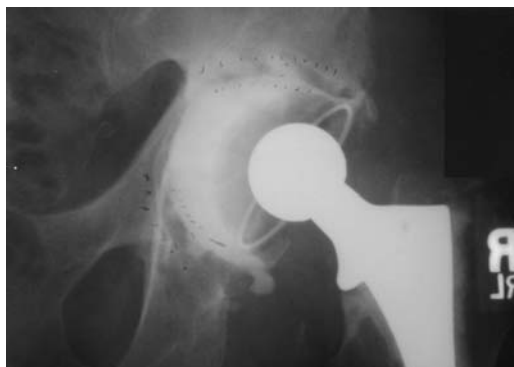


Fig. 3. Aseptic loosening of a cemented acetabulum developed 8 years after heavy athletic use in a 59-year-old professional tennis instructor.

surfaces promise a potential solution to activity-related wear. Although only long-term analysis will validate these claims, early-to-intermediate reports of ceramic on ceramic, metal on metal, and highly crosslinked polyethylene all show a significant reduction in annual wear rates [17,18]. With such a reduction in bearing wear, even the athletic patient is less likely to wear out the joint.

Aseptic Loosening

In addition to wear-induced loosening, higher loads from participation in sports stress the implant fixation surface. Early reports of failure in active patients were seen in cemented arthroplasties [1]. High repetitive loads led to fatigue fractures of the cement mantle, with eventual crack propagation (Fig. 3). Currently, cementless devices are more often chosen for this population, and may reduce the risk of fixation loss over time. Longer follow-up is necessary.

Periprosthetic Fracture

Aside from contact sports, most athletes are not at high risk of a periprosthetic fracture. Analysis of fracture risk describes more often a very different population than the motivated athlete [19]. Although possible, these fractures occur more commonly after a simple fall in the elderly patient who has poor balance and weakened bone.

SUMMARY

How do we define the restoration of function after THR? Current measures may not capture completely our patients' preoperative goals and postoperative activities. Their expectations vary, potentially extending beyond activities of daily living to include an ability to compete in sports. For their own safety, those patients who are athletically inclined deserve greater counseling, closer follow-up, and more careful scrutiny of surgical technique and implant choice. Ultimately, surgeons and patients together must find a balance between a return to activity and a return to too much activity.

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