Fares S. Haddad
Editor

The Young Adult Hip in Sport

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In Memory of
Sami Fares Haddad and Nina Tamari Haddad who gave me the tools, the motivation and the love and support to succeed
And with Thanks to
Jane, Isabella, Oliver, Florence, Imogen, Alice and Marina who make every moment a glorious one

Preface

The last 20 years have seen a revolution in our understanding of the pathophysiology of hip disease and of hip injuries in sport and have provided us with a plethora of new investigational and interventional modalities to unravel what was previously a mysterious field. This has encompassed an increased understanding of how the hip develops and functions, improved imaging modalities and a dramatic increase in joint preserving surgery using both open and the ever-expanding array of arthroscopic techniques that are now at our disposal. Our ability to diagnose, intervene and rehabilitate has evolved, and as a result it has become clear that the incidence of hip problems in sport is much greater than previously recognised. Many conditions that were blamed on the spine, the groin and the soft tissues or the pelvis have turned out to be hip related, and this in turn has led to a number of diagnostic dilemmas and novel solutions.

There is little doubt that the progress in this area has been vast and extremely impressive. This book gathers together the experts on hip pathology and hip disease and covers the anatomy, the imaging and the variety of surgical modalities available for the full spectrum of presentations of hip disease from problems in childhood and adolescence that lead to difficulties with high activity all the way through to sports-related problems with articular cartilage, the labrum and impingement.

We also increasingly recognise that there are many scenarios when the hip unfortunately fails at a young age and some form of arthroplasty surgery is required. The indication and outcomes of a variety of early arthroplasty options and their role in the management of the young active sporting patient with hip disease will also be covered.

This is an area that will continue to evolve rapidly. This book presents the state of the art in the evaluation and management of hip disorders in the active population.

London, UK — Fares S. Haddad

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Part I

The Basics of the Assessment of the Young Adult Hip

The Anatomy of Hip Disease

1

A. Malviya, A.R. Hunter, and J.D. Witt

Developmental Anatomy of the Hip

The developmental anatomy of the proximal femur is complex. In some mammals, including humans, the femoral head and greater trochanter emerge as separate ossification centres within a common chondroepiphysis and remain separate throughout ontogeny. In other species, these secondary centres coalesce within the chondroepiphysis to form a single osseous epiphysis. These differences in femoral ontogeny are critical to an understanding of femoral mineralization and architecture across a wide range of mammals and may have key implications for understanding and treating hip abnormalities in humans [1]. With the exception of some bipedal dinosaurs in which the femoral head is offset from the shaft, the femur of primitive reptiles is cylindrical and its proximal articular surface is aligned with the long axis of the shaft. Mammals differ from their reptilian ancestors by having increased flexibility of the axial skeleton and greater range of motion of the limbs. This difference is much more pronounced in the hindlimb than in the forelimb because of the latter's flexibility as provided by its synsarcotic fixation to the thorax. In many mammals, the femoral head has become offset from the shaft allowing greater flexibility at the more restrictive acetabulum. Thus, the constant coalescence of all osteogenic centres as in the proximal humerus may represent the primitive condition, with displacement of the femoral head from its shaft requiring a more complex developmental process in some species that necessitate increased hip mobility (i.e. rodents, hominoids, pinnipeds) relative to those characterized by more stereotyped limb movements (i.e. carnivores and artiodactyls). It has been hypothesised that geometry, rather than size, is the principal determinant of proximal femoral ossification pattern [1]. Specimens exhibiting separate ossification appear to have longer, more constricted and well-defined femoral necks than do those with coalesced ossification. The head and trochanter may remain separate in mammals with long and distinct femoral necks simply as a consequence of their increased spatial separation. Therefore, geometric changes, be they due to functional demands of loading and/or phylogenetic constraint are probably the basis for the differences in femoral ossification pattern.

The normal embryological growth and development of the hip joint requires well-balanced growth of the acetabulum and an enlocated and centred femoral head. The hip joint develops from mesenchymal cells forming both the acetabulum and the femoral head. The differentiation begins to occur at 7 weeks, with a cleft in the precartilagenous cells forming a hip joint by 11 weeks [2]. This is then surrounded by connective tissue that condenses to form the synovial tissue lining the future joint cavity.

After birth, the further growth of the acetabular cartilage and the proximal femur is interdependent and is crucial to the ongoing development of the joint. The acetabulum develops from the confluence of the pubis anteriorly, the ilium superiorly and the ischium inferiorly. Cartilage covers the acetabulum in the outer two-thirds, with the medial wall formed by the triradiate cartilage and part of the ilium superiorly and the ischium inferiorly [3]. The triradiate cartilage forms the primary growth centre of the acetabulum and is the common physis of the pubis, ilium and ischium (Fig. 1.1). With growth, the acetabulum expands in diameter. The outer cartilagenous aspect of the acetabulum is thus comparable to the cartilagenous epiphyses elsewhere in the axial skeleton. The acetabular articulating surface is made up of very cellular hyaline cartilage, which grows through appositional

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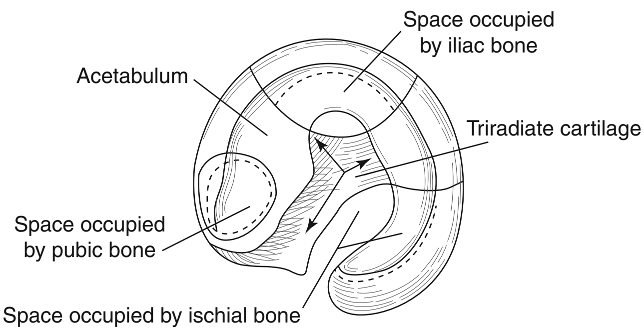

Fig. 1.1 Diagram of the triradiate cartilage complex viewed from the lateral aspect and its relationship with the pubic, iliac and ischial bones (Reprinted with permission from Ponseti [3], p. 577, Figure 1C. http://www.jbjs.org/data/Journals/JBJS/571/575.pdf)

growth under the perichondrium and interstitial growth in the cartilage [3].

The labrum is a fibrocartilaginous rim attached to the acetabular cartilage margin. It is triangular in cross-section, with the base attached to the rim and the apex a free edge, and acts to deepen the cup of the acetabulum. In fetal hips the anterior labrum has a marginal attachment and fibres are arranged parallel to the chondrolabral junction, whereas the posterior labrum collagen fibres are anchored in the acetabular cartilage [4]. The acetabular notch forms the inferior aspect of the acetabulum and is spanned by the transverse acetabular ligament, a fibrous continuation of the labrum. The capsule of the hip joint attaches to the acetabular margin and is continuous with the labrum on the intracapsular side and with the periosteum of the pelvis.

The depth of the acetabulum increases during its development and relies on several factors. A reduced spherical femoral head acts to stimulate deepening. Without its presence the acetabulum fails to develop and the cartilage atrophies as shown in an animal model study of rats with excised femoral heads [5]. The acetabular cartilage and surrounding bone must also grow normally. The primary ossification centres of the pubis, ilium and ischium meet in the acetabulum at puberty, with a Y-shaped portion of cartilage separating them (Fig. 1.2). The os acetabuli appears around this time and acts as the epiphysis of the pubis, ossifying and forming the anterior wall of the acetabulum. The epiphyses of the ilium and ischium undergo a similar process and contribute to further growth and deepening.

The femur ossifies through five centres – the shaft, the distal end, the head, and the greater and lesser trochanters. The shaft is largely ossified at birth, but in the infant, the whole of the proximal femur is cartilage. The proximal femoral ossification centre develops between the 4th and 7th months of age and is made up of a bony centrum and cartilagenous anlage. The proximal femur has three physes from which growth occurs in a finely balanced manner that determines the normal anatomical relationships - the proximal femur physeal plate,

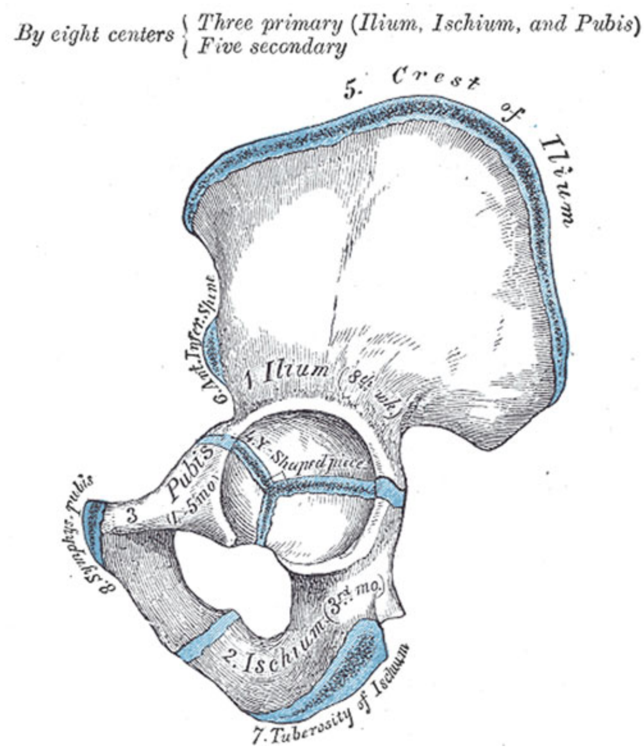

Fig. 1.2 The adolescent acetabulum and pelvis (Reprinted with permission from Gray et al. [6], p. 669, Figure 270A. http://education.yahoo.com/reference/gray/illustrations/figure?id=237)

the greater trochanter growth plate and as a continuation between them the growth plate of the femoral neck isthmus [7] (Fig. 1.3). The greater trochanter and the proximal femur grow larger by appositional cartilage cell proliferation [9].

The shape of the femoral neck is dependent upon the longitudinal and slightly medial growth of the proximal femur physeal plate balanced against the lateral growth from the trochanteric growth plate and the femoral neck isthmus [10]. The resulting directions of growth from these sites maintain the biomechanical forces around the hip joint whilst also allowing for the trajectory of growth to be in line with the long axis of the femur. Changes in the three physes can cause deformity of the proximal femur. For example, damage to the blood supply of the proximal femoralphyseal plate will result in a varus femoral neck, as the other plates continue to grow.

At birth, the femoral neck is anteverted approximately 35° and the acetabulum anteverted approximately 40°. The hips are most stable in flexion and mild abduction at this stage. Femoral neck anteversion reduces over the first 10 years of life towards the adult anatomy of approximately 15°. A child with increased femoral neck anteversion may present with in-toeing gait and increased internal rotation of the lower limb with spontaneously regression over a period of time [11].

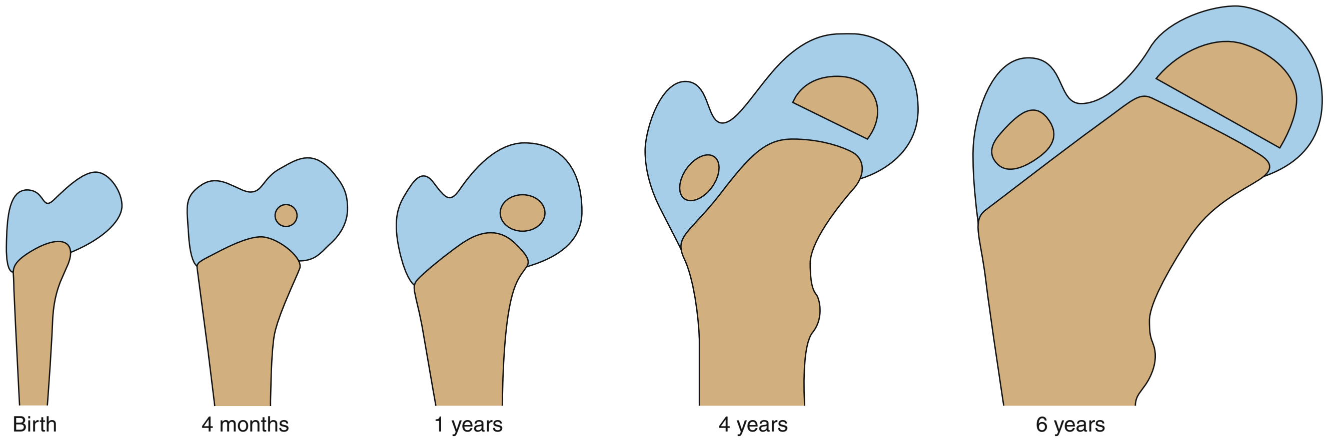

Fig. 1.3 Ossification of the proximal femur (Reprinted with permission from Staheli [8], p. 159, Figure A)

Vascular Supply of the Femoral Head

A disturbance to the blood supply of the developing femoral head can lead to deformity and subsequent disability. An arterial ring at the base of the femoral neck is the primary blood supply to the femoral head [12]. This is made up of the lateral circumflex femoral artery running anteriorly and the medial circumflex femoral artery (MCFA), which runs posteriorly forming the remaining medial, lateral and posterior aspects of the ring (Fig. 1.4). The ring gives off ascending cervical branches that run up the neck, penetrating the capsule to form an intracapsular ring at the border between the articular surface of the femoral head and the femoral neck. The lateral ascending cervical (retinacular) branch is the most prominent of these vessels, the medial branch is consistent, with the anterior and posterior branches less so. The anastomotic ring at the base of the neck of the femur undergoes involution after 1 year of age [13], with no anastomosis found between the MCFA and the lateral circumflex femoral artery around the neck in the adult [14]. The largest and most constant anastomosis with the MCFA was found to be a branch of the inferior gluteal artery running along the inferior border of piriformis [14].

In the infant epiphyseal branches of this intracapsular ring cross the perichondral ring of Lacroix and enter the epiphysis. Traversing vessels cross the physis directly. However, as the ossification centre of the femoral head develops, these transphyseal vessels are lost, leaving the epiphyseal vessels as the major vascular supply to the femoral head. The artery of the ligamentum teres plays a role in adolescence, and once the physis is closed the metaphyseal vessels make their contribution.

Knowledge of the extracapsular anatomy of the MCFA and surrounding structures is important when considering reconstructive surgery in order to avoid iatrogenic avascular necrosis of the head of the femur. A cadaveric study [14] showed the extracapsular course was constant, with a trochanteric branch at the proximal border of quadratus femoris coursing onto the lateral aspect of the greater trochanter. The MCFA then continues superiorly, running anterior to the conjoint tendon of the gamelli and obturator internus, before perforating the capsule at the level of gamellus superior. This has implications for the posterior approach to the hip and for trochanteric osteotomies. Simulated surgical dislocation in this study did not alter the extracapsular or intracapsular course of the MCFA as long as obturator externus was left attached. Based on anatomical studies of the blood supply gained from this study and others, the authors describe a technique for surgical dislocation of the hip [15]. This consists of an anterior dislocation through a posterior approach and a ‘trochanteric flip’ osteotomy; with 213 cases over 7 years, no case developed avascular necrosis.

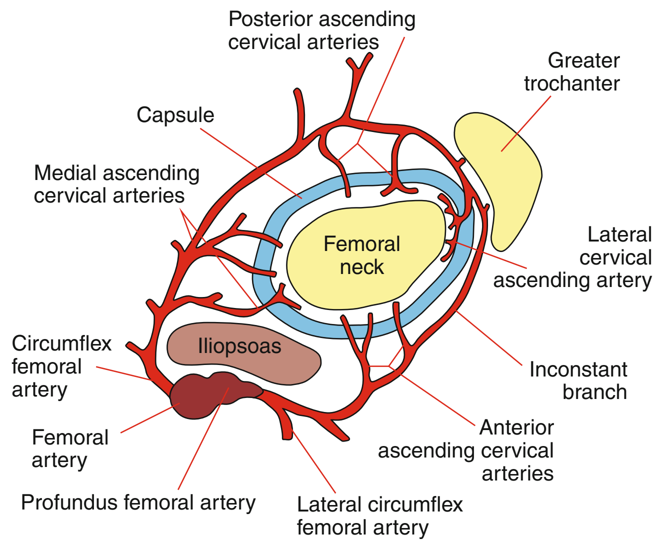

Fig. 1.4 The vascular supply of the femoral head (Reprinted with permission from Staheli [8], p. 160, Figure B)

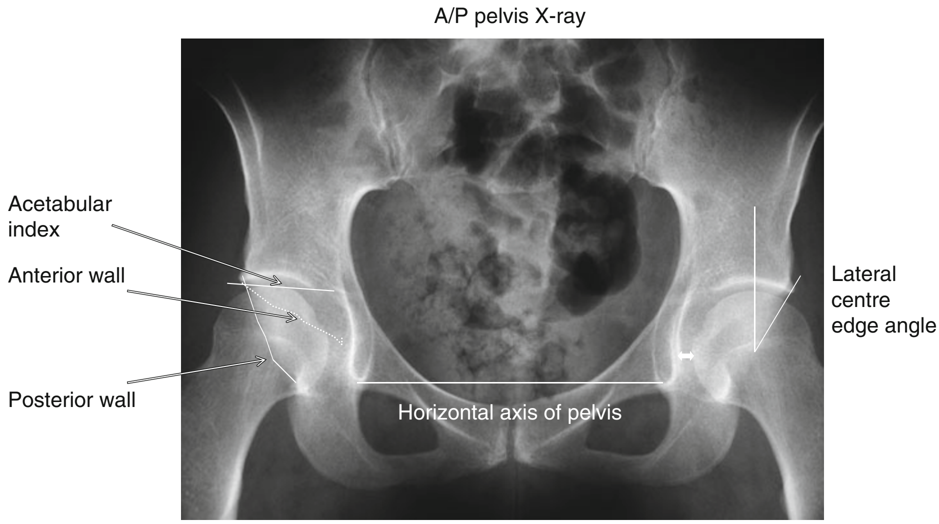

Fig. 1.5 Important radiological parameters in the AP pelvic radiograph

Normal Hip Morphology

During the various stages of development of the hip events may occur that compromise the final shape of the hip that may have implications on later function. For a hip to function normally, the shape of the femoral head needs to match that of the acetabulum which needs to have adequate depth. An anteroposterior (AP) pelvic radiograph should demonstrate a number of key features that indicate 'normality' [16]. Being clear about the parameters that make a hip normal allows the recognition of rather subtle abnormalities that may predispose the hip to injury or early degenerative change. Figure 1.5 shows important measurements that can be made. The slope of the weight-bearing zone of the acetabulum (acetabular index) should be more or less horizontal. If this is sloping in a craniomedial direction then the hip will be predisposed to medial osteoarthritis or a profunda – type abnormality particularly if combined with a varus femoral neck angle. A weight-bearing zone that slopes in a cranio-lateral orientation is associated with dysplasia and increased pressure on the lateral part of the acetabulum and labrum. The lateral centre edge angle gives an indication of the amount of lateral cover of the hip. This should be between 25° and 40° [17]. Assessment of the distance between the medial aspect of the femoral head and the ilioischial line allows the determination of whether the hip has a protrusio deformity or whether there is excessive lateralisation. Shenton's line drawn along the undersurface of the superior pubic ramus and the medial femoral neck gives an indication of femoral head subluxation. In dysplastic hips this may be quite subtle but is an indicator that the capsulo-labral complex is not able to stabilise the hip adequately.

The relationship of the anterior and posterior walls to each other is an important assessment and usually they should meet each other at the lateral margin of the acetabulum [18]. If the outline of the anterior wall of the acetabulum crosses over that of the posterior wall then that may be an indication that the acetabulum is relatively retroverted. The tilt and rotation of the pelvis has to be taken into account when making this assessment as this can greatly influence the relationship [19]. Prominence of the ischial spine projection into the pelvis may be another indicator of acetabular retroversion [20]. The shape of the femoral head can be determined by assessing its sphericity. This can be done by laying template circles over the femoral head to see if these follow the outline of the femoral head. Clearly the femoral head may be aspherical in other planes so other views may be important to assess this accurately. Similarly other views of the pelvis, such as the false profile view are helpful to provide further information about hip joint morphology. These further views are useful in providing a more detailed analysis of hip pathology but as a detailed diagnostic tool remain flawed in view of the variabilities in radiographic projection and interpretation [21].

Abnormal Anatomy

It has been increasingly recognised that the abnormal morphology of the hip predisposes the joint to particular patterns of injury and a predisposition to the development of osteoarthritic changes [22]. Clearly there are many conditions that may develop that result in the hip structure and function being compromised, ranging from inflammatory arthropathies to skeletal dysplasias. However, these are primarily related to biological phenomena that would require systemic interventions to reverse. The exciting challenge with regard to anatomical abnormalities of the hip is that potentially the correction of the structural abnormality will influence the outcome in terms of injury to the hip and later degenerative change. The non-inflammatory hip disease in young adult population can be commonly a result of either hip instability (secondary to hip dysplasia) or femoroacetabular impingement [21, 23, 24]. Each of these may be of varying spectrum and may co-exist. Injury to the labrum and associated degeneration in dysplastic hips are believed to result from chronic abnormal loading of the acetabular rim [25–27]. In non-dysplastic hips, it has been suggested that the cause is repetitive microtrauma from impingement of the femoral neck against the acetabular rim, or a cam-effect, in which a portion of the head with an increasing radius is squeezed under the acetabular rim [25].

Growth of the femoral head and the acetabulum appears to maintain a mutually dependent relationship in the formation of a congruent hip [10]. The acetabulum seems to require a spherical femoral head as a template for spherical growth [28]. Conversely, the development of a spherical femoral head seems to require a critical minimal amount of acetabular coverage [29]. Acetabular and femoral abnormalities are, therefore, often combined because the final acetabular shape and depth depends on the interaction with a spherical femoral head [28]. For example, hips with Legg-Calve´-Perthes disease or proximal femoral focal deficiency have a higher incidence of dysplasia, acetabular retroversion, and incongruity [29–31]. This might be due to a premature or eccentric fusion of the triradiate cartilage with subsequent alterations of the articular cartilage and changes of the acetabular dimension [32]. Similarly, Kitadai et al. [33] suggested that the lateral center-edge (LCE) angle was increased in patients with slipped capital femoral epiphysis compared to those with normal hips.

Hips with different acetabular coverage are associated with different proximal femoral anatomy. The abundant coverage as in a deep acetabulum seems to promote spherical growth of the head with a symmetric shape of the epiphysis. However, deficient coverage as occurs in DDH may promote an elliptic head shape with an asymmetric epiphyseal growth. A deep acetabulum has been reported to be associated with a more spherical head shape, increased epiphyseal height with a pronounced extension of the epiphysis towards the femoral neck, and an increased offset [34]. In contrast, dysplastic hips have been associated with an elliptical femoral head, decreased epiphyseal height with a less pronounced extension of the epiphysis, and decreased head-neck offset [34]. A nonspherical head in dysplastic hips could lead to joint incongruity after an acetabular reorientation procedure. The resulting nonspherical shape of the femoral head and acetabulum can potentially induce a painful femoroacetabular impingement or influence the result of reorientation procedure [34].

McCarthy et al. [35] identified the anterior acetabularchondro-labral junction as the "watershed lesion" as it was at a high risk of injury. They postulated several explanations for this anatomical predilection. These included potentially inferior mechanical properties, higher mechanical demands and a relative hypovascularity of the anterior acetabularlabral-chondral complex. Based upon further work, they proposed that a labral tear may alter the biomechanical environment of the hip leading to degeneration of the articular cartilage and eventual osteoarthritis [36].

However, work by Cashin et al. [4] identified consistent differences between the anterior and posterior acetabularchondro-labral complexes. The anterior labrum has a somewhat marginal attachment to the acetabular cartilage with an intra-articular projection. The posterior labrum is attached and continuous with the acetabular cartilage. Anteriorly, the chondro-labral transition zone is sharp and abrupt, but posteriorly it is gradual and interdigitated. The collagen fibres of the anterior labrum are arranged parallel to the chondro-labral junction, but at the posterior labrum they are aligned perpendicular to the junction. It is believed that in the anterior labrum the marginal attachment and the orientation of the collagen fibres parallel to the chondro-labral junction renders it less likely to withstand shearing forces and more prone to damage than the posterior labrum in which the collagen fibres are anchored in the acetabular cartilage [4].

Hip Dysplasia

The dysplastic acetabulum has long been recognised as a factor in the development of degenerative changes of the hip [22, 37–39]. A mal-oriented articular surface with decreased contact area leads to excessive and eccentric loading of the anterosuperior portion and subsequently promotes the development of early osteoarthritis of the hip [40–43]. The exact threshold when a dysplastic hip will inevitably develop degenerative change has yet to be determined. A study by Murphy et al. 1995 [44], looking at patients with severe dysplasia who had undergone total hip replacement for secondary osteoarthritis, found that the contralateral side was at risk of developing osteoarthritic changes by the age of 65 if the lateral centre – edge angle was less that 16° or the acetabular index greater than 15°. It is clear, however, that this relationship is not completely straightforward. Gosvig et al. [45] studied a cohort of patients with hip dysplasia (centre edge angles between 6° and 20°) who had no symptoms and looked at the development of degenerative changes over a 10-year period and found that the patients with dysplastic hips were no more likely than a group of controls to have developed degenerative changes. These findings were reproduced in a longitudinal case-control study by Jacobsen et al. [46] over a 10-year period. The authors [46] suggested that labral tears or detachments are critical events in otherwise well-functioning dysplastic hips, accelerating degeneration. If labral injuries do not occur in non-subluxed, dysplastic hips, articular cartilage may remain intact throughout life. However, the labrum in these patients is more at risk of detachment than the labrum in normal hips.

A number of radiological measurements have been described to assess dysplastic hips, but none either alone or in combination can accurately predict acetabular development in all cases [47]. Some dysplastic hips with favourable radiographic parameters fail to develop normally, suggesting that there are other factors, possibly cartilaginous or soft tissue structures that may have a bearing on the prognosis. The role of range of motion MRI scan in determining the labral angle and zone of compressive force which would be able to better define concentric reduction has been described [47]. A concentrically reduced hip is one in which the labrum is pointing downwards and in which the zone of compressive force is the inner acetabular zone. It has been proposed that any treatment surgical or non-surgical should aim to orient the labrum downward in the normal direction to facilitate the lateral and downward growth of the lateral part of the acetabulum and its deepening [47].

Once a hip becomes symptomatic it would seem that damage has started to occur that makes the hip vulnerable to further degenerative change. The early site of injury is the chondro-labral junction in the anterior part of the hip [48]. Anatomically the dysplastic acetabulum is globally deficient [40, 49]. This can be of varying degrees and the area of maximum deficiency can itself vary. The weight-bearing zone of the acetabulum is short and the overall area of articular surface available to articulate with the femoral head is less than normal. The orientation of the acetabulum may also vary in that although most are excessively anteverted (or anteriorly deficient) [50], some may be retroverted [31, 51, 52]. Kim et al. [53] reported that although the acetabular anteversion may be increased in the dysplastic hips, it is not a universal finding. This has implications in terms of the likely outcome of techniques to re-orientate the acetabulum. Even if the acetabulum is optimally oriented, the overall stresses within the articular cartilage are likely to be greater than in a normal hip.

A variety of surgical techniques have been developed to try and address the lack of cover of the femoral head and to address the malorientation of the acetabulum to try and normalise the stresses imparted to the articular surface and labrum [54–56]. Increasing evidence indicates that these techniques improve pain and function of the hip, and improve the longer-term outcome in relation to the development of osteoarthritic changes [55–57].

Femoroacetabular Impingement

Femoroacetabular impingement has been described as a bony dysmorphism of the hip caused by abnormal contact between the anterior rim of the acetabulum and the proximal femur leading to labral and chondral damage, and ultimately idiopathic osteoarthritis of the hip [43, 58]. There are two types of femoroacetabular impingement. Cam impingement is caused by a non-spherical head in an outside-in mechanism in the presence of decreased femoral head/neck offset, while pincer impingement is secondary to acetabular overcoverage of the femoral head and is present in almost a third of patients with cam deformity [43, 59]. Ganz et al. [43] concluded that labral and chondral damage occurred in the presence of structural bony abnormalities of the hip rather than as an intrinsic abnormality of the acetabular-chondro-labral complex, and that acetabularchondral damage is the initial insult leading to tearing of the labrum [58]. This was in direct contrast to the "watershed theory" by McCarthy et al. [35] who reported that the primary problem was an intrinsic abnormality in the anterior chondro-labral complex.

Indeed the prevalence of cam morphology has been found to be 14 % in a population of 200 asymptomatic volunteers [60], which is in keeping with the estimated 15 % prevalence of femoroacetabular impingement reported in the literature [61]. A relatively higher prevalence of cam morphology has been noted in men (24.7 % compared with 5.4 % for women) suggesting that cam impingement is primarily a disease of young males [45, 58, 62]. Hips with an alpha angle of more than 60° have an odds ratio of being painful in 2.59 compared with those with an alpha angle of less than 60° [63]. The alpha angle as a predictor of hip pain is consistent with the surgical finding that the presence of labral and acetabular cartilage damage correlates with the severity of the alpha angle [64].

Acetabular overcoverage exists in patients with deep sockets, which may lead to pincer impingement [43, 65]. Retroversion of the acetabulum, via a similar mechanism, has been implicated in causing anterior femoroacetabular impingement [18, 66]. However, making this diagnosis from plain radiographs is not straightforward and careful assessment is required in order to determine whether surgery to remove part of the acetabular rim or a re-orientation of the acetabulum is most appropriate to deal with the underlying abnormality [67].

Beck et al. have shown that hip morphology influences the pattern of articular cartilage damage [58]. Cam impingement causes damage to the anterosuperioracetabular cartilage with separation between the labrum and cartilage; during flexion, the cartilage is sheared off the bone by the non-spherical femoral head while the labrum remained untouched. In pincer impingement, the cartilage damage is located circumferentially along a narrow strip; during movement the labrum is crushed between the acetabular rim and the femoral neck causing degeneration and ossification [58].

The underlying cause of femoroacetabular impingement is a matter of debate. Hoogervorst et al. have proposed an evolutionary explanation for hip impingement [68, 69]. They propose that two types of hip joints, coxa recta and coxa rotunda, can conceptually describe nearly all the mammalian hips. Coxa recta is characterised by a straight or aspherical section on the femoral head or head-neck junction. It is a sturdy hip seen mostly in runners and jumpers. Coxa rotunda has a round femoral head with ample head-neck offset, and is seen mostly in climbers and swimmers. This concept can explain the morphological variants associated with impingement in the human hip. Coxa recta and coxa rotunda do not form adichotomy but a spectrum. Differentiation can be based on β or γ angles, offset ratios or combined measurements. In the human hip, coxa recta and coxa rotunda (when in a profunda hip) can produce osteoarthrosis through cam and pincer impingement, respectively [61]. The evolutionary conflict between upright gait and obstetric requirements is expressed in the female pelvis and hip, and can explain pincer impingement in coxaprofunda. For the male pelvis and hip, evolution can explain cam impingement as an adaptation for running.

In contrast to the evolutionary concept Ng and Ellis [70] propose that cam-type morphology is neither a redevelopment of coxa recta nor a malformation such as slipped capital epiphysis. The aspherical osteocartilaginous bump is associated with an extended physis and has been noted to appear during mid-adolescence. While this protuberance may contribute to future pathology, the authors feel that increased loading of the hip, not impingement activities during late childhood and early adolescence predispose patients to develop this morphology. This is further supported by the study performed by Siebenrock et al. [71] in an analysis of hip morphology in basketball players. High intensity training and impact during adolescence may explain why this morphology is more frequently seen in athletic individuals.

The role of genetic influences is also important in the aetiology of primary femoroacetabular impingement [72]. This risk appears to be manifested through not only abnormal joint morphology, but also through other factors, which may modulate progression of the disease. Pollard et al. [72] have shown that the siblings of those patients with a cam deformity had a relative risk of 2.8 of having the same deformity as compared with controls while the siblings of those patients with a pincer deformity had a relative risk of 2.0 of having the same deformity. Bilateral deformity again occurred more often in the siblings (relative risk 2.6, $p=0.0002$). The prevalence of clinical features in those hips with abnormal morphology was also greater in the sibling group compared with the control group (relative risk 2.5, $p=0.007$).

Whatever the underlying morphological abnormality of the hip, be it impingement or dysplasia, recognition by the clinician is important so that the opportunity for intervention prior to the development of significant degenerative change can be considered. It remains to be determined how effective current treatment is in terms of improving the long-term outcome of affected hips.

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2 Imaging of the Young Adult Hip in Sport

Warren Davis and Margaret Anne Hall-Craggs

Introduction

Imaging is used in the assessment of hip pain in the young adult sportsman or woman to aid diagnosis, to assess the extent of damage, and to guide treatment and rehabilitation. Imaging is clearly only part of the assessment of hip pain and should always be used in conjunction with the clinical assessment of the patient.

Imaging of hip pain in the young adult will be influenced by the tools and expertise available, together with the need to avoid using ionizing radiation wherever possible in a young population. Imaging tools available include plain radiographs, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), contrast studies and nuclear medicine imaging including isotope bone scans and SPECT.

The choice of the best and most appropriate imaging modality and the way that imaging is performed, (particularly for MRI) will be influenced by the likely cause of the hip pain. There is no such thing as a generic 'pelvic scan' or 'hip scan', the examination protocol must be tailored to the presenting problem and likely pathology. Consequently good communication between the radiologist and the clinician is key to yielding the best results.

The causes of hip pain in the sporting young adult are wide and can either be directly or indirectly related to the sporting activity. It can also be due to an incidental cause unrelated to the sport but just more common in this age group. Sporting injuries are due mainly to overuse or stress injuries, acute traumatic injury, or to sports related injuries exacerbated by a congenital predisposition. Imaging should therefore assess the actual injury, any underlying contributory abnormality (such as seen in patients with femoro-acetabular impingement) and also identify other non-sport related pathology.

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Hip Pain in the Young Adult and Imaging Appearances: Sports Related Causes

Tendon/Tendon-Bony Interface Abnormalities

Apophyseal Avulsion Injuries

Apophyseal avulsion injuries around the hip are most frequent before complete skeletal fusion has occurred. At this age the apophysis is the weakest component of the muscle – tendon – bone interface. Avulsion injuries can occur as a result of a single acute traumatic injury or with chronic repetitive overuse.

Imaging Features of Avulsion Injuries

Most avulsion injuries present with a classical history of acute pain following sporting activity. Apophyseal injuries are usually easy to diagnose on standard plain film images of the pelvis and appear as a well-defined fragment of bone that is separated from its site of origin. An antero-posterior (AP) radiograph of the pelvis and a frog leg lateral view should be performed as the latter helps exclude a slipped femoral capital epiphysis.

The most common site for these injuries is the hamstring attachment to the ischial tuberosity, accounting for approximately half of all injuries seen (Fig. 2.1).

Chronic avulsion injuries, secondary to overuse or repetitive micro trauma, appear as a clearly demarcated bony protuberance at the site of the tendon insertion. However they can also occasionally have an aggressive appearance, with mixed areas of osteolysis and sclerosis, and can be confused for a neoplastic or infective process. The characteristic site of the injury is often reassuring; however more advanced imaging is sometimes required.

MRI provides the best images of the muscle involved, degree of tendon retraction and extent of the adjacent soft tissue injuries (Fig. 2.2). It can also help distinguish between

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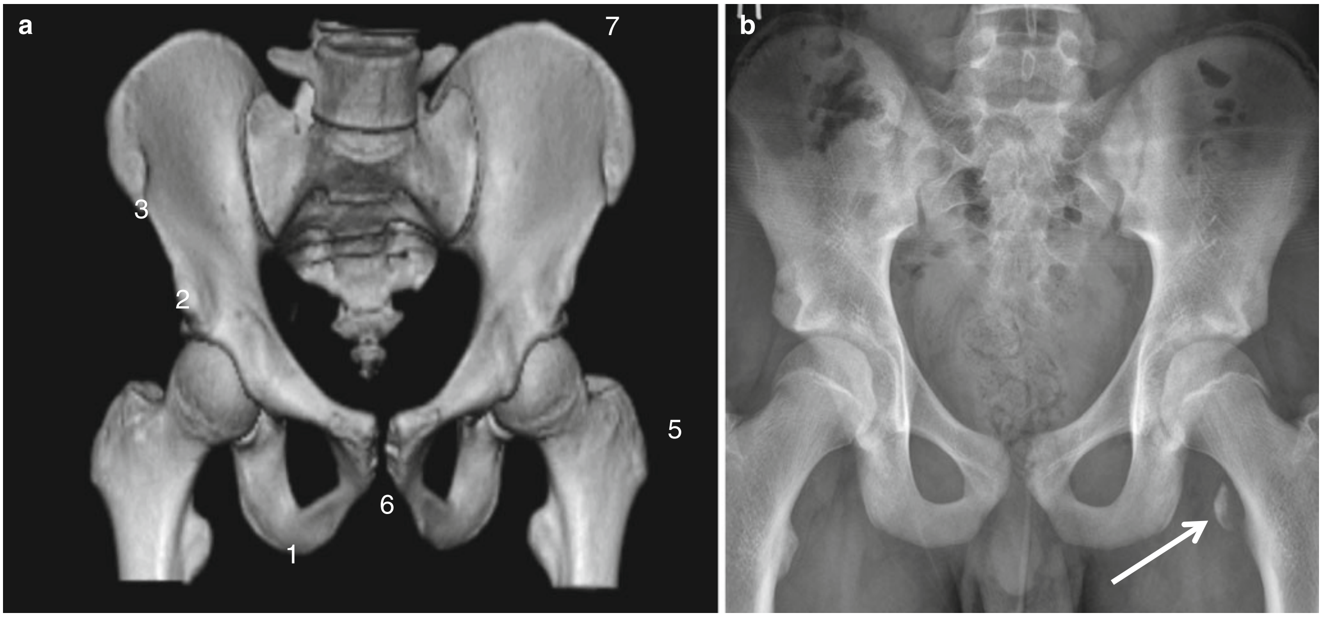


Fig. 2.1 (**a**) 3D reconstruction of a CT scan of the normal pelvis, demonstrating the most common sites for avulsion fractures. *1*. Hamstring attachment to the ischial tuberosity. *2*. Rectus femoris to the anterior inferior iliac spine. *3*. Sartorius to the anterior superior iliac spine. *4*. Iliopsoas to the lesser trochanter. *5*. Abductors to the greater trochanter. *6*. Adductors to the symphysis pubis/inferior pubic ramus. *7*. Abdominal muscles to the ilac crest. (**b**) AP radiograph demonstrating an avulsion fracture of the iliopsoas attachment into the lesser trochanter (*arrow*)

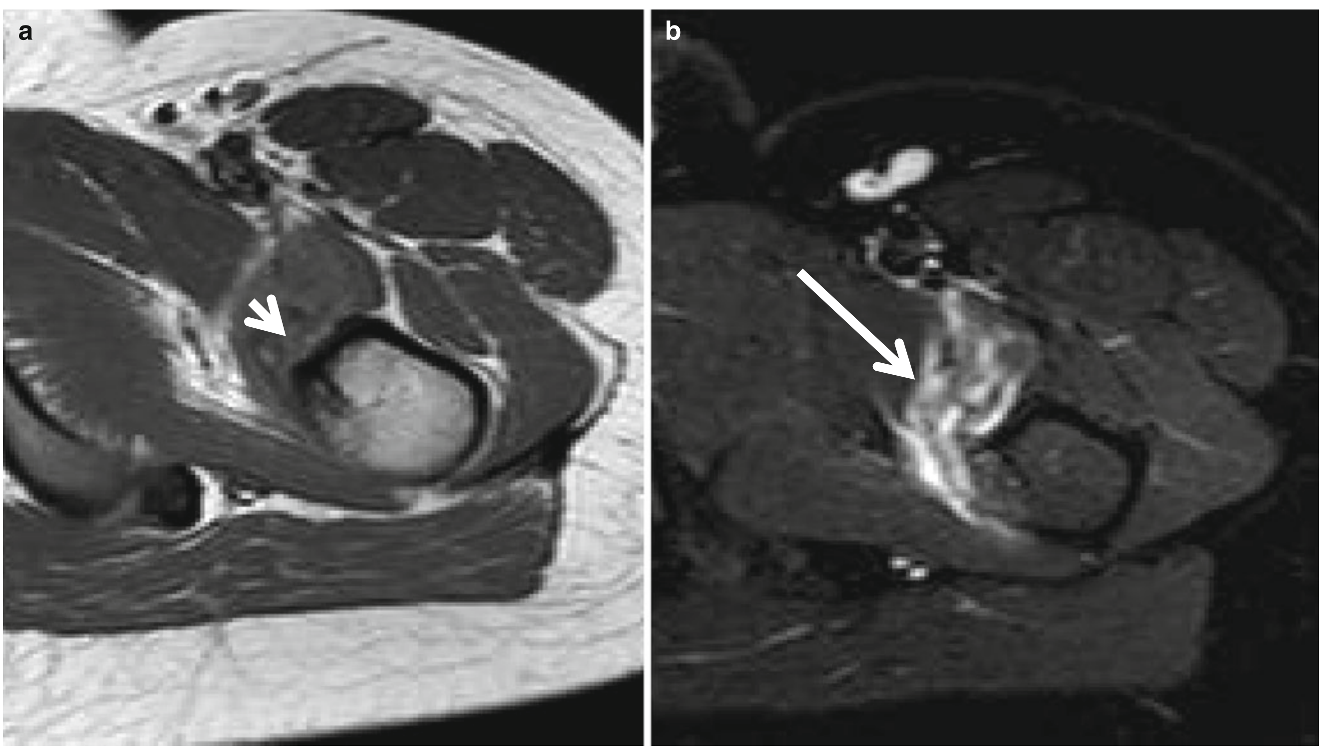


Fig. 2.2 T1 axial MRI (**a**) and STIR axial MRI scan (**b**) of a patient with an avulsion injury at apophysis of the left lesser trochanter. Note the loss of normal black tendon signal at the site of insertion of the iliopsoas into the lesser trochanter (*short arrow*), and the soft tissue oedema on the STIR axial (*long arrow*)

a chronic avulsion injury and a more aggressive process. Muscle atrophy and fatty replacement of the muscle fibres are seen in chronic injuries. It should be noted however that small bone fragments do not always contain bone marrow, and this can make them difficult to visualise on MRI.

CT is useful in detecting small bony fragments and delineating the degree of apophyseal displacement. It has also been used to help characterise sub-acute injuries that have an aggressive appearance on plain film.

Ultrasound can also be used to diagnose occult avulsion injuries. Findings include widening of the normal hypo-echoic physis, the presence of a hypo-echoic region around the site of injury in keeping with local haematoma or oedema, local hyperaemia on Doppler imaging and frank displacement of the apophysis [1]. In addition ultrasound is also useful in the exclusion of high grade tendon injuries.

Tendon and Muscular Injuries Around the Hip

Following skeletal fusion, the myotendinous junction becomes the weakest component of the muscle – tendon – bone interface, and is the most common site of indirect trauma secondary to muscle contraction. Muscle contusion secondary to blunt direct traumatic injury is also seen in contact sports. Tendons and muscles are easily visualised on both ultrasound and MRI, and these are the two most common modalities in the assessment of these injuries. Both acute and chronic injuries can be visualised. The hamstrings and quadriceps muscles are common sites of injury in the athletic population [2].

MRI

Normal tendons usually have a uniformly low signal appearance on all MRI sequences due to the relative absence of free protons (to provide signal) in their structure. An important exception to this rule is the so called "magic angle phenomenon" where increased signal is demonstrated in normal tendons when they are orientated at a 55° angle to the bore of the MRI scanner. This occurs with sequences using a short time to echo (TE) including proton density sequences that are commonly used in musculoskeletal imaging. It is important to recognise this normal variant to avoid misinterpretation of the images. Skeletal muscle demonstrates intermediate signal on all pulse sequences and can have a striated or feathery appearance.

MRI can be used to demonstrate acute and chronic injuries of the muscle-tendon-bone complex. Partial tears, full thickness tears, tenosynovitis and tendinopathy can all be diagnosed using MRI. This is often the preferred modality for assessment of these injuries due to its high contrast resolution and ability to assess deep injuries.

Partial thickness tendon tears have a variety of appearances on MRI; they can appear as areas of high signal

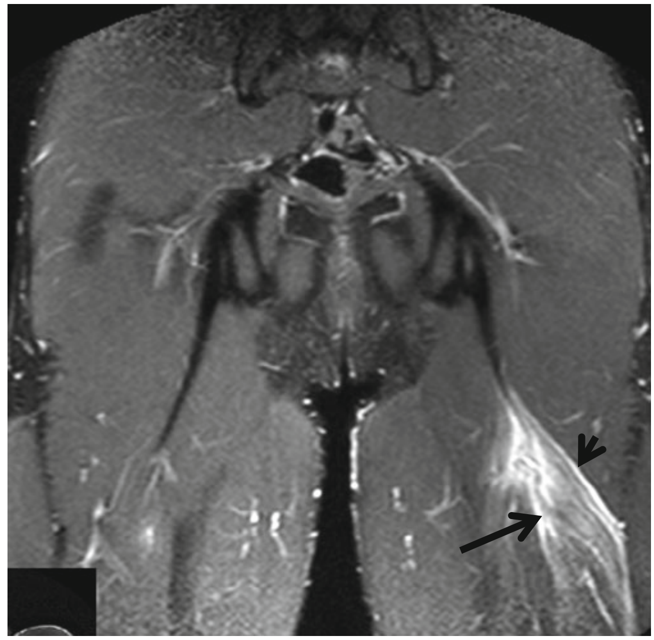


Fig. 2.3 STIR coronal MRI scan demonstrating a torn left hamstring muscle. The injury has occurred at the myotendinous junction. This represented a grade II injury. Note the feathery appearance in the muscle (*arrow*), this would be seen in a grade I injury. However the presence of fluid in the fascial plain (*arrow head*) and involvement of more than 5 % of the muscle volume is in keeping with a grade II injury

extending part of the way through an otherwise normal tendon, or abnormal thickening or thinning of the tendon. Complete disruption of the tendon fibres is present in full thickness tears and the length of tendon retraction can be measured directly on MRI. With chronic tenosynovitis, a T2 high signal ring around the tendon within the tendon sheath is seen and this can either be due to an effusion or to synovitis of the sheath. These can be distinguished as synovitis enhances with contrast whereas an effusion does not. Abnormal high signal on T2w/PD sequences within the tendon and local thickening of the tendon can also occur in chronic tendinopathy. It can sometimes be difficult on imaging alone to distinguish between tendinopathy and a partial tear, correlation with clinical history is important in such cases.

The MRI appearances of minor muscle tears include oedema and/or haematoma in the muscle, but more severe tears show complete loss of the normal muscle fibres with retraction (Fig. 2.3). Muscle atrophy and fatty replacement of the muscle tissue is seen in chronic injuries. Muscle tears are graded according to the severity of injury (see Table 2.1) [4].

MRI is used as the main method of assessing injuries to the pelvis and thigh, while ultrasound is used for problem solving and can help differentiate between grade 1 and 2 injuries. MRI grading can also help to provide prognostic information on the length of time required for recovery following injury.

Table 2.1 Grading of muscular tears dependent on the volume of muscle involved [3]

Grade 1	Involve <5 % of muscle volume	See a "feathery" appearance of high signal on STIR images at the myotendinous junction
Grade 2	Involve >5 % of muscle volume but do not cause complete rupture	Increased oedema or haemorrhage typically seen in the fascial planes between the muscles
Grade 3	Complete rupture with retraction of fibres and complete loss of function	Complete discontinuity of the fibres with fluid and haematoma filling the space created by the tear

Ultrasound

Ultrasound is also used in assessment of the muscle-tendon-bone complex, and provides excellent details of the superficial structures [5]. Normal tendons appear as linear parallel hyper reflective bundles that have a rope like appearance and are clearly distinct from the surrounding tissue. Tendinopathy can lead to loss of the normal internal signal and expansion of the tendon. Partial tears appear as hypo echoic deficits in the tendon structures, while full thickness tears involve a complete loss of the normal tendon fibres. Fluid surrounding the tendon sheath is readily demonstrated in tenosynovitis. Doppler ultrasound can also demonstrate abnormal vascular flow (neo-vascularity) of a tendinopathy and tenosynovitis.

Muscle injuries can also be demonstrated and graded on ultrasound. Appearances range from subtle areas of altered echogenicity in first degree strains, to complete disruption of fibers with associated haematoma in third degree muscle injuries. Muscle and tendon retraction, seen in grade 3 injuries, can also be highlighted on ultrasound by the use of passive and active movements of the muscle/tendon involved. Haematoma has a variable appearance with age on ultrasound, varying from hyper echoic in acute injury, to hypo echoic/mixed echogenicity with time. As the haematoma is reabsorbed by the body and reduces in size, the periphery can become more echogenic in appearance. Occasionally a seroma (anechoic fluid) can persist at the site of injury once the haematoma has been completely resorbed.

Snapping Hip

Snapping hip syndrome (coxa saltans) is the presence of an audible or palpable snap accompanying hip movement. It is often associated with pain and can occur with exercise and normal activity. The condition is classified into three main groups, external, internal and intra-articular.

External Snapping Hip

The external type is caused by the catching of the ilio-tibial band or the anterior edge of the gluteus maximus muscle over the greater trochanter. This is traditionally seen as a clinical diagnosis; however both direct and indirect imaging features have been described in this condition [6]. The abnormal catching can be directly visualised on dynamic ultrasound. Indirect signs, including thickening of the ITB, trochanteric bursitis and muscle wasting can also be seen on MRI and ultrasound.

Internal Snapping Hip

Abnormal movements of the iliopsoas tendon are the most common cause of an internal snapping hip. It was previously thought that the cause was due to abnormal movement of the tendon over a bony prominence such as the femoral head. However more recently it has been suggested that in most cases the abnormal snap is secondary to abnormal movements of the tendon over the iliac muscle [7].

Dynamic ultrasound (in experienced hands) can be used to make the diagnosis by observing abnormal jerking movements of the tendon on rotation as opposed to the normal gliding motion present in the normal hip.

Indirect static signs seen on both MRI and ultrasound include iliopsoas tendinopathy, fluid around the tendon sheath and bursitis (Fig. 2.4). These findings are non specific and are present in a variety of other conditions.

Intra Articular Causes of Snapping Hip

Intra articular causes include synovial chondromatosis and loose bodies, labral tears or cartilaginous flaps. Plain film, CT and MRI can each be helpful for diagnosis; CT showing mineralized intraarticular abnormalities well and MRI or MR arthrography demonstrating labral tears and cartilage flaps.

Pubic Inguinal Pain Syndromes

Chronic groin pain is a common condition, occurring in, but not confined to elite athletes. The reported incidence is between 0.5 and 6 % [8]. It is seen most commonly in those who participate in sports that involve twisting movements [9]. The underlying causes and mechanism of injuries remain controversial and this is partly due to the variety of terms used to describe them, including sportsman's groin, Gilmore groin, athletic pubalgia, and more recently pubic inguinal pain syndrome [8, 9].

Plain film, ultrasound, herniography, CT and MRI have all been used in the investigation of chronic groin pain, MRI

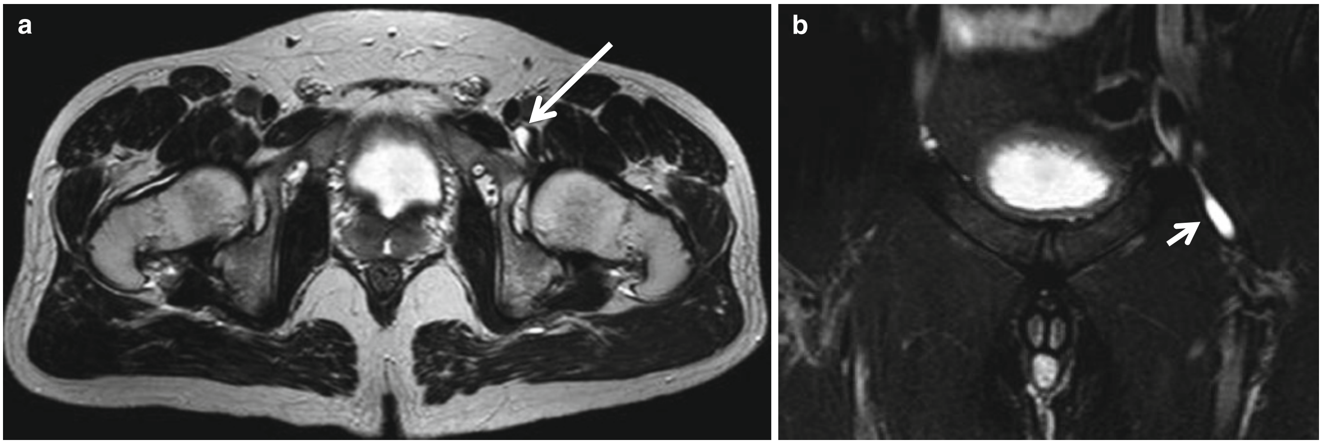


Fig. 2.4 (**a**) Axial T1 MRI and (**b**) STIR coronal demonstrating fluid around the left iliopsoas tendon (*arrows*). This is a recognised secondary sign of an internal snapping hip

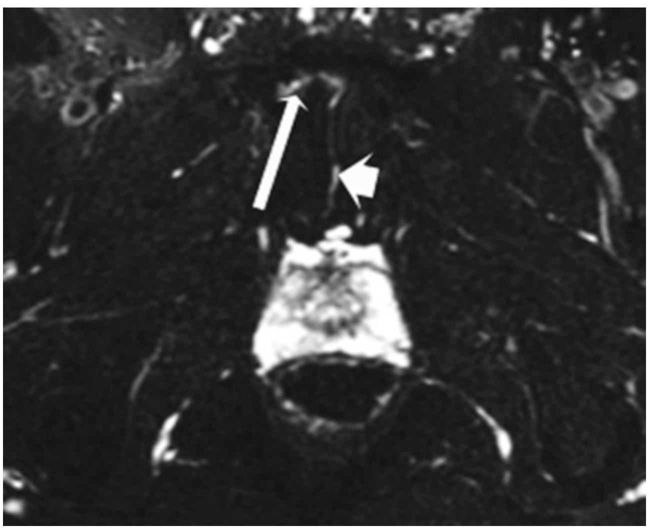


Fig. 2.5 T2w fat saturated MRI of a professional sportsman presenting with right groin pain. The scan demonstrates abnormal fluid signal (*arrow*) extending anterior and to the right of the symphyseal cleft (*arrow head*), representing the secondary cleft sign

now being the preferred modality. Pubic inguinal pain syndrome encompasses several conditions including adductor dysfunction and tear, rectus abdominis injury, osteitis pubis and pre-hernia complex. The first three have been well described in the radiological literature, while the pre-hernia complex remains difficult to image.

MRI is the most sensitive modality for the assessment of pubic inguinal pain syndrome [9]. Findings that have been described include abnormal signal in the body of the pubic bones, signal abnormalities at the rectus abdominis and adductor musculotendinous complexes, focal bulging of abdominal wall musculature, and the secondary cleft sign (a pathological high signal J shaped cleft extending away from the physiological cleft in the symphysis pubis) [10] (Fig. 2.5).

Adductor Dysfunction and Rectus Abdominis Injury

Injuries to the rectus abdominis and adductor insertion into the symphysis pubis are demonstrated well on MRI, with a reported sensitivity of 68 and 86 %, and specificity of 100 and 89 % respectively [11]. These can either be seen as separate entities, or can occur together involving their common aponeurosis. Muscle tears, tendon tears, chronic tendinopathy and injury to the common aponeurosis have all been described [9]. The tears are also seen in conjunction with the secondary cleft sign and bone marrow oedema at the symphysis pubis.

Sportsman's Hernia

Clinical evaluation remains the gold standard for the diagnosis of the 'sportsman's hernia'. Abnormal bulging of the facial plains, signal changes in the muscle on MRI and laxity of the internal ring on herniography have all be described in the radiological literature but are rarely reported [12]. In addition although inguinal hernias can be easily demonstrated on MRI, these true hernias are seen exceedingly rarely in young athletes.

Bone Trauma

Hip Fractures Including Stress Injuries

Fractures around the hip occur in sport either due to high impact trauma or to overuse. The latter occurs with high levels of activity and can be seen, amongst others, in runners, footballers, dancers and in military recruits [13, 14].

Fractures from high impact trauma are generally imaged by plain film and this can be supplemented by high resolution CT. Complex fractures around the acetabulum require CT assessment. 3D-surfaced rendered images are extremely useful for displaying and understanding the complexity and displacement of a fracture, and 'image surgery' facilitates the understanding of a fracture by removing overlapping bone.

There are a variety of classifications of acetabular fractures but one CT-based classification [15] describes 4 categories; 0 = wall fractures alone, I = fractures limited to either the anterior or posterior column, II = fractures involving both the anterior and posterior columns, III = 'floating' acetabulum separated from the axial skeleton both anteriorly and posteriorly.

Stress or fatigue fractures occurring with overuse present with anterior hip or groin pain. The most common site to see this around the hip is in the medial femoral neck, but they can also occur in the pubic rami, lateral margin of the femoral neck and proximal femoral shaft. Stress fractures occur when there is an imbalance of bone absorption and formation. Unbalanced osteoclastic activity causes increased bone absorption and structural weakening of the bone.

Plain radiographs are often the first investigation but may be difficult to appreciate around the pelvis due to the presence of dense overlapping bone and because they are rarely complete or displaced fractures. They are usually seen as radiolucent lines with surrounding sclerosis, but can also be purely radiolucent or show only subtle sclerosis.

MR is highly sensitive for the diagnosis of stress fractures [16]. Fractures are initially seen as areas of high signal subcortical bone marrow oedema. As they mature a low signal line perpendicular to the cortex develops. On very high resolution images early fractures are seen as areas of endosteal bone marrow with tiny high signal spotty foci seen in the cortex. There is frequently oedema of surrounding soft tissue. CT scans show radiolucent lines perpendicular to the cortex, lifting of the periosteum and some overlying soft tissue changes. CT is very useful for the follow up of fractures if there is clinical uncertainty, and with healing there is infilling of the lucent bone and remineralisation of the periosteum. MR is the best technique for differentiating stress fractures from other causes of hip pain in the young athlete [17].

Hip Impingement

Femoral Acetabular Impingement

Femoral acetabular impingement (FAI) is a condition caused by an abnormal anatomical relationship between the femoral head neck junction and acetabulum that leads to early degenerative changes to the acetabular labrum and articular cartilage. There are two main types; type 1 or CAM impingement is characterised by an abnormal bony prominence at the femoral head neck junction and type 2 or pincer type FAI is due to over coverage of femoral head by the acetabulum [3]. In practice many patients have a combination of both types. All major imaging modalities can be used in the diagnosis of FAI.

Plain Film Imaging of FAI

Plain radiographs are usually the first line of investigation for patients with FAI. The classic appearance in CAM impingement is a bony bump at the superior lateral aspect of the femoral head neck junction, this is seen as the classical "pistol-grip" deformity on plain film (Fig. 2.6). The CAM deformity is best seen on a lateral view, but can also be appreciate on AP and frog leg lateral views.

Over coverage of the femoral head by the acetabulum in pincer type FAI is also demonstrated on plain film, CT and MRI. Coxa profunda, protrusio acetabuli and acetabular retroversion are also all associated with the pincer type deformities. Acetabular retroversion can be demonstrated by several plain film signs. The "cross over sign" is seen when the anterior acetabular rim is lateral to the posterior rim at its superior lateral corner (causing a figure of 8 configuration). The posterior wall sign is where the centre of the femoral head is lateral to the posterior wall of the acetabulum. Finally the ischial spine sign is present when the ischial spine is seen to be medial to the pelvic brim. The signs can only be used in a well centred radiograph and there is a recognised error rate in the interpretation of all three signs, even on a good quality study [18].

Other signs of FAI include the presence of synovial or Potts pits; these are well defined lucent areas in the superior lateral femoral neck, that are thought to either be local fibrocystic change, or intraosseous ganglia secondary to the abnormal biomechanics (Fig. 2.7).

MRI Imaging

MRI and MR arthrography are commonly used investigations in patients with suspected FAI. Both investigations demonstrate the bony morphology and orientation of the hip joint and proximal femur. However MR arthrography is the optimal modality for the assessment of the acetabular labrum and articular cartilage. Although the joint can be assessed in several planes, the oblique axial plane (i.e. parallel to the femoral neck) is optimal for the measurement of the alpha angle and evaluation of the labrum and cartilage.

The importance of MRI in the assessment of FAI was recognized by Nötzil et al. [19] who analyzed the alignment of the femoral head neck junction and developed the concept of the alpha angle in the assessment of CAM impingement (Fig. 2.8). The alpha angle describes the loss of spherical congruity between the acetabulum and the femoral head. The

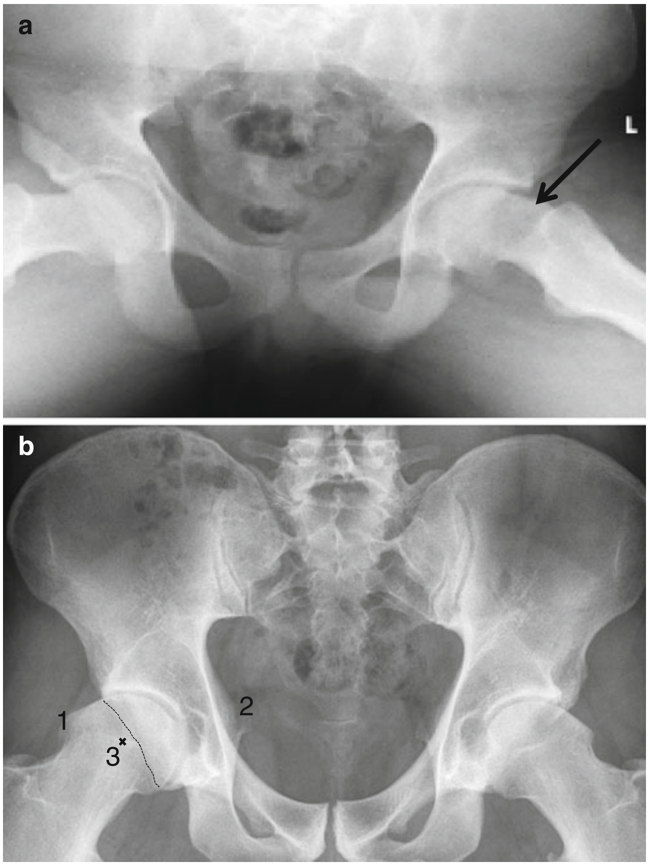


Fig. 2.6 (**a**) Plain radiograph demonstrating a pistol grip deformity to the left femoral head neck junction (*arrow*). (**b**) Plain film of a young male patient with a mixed CAM and Pincer femoral acetabular impingement. *1*. Abnormal prominence of the femoral head neck junction in keeping with the CAM deformity. *2*. "Ischial spine sign" the ischial spine is seen to be clearly medial to the pelvic brim bilaterally, this is suggestive of acetabular retroversion. *3*. Posterior wall sign. The centre of the femoral head is lateral to the posterior wall of the acetabulum. This is also a sign of acetabular retroversion. The *dotted line* represents the posterior wall of the acetabulum, while the *x marks* the centre of the femoral head

mis-match in the spheres, which is due to the bony protuberance at the femoral head-neck junction, caused impingement between the femoral head and acetabulum at the extremes of movement of the hip.

Measurement of the alpha angle in FAI remains controversial. There is no clear 'normal' or 'abnormal' range and there is wide inter-observer variation [18]. Alternative measurements such as anterior femoral distance (the greatest perpendicular depth of epiphyseal growth plate at the femoral head neck junction) have been suggested.

The degree of over coverage of the femoral head by the acetabulum in pincer type FAI is also demonstrated on MRI. The over coverage can either be symmetrical (for example protrusio acetabuli) or asymmetrical (acetabular retroversion) in nature.

In CAM impingement the damage to the labrum and articular cartilage characteristically occurs at the anterior and anterio-superior aspects of the acetabulum. Secondary ossification of the labrum is seen in pincer FAI; this increases the degree of over coverage and exacerbates the problem. Posteroinferior cartilage lesions and damage to the posterior and posteroinferior labrum are characteristic of pincer type FAI.

CT Imaging

Although MR/MR arthrography, CT can also be used in the imaging of FAI. Multiplanar reformat images can be performed that provide excellent bony structural detail. 3D CT can clearly demonstrate cam (Fig. 2.8) and pincer abnormalities, and can be used to calculate the alpha angle. CT obviously carries a significant radiation burden and is less sensitive in demonstrating damage to the labrum and articular cartilage.

More recently highly sophisticated image processing of 3D CT reconstructions of the hip has been developed which models movement of the femoral head within the acetabulum. This allows the pinch points between the acetabulum and the femoral head to be highlighted and it is these areas that the surgeon will want to remove during osteoplasty. This technique can also be used to measure the alpha angles around the entire acetabulum although, as with any mathematical modeling technique, it makes a number of assumptions about, for example, the axis of motion.

Bone Scintigraphy

Although not part of the usual work up for FAI, three phase bone scanning and single photon emission tomography (SPECT) can also demonstrate features of femoral acetabular impingement. Focal uptake of tracer localised to the superior lateral acetabulum and anterior femoral head neck junction is seen in FAI, this corresponding to the underlying damage to the articular cartilage, the sensitivity being reported as 85 % [20].

Future Developments

One of the main reasons of imaging FAI is to determine damage to the articular cartilage and identify what patients may benefit from early surgical intervention prior to the establishment of secondary degenerative changes. Evaluation of articular cartilage can be a diagnostic challenge with current imaging techniques due to the thinness and curved orientation of the cartilage. Recent developments have investigated the use of biological markers to assess the degree of cartilage damage. One potential marker is gluycosaminoglycan (GAG) a key component of articular cartilage. Delayed gadolinium enhanced MRI imaging of cartilage (dGEMRIC) is a relatively new technique that has shown to be useful in the

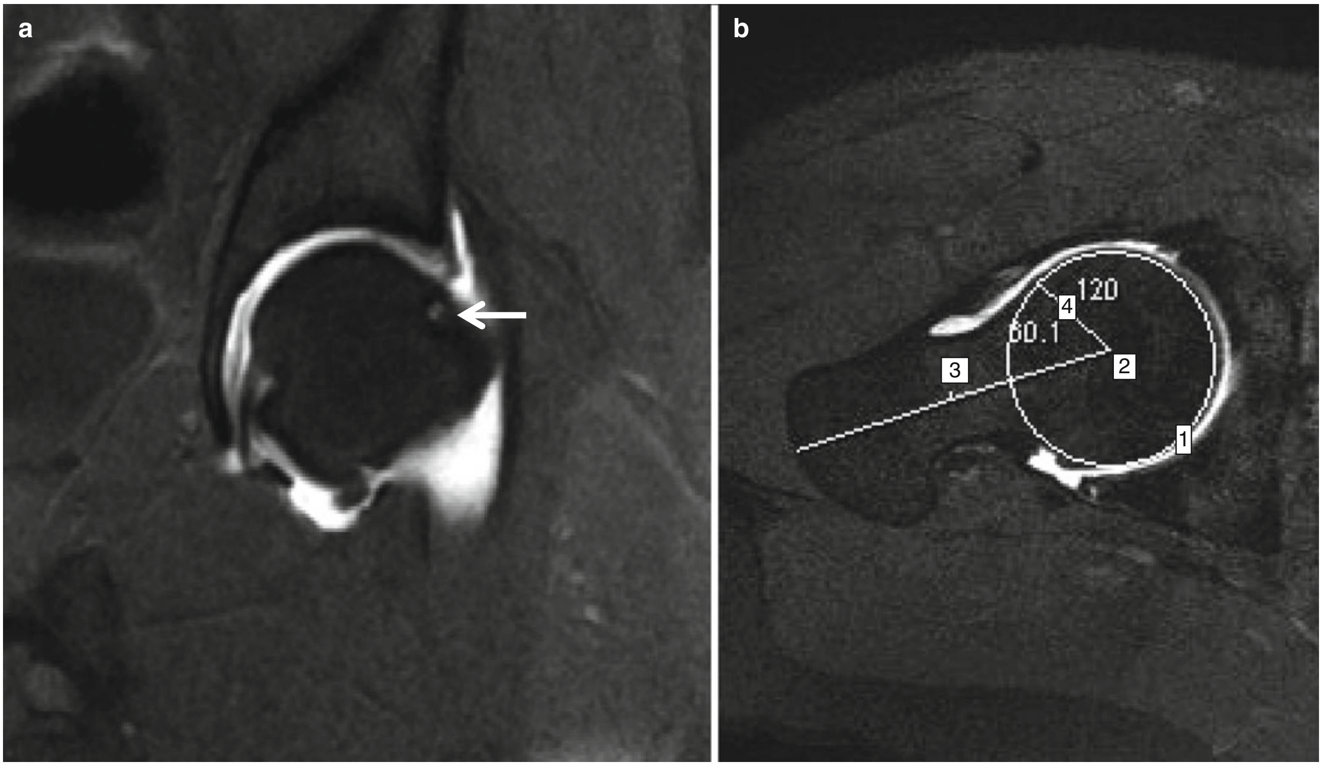
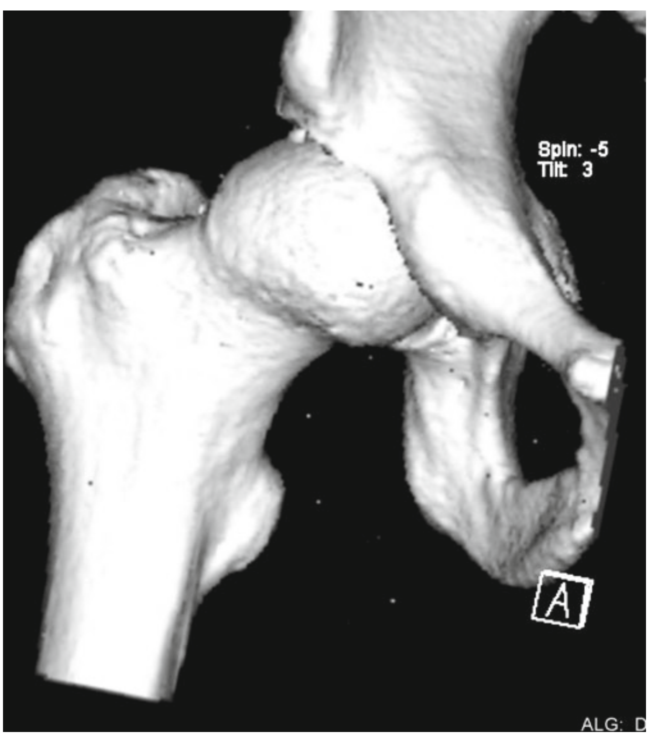


Fig. 2.7 (**a**) Coronal STIR MR arthrogram demonstrating a subchondral bone cysts in the lateral aspect of the femoral head neck junction (*arrow*), in keeping with a Pott's pit. (**b**) Axial TI Fat sat MR arthrogram of the right hip demonstrating calculation of the alpha angle using the following steps. 1. A best fit circle is drawn around the circumference of the femoral head. 2. The centre of the femoral head is identified. 3. A line is drawn from the centre of the femoral head down the centre of the axis of the femoral neck. 4. A second line is drawn from the centre of the femoral head to the point where the anterior femur first leaves the best fit circle. The angle formed between the two lines is the alpha angle



assessment of the amount GAG content of hip articular cartilage in FAI [21]. dGEMRIC has been shown to be reliable in the identification of early osteoarthritis and specific patterns of cartilage damage have been demonstrated in FAI [21]. The technique is quantitative and can therefore be used serially to assess cartilage healing/deterioration.

Labral Tears

The acetabular labrum is a horse shoe shaped fibro cartilaginous structure that deepens the acetabulum in a similar fashion to the glenoid labrum in the shoulder. Damage to the

Fig. 2.8 3D CT of cam type femoro-acetabular impingement. The 3D surface rendered image of the right hip shows a marked hump of the anterior margin of the femoral head-neck junction and there is loss of the *spherical shape* of the femoral head at its margin. The hump impacts on the lateral margin of the acetabulum during flexion causing labral and articular cartilage damage acetabular labrum alters the hip biomechanics leading to early degenerative change. Plain film and ultrasound are inadequate at demonstrating labral pathology, although an os acetabuli is a recognised secondary plain film sign.

MR arthrography is currently the recognised gold standard investigation of labral tears, and several studies have demonstrated a good correlation between MR arthrography and operative findings.

Images are obtained in multiple planes, although axial and coronal oblique images are particularly useful, and both large field of view images (of the pelvis) and small field of view images of the affected hip are usually performed. One study showed that images obtained in the axial oblique plain were the most sensitive for detection of labral tears and the use of three sequences (coronal T2 fat sat, axial oblique T1 fat sat and sagittal T1 fat sat) gives a sensitivity of 96 % for the detection of labral tears [22].

The acetabular labrum usually has a low signal triangular shape on T1w and T2w imaging, this morphology being present in approximately two thirds of people, and is the most common shape seen in adolescents and young adults [23]. Round and flat shapes to the acetabular labrum have also been described in normal individuals. A small but significant number of people have an absence of the acetabular labrum, this being more common with age.

Degenerative changes in the labrum are seen as abnormal increased intra substance high signal on T2w and gradient echo sequences, or a frayed appearance to the labral edge. Tears are seen as abnormal linear high signal bands of intra substance fluid extending into the labrum, most commonly on the articular side of the labrum. The labrum can also become detached from its insertion into the acetabulum and this is seen as high signal extending completely between the labrum and acetabulum. Ossification can occur, causing a similar appearance to the adjacent bone. Para labral cysts, are also seen in some patients, in a similar fashion to para meniscal cysts in the knee.

Tears most frequently occur in the anterior and antero superiorly aspect of the labrum while posterior tears tend to be seen in patients with underlying dysplasia or previous dislocations [24] (Fig. 2.9).

Hip Pain in the Young Adult and Imaging Appearances: Non-sport Related Causes

Slipped Capital Femoral Epiphysis (SCFE)

SCFE occurs in the immature skeleton when the physeal plate of the femoral head separates and the epiphysis slips posteriorly and medially. It most commonly occurs during the growth spurt of adolescence and is associated with obesity. It presents with hip, thigh or knee pain and a limp in early adolescence.

Plain radiographs are the mainstay of diagnosing this condition but can be supplemented by CT and MRI as necessary. An AP and lateral view of both hips should be obtained. With an early slip, the AP view can be normal as the head moves posteriorly, and then the diagnosis is made from the lateral view. On the lateral view a step is seen between the epiphysis and the metaphysis. On an AP view, a line drawn along the lateral femoral neck will intersect the femoral head in the normal hip. In an established slipped epiphysis, the line drawn will pass above the femoral head (Fig. 2.10).

Where a SCFE has been missed and the patient presents with a fused skeleton, the femoral head is often malformed with a rather drooped appearance, commonly a varus deformity and persistent asymmetry of the growth plates. Chondrolysis and bone necrosis can complicate SUFE and the imaging appearances will then be affected by these features.

Recognition of a SCFE is important as it requires urgent treatment with surgical fixation of the femoral head.

Legg-Calve-Perthes Disease

This self-limiting disease is an idiopathic form of osteonecrosis of the hip and the imaging features are those of bone necrosis/avascular necrosis. The imaging diagnosis is usually made by radiography, bone scintigraphy and more recently MRI. It is characterized by bone resorption, subchondral fractures, subcortical bone marrow oedema and repair with bone sclerosis. It can lead to growth disturbance of the femoral head (Fig. 2.10).

As with other forms of avascular necrosis, MR is useful for showing early disease when rather non-specific bone marrow oedema, seen as high signal on T2/STIR images and lower signal on T1 images, is seen in the femoral head. As the damage progresses subcortical linear high signal develops, then low signal fracture lines. This is eventually followed by fracturing and collapse of the cortex. MR can also show damage to the articular cartilage and the labrum.

In later life, the mature femoral head is flattened and widened, and there is shortening and abnormal modeling of the femoral neck (Fig. 2.10)

Hip Dysplasia

Despite a program of neonatal hip screening, hip dysplasia can present late in the adult population [25]. This varies from frank dislocation of the hip to quite subtle forms of acetabular dysplasia where there is insufficient anterior coverage of

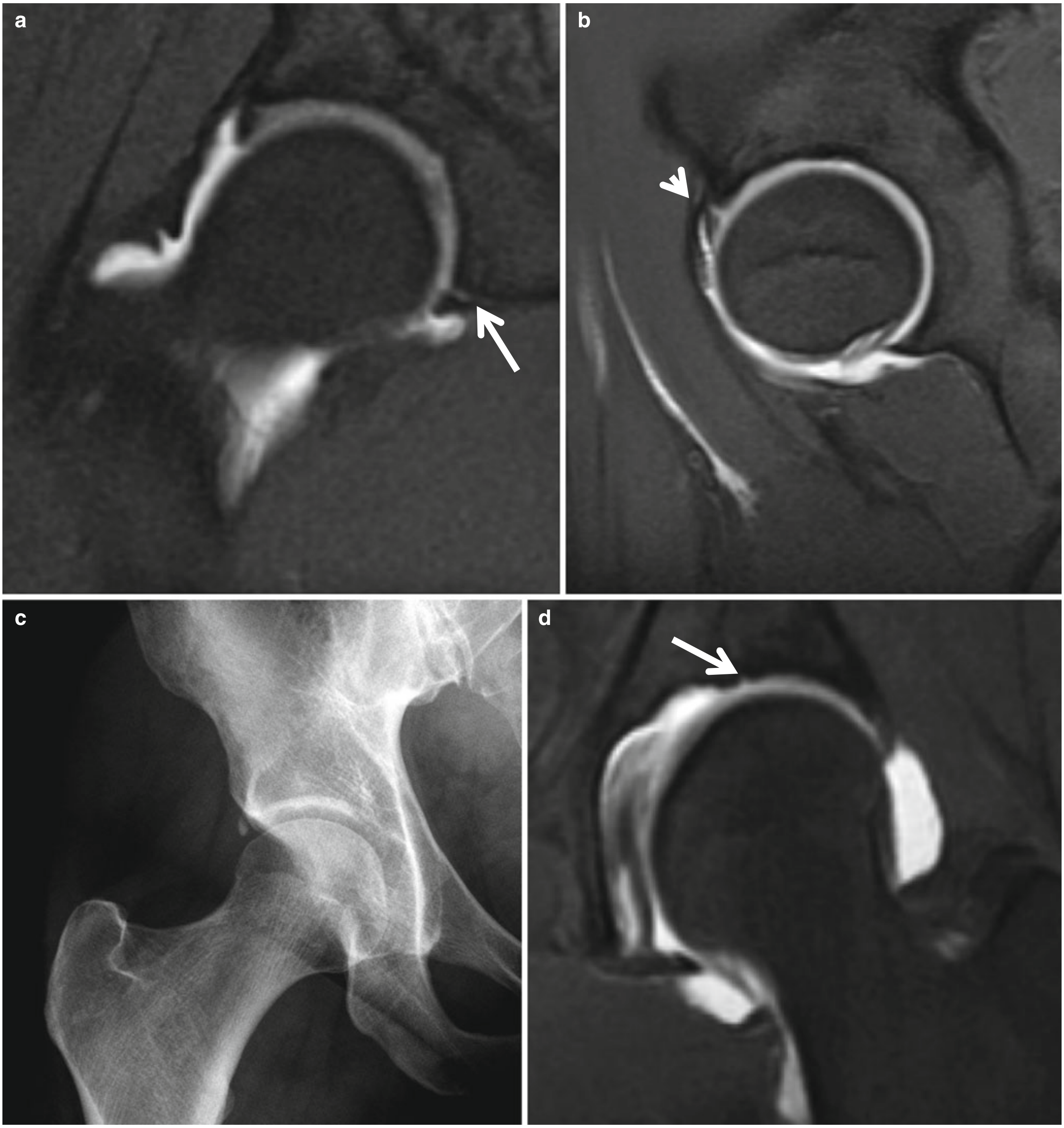


Fig. 2.9 (**a**) Coronal T1 FSE Fat Sat MRI arthrogram (**b**) Sagittal T1 FSE fat sat MRI arthrogram (**c**) AP right hip (**d**) Coronal T1 FSE Fat Sat arthrogram. (**a**) High signal (*arrow*) between the acetabulum and labrum in keeping with a posterior labral tear. (**b**) Linear high signal (*arrow head*) is present in the anterio-superior labrum in keeping with a tear. (**c**) Small rounded bony density adjacent to the labrum, representing an os acetabuli. This can be a secondary sign. (**d**) Loss of articular cartilage (*arrow*) in the superior portion of the acetabulum in a patient with early degeneration secondary to a CAM deformity

the femoral head by the acetabulum. It is this latter form of dysplasia that is more likely to present in the young adult participating in sport, as there is premature damage to the labrum and articular cartilage which can present with hip pain and stiffness.

The plain radiographic appearances of the dysplastic acetabulum can be subtle. The centre edge angle can used to quantify the coverage of the femoral head. The angle is formed from two lines each originating from the centre of the femoral head. One line is drawn vertically and the second to the lateral

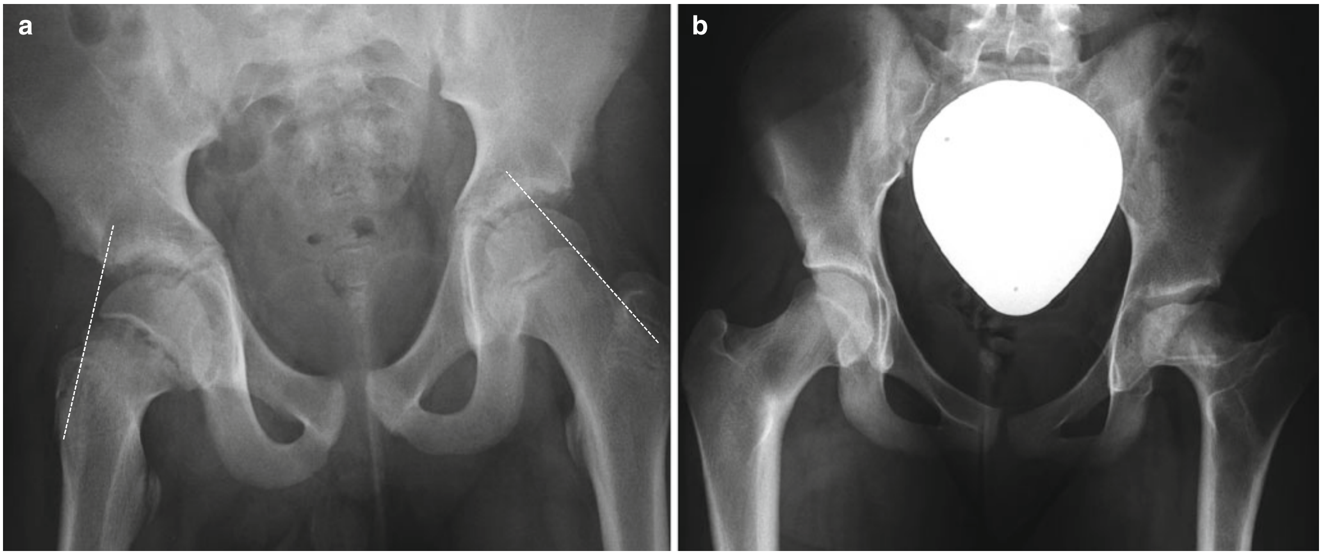


Fig. 2.10 (**a**) AP radiograph of a patient with a slipped upper femoral capital epiphysis of the right hip. Note that the a line drawn along the lateral border of the femoral necks (*Klein's line*) intersects the femoral epiphysis on the normal left side, but not the abnormal right. *Klein's line* should intersect approximately one sixth of the epiphysis. (**b**) AP radiograph of the pelvis demonstrating a patient with a missed diagnosis of Legg-Calve Perthes disease. Note the abnormal modelling of the left femoral head

margin of the acetabulum. The normal angle is greater than 25° on an AP radiograph and is less in dysplasia.

MRI is mainly used in dysplastic hips to show the degree of cartilage and labral damage. Three-dimensional surface rendered CT is very useful for showing the lack of anterior coverage of the hip.

Infection and Inflammation

Septic Arthritis and Osteomyelitis

This is a very uncommon cause of hip pain in a healthy young adult but is more commonly seen after surgery to a joint and in patients who have sickle cell disease or are immunocompromised. A recent multivariant analysis for diagnosis of a septic hip has shown that the significant clinical and radiological factors for a positive culture from a hip aspirate were a raised WBC, a high percentage of PMN leucocytes in the aspirate, fluid turbidity, a history of drug use and the radiological presence of a sinus tract [26].

The MR features of septic arthritis are a joint effusion, synovial thickening, soft tissue oedema surrounding the joint and frequently subchondral oedema of the joint margins (Fig. 2.11). Each of these features will be of high signal on STIR and T2 weighted images and the bone marrow edema and synovitis will enhance with contrast. Bone marrow oedema is not seen with transient synovitis of the hip and this is a helpful diagnostic feature [27]. Osteomyelitis around the hip will be seen as marked bone marrow oedema, and this will progress to bone destruction, a defect in the cortex and a sinus tract as the infection becomes chronic.

Chronic Relapsing Multifocal Osteomyelitis (CRMO)

This is a rare autoinflammatory disorder that presents with intermittent bone pain and fever. It presents with bone pain and sometimes a limp. Although is more common in younger children it can affect young adults. The exact cause of the condition is not understood, but it does not appear to be due to an infection. The disease is associated with multifocal bone lesions and these can occur in the pelvis and proximal femora, thus presenting with pelvic and hip pain.

The radiographic feature of early disease is bone lysis. However, chronic lesions characterized by a periosteal reaction, marked bone sclerosis and hyperostosis are more commonly seen. On MRI, these lesions show a mixture of features of inflammation (high signal T2/STIR images) and bone sclerosis (low signal on all sequences). They show increased activity on bone scintigraphy, and are usually seen as areas of sclerosis on CT. The diagnostic features of the disorder are its multifocal nature, and the confluent sclerosis in the effected bones.

Treatment with non-steroidal anti-inflammatory drugs is most common and steroids, methotrexate and bisphosphonates are used less frequently.

Inflammatory Arthropathies: Juvenile Inflammatory Arthritis (JIA) and Enthesitis Related Arthropathies (ERA)

There is a wide spectrum of inflammatory joint disease in children and adolescents varying from SLE type variants

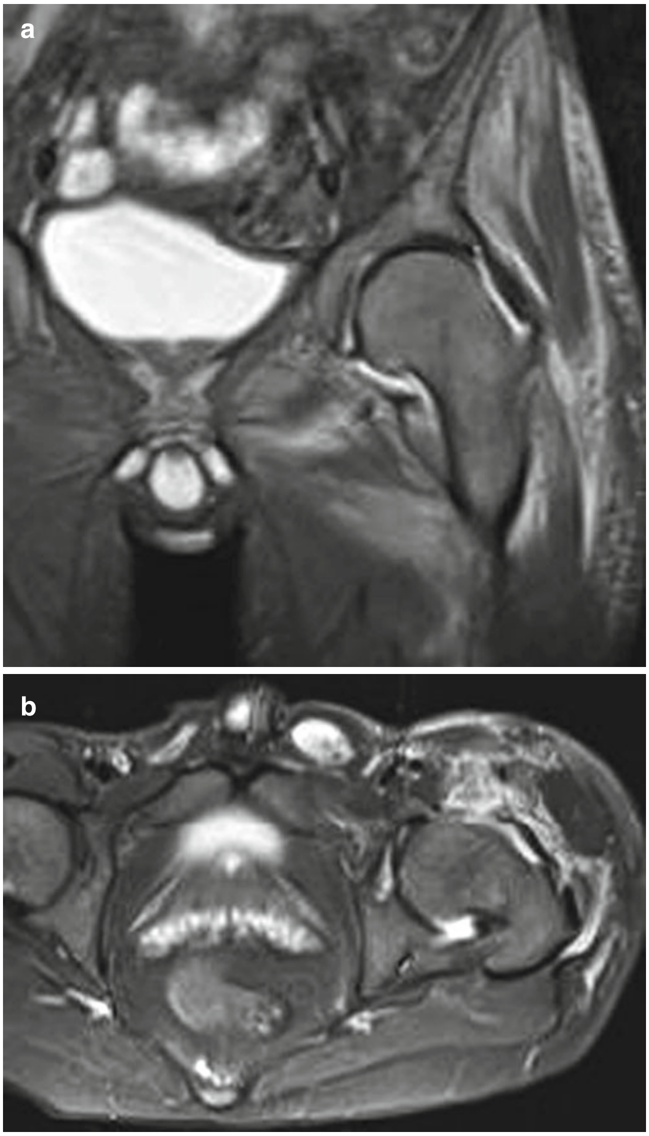


Fig. 2.11 Septic Arthritis. A contrast enhanced MR scan through the left hip in a 16 year old footballer presenting with hip pain. (**a**) Coronal and (**b**) Transverse T1W image with fat saturation. There is synovitis of the hip seen as a high signal rim around the femoral head within the joint space. There is also extensive high signal in the soft tissues around the joint, particularly anteriorly and laterally. There is, however, no enhancement of the sub-articular bone and so there is no co-existent osteomyelitis

through peripheral inflammatory disease to spondyloarthropathies. The hips and sacroiliac joints can become involved and patients can present in adolescence or as young adults with hip, groin or low back pain and stiffness.

The early features of an inflammatory arthropathy in the hips are synovitis and effusion. These are very well seen on contrast enhanced MR scans. Although both the effusion and inflamed synovium will appear as high signal on T2 weighted images, only the thickened and vascular synovium will enhance with contrast. As disease progressed, erosion of the articular surfaces of the joint can occur. Avascular necrosis can be superimposed on these changes, occurring as a complication of steroid therapy. Ultrasound can be used to identify large effusions or bulky synovitis but it is less sensitive than MR. Ultrasound is very useful for guiding injection or aspiration of the joint.

Sacroiliitis can occur in patients with inflammatory arthropathies, and in particular in patients with enthesitis related arthropathy [28, 29]. This can be difficult to see on plain X-ray as the immature SIJ is widened and poorly defined and the normal appearances can be confused with disease. MRI and CT can both demonstrate erosions, but MR is particularly useful for showing the inflammation associated with acute disease and the fatty infiltration around healing disease [30, 31] (Fig. 2.12).

Tumour and Tumour Like Conditions

Osteoid Osteoma

Osteoid osteoma is a benign skeletal neoplasm of unknown etiology that is composed of osteoid and woven bone and occurs most commonly in young adults [32]. The tumor is usually smaller than 1.5 cm; if larger than this it forms an osteoblastoma. The lesion can occur in any bone but the majority occur in the appendicular skeleton. Pain occurs at the site of the lesion, and is typically worst at night. It is relieved by aspirin and this feature is virtually diagnostic. The condition may be self limiting.

Imaging Features of Osteoid Osteoma

The typical plain radiographic appearances of are of a ring of sclerosis within bone, surrounding a central radiolucent centre. However, when an osteoid osteoma is based on subcortical bone within a joint capsule, such as in the hip, sclerosis is an exception and a radiolucent lesion with a joint effusion is the most common finding.

On MRI, the main feature of an osteoid osteoma is bone marrow oedema. This is seen best on STIR images or T2 scans with fat saturation as an area of high signal. The sclerotic bone may also be seen as a focus of low signal in some cases. The oedema itself is a very non-specific appearance and the diagnosis is usually confirmed by a CT scan.

On CT, the typical imaging characteristics are of a sclerotic ring of bone around a central area of reduced bone density. Within the centre of this, a tiny highly vascular enhancing focus is usually seen and this is a useful diagnostic feature. Isotope bone scans show strong uptake at the site of the osteoma. SPECT scans, which tomographically localize the area of increased uptake, are particularly helpful in patients who have recurrent osteomas at a site of previous treatment when post surgical or treatment sclerosis on CT can be difficult to differentiate from the recurrent lesion. The main differential diagnosis is of a Brodie abscess.

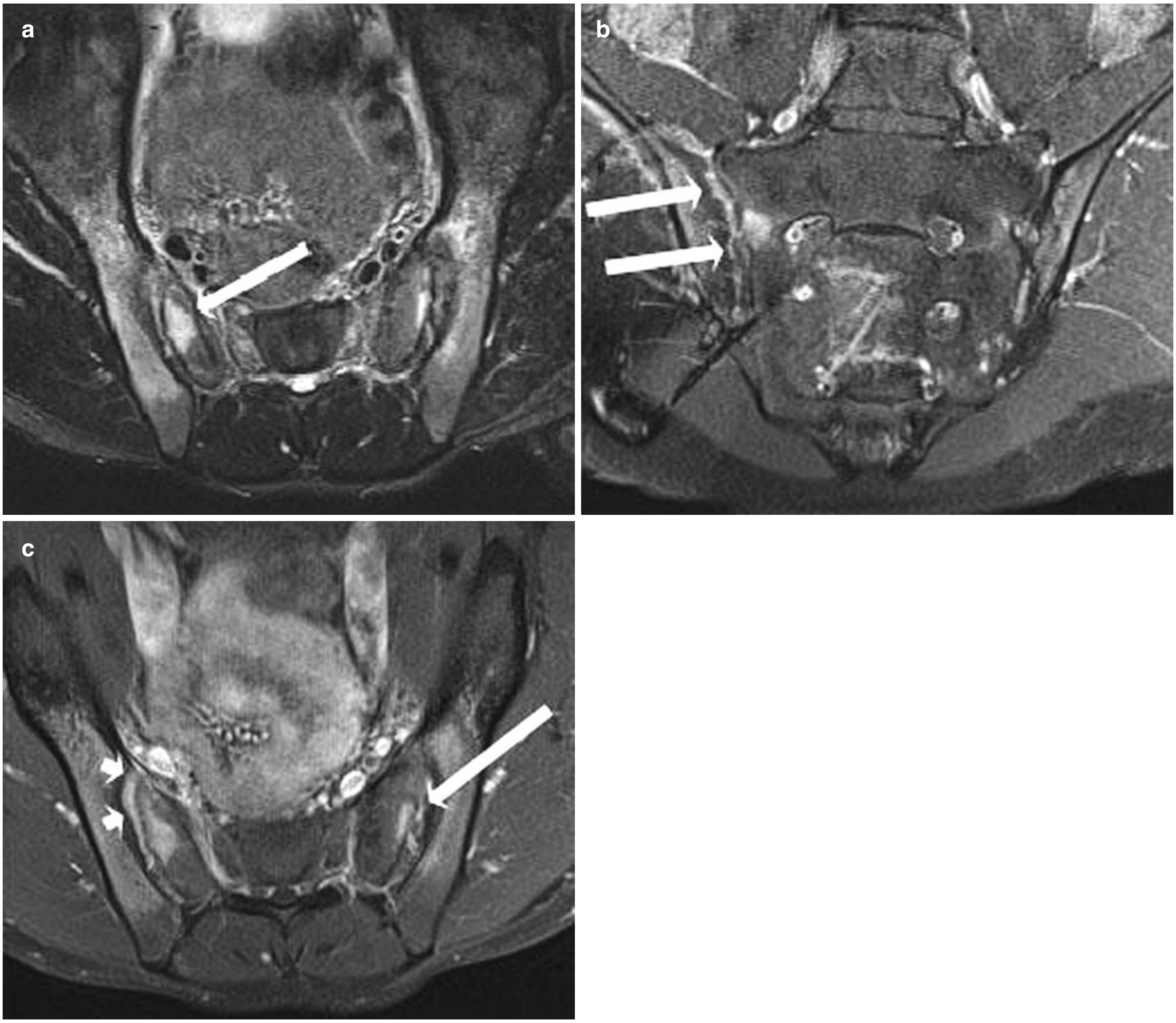


Fig. 2.12 Sacroiliitis. This 18 year old sprinter presented with back pain and stiffness which was preventing him training. Transverse (**a**) STIR image and coronal (**b**) and transverse (**c**) T1W image following contrast, showing chronic but very active sacroiliitis. There is high signal oedema of the bony margins of the sacroiliac joints (*arrow*, **a**). The joint margins are irregular (*arrow*, **b**) due to erosions, and there is enhancement of the bone marrow oedema (*arrow*, **c**) and the joint space (*arrow heads*, **c**)

Other Tumours

Primary bone tumours are uncommon malignancies but do occur in the young adult. The first of the bimodal peaks of osteogenic sarcoma (OGS), the most common primary bone tumour, occurs in the adolescent age group [33]. Ewing's sarcoma also has a peak incidence in childhood and adolescence [33].

Primary bone tumours around the pelvis present most commonly with pain. They may be difficult to diagnose on plain films in the early stages for several reasons. This is particularly the case for sacral tumours. However persistent and increasing pain in a young adult must be imaged and even when the plain radiograph appears to be normal, an MR scan or an isotope scan should be used to exclude serious underlying pathology.

Primary bone tumours cause bone destruction initially and as the tumour enlarges it will either lift or breach the periosteum and cause an extraosseous mass that extends into the soft tissue around the bone. Osteogenic sarcomas form bone and irregular new bone formation is a feature of this tumour. With very aggressive OGS, the tumour may be very destructive with little bone formed. Ewing's sarcomas mineralize in layers under the periosteum as this lifts causing the onion skin appearance sometimes seen. Consequently the MR appearances of tumours are signal abnormality within the involved bone, patchy low signal where there is tumour mineralization, destruction of the cortex and a soft tissue mass. CT will show bone destruction of the intramedullary bone and then cortical bone, together with a soft tissue mass if present. There are many other tumours that can occur in the pelvis and hip of the young adult including bony, chondroid and synovial tumours as well as metastatic disease, but these are rare.

Diagnosis of these tumours is confirmed by biopsy, and in most cases this will be done percutaneously with imaging to guide the needle placement. These patients should be referred to and managed within specialist tumour services. Biopsy should be performed in the context of specialized services as the histology of these lesions requires specialist expertise.

Summary

Hip pain in the young adult is non-specific and can be due to sports-related or non-sports related conditions. Imaging plays an integral part in the diagnosis and management of these patients. The most successful imaging requires choice of the most appropriate modality, good equipment, the best imaging protocols and a well-trained observer. Good communication between the clinician and the radiologist is key to optimizing the value of imaging for the benefit of the patient.

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Glossary

CT Computed Tomography
Fat Sat Fat Saturation
MRI Magnetic Resonance Imaging
PD Proton Density
STIR Short Tau Inversion Recovery
T1W T1 weighted
T2W T2 weighted

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Clinical Diagnosis in Hip Disease

3

Michael D.J. Cronin and Marcus J.K. Bankes

Hip disease in the sporting young adult patient has traditionally been difficult to accurately diagnose. It is not uncommon for patients to have been given more than one diagnosis and several modalities of treatment before the true pathology is found. A systematic approach including history, examination and specialist investigations will give the highest possible chance of accurate diagnosis. However, our knowledge of hip pathology and its causative factors is still evolving and therefore the standard hip examination learnt during early medical training should now be replaced with a more thorough set of questions and clinical tests suited for active young adults.

With recent advances in diagnostic imaging one would expect the accuracy of diagnosis to increase. However, this should not lead to complacency about the clinical assessment which is still essential to help distinguish between intra-articular pain, extra-articular pain and pubic pain. Without systematic and accurate clinical diagnosis a proportion of patients will be over-diagnosed due to the high false positive rates involved in current imaging [1]. In fact, our clinical skills are now more important than ever.

The first part of this chapter describes a baseline history and examination useful for all patients with symptoms in the region of the hip. This is followed by a number of tests, which are useful in more specific circumstances. We attempt to provide a guide as to when these tests should be added but this is obviously not exhaustive. Finally we discuss the role of injections in the diagnosis of hip pathology.

History

A full history should be taken from the patient including their age and occupation. The age not only provides help with the likely pathology and underlying diagnosis but also allows thought to be given to the treatment options available, the likely rehabilitation and the long-term results of any intervention. Manual occupations predispose to certain types of repetitive or traumatic injury. Equally sedentary desk based jobs can cause problems with long periods of sitting at 90° [degrees] hip flexion. Obviously manual workers require longer periods of rehabilitation or even a staged return to work although office workers are not free of the physical challenges of the daily commute. All of this information helps to begin building a picture of the patient's level of disability.

The main focus of the history will be on 'hip pain'. This can be described in many forms and is often a cause for confusion. The position of the pain should be sought. Groin pain is often associated with intra-articular pathology whereas lateral thigh pain will more likely be extra-articular. Buttock and low back pain need to be discerned from spinal or sacro-iliac joint (SIJ) pathology. If a patient with anterior rim damage is directly asked where the pain is felt often a single finger is seen to point to the centre of the groin crease. Another response is to point with 'co-ordinate fingers' with the pain being shown as deep between two points. Patients often use metaphors involving sharp objects deep in the hip to describe the pain. A third well described 'C Sign' is seen when the patient uses the thumb and index finger to form a clasp around the lateral thigh, with the thumb on the buttock and index finger in the groin [2]. This has been shown to have a high correlation with intra-articular pathology. However, these classical locations of pain may not always be present. A recent study has shown that many patients may present with pain in the lateral thigh, posterior thigh, low back, or knee. Although, on further questioning, 86 % of patients had groin pain as well as pain in the above locations [3] (Fig. 3.1).

The nature of the pain is of great importance. Constant, dull aching pain, including night pain is likely to signify a more degenerate pathology. Sharp, stabbing pains indicate a more mechanical cause such as anterior labral tears or localised chondral damage. Patients with anterior rim damage often describe feelings of catching, clicking or popping originating from deep in the hip. The location of the pain and the provocative

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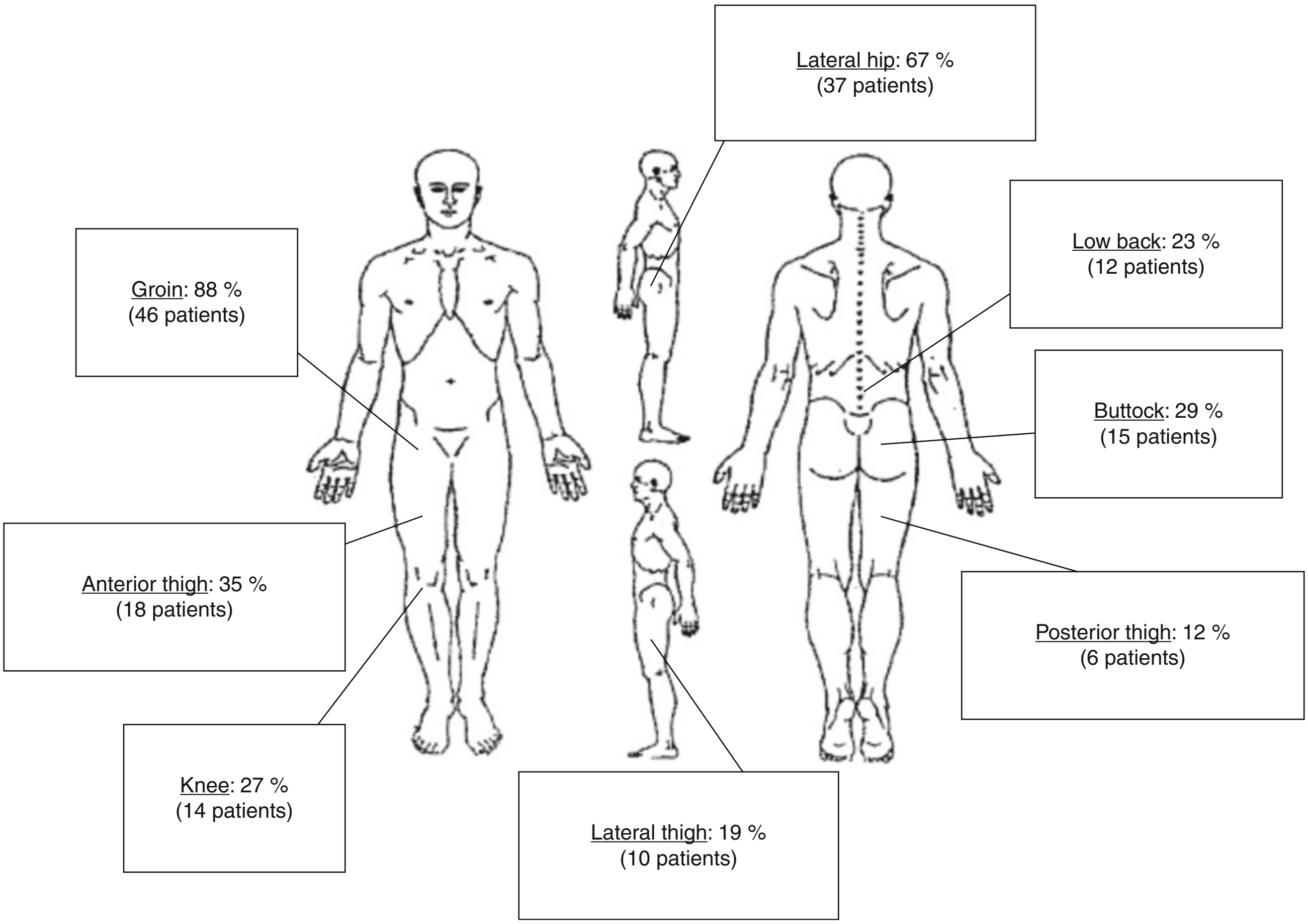

Fig. 3.1 Localisation of pain (Body diagram: Permission requested [3])

movements can help to distinguish symptoms from anterior rim and hip joint from psoas or greater trochanter. During sport, symptoms may only be present in twisting activities, running on uneven ground or during team sports but may be absent with straight line running on flat surfaces or during gym work. Cycling is often the last sporting activity to be affected. Severity of the pain must be quantified; pain only interfering with high end sporting activity should be differentiated from pain during normal daily activities. Clearly, this factor is of huge importance in deciding on surgical treatment. Recreational athletes who only have symptoms during or following severe exertion may only have to modify their training schedule or choice of sports to avoid symptoms completely. However patients with pain on daily activities and who have given up exercise altogether clearly need surgery, and also feel the benefits of surgery earlier in their postoperative rehabilitation. There should be a low threshold for surgical treatment of *professional* athletes, and it must be remembered that this group includes trainers and sports teachers, not only elite athletes.

A history of an acute groin injury may represent an acute labral tear with no significant underlying cause but could also be caused by the first episode of rim damage from Femoro-Acetabular Impingement (FAI). In athletes with FAI, however, there is often a long preceding history of hip stiffness and reliance on extensive pre and post-exercise stretching rituals.

Daily activities are often affected by hip pathology and their nature can help differentiate from low back or SIJ pathology. These include ascending/descending stairs, reaching down to feet to put on shoes and socks (foot access), swinging legs into/out of a car (car access) and sitting/rising from a low chair. All of these require deep hip flexion with or without an associated rotational movement. After getting up from a chair, patients may also describe that the hip needs a few steps to “get going”.

Trochanteric pain is worse both lying on the affected side, and also lying on the non-affected side when the leg falls into adduction. A snapping iliotibial band (ITB) is frequently described by the patient as a feeling of the hip coming out of joint and spontaneously reducing. This can feel so severe they are often reluctant to agree that their symptoms could be simply a tendon flicking across the side of the trochanter. Generalised anterior symptoms with clicking can be from the psoas tendon. Distinction between psoas irritation and hip joint pain can be difficult however and this is a common use for diagnostic local anaesthetic injection. Meralgia paraesthetica (compressive symptoms from the lateral cutaneous nerve of the thigh) often has associated sensory symptoms but can present as severe 'hip pain'. Very medial pain should raise a suspicion of adductor tendon tears or a 'sports hernia'.

Any relieving factors should be recorded along with any reliance on analgesia or anti-inflammatories and the pattern of their usage.

A thorough past medical history may reveal previous underlying pathology such as Developmental Dysplasia of the Hip (DDH), Legg-Calve-Perthes' disease, childhood hip sepsis or Slipped Upper Femoral Epiphysis (SUFE). These are all associated with both labral and degenerate pathology in later life. Patients may even have a history of previous ineffective surgical treatment of groin strains, hernias or even varicocele on the side of the current symptoms.

Connective tissue and collagen disorders can lead to hypermobility with symptomatic laxity or labral pathology [4]. Other medical conditions such as sickle cell or steroid therapy can directly lead to Avascular Necrosis (AVN). Indirect causes of AVN and stress fractures have been associated with certain medications such as the recent link between fractures and bisphosphonates [5].

A family history may reveal hip dysplasia, hip replacement at an early age or haemoglobinopathy.

Baseline Examination

A systematic examination of the hip and surrounding joints should help to narrow the differential diagnoses made from the history. Therefore, although an almost exhaustive set of clinical tests can be described it is important to perform them in a manner likely to further the diagnosis. A set of standard baseline tests should be employed with a selection of more specific tests added depending on the history and potential diagnoses. A recent study looking at hip examination tests showed a great variety of tests can be employed to provide the same answer but also that surgeons who employed more tests in their work up actually had a higher percentage of negative tests [6].

The examination should flow for both the patient and examiner with the proposed sequence being standing, seated, supine, lateral and finally prone examination.

Standing

The patient needs to be exposed adequately to allow free movement of the hips and visualization of the active muscle units. In practical terms, this means exposure down to gym wear or athletic shorts. Modesty is an important consideration with young female patients and a chaperone is strongly recommended. Pre-warning the patient to bring some shorts to change in to is also helpful as traditional examination gowns obscure the gait pattern. Gait is assessed and is often normal in this patient group. However, the patient should be asked about limp following or during sport, or one that develops during the day as, often, subtle limps may only develop with prolonged walking.

With the patient standing it is often a good opportunity for them to demonstrate any clicking or mechanical symptoms, which are often reproduced with specific flexion to extension movements or during the gait cycle.

A traditional Trendelenburg test should be performed to assess abductor function. Recent literature has updated the description of the test calling it a 'Single leg stance phase test' [7]. This requires the patient to stand with feet shoulder width apart raising the unaffected leg to 45° knee and 45° hip flexion. The test is completed after 6 s and is positive if the trunk falls more than 2 cm. Spinal mobility is also assessed with flexion, extension, lateral flexion and rotational movements.

Before seating the patient, hypermobility can be quantified with a Beighton score [8].

Seated

Seated examination can begin with pure observation during history taking. The patient will often sit with the leg slightly extended at the hip causing them to slouch and list slightly to the unaffected side.

After standing the patient, they can be further examined sat on the edge of the examination couch. The height must be sufficient to allow the legs to hang freely. An effort should be made to examine in 90° of hip and knee flexion, in this position passive range of internal and external rotation can be reproducibly measured. It is also easy to appreciate differences between left and right hips in this position and if necessary use a goniometer for measurements (Fig. 3.2).

Supine

With the patient lying flat, traditional measurements of leg length can be performed visually and clinical estimates confirmed using a tape measure as necessary [9]. Passive Range of Motion (PROM) can again be tested in this position with subtle differences in deep flexion noted between sides (Fig. 3.3).

Fixed flexion deformities can be assessed in the usual manner with the Thomas test [9].

Review of recent literature suggests that a series of impingement tests should be routinely included with both passive and dynamic testing.

Passive testing includes the classic "Impingement" test or Flexion Adduction and Internal Rotation (FADDIR) test [10], which can be preformed in both the supine or lateral positions. It aims to reproduce the patient's symptoms by pushing the femoral neck or femoral cam up against the anterior labrum and anterior articular cartilage rim (Fig. 3.4).

The authors prefer performing the test in the supine position, with the leg brought up to full flexion, adduction and internal rotation; reproduction of the patient's pain signifies damage to the anterior acetabular rim, be it labrum, cartilage or both. The hip is gently taken up to the limit of pain free flexion and, whilst looking at the patient's face, it is gently moved into adduction and internal rotation whilst not only listening to the patient but also observing for signs of discomfort. Usually a painful segment of the acetabular rim can be identified with gentle combinations of these movements, although this is better described in the dynamic tests below. The authors commonly grade the response to this test as 1+ to 3+ depending on the type of movements required to reproduce the patient's symptoms (+ requiring flexion, adduction and internal rotation, ++ requiring flexion and adduction, with +++ just requiring flexion). It is critically important that the pain reproduced during this test reproduces the patient's symptoms and is familiar to them. Groin pain or a sense of obstruction to hip movement may be produced by this manoeuvre alone in patients with femoral cams who do not experience traditional FAI symptoms at other times. This is a group who may benefit from local anaesthetic studies (Fig. 3.5).

Whilst the hip is in this position, an estimate and comparison can be made of internal rotation in 90 flexion (IR90). Comparison with the other side is important for both the impingement tests and IR90. Reduced IR90 is a common finding in the painful hip and is a *strong indicator of hip joint pathology* rather than psoas tendon. Modifications to this test include using an axial load on the knee during testing to allow detection of more subtle pathology. Internal and external rotation can also be compared in full extension. Abduction and adduction can be recorded in a traditional manner whilst fixing the pelvis with the examiners free hand. These are seldom reduced in the athletic patient group, and indeed may be increased in the presence of hypermobility.

Fig. 3.2 Seated rotation (Photograph: Guys medical illustration)

Fig. 3.3 Deep flexion supine (Photograph: Guys medical illustration)

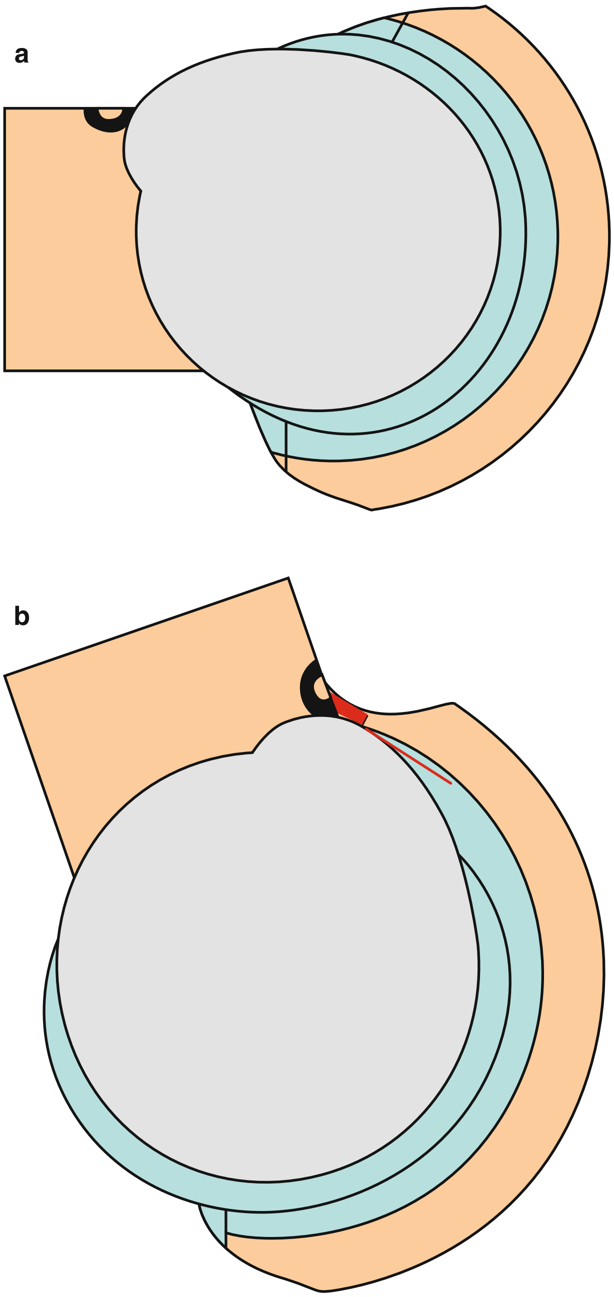

Fig. 3.4 Cam impingement (Diagram: Permission requested [11]) (**a**) Cam lesion sat outside the acetabulum (**b**) Cam lesion rotated into the acetabulum/labrum

Fig. 3.5 FADDIR (Photograph: Guys medical illustration)

The Flexion Abduction External Rotation (FABER) test, also know as the Patrick test [12] is performed by bringing the foot of the tested leg onto the thigh of the opposite leg, forming a figure of four position. From this position the examiner places downward pressure on the tested knee. Reproduction of pain signifies a positive test but the position of the pain is required to interpret it further. Posterior pain suggests SIJ involvement. Lateral pain suggests Lateral/Postero-lateral impingement and anterior pain suggests iliopsoas involvement.

Dynamic tests have been described with recent consensus on terminology [6] giving the Dynamic External Rotatory Impingement Test (DEXRIT) and Dynamic Internal Rotatory Impingement Test (DIRI test). These are based on the McCarthy test [13] and the authors suggest if this terminology is to be adapted, for consistency they should probably be called DEXRIT and DIRIT. The starting point for both tests is with the contra-lateral hip in deep flexion to eliminate any lumbar lordosis. DEXRIT moves the hip from a flexed, slightly adducted position through an arc of external rotation and abduction. Reproduction of symptoms confirms anterior pathology.

DIRIT moves the tested flexed leg through an opposite arc of internal rotation and adduction again attempting to reproduce the patient's symptoms. McCarthys original test is positive if the patient complains of a 'painful click' or 'painful searing sensation' [14]. However, there is some debate over the nature of the pathology, with McCarthy suggesting a DEXRIT type manoeuvre signifies a posterior rather than an anterior labral lesion (Fig. 3.6).

Fig. 3.6 DEXRIT + DIRIT (Photograph: Guys medical illustration)

A further test for Posterior Rim Impingement (PRI) has been described [7]. The patient moves to the end of the couch so the legs hang freely off the bottom. With the contra-lateral leg held in flexion to eliminate the lumbar lordosis, the tested leg is moved into extension, abduction and external rotation. In this position any posterior impingement will reproduce the patient's posterior pain. Anterior pain felt during this test can be either from a contra-coup lesion of the anterior acetabulum/femoral head or an instability feeling associated with anterior under-coverage. This is synonymous with Ganz's 'Apprehension test' [15] (Fig. 3.7).

Lateral

In the lateral position the hip to be tested is placed towards the ceiling.

In this position it is easy to palpate the whole hip region for areas of tenderness. Although palpation has traditionally been part of the standard "look, feel, move" orthopaedic examination, its use around the hip is often neglected as it has been thought to provide little useful information. This may indeed be the case in the straightforward arthritic hip but, for the young sporting hip, it is a useful diagnostic tool. Systematic palpation can assess the pubic symphysis, adductor origin, iliac crest, and greater trochanter. The greater trochanter can be divided up into anterior, superior and posterior portions. The piriformis tendon, ischial tuberosity and SIJ can also be palpated in the lateral or prone positions.

The PRI and FADDIR tests can be repeated as in this position the pelvis is allowed to tilt during the test allowing any dynamic impingement to become apparent.

Fig. 3.7 PRI (Photograph: Guys medical illustration)

A series of passive adduction tests can be performed similar to the described Ober test [2]. These test tightness in the components of the lateral thigh compartment. Moving the leg into adduction with the hip and knee extended tests the Ilio-Tibial Band (ITB) and tensor fascia lata. Repeating the test in 45–90° of knee flexion releases the ITB and adduction tests tightness in the gluteus medius, whereas gluteus maximus tightness is tested with the hip flexed.

Abductor function can be further tested in this position. Resisted abduction with the knee flexed isolates gluteus medius from ITB and weakness can be indicative of a tear of the gluteus medius muscle-tendon unit.

Prone

Moving the young adult patient into the prone position does not cause the same difficulty and distress as in the elderly hip patient and can therefore become a more routine part of the hip examination.

In the prone position an assessment of femoral anteversion can be made using the technique originally described by Craig [7]. With the knee flexed at 90° the greater trochanter (GT) is palpated and the hip rotated until the GT is at its most prominent. The angle of the tibia from the vertical signifies the degree of version.

Additional Tests

A series of additional tests can be used to further confirm the suspected diagnosis following the initial history and examination described above. It is important not to perform all of the tests all of the time as accurate diagnosis will actually become more difficult.

Clicking Tests

The bicycle [7] and fan [16] tests are commonly used to differentiate between ITB and psoas clicking. With the patient in a lateral position, the affected hip is actively put through the motion of cycling. This should reproduce any ITB clicking as the hip goes from extension to flexion. The patient may feel this as a painless click/pop, as a sharp catching pain or even describe it as a feeling of 'the hip coming out of joint'.

In the fan test, with the patient supine, the affected leg is taken through an arc of movement from a flexed, abducted externally rotated position to extension and internal rotation. This should reproduce any psoas clicking as the tendon catches across the anterior femoral head, iliopectineal eminence or even a lesser trochanter exostosis. Again this may be a painless sensation or be painful depending on the degree of inflammation involved.

Although both of the above tests are commonly used, it is often easier for the patient to reproduce the click from either the ITB or psoas with a well-practiced manoeuvre that is individual to them.

Lateral Rim Impingement Tests

For patients with a positive FABER test it can be useful to perform this further test to confirm the pain is from lateral impingement rather than SIJ pathology. With the patient in the lateral position and therefore with a functional lordosis, the hip is moved through an arc of flexion and extension with abduction and external rotation with the examiners arm supporting the leg and knee in flexion. Reproduction of pain confirms lateral impingement [7]. However, a feeling of apprehension is more suggestive of an instability problem, whether osseous or ligamentous. As with the PRI and FADDIR tests repeated in the lateral position, performing this test in the lateral position rather than the supine ensures the pelvis is not fixed in its inclination and will allow reproduction of any dynamic impingement.

Hip Flexor Tests

The modified Thomas test and Ely test can be used to differentiate between hip flexor tightness [17]. In the modified Thomas test, the patient is positioned prone and both legs are extended at the hip, any raising of the pelvis off the couch is thought to signify an iliopsoas contracture. The more traditional Ely test is again with the patient prone. The thigh begins flat on the couch and the affected leg is flexed at the knee until its maximum flexion. Any tightness in the rectus femoris will be evident as the thigh raises off the couch with increased knee flexion. These tests may be useful to discern rectus femoris from iliopsoas tightness, something which can be easily confused.

Laxity Tests

Capsular or ligamentous laxity of the hip can be assessed with the patient in the supine position using the dial test. The examiners hands are placed above and below the knee and the tibia is internally rotated. On release of the internal rotation, any external rotation beyond 45° signifies capsular laxity [18].

Straight Leg Raise

A standard straight leg raise test will help to exclude any lumbar spine or radicular pathology. The Stinchfield test is described when the leg is raised to 45° before further movement is resisted by the examiners hand. A positive test is the reproduction of groin pain signifying either labral or iliopsoas pathology [6].

Heel Percussion

This simple manoeuvre involves striking the heel of the patient producing axial compression whilst supine [17]. Along with the ability to straight leg raise against resistance, pain during this test may signify an underlying bony pathology such as a stress fracture.

Seated Piriformis Stretch Test

With the patient sat over the end of the couch, hips flexed 90° the examiner places the knee in extension and moves the leg into adduction and internal rotation. A hand placed in the region of the piriformis should reproduce the patient's symptoms [7]. An active version of this test with symptoms being reproduced on resisted abduction and external rotation with the patient in the lateral position has been described.

Foveal Distraction Test

Gentle distraction of the extended hip relieves intra-articular pain by reducing the pressure in the joint [12]. This may be used as part of the series of tests for labral pathology but appears to have a low sensitivity and specificity [6].

Resisted Sit Up

Reproduction of groin pain on resisted abdominal crunch with associated tenderness in the region of the deep inguinal ring may signify a hernia [7].

Common Diagnoses and Patterns of Testing

It would not be practical to perform all of the described tests on every patient and therefore, below are described some common patterns of symptoms with the relevant tests necessary to make a firm diagnosis. Dividing the area into several separate regions may help to formulate a diagnostic and treatment plan.

Suspected Acetabular Rim Pathology

Groin pain, a 'C sign' and a history of catching and pinching in the groin must raise suspicion of a labral tear and/or chondral damage in the sporting patient. Labral injury may be due to a traumatic injury (History), Femoro-acetabular impingement (Impingement tests) or hypermobility in the absence of bony abnormality (Beighton score and hip ROM). The full range of provocative tests should confirm the diagnosis. Anterior tears should reproduce groin pain on DIRIT and FADDIR tests and a loss of IR90. Lateral tears should give positive FABER and Lateral impingement tests, and posterior tears, positive PRI tests. However, it should be remembered that severe pain during testing, globally reduced ROM or more constant pain from the history increases the likelihood of articular cartilage damage and early degenerate change.

The Snapping Hip

The patient may describe a snapping, catching or popping sensation during certain movements. This may be the primary reason for referral or commonly a painless additional symptom to the main complaint. Snapping can be due to intra-articular pathology, extra-articular pathology or a combination of both. Intra-articular causes are labral tears, synovitis or loose bodies. Labral tears usually produce the feeling in the anatomical region of the tear but synovitis and loose bodies can cause different symptoms on different movements or at different times. Extra-articular snapping is most commonly Psoas (Coxa saltans internus) or ITB (Coxa saltans externus) in origin. Other causes include the iliofemoral ligament or the long head of biceps femoris catching on the femoral head or ischial tuberosity respectively [13]. The position of snapping gives the first indication as to its origin anterior and lateral being attributed to Psoas and ITB respectively. Further tests to confirm this include the Bicycle and Fan tests previously described. The greater trochanter may be tender from bursal inflammation and the ITB may be tight on Adduction testing in a lateral position.

Combinations of pathology can often occur with a labral tear and psoas snapping occurring concurrently in many cases. In this situation it is important to try and ascertain which symptom is most troublesome as sometimes the patient becomes fixated on the audible snapping even though it is less disruptive to their sporting activities. This is certainly one of the occasions that guided injection can be useful to separate the concurrent pathologies.

Bursitis

The sporting hip is susceptible to bursitis due to either direct injury or overuse syndromes. The three common bursae involved are the trochanteric bursa, iliopsoas bursa and ischiogluteal bursa.

Trochanteric bursitis is easily recognized with tenderness over the GT, pain on resisted abduction and is often associated with ITB tightness or snapping. It appears to be more common in females and athletes running on a banked surface.

Iliopsoas bursitis can present as a snapping psoas tendon but equally can present with a more vague groin pain associated with activity. Iliopsoas contracture can be identified with a modified Thomas test as previously described.

Ischiogluteal bursitis is often associated with acute injury or periods of prolonged sitting. Pain often radiated to the posterior thigh and tenderness is felt over the ischial tuberosity.

Piriformis Pain

Pain just posterior to the greater trochanter with a history of buttock trauma, pain on abduction and external rotation and tenderness lateral to the ischium may indicate piriformis tendon involvement. A seated piriformis stretch test as described previously may be diagnostic but often guided injection is of both diagnostic and therapeutic benefit.

Pain and neurological symptoms in the distribution of the sciatic nerve can be associated with compression anywhere along its course. Piriformis syndrome has been described with sciatic neurological symptoms alongside the above localised symptoms and must be considered as a differential to low back pathology.

Hip Instability

Patients often complain of a feeling of instability or giving way from the hip but this does little to further the diagnosis. Diagnoses can range from Coxa saltans externus/internus to labral pathology or even widespread degenerate change. The use of impingement and labral tests can confirm these pathologies although patients with true instability often have these as secondary lesions. Attempts at apprehension testing can help to confirm instability but does not discern between osseous and soft tissue causes. Obviously generalized ligamentous laxity would be seen on a Beighton score and a dial test will confirm capsular hip involvement.

Pubalgia Athletica

The presence of groin pain following exertion is often associated with a hyperextension or hyper-abduction injury. Differentiating this from intra-articular pain can be a challenge and they often coexist. Tenderness in the adductor region, pain on resisted adduction or resisted sit-up can help in the diagnosis. The diagnosis however is still an umbrella term for a group of pathologies which are often impossible to fully separate. The use of MRI scanning and expectant surgical treatment of sportsman's hernias still appears to play a role in the diagnosis and treatment of these conditions.

Muscle/Tendon Injury

Muscular injuries can be graded depending on the degree of tissue damage. A grade 1 injury would include a degree of stretching of the fibres, grade 2, a partial tear and grade 3, a complete tear. An obvious history of trauma should be present and inspection will reveal a spectrum of soft tissue signs from mild swelling to frank haematoma. Tenderness may be superficial or deep to muscle planes depending on the degree of surrounding contusion.

Bony Involvement

The athletic population may be at higher risk of stress fracture due to repetitive high intensity exercise and the female athletic triad of eating disorder, amenorrhea and osteopenia should always be considered. Longstanding bony pain, worse with activity, night pain and a positive heel strike may warrant further investigation.

Avascular necrosis may be associated with the use of corticosteroids or with certain sports such as sub-aqua diving. Again suspicion should be based on history and the absence of any localizing signs rather than a particular positive test.

Finally tumours should always be considered in the differential list of undiagnosed hip pain. Although there are no associations with sporting activity, incidental findings of this importance should never be missed.

Surrounding Joints

The ability to differentiate between true hip pathology and lumbar or SI pathology still remains a challenge. The routine addition of screening tests such as the straight leg raise and FABER tests should allow these joints to at least be considered. However this is another region where the use of diagnostic imaging and selective injections can play a useful role.

The Role of Injections in the Diagnosis of Hip Pathology

Even after completing a thorough history and examination, it may still be difficult to come to a definite diagnosis in this complex group of patients. The use of injections for both diagnostic and therapeutic goals is therefore commonplace. Pure diagnostic injections can be undertaken with local anaesthetic agents but it is more common to add a dose of steroid to at least attempt some longer lasting effect. In the active sportsperson this may be all that is needed to settle down a period of inflammation especially if accompanied by a period of rest and active rehabilitation. However the use of injections to mask obvious underlying abnormalities which may progress without formal treatment is controversial.

Injections can be undertaken in a theatre setting or the radiology department depending on available resources and personal preference. The authors prefer the theatre setting as it allows better control of patient sedation and with it the advantage of being able to examine the hip joint and region under anaesthetic (EUA).

Injections can be placed into the joint under either fluoroscopic or ultrasound guidance. Although fluoroscopy adds an extra level of resources, commonly requiring a radiographer present, it again allows additional information to be collected in the form of an arthrogram and EUA.

Extra-articular injections into bursae or tendon sheaths can often be done without screening using palpation and trigger points to localise the injection. However, accuracy is obviously improved if they are performed under ultrasound (GT Bursa) or fluoroscopic (Psoas) control.

Following the injection it is important for the patient to attempt to resume the activities that were previously painful as without this level of function the true effect may not be obvious especially if only high end activities were symptomatic. An important part of the diagnostic process is to advise the patient to keep a pain diary as often on return to clinic at 6 weeks they are poor at recalling the exact relief they gained within the first few hours or days post injection.

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4 Biomechanics of the Hip

Nemandra A. Sandiford and J.A. Skinner

Introduction

Anatomical reconstruction of the hip (restoration of the center of rotation, leg length and femoral offset) has been shown to produce improved abductor strength [1], decrease bearing surface wear [2] and is associated with better overall clinical function in patients treated with total hip arthroplasty (THA).

Failure to achieve accurate restoration of normal hip anatomy can result in leg length discrepancy [3], limping [4], abductor muscle weakness [5], dislocation [6] and early failure of the implant [7].

In an attempt to achieve the goals mentioned above a multitude of different designs of acetabular and femoral components exist with various levels of modularity in order to improve their versatility. When commercially manufactured components are not ideal, bespoke custom computer assisted design – computer assisted manufacture (CADCAM) components can be used (Fig. 4.1).

Biomechanics can be summarised as the study of internal and external forces acting on the human body and the net effect of these forces [8]. Understanding the muscular anatomy around the hip, the forces they exert, their impact on the joint reaction force as well as the skeletal anatomy is vital to achieving the objectives outlined above. Biomechanics of the human hip joint has fascinated scientists for centuries. Julius Wolff examined loading of the proximal femur and its relation to the inner architecture of this bone. Pauwels assessed the effect of femoral neck shape on fracture stability [9]. He was one of the first to clearly define the association between femoral neck shape (varus, valgus), abductor tension and joint reaction forces [10].

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Over the last decade there has been a shift in the population of patients being treated with hip arthroplasty. Patients are now younger and wish not simply to have their pain relieved but to return to a normal level of functional and sporting activity. Average life expectancy has also increased hence the implant must survive in vivo for a longer duration. These factors have fuelled the development of new bearing surfaces and technologies such as modern metal on metal hip resurfacing arthroplasty (HRA). They have also prompted detailed analyses of the structure and function of the human hip joint as all parameters, which influence the biomechanics of the hip – and subsequent implant survival –, are affected by arthroplasty procedures. Some of the major factors which influence function of the hip include centre of rotation, range of motion, offset and neck angle. Failure to accurately restore these factors to as near normal as possible can lead to abnormal loading, wear and early failure of the acetabular and femoral components, as well as dislocation of the hip. Aseptic Loosening (due to wear) and dislocation account for 30 and 28 % respectively of all revision THA's performed in Australia [11], 56.5 and 11.5 % respectively as reported by the Swedish Arthroplasty Registry [12]. In the United Kingdom aseptic loosening and dislocation account for 42 and 13 % of all revisions respectively [13]. These significant numbers emphasize the importance of reproducing normal biomechanics during THA procedures.

The Joint Reaction Force

An understanding of the normal arrangement of the hip joint, the joint reaction force (JRF) and the factors contributing to this are central to understanding the management of painful osteoarthritis of the hip.

Normal daily activities require a flexor/extensor arc of 124°, abduction/adduction of 28° and internal/external rotation of up to 33° [14]. The average JRF can reach 4.2 times body weight (BW) during stair climbing, 3.2 times BW during walking, up to 10 times BW during running and

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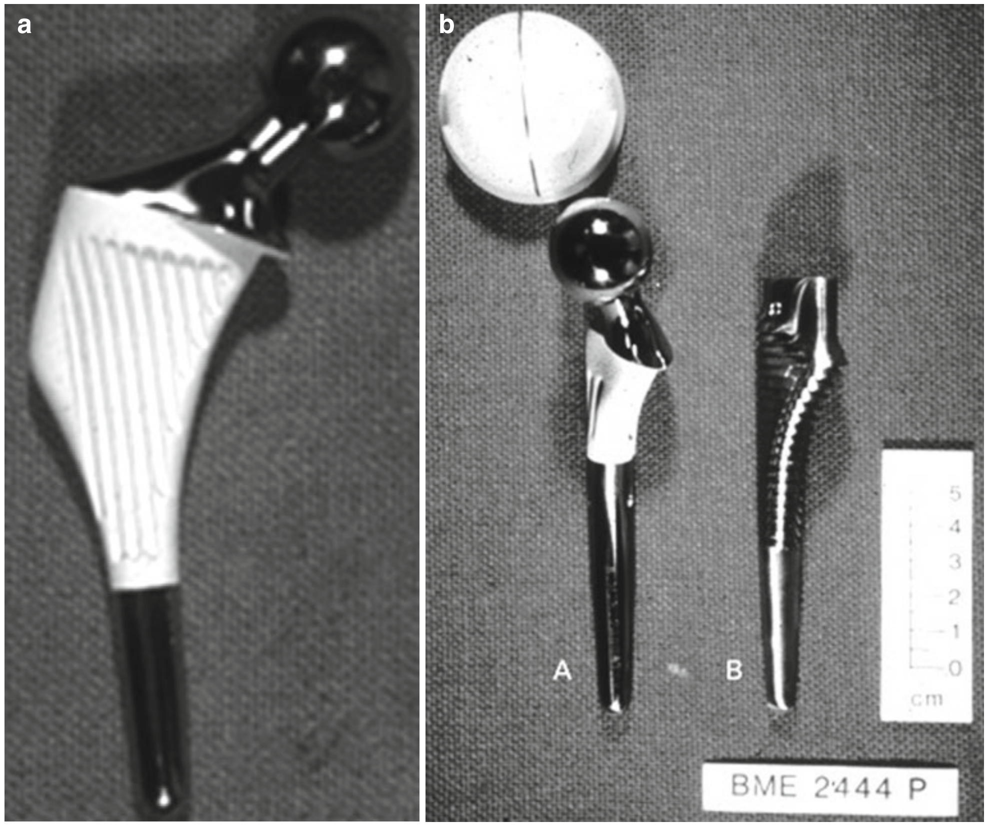

Fig. 4.1 Custom CADCAM femoral components. (**a**) An illustration of a CADCAM hip replacement (**b**) shows a CADCAM hip replacement with anteversion built into it

11 times BW if the patient stumbles [10]. It is logical that the lower the body weight, the smaller the forces are across the hip joint. Other issues as well as calculation of the JRF are discussed below. It must be remembered that the abductors have a downward acting force which stabilises the pelvis during single leg stance (Fig. 4.2).

Free body analysis makes several assumptions which need to be considered. These include:

- The bones are solid and rigid rods
- The leg is 1/6 of total body weight
- The joint behaves as a frictionless hinge
- Forces act along the central axis of the muscle belly
- There is no antagonistic muscle action

This arrangement does, however, allow us to determine the major factors that contribute to the Joint Reaction Force (JRF). These are as follows:

1. Body weight
2. Body weight moment arm
3. Abductor force
4. Abductor force moment arm

From a pathological perspective, an increase in factors 1 and 2 or a decrease in factors 3 and 4 are disadvantageous to the hip joint and can lead to pain. In cases where abductor function is impaired due to primary muscular or neurologic injury, patients tend to lean towards their affected side during the single stance phase of gait. This has the effect of decreasing the body weight moment arm and the overall work that is required of the abductors. This is observed clinically as a Trendelenburg gait or abductor lurch.

Conservative or surgical management must address either one or all of these factors in order to decrease pain experienced by the patient. Surgical management must also address anatomical aspects such as bone defects, abnormal version etc. but that is beyond the subject of this discussion.

Conservative Management Options

Non operative interventions include using a stick in the opposite hand and weight loss in overweight patients. The benefits of these measures are clearly seen if we consider them in the following free body diagram. If a walking stick is used in the opposite hand then the JRF decreases (Fig. 4.2b). Lifting a suitcase with the ipsilateral hand has the same effect.

Surgical Options

Several surgical techniques can be used to address painful coxarthrosis. These include, among others, osteotomy or arthroplasty. A major aim of both procedures is to augment

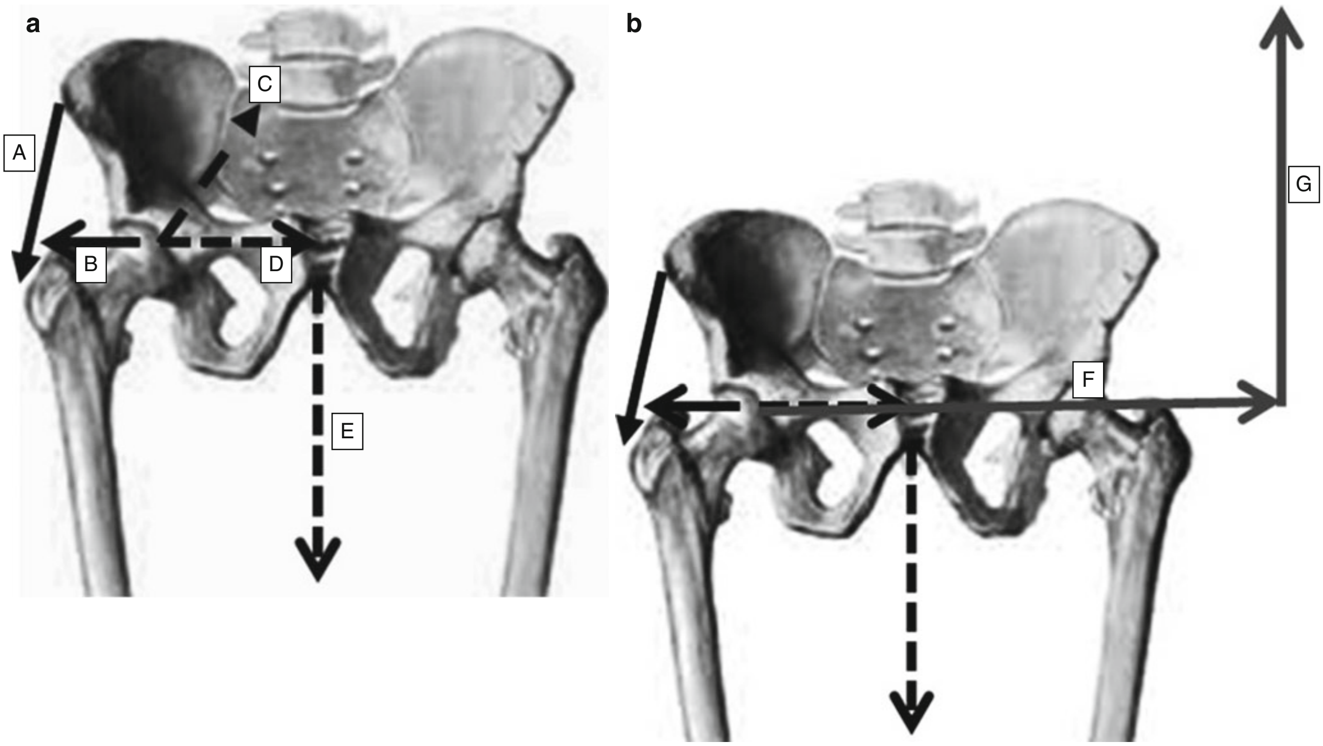

Fig. 4.2 (**a**) Free body diagram of the right hip illustrating forces acting about the joint. *A* abductor force, *B* abductor moment arm, *C* joint reaction force, *D* body weight moment arm, *E* 5/6 body weight. (**b**) Biomechanical effect of using a walking stick in the opposite hand. *F* represents the moment arm of the stick and *G* the direction of the force exerted by the stick. This is in the same direction as and augments abductor force. Resolution of the moments in this scenario will show that using a stick in this way reduces the JRF by 67 %

the abductor force or its moment arm. This can be achieved by increasing the offset of the joint (the distance from the centre of the joint to the central axis of the femur), lateralising the greater trochanter or varus positioning of the femoral component. The last option is not practical as this increases the risk of loosening and revision.

Charnley recognised the four major issues previously mentioned. By medialising the socket, using a small head and lateralising the greater trochanter which was detached during his approach, he was able to address all three factors which can be influenced by the surgical procedure.

Biomechanics of THA

The relatively high incidence of aseptic loosening and osteolysis as well as the potential for dislocation are all influenced to some extent by design of the prosthesis, orientation of the femoral and acetabular components, the range of movement, type of fixation, soft tissue injury as well as the bearing material used. The factors stated above are those that manufacturers and surgeons have addressed in order to recreate, as closely as possible, the natural hip joint. We will discuss the impact of each factor.

Range of Motion and Prosthesis Design

This is closely related to prosthesis design hence these issues are covered together. Approximately 10,000–100,000 different femoral components are used globally [10]. In the UK alone 142 femoral different stem designs and 119 different types of acetabular components are used [13].

Femoral components vary in the stem size, length, surface texturing and coating and in principle of fixation i.e. cemented versus non cemented. They also differ by the modularity of the articulating femoral head or neck. Femoral head size can vary from 22.25 to 60 mm. Acetabular components vary by size, shape (hemispherical versus sub-hemispherical), surface coating (which influences fixation and modularity of the bearing surface. Monobloc acetabular components are now present in which a ceramic bearing surface is pre fixed into a metal shell order to allow a relatively large ceramic femoral head to be used with a relatively small acetabular cup.

Increasing femoral head size theoretically increases range of motion (ROM) and stability of the hip joint. It has been suggested that an increase of 8 mm theoretically increases intra operative passive ROM by 13° [10]. Final ROM is also related to the head neck ratio and the cup shape i.e. hemispherical versus subhemispherical (Fig. 4.3). It can only be

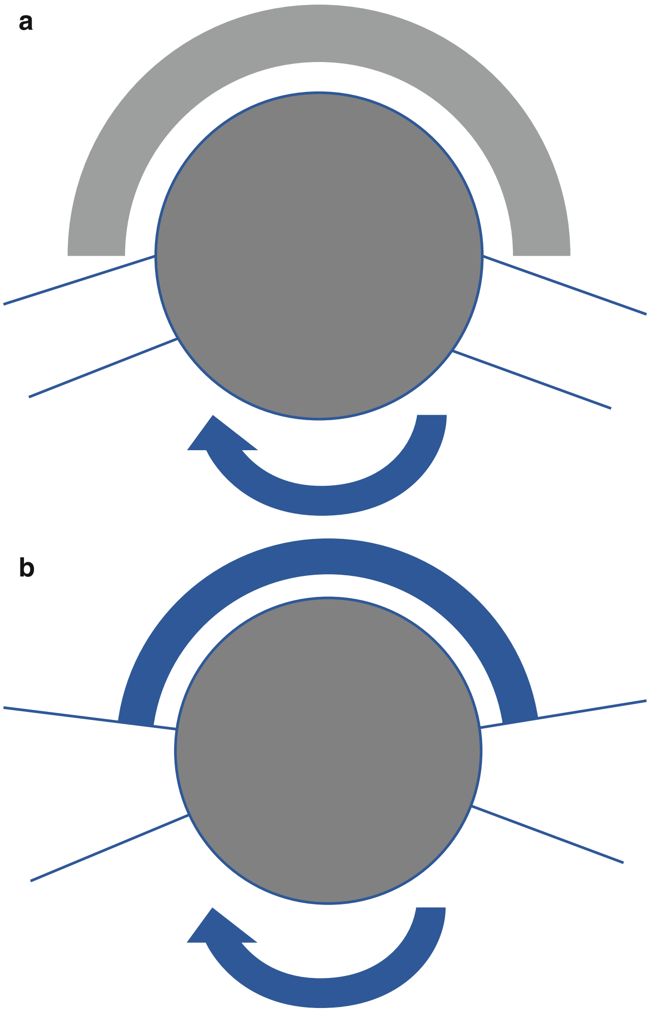

Fig. 4.3 Range of movement with a hemispherical acetabular component (**a**) compared to a subhemispherical cup (**b**) The arc of movement is greater with **b** but the potential for edge loading is greater hence subhemispherical acetabular components are very sensitive to acetabular abduction angle

experienced by the patient if other aspects of the procedure such as soft tissue balancing and component orientation are optimal [15].

Femoral head size also has a direct relation to dislocation rates [16] (Table 4.1). An increase in head circumference leads to an increase jump distance before dislocation occurs. Increasing head size has no effect on revision rates however suggesting that other aspects of surgical technique are at least equally important. An ideal head size has not been proposed for either primary or revision THA. For patients with HRA procedures the incidence of failures are elevated when femoral component diameter is 42 mm or less [17]. The reasons for this are not clear.

Volumetric wear rates are higher with larger heads however. This along with start up friction have been implicated in loosening of the acetabular component [18] as well as taper corrosion [19] when used with large diameter femoral heads. Another potential issue with large heads is the technical difficulty of achieving closed reduction if it does dislocate. Efforts to achieve reduction in this situation could lead to damage to the soft tissue structures around the hip.

Table 4.1 Relationship between head size and dislocation rates

Head size (mm)	Dislocation risk (%), (range)
22	3.8–18.8
28	0.6–2.5
32	0.5
38	0

Taper geometry also influences ROM achieved. A large neck reduces the primary arc of movement before impingement on the acetabulum occurs [20]. This explains why a stemmed prosthesis has a ROM which is 31–48° greater than a resurfaced hip.

The entrance plane of the acetabular component varies with its shape (i.e. hemispherical, sub hemispherical or elevated liners). With hemispherical cups the centre of rotation is in line with the entrance plane of the component. The primary arc lies between the points where the neck comes into contact with the acetabular liner. In components with lipped liners the arc is decreased and it is conversely increased in sub-hemispherical designs.

The latter design can lead to edge loading however which can increase the wear rate. This has been implicated as a factor that might be responsible in poorly performing hip resurfacing designs [17].

Influence of Fixation Techniques

Fixation in primary THA is either cemented or uncemented with or without screw augmentation. In the UK the average age of patients undergoing primary THA with cemented components is 72.8 years. The average age of patients treated with uncemented THA and HRA are 65.4 and 54.2 years respectively [13].

This age difference likely reflects the fact that the results of cemented THA in the young, active population have been less encouraging than in the older patient group. It also reflects that HRA is intended for the young, high demand population. The trend of increasing use of uncemented components does, however, seem to be against current evidence as early revision rates are higher for uncemented THA based on data from the Swedish Hip Arthroplasty Register.

Uncemented (biological) fixation requires achievement of primary stability during component implantation. This maximises bone prosthesis contact – facilitating bone ongrowth – while minimising potentially harmful micromotion. Some surgeons allow patients to partially weightbear during the first few weeks post surgery in an attempt to minimise this micromotion. This practice has been criticised by some authors who have suggested that the quality of primary stability achieved, characteristics of the surface coating or texture, and the quality of the patient's bone are more important in minimising micromotion of the implant than partial weightbearing [10, 21].

Soft Tissue Management

The surgical approach determines which muscle groups are divided or separated while accessing the hip joint. The amount of soft tissue injury depends on surgeon factors (experience, training), patient factors (obesity, friable disuse e.g. rheumatoid arthritis, patients on long term steroids) and surgical factors (primary versus revision). Several surgical approaches to the hip have been described [22] each with its own unique benefits and potential risks.

Data from the UK NJR suggests that the posterior approach is most commonly used (59 %) followed by the lateral (Hardinge) approach (35 %) [13].

The posterior approach is preferred among specialist hip surgeons. Increased dislocation rates have been reported with this approach. This issue seems to have been addressed by repair of the posterior structures (Table 4.2).

Alignment of the Femoral and Acetabular Components

Accurate component orientation is potentially the single most important factor in recreating a hip joint which is biomechanically as close to the natural joint as possible.

Lewinnek described the safe zones for acetabular inclination and anteversion in 1978 [28]. His group found a six fold increase in dislocation in cases where the socket was outside of 40° ± 10° abduction and 15 ± 10° anteversion.

Suboptimal alignment increases friction, wears and effectively reduces the jump distance required for dislocation [15, 29].

Acetabular component malalignment greater than 50° has been associated with increased wear, increased incidence of adverse reactions to metal debris (ARMD) and failure of metal on metal hip resurfacing [17].

Rim loaded ceramic components exhibit stripe wear as a result of increased friction. This is due to local surface damage of the ceramic head with resulting break out of grains and roughening of the bearing surface. If enough friction is generated, vibration can occur which is thought to be a potential cause of squeaking [10]. Such friction can also lead to increase in the moments at the bone prosthesis interface and cause loosening of the stem, cup or both [18, 19].

The superior tribological characteristics of hard on hard bearings (i.e. fluid film lubrication) are dependent on optimal alignment. Deviation from the 'safe zones' previously mentioned can lead to accelerated wear and early failure [17].

Femoral component position is becoming increasingly more important with the shorter 'bone conserving' components which are being used. Such short prostheses have a shorter lever arm to resist forces generated by the hip. Their decreased surface area incurs higher stresses at the bone prosthesis interface [30]. This becomes less of a problem once full osseointegration has occurred as forces are then transmitted to the proximal femur (Fig. 4.4).

Clinical Results of Biomechanical Reconstruction of the Hip

The major focus of current literature on this topic has been comparison of total hip arthroplasty to hip resurfacing arthroplasty. Girard et al. [31] prospectively studied 49 patients treated with HRA using the Durom system (Zimmer, Winterthur, Switzerland) and 55 patients treated using conventional THA. They found that restoration of the horizontal center of rotation, femoral offset and limb length were significantly closer to the patients' normal contralateral hip in the HRA group. This was despite placing the femoral resurfacing component in a greater degree of valgus relative to the natural femoral neck. Clinical results were not presented.

Table 4.2 Incidence of dislocation among common surgical approaches used for total hip arthroplasty

			Dislocation rates (%)			
Authors	Date (study design)	Number in study	Posterior	Posterior with repair of SER[a]	Anterolateral	Direct lateral
Palan et al. [23]	2009 (prospective)	1,089	2.3	–	2.1	–
Tsai et al. [24]	2008 (retrospective)	204	6.38	0	–	–
Kwon et al. [25]	2006 (meta analysis)	–	4.46	0.49	0.75	0.43
Wilson et al.	2005 (retrospective)	2,213	3.9	0.9	–	–
Suh et al. [26]	2004 (prospective)	346	6.4	1	–	–
Masonis and Bourne [27]	2002 (review)	13,203	3.95	2.03	2.18	0.55

[a]*SER* short external rotators

Fig. 4.4 Femoral components in contemporary use. (**a**–**c**) are components with proven long term survivorship while (**d**–**f**) represent contemporary prostheses. Differences in design are distinct. (**a**) Corail, (**b**) Furlong HAC, (**c**) Exeter, (**d**) Proxima, (**e**) Silent hip, (**f**) Birmingham hip resurfacing prosthesis

This study contrasts with the reports of Loughead et al. [32] who found that femoral offset and overall leg length were more accurately restored with hybrid THA when compared to HRA. Silva and colleagues [33] acknowledged that accurate biomechanical restoration of the hip depended on the pre operative anatomy, whatever the technique of arthroplasty used. They suggested that THA was more suitable than hip resurfacing for recreating anatomy and optimising the biomechanics of hips with a low femoral offset and in patients with a leg length discrepancy of more than 10 mm.

The results and conclusions of studies comparing biomechanical reconstruction using different components are often based on measurements obtained from static radiographic images. Very little or no references are made to actual forces in the abductor muscle groups or changes in the joint reaction force after these procedures. Likewise there is limited discussion of the correlation of radiographic measurements with clinical function and patient reported outcomes. Such results therefore need to be interpreted in context.

Concerns Regarding Modern Prostheses

Morlock has expressed certain concerns which have been echoed at recent meetings of the Hip Society section of the British Orthopaedic Association as well as the European Hip Society.

The successful results of THA have been achieved with established implants. Despite this, there is continuous development of short prostheses, lower wearing materials and smaller surgical approaches, all of which are being used without enough robust evidence of their clinical benefit. As a group new components account for the highest failure rates in the UK and Swedish registries [12, 13]. These inferior results are often due to failure to restore the normal anatomical and biomechanical structure of the hip. In the UK data for less than 50 % of acetabular and femoral prostheses used have been submitted for review by the Orthopaedic Data Evaluation Panel (ODEP). The importance of continuous surgeon education has been highlighted.

In conclusion the population being treated with hip arthroplasty has changed. Patients are now physiologically and chronologically younger, more demanding and more is required of the implant for a greater duration of time. The ultimate goal of hip arthroplasty is to create a biomechanically normal hip that lasts the patient's lifetime. Understanding the forces acting on this joint, the contribution of the surrounding musculature and how they all influence the joint reaction force takes us a step closer to achieving this.

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Part II

The Conditions that Underpin Hip Pain in the Young Adult

Slipped Capital Femoral Epiphysis and Its Variants

5

Michael Leunig, Reinhold Ganz, Ira Zaltz, and Lisa M. Tibor

Introduction

Slipped capital femoral epiphysis (SCFE) has been discussed in the orthopaedic literature since the late nineteenth century [1]. Classically, the goals of treatment have been to stabilize the physis and prevent the iatrogenic complications of osteonecrosis and chondrolysis [2, 3]. This schema is currently undergoing re-evaluation and considerable debate, due to the recognition that even mild stable SCFE can cause femoroacetabular impingement (FAI) [4–12]. Although the potential for impingement in SCFE has been recognized for some time [4, 5, 13–16], preventing impingement and the resultant damage to the cartilage and labrum is becoming a more important principle of SCFE treatment. This has occurred in part because the idea of FAI has gained acceptance in the orthopaedic community. In addition, improved knowledge of the vascular anatomy responsible for femoral head perfusion [17] has allowed the development of a safe technique for open reduction and internal fixation of the displaced epiphysis [5, 18].

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Background

Strictly defined, a SCFE is displacement of the capital femoral epiphysis from the metaphysis, through the physis. The epiphysis remains located in the acetabulum, tethered by the ligamentum teres, and the metaphysis moves relative to the epiphysis. The most common pattern is a varus slip, where the metaphysis moves superiorly and anteriorly. Valgus slips, where the metaphysis slips inferiorly and posteriorly, occur in about 4 % of cases [19, 20].

The natural history of SCFE is controversial. While it is generally accepted that more severe slips and unstable slips have a worse prognosis than a stable mild slip [3, 7, 21], a closer look at the long-term outcomes reveals a more complicated picture. Long-term follow-up of patients who underwent treatment of SCFE in the mid-twentieth century, reveals slow yet progressive decline, with about 10 % of patients undergoing an additional reconstructive procedure [21, 22]. Patients in their mid-40s with mild SCFE reported an average Iowa hip score of 87, consistent with good but not excellent function. This represented a clear shift from their average Iowa Hip Rating of 93, when the patients were in their 20s and 30s. For patients with moderate and severe slips, the average Iowa Hip Rating decreased to 80 and 70, respectively, when the patients were in their 40s. This is as compared to average scores in the mid-80s a decade previously. A score of 80 is still considered to be good function, while a score of 70 is considered borderline fair function [21]. Investigation of the Hamann-Todd osteological collection revealed a greater prevalence of grade 2 or 3 osteoarthrosis in femurs with mild post-slip morphology as compared to age and gender-matched controls [23]. In the specimens with mild arthrosis, the authors observed flattening and the first arthritic changes in the anterosuperior region of the acetabulum, consistent with an impingement mechanism of cartilage damage. Arguably, this paper was published prior to the description of FAI, such that some of the femurs that were considered to have post-slip morphology may have actually had idiopathic cam deformities.

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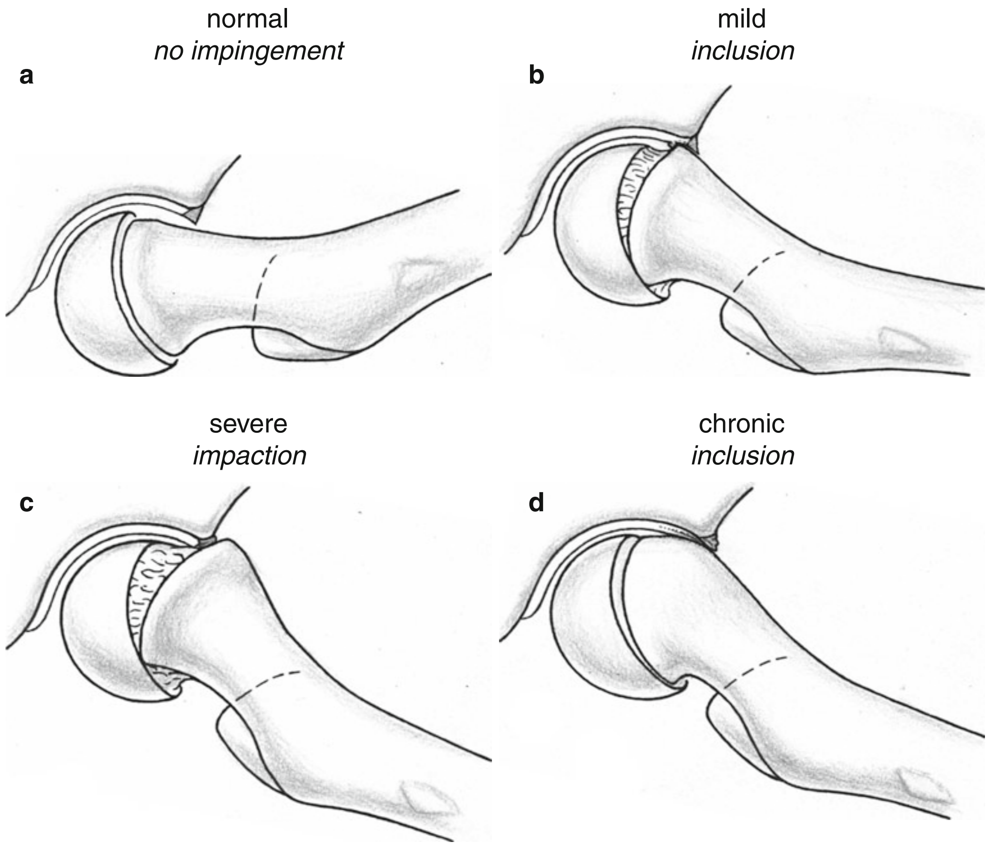

Fig. 5.1 Inclusion and impaction-type impingement in SCFE. (**a**) Normal hip. (**b**) Inclusion occurs with mild to moderate SCFE, where the metaphyseal deformity is still small enough to be included in the acetabulum. The prominent metaphysis causes cartilage and labral damage when the hip is flexed, analogous to cam FAI. (**c**) Impaction occurs in moderate to severe SCFE when the metaphyseal deformity is too large to enter the acetabulum. The deformity limits range of motion, and the metaphysis impacts the acetabular rim causing labral crushing analogous to pincer FAI. With forced flexion, the femur levers on the acetabulum, which also occurs in pincer-type FAI. (**d**) With metaphyseal remodeling in chronic SCFE, the deformity is reduced enough that inclusion impingement can occur again (Reprinted with permission, Leunig [5])

Although the terms cam and pincer impingement are used to describe FAI, slightly different terminology has been used to describe the impingement that occurs as a result of SCFE (Fig. 5.1) [4, 5]. Inclusion describes the impingement that occurs when the deformity is small enough to be included in the acetabulum when the hip is flexed. This happens with mild slips and after femoral neck remodeling in severe slips. With inclusion, the prominent anterior metaphysis abrades the cartilage and the labrum, analogous to cam impingement [4, 5]. Impaction describes impingement that occurs when the metaphysis impacts the acetabular rim because the deformity is too large to enter the acetabulum. Chronic impaction can cause erosion of the acetabular rim, and forced motion can cause the femoral head to lever on the acetabular rim [4, 5]. This is analogous to pincer impingement. The concepts have been somewhat validated by three-dimensional computer modeling of range of motion in mild, moderate, and severe slips demonstrating limited range of motion and alterations of the gait cycle to accommodate the impingement [4, 8].

The development of a safe surgical hip dislocation [24] allowed intraoperative observations of cartilage and labral damage in SCFE [5], providing further insight and confirmation of these ideas. The metaphysis is rough and at least level, if not more prominent than the femoral head, creating a cam deformity (Fig. 5.2a). In these cases, hip flexion causes impingement of the metaphysis on the anterosuperior acetabulum and labrum (Fig. 5.2b) [5, 10]. The degree of the slip determines whether the metaphyseal prominence is able to enter the acetabulum. In severe SCFE, the metaphysis is so prominent that it cannot enter the joint [5] and, consequently, damage is limited to the labrum and rim. Metaphyseal remodeling, which previously was interpreted as a positive adaptation, enables the metaphysis to once again enter the acetabulum. This changes the severe SCFE from pincer-type impingement into cam-type impingement, which is more destructive to the acetabular cartilage. In this setting severe labral and cartilage damage occurs at the zone of impingement, and full-thickness acetabular cartilage lesions are often observed (Fig. 5.2c) [5, 10, 25, 26]. This degree of FAI is also the likely mechanism for radiographic chondrolysis occurring after a severe SCFE, analogous to mechanical chondrolysis occurring when an implant is prominent within a joint.

Classification

Traditionally, SCFE was classified as pre-slip, acute, chronic, or acute-on-chronic, depending on whether symptoms were present for more or less than 3 weeks. This has been replaced by a different system; slips are now more often described as

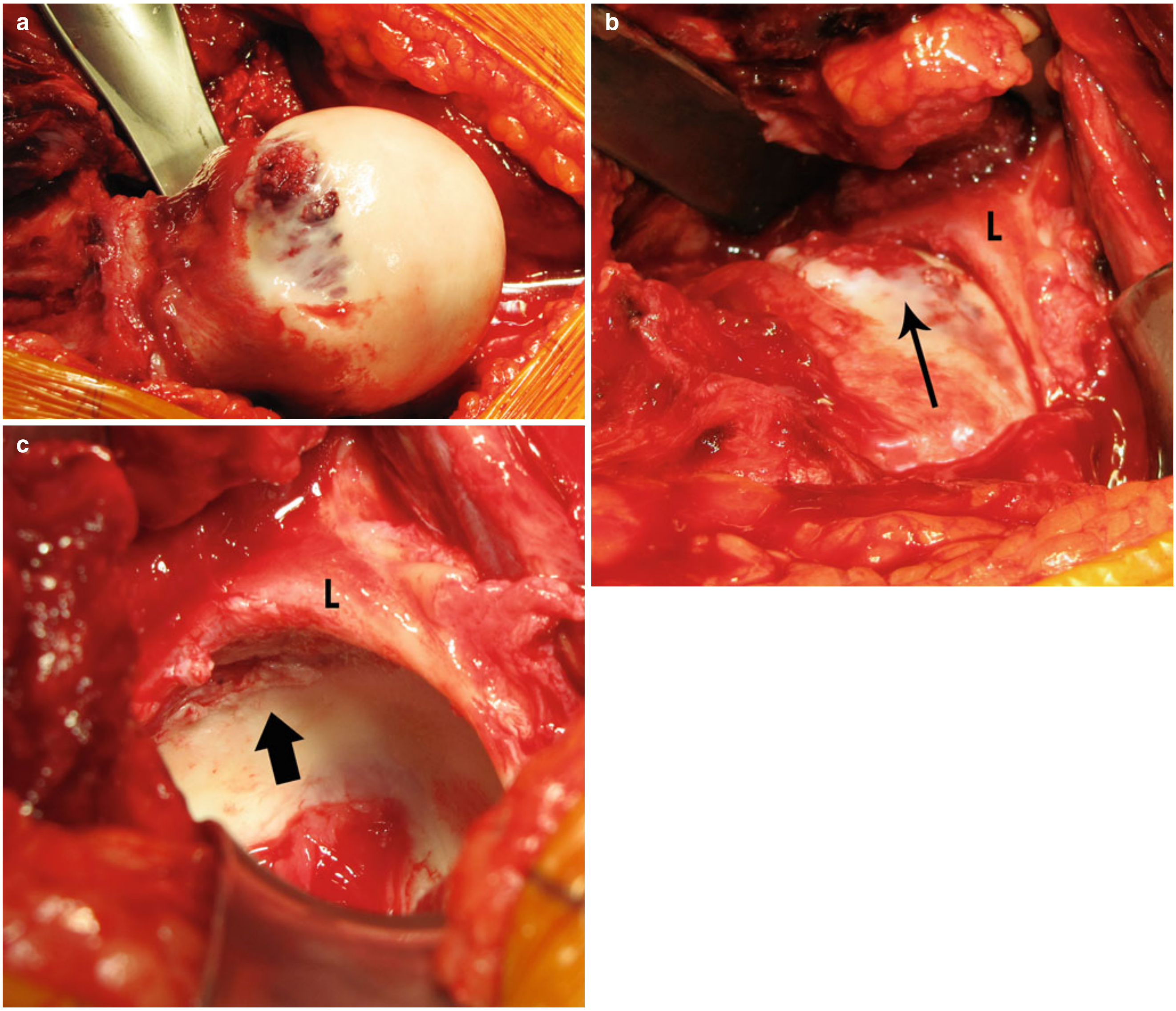

Fig. 5.2 The appearance of the femoral head (**a**, **b**) and acetabulum (**c**) in a moderate SCFE. The periosteum over the metaphysis is partially torn (**a**) and the rough surface of the metaphysis (*thin arrow*) protrudes above the femoral head cartilage. (**b**). With the hip flexed, the rough metaphysis abraded the acetabulum and caused a full-thickness cartilage lesion (*thick arrow*) (**c**), *L* labrum

either stable or unstable, regardless of symptom duration. Classification by physeal stability also has prognostic value [27, 28]. A slip is considered stable if the patient can walk or weight bear, with or without crutches. Patients with unstable slips are unable to walk, and are more likely to develop avascular necrosis [27, 28].

Interestingly, the clinical assessment of physeal stability does not always correlate with the intraoperative physeal stability [29]. The stability of the physis has been assessed in series of patients undergoing open reduction for SCFE [26, 29]. Stability was categorized as grossly unstable, easily separable, or stable. In grossly unstable physes, the anterior periosteum was visibly torn and the physis separated easily from the metaphysis. In easily separable physes the periosteum was intact, but once the periosteum was freed the physis separated easily from the metaphysis. Patients with a stable physis had an intact periosteum requiring dissection and separation of the physis for reduction on the metaphysis [26]. Comparison of physeal stability at the time of surgery with the clinical classifications reveals the limitations of this system [29]. In this series, 61 % of patients with clinically classified stable slips were found to have mechanical disruption of the physis, while 24 % of patients were classified clinically as unstable but had stable physes intraoperatively [29]. These patients with stable physes may be unable to weight-bear because of painful impingement-related chondrolabral damage.

Open reduction of SCFE has also provided some explanation about the potential etiology of avascular necrosis. It is commonly thought that the separation between epi- and metaphysis is the main cause of necrosis. However, intraoperatively all but two unstable epiphyses were perfused, regardless of the time between the onset of symptoms and surgery [29]. This means other factors, like the type of treatment (e.g. a "gentle" reduction), must play a role in causing avascular necrosis.

Clinical and Radiographic Evaluation

In an unstable SCFE, the patient may report a history of prodromal or "pre-slip" symptoms. These consist of leg weakness, limping, and groin or knee pain, all of which may be exacerbated by standing or walking. An unstable slip is characterized, however, by extreme pain such that the patient resists any attempt at weight bearing or movement of the leg, with or without crutches. There may also be an external rotation deformity or shortening of the leg [3, 7]. Patients with stable SCFE may describe groin, thigh, or knee pain and often walk with a limp. Not infrequently, the initial symptom is knee pain, and some SCFE patients do not develop groin pain. Symptoms may be present for months or years and may have a waxing and waning course. Up to 50 % of patients have bilateral SCFE, so the presence of symptoms in the other hip is also important to note [30, 31]. Physical exam reveals a loss of flexion and internal rotation, and hip flexion may cause spontaneous abduction and external rotation [3, 7], known as the Drehmann's sign. These patients may also have a leg length discrepancy and demonstrate an antalgic gait with loss of internal rotation, abduction, and flexion.

Patients with suspected SCFE should have both AP and lateral pelvic radiographs (Fig. 5.3). Obtaining a frog-lateral radiograph may be difficult or impossible for a patient with an unstable slip, but a Dunn or true cross-table lateral x-ray of the affected hip is also appropriate. The symptomatic side should be compared to the contralateral side. If the SCFE is early or mild, it may only be visible on the lateral radiograph or relative to Klein's line. Normally, a line drawn tangent to the lateral femoral neck (Klein's line) bisects some portion of the femoral head, however in SCFE the line is lateral to the head (Fig. 5.3) [32]. Steel's sign is also occasionally visible in early or mild SCFE, with increased density adjacent to the physis. This occurs when the epiphysis has displaced posteriorly but not medially, causing the epiphysis and metaphysis to overlap radiographically (Fig. 5.3) [33]. The severity of the SCFE can be evaluated by the Southwick angle which is measured on a lateral radiograph and represents the difference between the head-shaft angle of the affected and normal side. Mild slips measure less than 30°, moderate slips are between 30° and 50°, and severe slips are greater than 50°. Alternatively, the

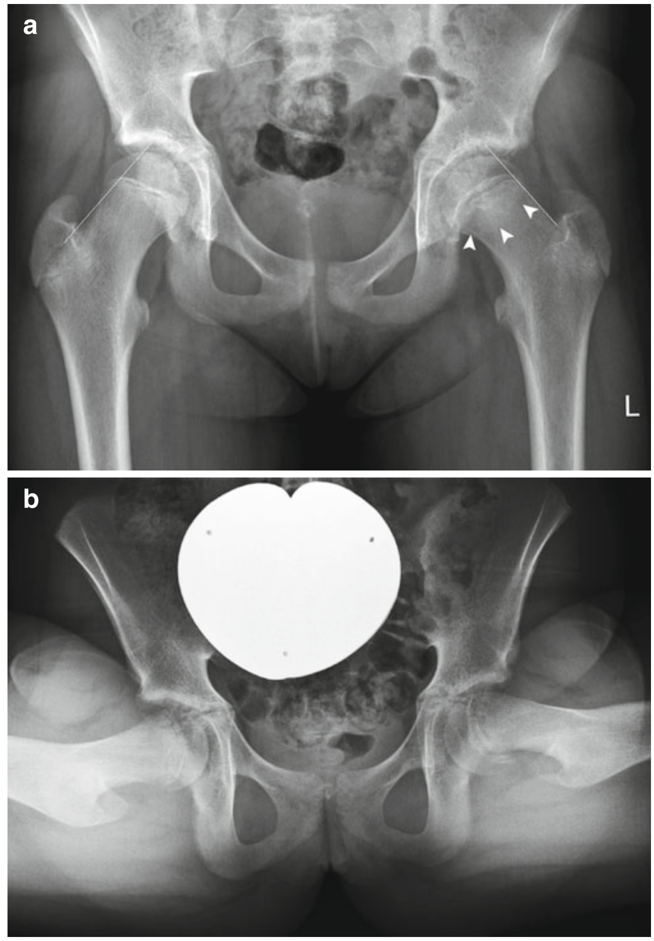

Fig. 5.3 (**a**) AP pelvis radiograph of a mild slip. The physis is widened and more of the femoral head is medial to Klein's line when compared to the contralateral side. Steel's sign, increased metaphyseal density (*arrow heads*) is also visible. (**b**) The slip is clearly visible on the frog lateral radiograph

slip severity can be evaluated by the amount of relative displacement between the epiphysis and metaphysis [34]. In this system, mild SCFE have less than 33 % displacement, moderate slips have 33–50 % displacement, and severe slips have greater than 50 % displacement. In chronic slips, a periosteal reaction, remodeling, or new bone formation may be visible.

In the pre-slip stage, an MRI will reveal bone marrow edema around the physis [35], but no physeal displacement. MRIs obtained in patients with "acute" slips demonstrated some evidence of callus in all patients, even for those with SCFE associated with a fall (Fig. 5.4) [36]. Patients whose SCFE was associated with a fall also had visible disruption of the physis and periosteal sleeve on the MRI, indicative of an unstable slip [36]. MRI can also provide early diagnosis of osteonecrosis in chronic slips and radial MRI slices are useful for evaluating the head-neck offset and impingement in chronic SCFE [37, 38].

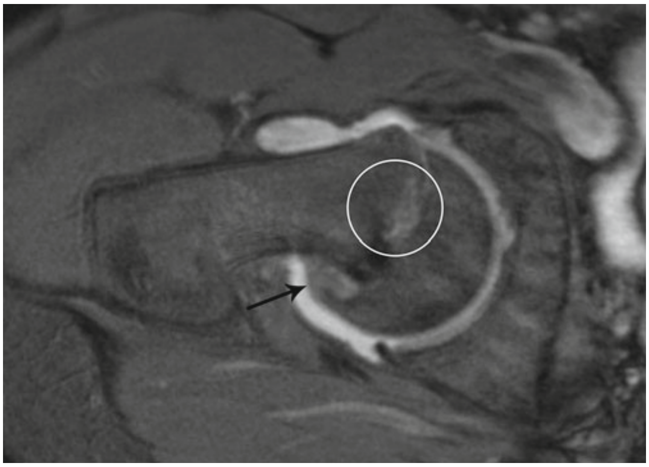

Fig. 5.4 Radial T2 MRI of an acutely unstable slip. Callus is visible posteriorly (*arrow*) and bone marrow edema is present around the physis (*circle*). A closed reduction of the epiphysis would stretch the retinacular vessels over the posterior callus, endangering the blood supply to the femoral head

Treatment

The ultimate goal of treatment is to obtain the best possible hip function. For SCFE this involves stabilizing the physis, correcting the deformity, and avoiding iatrogenic complications of osteonecrosis and chondrolysis. Thus, important factors to consider when deciding on treatment include whether or not the physis is open or closed, the stability of the physis, the degree of the deformity and the potential for impingement, and the treating surgeon's ability and experience with complex hip surgery.

For acute or unstable SCFE, one goal of treatment is to stabilize the physis and prevent progression of the slip. Pinning in situ has long been the standard of care [2, 3, 7], with reasonable results after long-term follow-up [21, 22]. Closed reduction is not recommended due to the risk of osteonecrosis. It is now understood that most SCFE have some amount of posterior callus, regardless of the duration of symptoms [18, 36, 39]. Reducing the epiphysis without removing the posterior callus stretches the retinacular blood vessels and places the blood supply of the femoral head at risk, regardless of how "gentle" the reduction maneuver is. The disadvantage of pinning in situ is that it does not correct the anatomic deformity caused by the SCFE, meaning that the patient is likely to have FAI.

Contemporary treatment of SCFE should, then, also correct the anatomic deformity to prevent impingement, continued cartilage damage, and subsequent arthrosis. For mild SCFE with slip angles <30° and no translation of the epiphysis on the metaphysis, the slip may be pinned in situ and the anterior metaphysis can be decompressed either arthroscopically or via a mini-open anterior approach, similar to standard treatment for FAI [25]. These approaches are discussed extensively in other chapters of this book, and the reader is directed to these for further details regarding the technique.

Authors' Preferred Technique

If the surgeon is technically capable, open reduction and internal fixation of unstable or moderate to severe SCFEs via a surgical hip dislocation and a modified Dunn approach is the ideal treatment method as it enables safe correction of the deformity as well as stabilization of the physis [5, 18, 24, 26, 40]. The procedure is complex and should not be attempted by those inexperienced with the technique. Thus, for patients with moderate to severe deformity, we recommend that patients be referred urgently to a tertiary-care center with this capability. Depending on the clinical circumstances and the proximity to a tertiary care center, the surgeon unfamiliar with the modified Dunn procedure may consider temporary stabilization of the epiphysis prior to transfer of care.

The patient is placed in the lateral decubitus position and the leg is draped freely. A sterile bag is placed at the anterior portion of the table to maintain sterility of the leg when the hip is dislocated. The incision is centered over the anterior third of the greater trochanter, and is generally about 20 cm long. Proximally, the fascia is split between the gluteus maximus and medius, distally the iliotibial band is divided in line with the femur. Patients with SCFE frequently have an external rotation contracture, which can narrow the normal distance between the posterior border of the greater trochanter and the posterior acetabulum and may render the execution of the trochanteric osteotomy more difficult. Internal rotation of the leg and dissection of the overlying bursa and adipose tissue facilitates identification of the posterior border of the gluteus medius. The trochanteric osteotomy should be performed so that the gluteus medius, gluteus minimus tendon, and vastus lateralis, are attached to the trochanteric fragment, but that the external rotators and piriformis remain attached to the femur. The osteotomy itself is made from the postero-superior edge of the trochanter to the posterior border of the vastus lateralis, anterior to the trochanteric crest. This creates a fragment that is usually 1–1.5 cm thick, depending on the size of the patient.

The trochanteric fragment is then mobilized with careful dissection between the piriformis tendon and gluteus medius and elevation of the vastus lateralis along its posterior border to the level of the gluteus maximus tendon insertion. Any remaining gluteus medius fibers on the femur are also released so that the fragment can be taken anteriorly. With the leg in flexion and external rotation, the gap between the piriformis and gluteus minimus is easier to identify. The capsular insertion of the gluteus minimus is carefully released, further exposing the superior and anterior capsule. It is important that

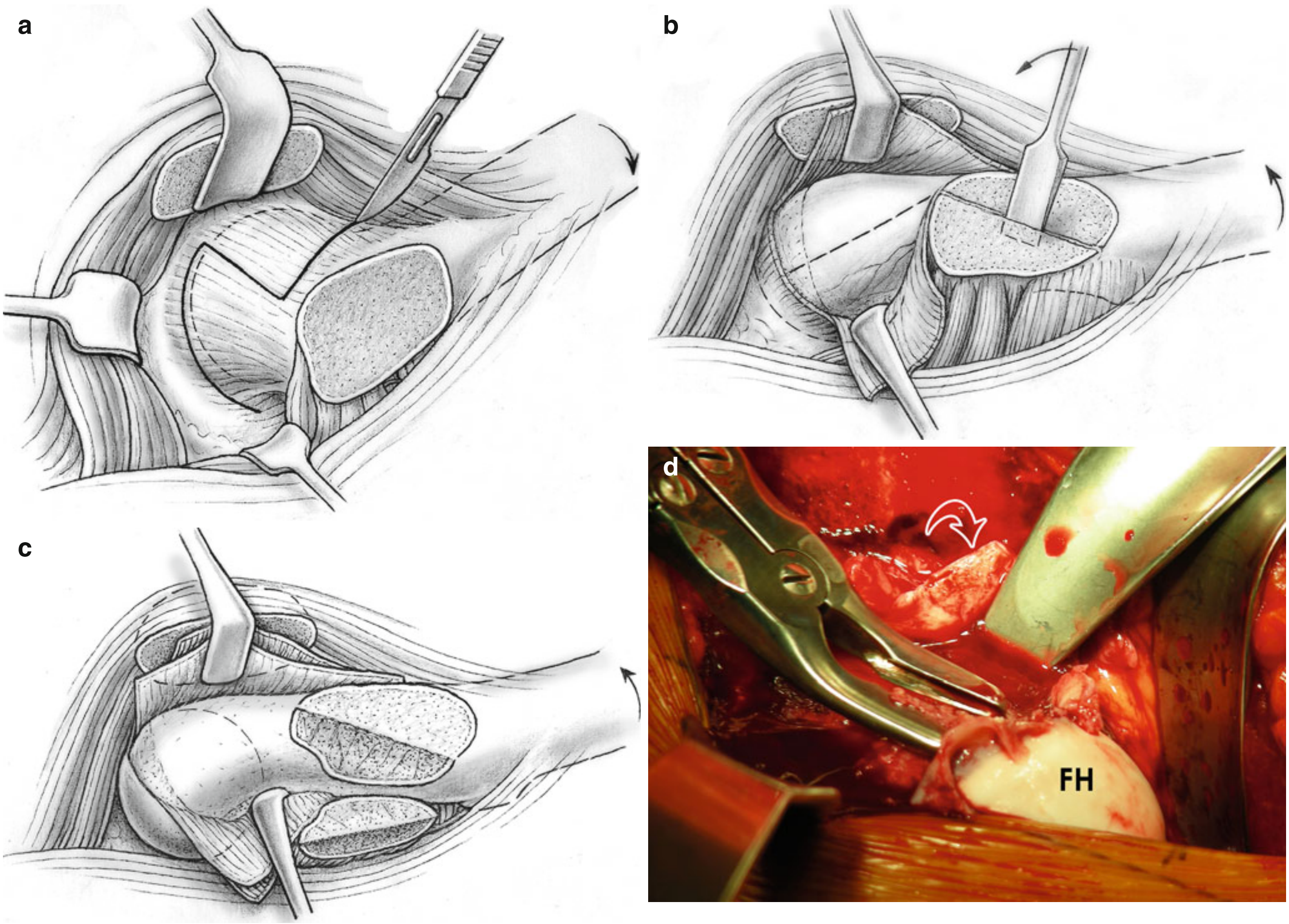

Fig. 5.5 Capsulotomy and creation of the extended soft tissue flap. (**a**) The first cut of the capsulotomy is made along the axis of the femoral neck, beginning at the anterior edge of the stable trochanter. The proximal and distal limbs are made in an inside-out manner to protect the cartilage and the labrum. Proximally, the cut can be made to the piriformis tendon but should not extend beyond the tendon (Reprinted with permission, Ganz [40]). (**b**) An extended soft tissue flap must be created to mobilize the retinacular vessels perfusing the femoral head. This allows the epiphysis to be safely separated from the metaphysis. The external rotator muscles are first mobilized through the apophysis of the greater trochanter (Reprinted with permission, Leunig [18]). (**c**) The remainder of the soft tissue flap is carefully mobilized via subperiosteal dissection (Reprinted with permission, Ganz [40]). (**d**) Intraoperative photo of the soft tissue flaps (*open arrow*) following mobilization

the dissection remains anterior to the piriformis tendon so that the deep branch of the medial femoral circumflex artery as well as the anastomosis between the inferior gluteal artery and medial femoral circumflex arteries are undisturbed.

The first cut of the capsulotomy is made in line with the femoral neck axis, beginning at the anterior superior edge of the stable trochanter (Fig. 5.5a). The capsulotomy is then extended perpendicularly along the capsular insertion at the anterior femoral neck, allowing creation of a capsular flap. The rest of the capsulotomy can be performed in an inside-out manner, which helps to protect the cartilage and labrum. The proximal portion of the capsulotomy is extended along the postero-superior rim of the acetabulum to the piriformis tendon. Retraction of the capsular flaps with two Langenbeck retractors and a narrow spiked Hohmann retractor placed just lateral to the anterior inferior iliac spine facilitates examination of the joint.

If the epiphysis is frankly unstable or its stability is uncertain, it should be prophylactically pinned with two 2 mm Kirschner wire prior to dislocation. No attempt should be made to reduce the epiphysis at this time, because of the risk of stretching the posterior retinacular blood vessels over the posterior callus. The hip is then gently flexed and externally rotated and the leg placed into the sterile bag at the anterior aspect of the table. The femoral head subluxes but will not frankly dislocated until the ligamentum teres is divided. After dividing the ligamentum teres, the head can be dislocated and the degree of acetabular damage fully assessed. In severe slips, dislocation may be difficult or impossible at this stage. If the epiphysis spontaneously falls into the acetabulum after mobilization, it is difficult to retrieve, thus a sponge should be placed into the acetabulum to prevent this.

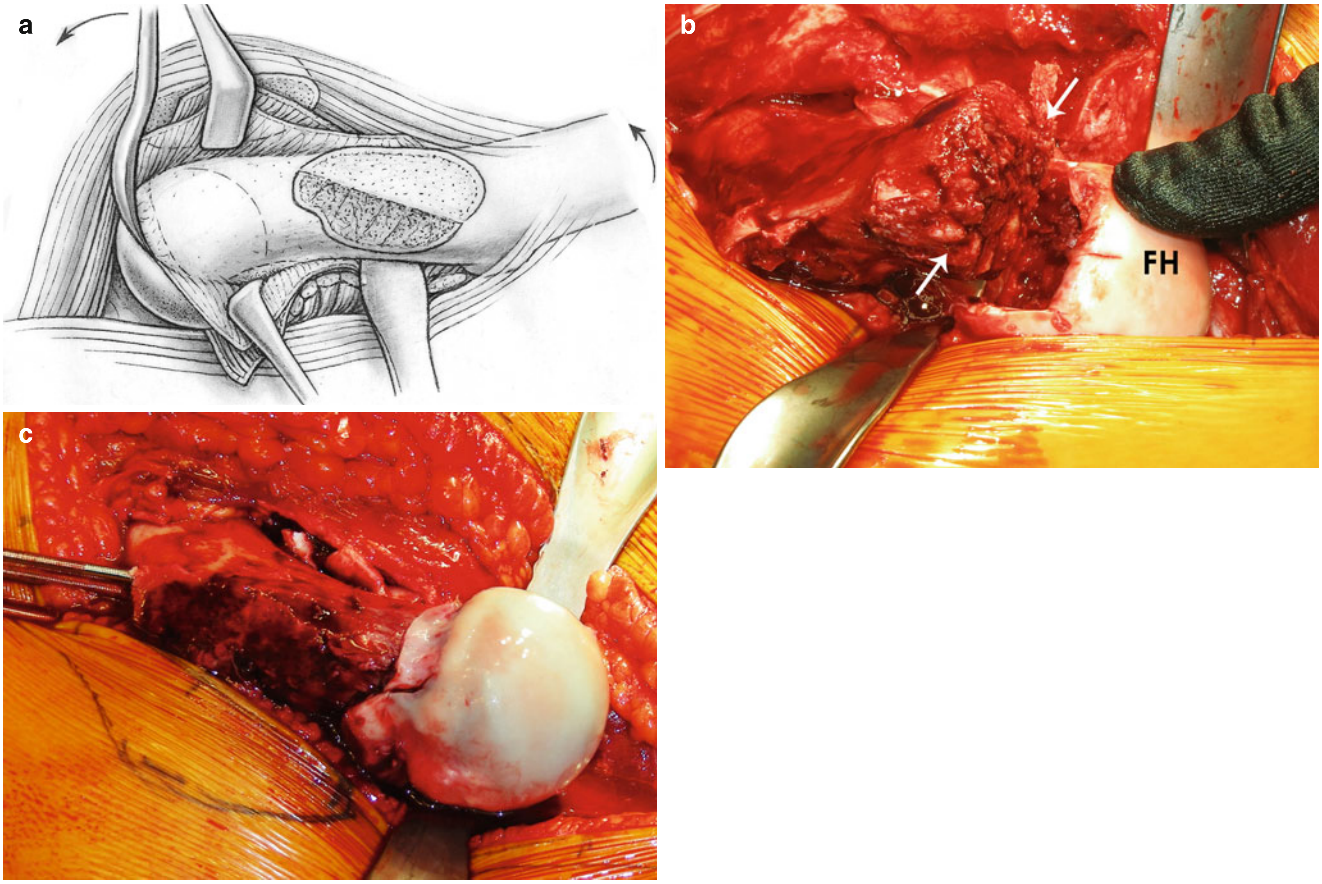

Fig. 5.6 Reduction of the epiphysis. (**a**) Using a chisel, the epiphysis is carefully mobilized through the physis (Reprinted with permission, Leunig [18]). (**b**) Intraoperative photo of the femur, following epiphyseal mobilization. The posterior callus can now be removed from the metaphysis (*arrows*) and the remainder of the physis is curettaged from the epiphysis. (*FH* femoral head) (**c**) The epiphysis is then reduced and pinned with a K-wire from the fovea to the lateral cortex. Note the significant improvement in the head-neck offset

The retinaculum containing the blood vessels is a slightly mobile layer of connective tissue located on the posterior superior aspect of the femoral neck. To more effectively protect the blood vessels from tension or tearing during the manipulation and reduction of the femoral epiphysis than with the original Dunn technique [41], a larger soft tissue flap must be created. The head is reduced back into the acetabulum during this step. The posterior aspect of the stable trochanter proximal to the visible apophysis is mobilized with an osteotome. The cancellous bone is carefully removed in an inside-out manner from the periosteum down to the level of the neck surface. Simultaneously, the periosteum along the antero-lateral femoral neck is incised along the neck axis, beginning at the greater trochanter, and is carefully elevated using an elevator and scalpel. Care is taken to preserve the attachment of the periosteum and retinaculum at the femoral head. The periosteal release is carried out distally and posteriorly to the base of the lesser trochanter. To release the periosteum anteriorly, the femoral head is gently re-dislocated and the periosteum is elevated to the level of the lesser trochanter. Care must be taken to keep Weitbrecht's ligament as part of this medial flap. Following the full release, there should be a periosteal tube around the femoral neck that remains attached to the epiphysis. If there are concerns about the perfusion of the head, it can be reduced and the perfusion re-evaluated with a drill hole or with laser-Doppler flowmetry [42].

With the femoral head dislocated, the epiphysis can be mobilized from the metaphysis (Fig. 5.6). K-wires that were used to stabilize the epiphysis can be removed. A curved 10 mm chisel is used to carefully mobilize the physis. In unstable slips, it may take little to no effort to mobilize the physis whereas in more chronic slips division of bridging callus in the postero-medial recess between epiphysis and metaphysis may be necessary or helpful for mobilizing the physis.

Once the epiphysis has been mobilized, it is manually tilted behind the metaphysis and the working space is increased with adduction and slight external rotation of the femur. This maneuver is executed slowly, with constant visualization of the soft tissue flap to ensure that it remains relaxed. The callus on the posterior aspect of the neck is then palpable and can be removed in a proximal to distal direction with a straight chisel.

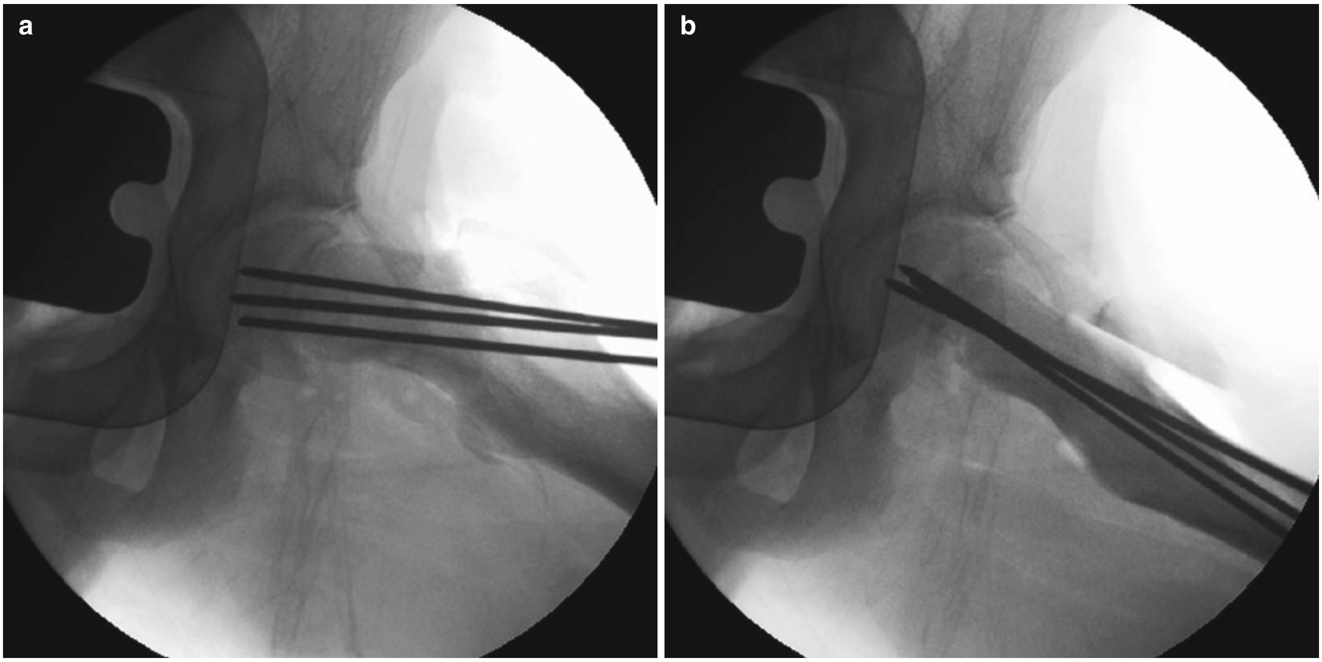

Fig. 5.7 Intraoperative fluoroscopic images following femoral head reduction. The epiphysis is centered on the metaphysis in both the AP (**a**) and lateral (**b**) views

Rounding of the upper surface of the metaphysis can also be performed to create a larger area of contact with the epiphysis. The remaining physis is curettaged from the epiphysis under manual stabilization. Usually, intact femoral head perfusion can be observed with bleeding of the newly exposed epiphyseal bone. However, sometimes bleeding becomes demonstrable only after anatomic reduction of the epiphysis or after the head has been reduced back into the acetabulum, allowing complete unfolding of the retinacular flap.

The epiphysis can now be reduced onto the metaphysis. If there is any tension on the retinaculum, the reduction maneuver is stopped and the cause of the tension is addressed. The epiphysis should be centered on the neck, with an equal distance between the border of the epiphysis and the metaphysis in all planes. The rotation of the epiphysis is evaluated with respect to the location of the retinaculum and the fovea. The epiphysis is provisionally fixed with a fully threaded K-wire inserted retrograde, from the fovea to the lateral cortex of the femur. The wire is cut and withdrawn from the lateral cortex so that the tip is level or just slightly below the femoral head cartilage. The head is reduced and the reduction evaluated. Intraoperative fluoroscopy is used to evaluate the angle of the head on the neck—the relative varus or valgus of the head (Fig. 5.7). Once the optimal alignment of the femoral head is achieved, one or two additional fully threaded K-wires are placed from lateral to medial to definitively fix the femoral head (Fig. 5.6d). No bone grafting is necessary as any existing gaps heal spontaneously (Fig. 5.8).

The periosteum is loosely readapted with a few interrupted stitches, taking care to avoid any tension on the repair or vessels. The capsule is also closed in a tension-free manner. Occasionally, the piriformis tendon can create capsular tension; if this occurs, the tendon should be released. If the trochanter fragment is reduced slightly more distally, care must be taken that it does not compress the capsular tissue at the level of the distal neck. The trochanteric fragment is fixed with two cortical screws and the soft tissue is closed in a layered fashion. In general, a layered closure eliminates any dead space, such that a drain is not necessary.

Postoperatively patients remain toe-touch weight-bearing for 6–8 weeks. Patients use continuous passive motion for 3 weeks postoperatively. The initial postoperative physical therapy is quite limited to allow the trochanter and epiphysis to heal. While inpatient, patients are taught how to safely use crutches, lift their leg, and navigate the stairs. An x-ray is obtained 4–6 weeks postoperatively to assess healing and whether the patient should continue toe-touch weight bearing or may gradually advance weight-bearing. Patients may fully weight-bear once there is radiographic evidence of both femoral neck and trochanter healing which normally occurs 8–10 weeks postoperatively. Exercises for abductor strengthening and gentle range of motion are started 6–8 weeks postoperatively and the patient is re-evaluated 12–16 weeks after surgery. Implant removal may be scheduled 1 year post-operatively.

The treatment of healed SCFE depends on the degree of the slip and the associated deformity. In cases with a mild to moderate head tilt, treatment can address the resultant FAI. This can be achieved arthroscopically (Fig. 5.9), open, or via a mini-open approach, depending on the degree of

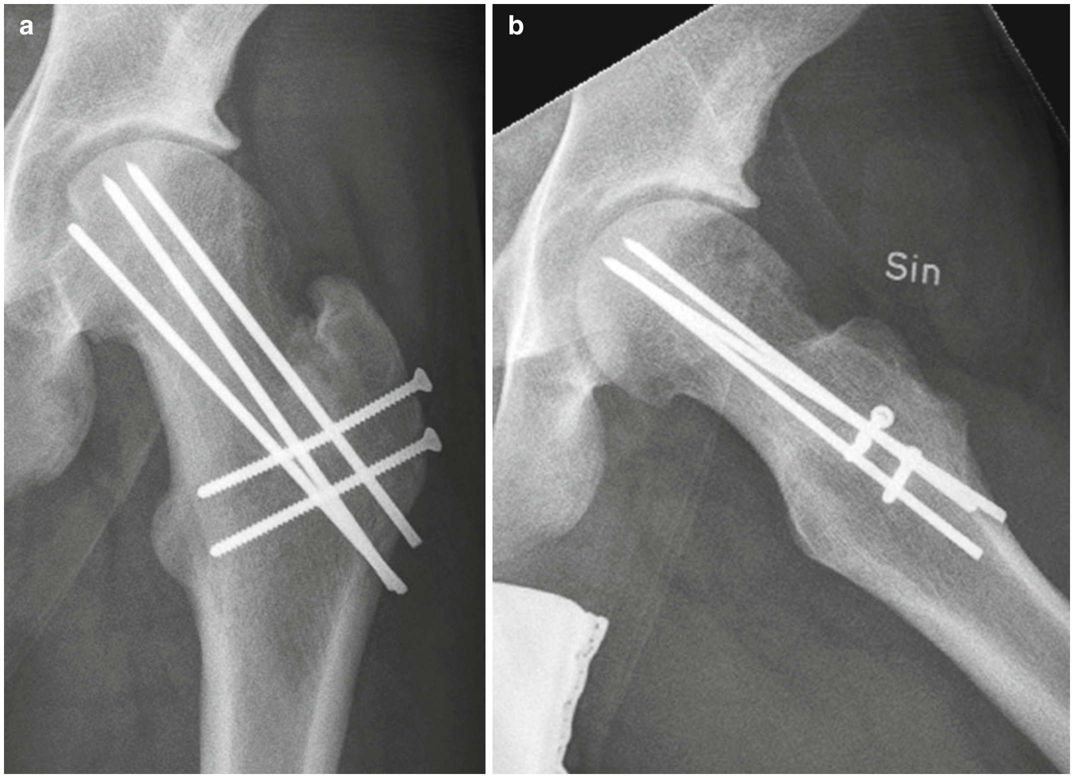

Fig. 5.8 AP (**a**) and lateral (**b**) hip x-rays of a healed SCFE after open reduction and internal fixation

the deformity and the resultant cartilage or labral pathology. Patients with SCFE are more likely to have associated acetabular retroversion or overcoverage [43], thus acetabular rim trimming may be necessary to fully address the impingement. Rarely, patients with acetabular overcoverage or deep sockets may need an accentuated femoral neck osteochondroplasty. Because SCFE patients can have large cam deformities, the surgeon should be aware that resecting more than 30 % of the femoral neck places the patient at risk of femoral neck fracture [44]. Larger retrotilt of the epiphysis also shifts the load distribution towards the postero-superior aspect of the joint while the anterosuperior acetabular roof remains unloaded. To correct these biomechanics, patients with chronic remodeled SCFE, severe gait dysfunction, and functional femoral retrotorsion may require a femoral neck osteotomy or derotational femoral shaft osteotomy. Because patients with large or severe SCFE often require complex osteotomies for deformity correction, they should be referred to tertiary care centers with experience treating complex hip pathology.

Results

Published results of in situ pinning and arthroscopic femoral head-neck osteoplasty are limited [25, 45] and consist of the short-term outcomes of two small case series. Nonetheless, the patients improved by all outcomes measures. In one series, UCLA activity scores were 9, 9, and 8 with all patients reporting pain-free activity and full return to sport [25] at a minimum of 6 months of follow up, while in the second series, the average WOMAC score improved by 9.6 points [45]. Range of motion improved to at least 90° of flexion and neutral internal rotation for all patients [25, 45] and post-operative alpha angles measured on lateral radiographs were reduced to near-normal values (<55°) [25, 45]. This method for addressing mild SCFE appears promising, but mid-term and long-term results are necessary to determine if this approach will also prevent arthrosis.

Short to mid-term results are available for patients undergoing open reduction of the epiphysis via the surgical dislocation approach. When assessed by validated outcomes measures, most patients report good, if not excellent, hip function [26, 39, 46, 47].

Clinically, patients demonstrate restoration of normal range of motion and radiographically, normal femoral head-neck anatomy is restored and maintained [26, 39, 46]. Reported complications after this procedure include reoperation for prominent, bent, or broken hardware [26, 39, 46] and heterotopic ossification [26]. Two cases of avascular necrosis have been reported, in patients who had no femoral head perfusion at the time of capsulotomy in the index operation [39, 46]. No patient who was observed to have intact femoral head perfusion developed subsequent avascular necrosis [26, 39, 46]. Long term results are not yet available but it is to be expected that open reduction ultimately produces better outcomes than in situ fixation.

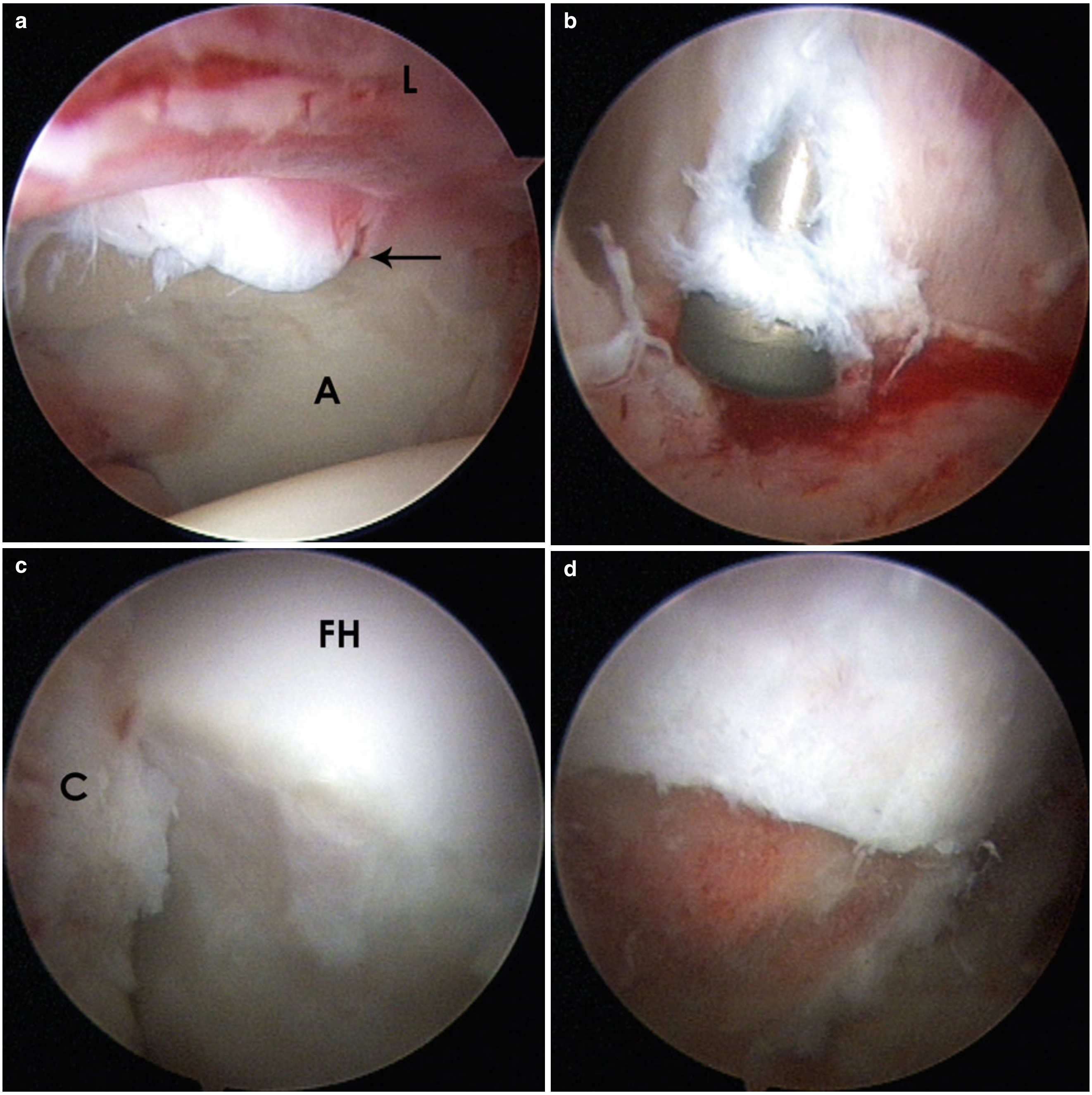

Fig. 5.9 Arthroscopic images demonstrating FAI after in situ pinning of a mild SCFE. (**a**) The labrum is abraded and inflamed. There is a large cartilage flap (*arrow*) in the same region as the labral tear. (*L* labrum, *A* acetabulum) (**b**) The screw at the base of the femoral neck from the in situ pinning. (**c**) Decreased head-neck offset due to the slip. (*C* capsule, *FH* femoral head) (**d**) Improvement in the head-neck offset after femoral neck osteoplasty

Traditionally, SCFE has been associated with both osteonecrosis and chondrolysis. The incidence of osteonecrosis is clearly higher in patients with unstable SCFE [27, 28]. As discussed previously, one speculated cause of osteonecrosis is closed reduction of the epiphysis over posterior callus with subsequent stretching or tearing of the retinacular vessels perfusing the femoral head [18]. Correspondingly, overreduction of an unstable SCFE and attempted reduction of a stable SCFE are both associated with an increased risk of osteonecrosis [7, 21, 28]. Chondrolysis, or rapid destruction of the articular cartilage, was first described for patients with SCFE. It is thought to be the result of unrecognized intra-articular hardware following in situ pinning [3, 7]. However, intraoperative observations of full-thickness cartilage damage, particularly in severe SCFE, indicate that the associated impingement may also be responsible for the rapid progression of arthrosis [5, 39].

Summary

Although SCFE has been recognized and treated by orthopaedists for over a century, significant advances in the understanding and management have occurred in the past decade. In addition to stabilizing the physis, addressing the anatomic deformity to prevent impingement and arthrosis has become an important treatment priority. Although the surgical dislocation and open reduction are technically demanding, safe correction of the physis is now possible and the short to mid-term results are good. Long term results should be similar, but may be influenced by the amount of cartilage and labral damage at the time of surgery.

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Femoroacetabular Impingement

6

Brandon J. Yuan and Robert T. Trousdale

Until recently, the mechanism for osteoarthritis (OA) of the hip was based on the biomechanical principles of force transmission and chronic axial overload leading to intraarticular cartilage degeneration. It has been revealed that primary OA of the hip is in fact a rare occurrence [1] and that the majority of patients with degenerative joint disease (DJD) of the hip severe enough to warrant total hip arthroplasty (THA) have a structural disorder of the hip joint [1–3].

Mechanisms of Impingement

In femoroacetabular impingement (FAI), normal motion of the hip, most often flexion, results in abnormal contact between the femoral head or the proximal femur at the head-neck junction and anterior rim of the acetabulum. This can be a result of morphologic abnormalities in the proximal femur, the acetabulum, or more frequently a combination of the two (Fig. 6.1) [2]. Two distinct types of FAI have been characterized and differentiated by their etiology, structural morphology and pattern of damage to the hip.

The first is cam impingement, which is caused by deformity of the proximal femur or femoral head [4]. Impingement occurs during flexion as an aspherical femoral head with increasing radius is rotated into the acetabulum, placing undue stress on the adjacent cartilage of the anterosuperior acetabular rim (Fig. 6.2) [2]. The force is concentrated at the junction of the labrum and cartilage, resulting in a strong compressive force on the acetabular cartilage while simultaneously stretching the labrum from its cartilaginous attachment (Fig. 6.3) [2]. Any deformity of the proximal femur resulting in femoral retroversion or decreased head-neck offset can result in cam impingement, including pure asphericity of the femoral head, decreased femoral head-neck ratio, retroversion of the femoral neck due to a malunited fracture, Legg-Calvé-Perthes disease or slipped capital femoral epiphysis

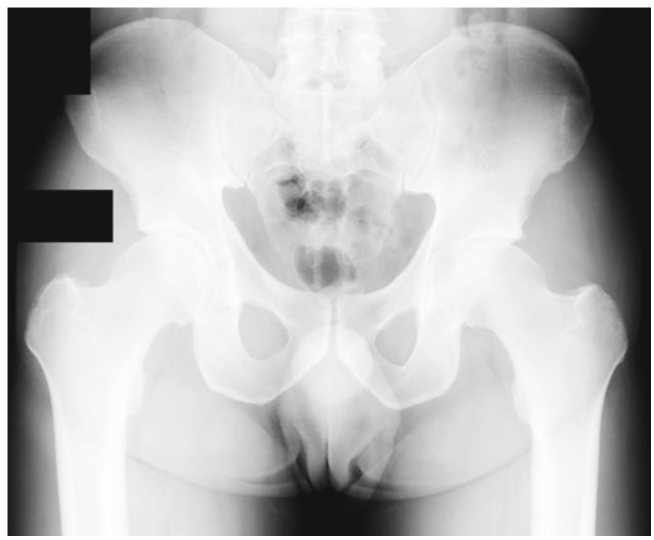

Fig. 6.1 Anteroposterior radiograph of young man with bilateral impinging hips

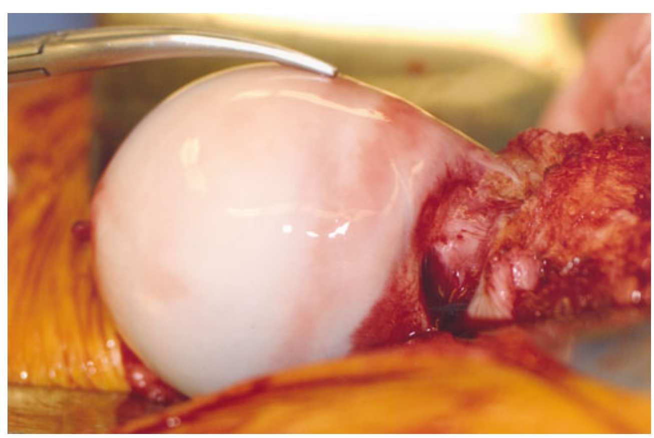

Fig. 6.2 Photograph of abnormal head-neck junction in face of good articular cartilage

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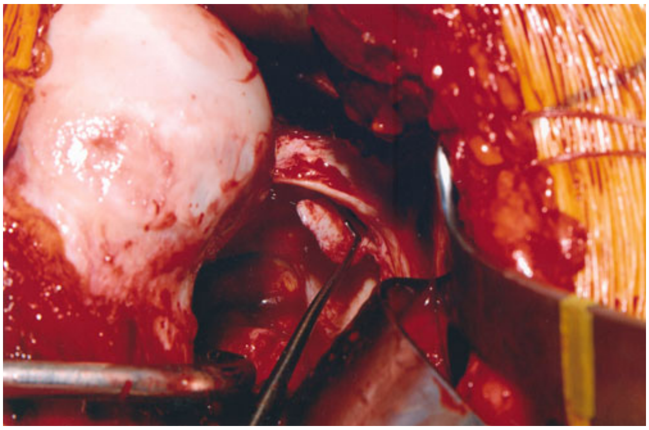

Fig. 6.3 Photograph of typical delaminating articular cartilage seen in cam-type impingers

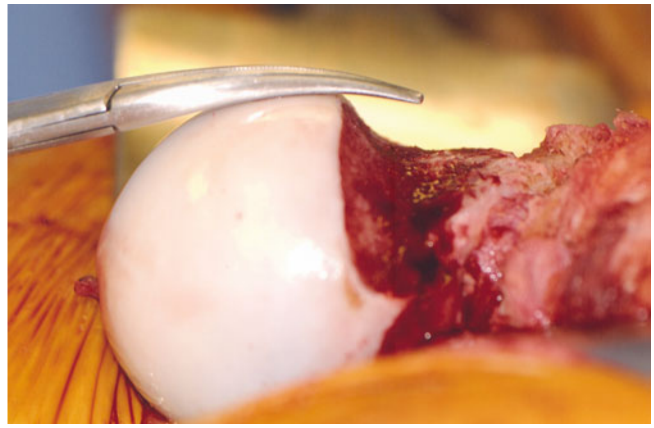

Fig. 6.5 Photograph of same hip in Fig. 6.2 after osteochondroplasty

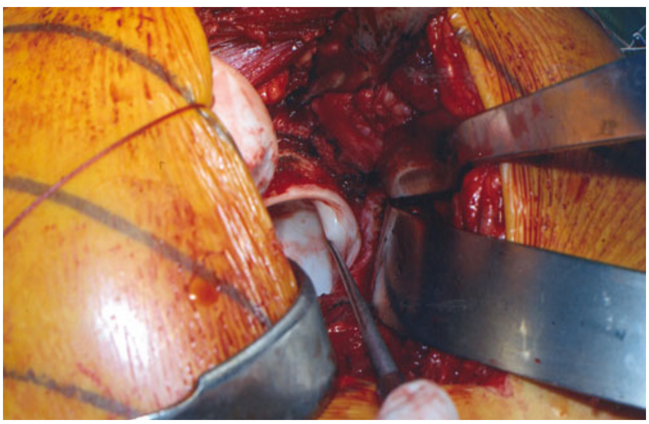

Fig. 6.4 Photograph of typical labral pathology seen in cam type impingers. Note tear is in the anterior-superior aspect of acetabulum

(SCFE) (Fig. 6.4). Pincer impingement results from local or global over-coverage of the femoral head by the acetabulum. As the normal femoral neck approaches the terminal arc of movement, it is limited by the relatively deep socket and subsequently compresses the labrum against the acetabular rim. The forces are transmitted through the labrum and to the underlying cartilage along the acetabular rim, resulting in a narrow band of damage extending around the lip of the acetabulum [2]. Thus the primary pathologic mechanism is labral injury with secondary cartilage damage; and as expected, the injury to the acetabular cartilage in pincer impingement is not as severe as is seen in isolated cam impingement [2]. Over time, chronic impingement of the labrum stimulates excessive bone growth at the acetabular rim and osseous metaplasia of the labrum itself, thus functionally limiting motion of the femoral neck even further. Any morphologic anomaly that results in relative deepening of the socket can lead to pincer impingement, including retroversion of the acetabulum [5], protrusio acetabuli, and coxa profunda.

Treatment

The goal of treatment in symptomatic patients with FAI is the restoration of anatomy to as close to normal as possible while removing factors contributing to abutment of the femoral head and/or neck and the acetabular rim.

There have been several previous descriptions of the surgical approach for treatment of FAI [6]. Traditionally, open methods utilize a posterior or straight lateral approach, trochanteric slide, and capsulotomy to allow for a full dynamic assessment of impingement intraoperatively. Care must be taken to preserve the retinacular vessels supplying the femoral head. The hip is subsequently dislocated anteriorly to allow for full visual assessment of the articular cartilage, acetabular rim and femoral head-neck junction [6]. Treatment of intraarticular pathologies can be accomplished at this time, including proper treatment of damaged cartilage. In patients with isolated cam impingement, treatment is directed at reshaping the proximal femur through resection osteoplasty of the anterolateral head-neck junction, thus improving the femoral head-neck ratio and relieving impingement (Fig. 6.5). The size of the resection should be determined by the severity of limitation in range of motion, but should be aimed at restoring the normal sphericity and contour of the femoral head and head-neck junction. Biomechanical studies have shown that resection of up to 30 % of the diameter of the femoral head-neck junction can be undertaken without significantly affecting the load-bearing capacity of the femur [7], while taking care to preserve the retinacular vessels located over the posterolateral aspect of the femoral head-neck junction.

In cases of anterior acetabular over-coverage, several important factors must be taken into account in surgical planning. Hips with adequate posterior wall coverage are most often treated with resection osteoplasty of the anterosuperior rim. Access to the acetabular rim is best accomplished through sharp transaction of the labrum from the area of the acetabular

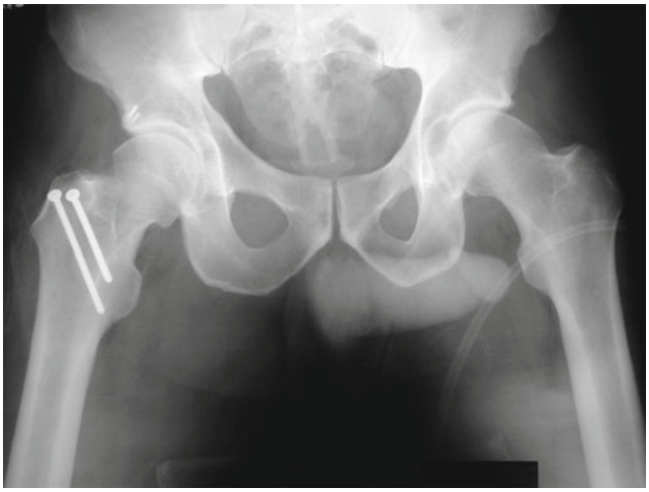

Fig. 6.6 Postoperative radiograph of same patient in Fig. 6.1 after labral repair and osteochondroplasty

rim to be osteotomized. Just enough rim should be resected to allow for full, impingement-free range of motion following reduction of the hip. Assessment is often difficult. Previously, local or complete resection of the labrum was recommended if it was noted to be extensively scarred or ossified, however more recent data suggests that the more peripheral portion of the labrum remains relatively intact in FAI. Espinosa et al. [8] have reported favorable results of labral debridement and refixation with suture anchors following trimming of the acetabular rim and this is the correct recommended management (Fig. 6.6).

In those hips with posterior wall deficiency or lack of posterior over-coverage, previous authors have recommended treatment with reverse periacetabular osteotomy [5], allowing for correction of acetabular version. However, the degeneration of the anterior acetabular cartilage must be carefully considered, as this commonly injured area will be rotated into the primary weight-bearing portion of the joint. Additionally, this procedure does increase posterior wall coverage and may predispose to the development of posteroinferior impingement.

The most recent development in the treatment of FAI is the use of arthroscopic techniques [9, 10], although there remains a paucity of reports on mid or long-term outcome. Arthroscopy allows for visualization and treatment of pathologies of the labrum and articular cartilage, as well as access to the anterior femoral head-neck junction without the need to dislocate the hip and thus avoiding complications associated with this. Some have utilized a combined approach, first using arthroscopy to treat labral and cartilaginous lesions followed by a limited anterior incision to allow for correction of femoral head-neck offset [9].

Summary

Femoroacetabular impingement is a cause of hip pain in young adults. There is increasing evidence that FAI predisposes to the development of degenerative disease of the hip. The various mechanisms of FAI and their patterns of damage to the hip have been well described. Treatment of FAI focuses on the restoration of the anatomy of the hip to as close to normal as possible and the early results of surgical treatment are favorable. While the traditional open approaches are the best option to address the presence of multiple anatomical abnormalities, the future of treatment will focus on less invasive techniques for correction of impingement. The expectation is that these early results will translate into long-term relief of symptoms and delay the development of degenerative disease of the hip. In patients with early degenerative disease of the hip, the return of function and resolution of symptoms over the long-term is a significant challenge. Thus the ability for early diagnosis and treatment of FAI has the potential to delay or even eliminate the need for future replacement of the native hip joint.

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7 The Pathology and Management of Osteonecrosis of the Hip

Aaron Glynn and Javad Parvizi

Introduction

Osteonecrosis of the hip is a pathological condition characterised by a vascular insult to the femoral head and progressive collapse of the bone. This results in pain, secondary degenerative wear of the hip joint (Fig. 7.1a, b) and loss of function. The condition was first described by Alexander Munro in 1738 [1]. It is also known as avascular or aseptic necrosis indicating that infection does not play a causative role.

Blood Supply of the Femoral Head

The primary blood supply to the femoral head is via the medial femoral circumflex artery (MFCA) which is a branch of the profunda femoris artery. The MFCA anastamoses with branches of the lateral femoral circumflex and inferior gluteal arteries to form an extracapsular arterial ring at the base of the femoral neck [2]. Retinacular vessels arise from this arterial ring and travel subsynovially along the capsule of the hip joint to supply the femoral head. Additional intraosseus vessels travel to the femoral head from the femoral nutrient artery. The artery of the ligamentum teres usually derived from the obturator artery and occasionally from the MFCA supplies a small and variable portion of the medial femoral head. The nature of the supply from the artery of the ligamentum teres is more consistent in children and may be negligible in adults.

Aetiology

Many factors have been implicated in the development of osteonecrosis of the femoral head. These can be divided into traumatic and atraumatic conditions. Trauma-induced osteonecrosis is due to mechanical disruption of the arterial blood supply to the femoral head. It is associated with displaced fractures of the femoral neck, with a reported incidence of 15–50 % depending on fracture type, time to reduction and accuracy of reduction [3]. Traumatic dislocation or subluxation of the hip joint may occur in sport, with anterior subluxation of the hip occurring when a ball player is tackled from behind, or full anterior dislocation occurring in a water skier with extreme abduction and external rotation of the hip. Posterior hip dislocation commonly occurs in the setting of a motor vehicle accident. The mechanism is that of axial loading of the femur with the hip in flexion and adduction (dashboard injury). It carries a 10–25 % risk of developing osteonecrosis with higher risk associated with delays in reduction [3]. Osteonecrosis of the hip may also be seen after trauma in the absence of any demonstrable injury.

The commonest causes of atraumatic osteonecrosis are corticosteroid use (seen in up to 30 % of cases), and excessive alcohol intake. Idiopathic cases represent the third largest group of patients with the condition. The dose and duration of corticosteroid therapy necessary to cause osteonecrosis remains controversial. Doses of corticosteroid in excess of 20 mg per day have been associated with a higher risk [3]. This risk may be reduced by concomitant use of cholesterol lowering HMG-CoA Reductase inhibitors (commonly known as Statins) [4]. Anabolic steroids, which may be abused by athletes, have also been implicated in the development of osteonecrosis [5].

Alcohol excess has long been recognised as a causative factor in osteonecrosis. Individuals consuming 400 mg of alcohol or more per week have a 10–18 times higher relative risk of developing osteonecrosis [6]. Less common causes of osteonecrosis include glycogen storage disorders, haemoglobinopathies (e.g. sickle cell disease and thalassaemia), coagulopathies (e.g. Factor V Leiden, and anticardiolipin antibodies seen in SLE), Human Immunodeficiency Virus (HIV) [7], chronic liver disease, radiation and dysbaric disorders (e.g. rapid decompression in deep sea divers, a condition formerly known as "the bends").

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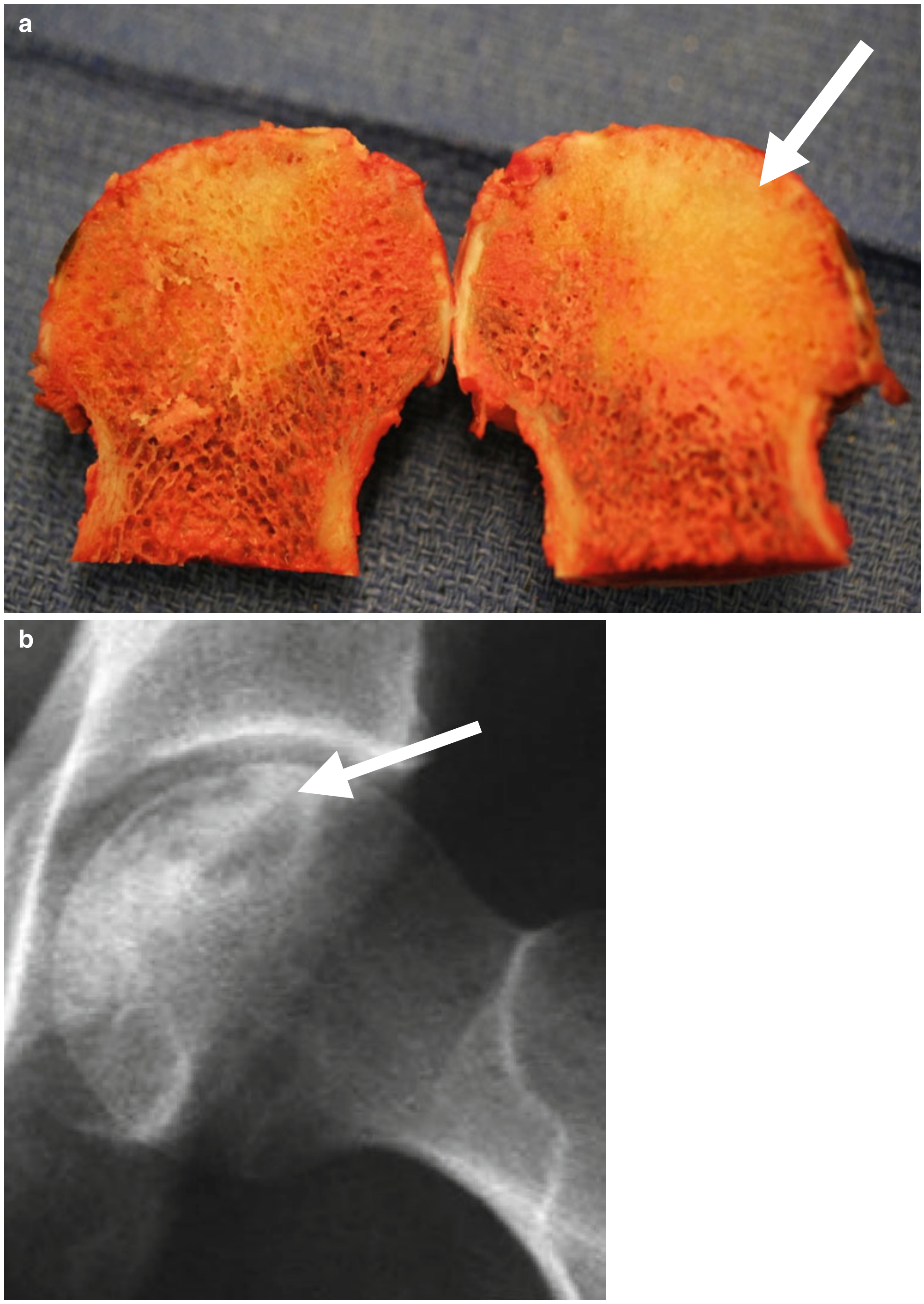

Fig. 7.1 (**a**) Operative specimen with cross section of a femoral head showing necrotic bone in the antero-medial portion and loss of normal trabecular structure and increased density (*arrow*). (**b**) Cystic appearance of collapsed avascular bone in the femoral head is the first radiographic evidence of osteonecrosis (*arrow*)

In atraumatic osteonecrosis the final common pathway is postulated to be ischaemia caused by obliteration of the femoral head microvasculature. This may occur either through obstruction of smaller vessels in the femoral head by thrombus (e.g. secondary to coagulopathy or haemoglobinopathies), emboli (fatty tissue in alcoholic liver disease) or hypertrophy of non haematopoietic bone marrow (thought to occur with steroid therapy, alcohol excess

Fig. 7.2 Osteonecrosis is bilateral in up to 50 % of cases, but there may be asymmetry in degree of femoral head involvement at presentation

and glycogen storage disorders) resulting in extravascular compression and secondary thrombosis of the vessel. Bone is a Starling resistor, and does not allow for any expansion to facilitate the inflow of blood; thus any increase in volume of extravascular soft tissue leads to reduced blood flow and ischaemia. Ischaemia leads to necrosis of marrow adipocytes and haemopoietic tissue. Two to three hours of ischaemia may lead to osteocyte necrosis and bone infarction [3]. Infarcted subchondral bone at the periphery of the femoral head subsequently collapses under compressive load, leading to the classical radiographical changes associated with osteonecrosis.

Not all individuals with these risk factors are affected by osteonecrosis, and recent attention has turned to factors such as endothelium-dependent nitric oxide synthase to explain why some are more susceptible to its development. Nitric oxide is a known vasodilator of capillaries in bone [8]. A genetic predisposition may also exist, with mutation in a collagen type-II gene recently being implicated with autosomal dominant inheritance of osteonecrosis of the femoral head [9].

Epidemiology

Osteonecrosis typically affects individuals in their third, fourth and fifth decades of life. It has a male predominance and is bilateral in approximately 50 % of cases (Fig. 7.2). The prevalence of hip osteonecrosis varies between 300,000 and 600,000 cases in the USA [3] and it is estimated that osteonecrosis of the femoral head accounts for 5–18 % of the 500,000 total hip arthroplasties performed annually in the USA [10].

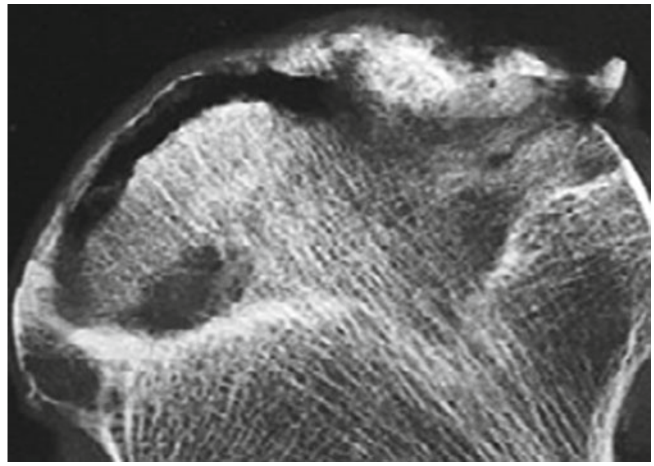

Fig. 7.3 Subchondral collapse of the avascular segment is visible on plain radiograph as a 'crescent sign', which correlates with stage three of both the Ficat and Arlet, and University of Pennsylvania staging system

Presentation

The typical presentation if that of pain in the hip, most commonly localized to the groin and exacerbated by weight bearing. The pain may however be referred to the buttock, knee or trochanteric region and mimic referred pain from the lumbosacral spine leading to delays in diagnosis. On physical examination, patients may have reduced range of motion of the hip at more advanced stages of the condition. Stinchfield's resisted hip flexion test is commonly positive. Pain on internal rotation of the hip is sensitive but not very specific. A detailed history should elicit any risk factors associated with the development of osteonecrosis.

Diagnosis

Diagnosis is typically made on plain radiographs, with anteroposterior (AP) views of the pelvis and lateral views of the hip but it is important to bear in mind that early osteonecrosis may not be evident on plain radiographs. Typical findings on X-ray include sclerosis, cysts or a 'crescent sign', which represents subchondral collapse of bone (Fig. 7.3). Radiographic change in the femoral head usually occurs many months after onset of the condition. MRI scanis considered the gold standard for early stages of the disease, and is 99 % sensitive and specific (Fig. 7.4). MRI is also a useful tool for staging the process, and provides

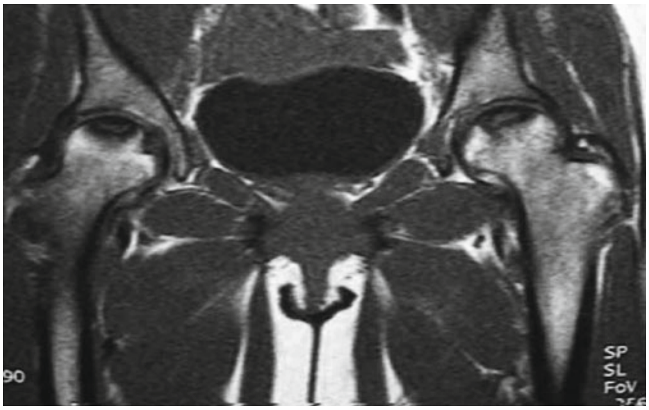

Fig. 7.4 MRI is the most sensitive and specific investigation for avascular necrosis. Oedema of the metaphyseal bone in the femoral head with cyst formation is apparent before changes appear on plain radiographs

information on the level of involvement of the femoral head. Technetium-99 bone scanning can be used, but has a high false negative rate (between 25 and 45 %) [3]. Invasive methods of diagnosis including venography, biopsy and marrow pressure readings are largely of historical interest and no longer employed. Arthroscopy can be a useful adjunct in determining management options for patients with osteonecrosis. Ruch et al. found that arthroscopy revealed osteochondral degeneration not detected by radiographs or MRI in over one third of post collapse femoral heads [11].

Laboratory studies are usually of little value in diagnosing femoral head osteonecrosis, although haemoglobinopathies may be diagnosed by electrophoresis. Differential diagnosis in the athlete includes femoral neck stress fracture, labral tear and adductor tendinitis.

Classification

Classification systems typically divide osteonecrosis into pre- and post- collapse stages. The system developed by Ficat and Arlet is based on plain radiographs [12].

Classification System of Ficat and Arlet

Stage	Radiographic findings
1	None
2	Diffuse sclerosis and cysts seen on plain radiographs
3	Subchondral fracture (crescent sign)
4	Femoral head collapse and associated degenerative joint changes

Steinberg adapted this classification to incorporate the use of MRI in the diagnosis of the condition [13]. MRI permits diagnosis of osteonecrosis at a stage before it is evident on plain films, and also allows quantification of femoral head involvement.

University of Pennsylvania system for staging avascular necrosis

Stage	Criteria
0	Normal or nondiagnostic radiograph, bone scan, MRI
I	Normal radiographs; abnormal bone scan and/or MRI
	A–Mild (<15 % of femoral head affected)
	B–Moderate (15–30 %)
	C–Severe (>30 %)
II	Cystic and sclerotic changes in femoral head
	A–Mild (<15 % of femoral head affected)
	B–Moderate (15–30 %)
	C–Severe (>30 %)
III	Subchondral collapse (crescent sign) without flattening
	A–Mild (<15 % of articular surface)
	B–Moderate (15–30 %)
	C–Severe (>30 %)
IV	Flattening of femoral head
	A–Mild (<15 % of surface and <2 mm depression)
	B–Moderate (15–30 % of surface and 2–4 mm depression)
	C–Severe (>30 % of surface and >4 mm depression)
V	Joint narrowing or acetabular changes
	A–Mild
	B–Moderate
	C–Severe
VI	Advanced degenerative changes

From Steinberg et al. [58], with permission

Natural History

Patients with asymptomatic disease of their femoral head developed symptoms in almost 60 % of cases in a review of the literature performed by Mont et al. [14]. Collapse of the femoral head occurs in 75–85 % of patients within 3 years of presentation [15, 16]. The rates for preservation of the femoral head are 35 % for stage 1 hips, 31 % for stage 2 hips, and 13 % for stage 3 hips [16]. Less than 10 % of small, medially located lesions show progression [14]. Aaron et al. reported that 50 % of patients with osteonecrosis required total hip arthroplasty within 3 years of onset of diagnosis [17]. There is some evidence that the underlying aetiology may influence the course of the disease, with 73 % of patients with sickle cell disease progressing to collapse, but only 17 % of those with systemic lupus erythematosus (SLE) similarly progressing (Table 7.1).

Table 7.1 Prevalence of progression to femoral head collapse in patients with osteonecrosis stratified by underlying condition

	Total no. of hips	No. of hips with collapse	Prevalence of collapse (%)
Total population	282	102	38
Corticosteroids	31	8	26
Excessive alcohol intake	45	21	47
Idiopathic	32	12	38
SLE	59	10	7
Sickle cell disease	40	29	73
Renal failure (± transplant)	48	22	46
HIV	27	4	15

From Mont et al. [14], with permission

Management

The goal of management in osteonecrosis of the hip is to preserve the native femoral head, while treating pain and loss of physical function associated with the condition. Management is based on the stage of the disease, however attempts to develop clear protocols in treating the condition have been confounded by the fact that it behaves differently based on the age of the patient and the underlying aetiology. The evidence for different management strategies is also limited by the natural history of the disease still being poorly understood. Certainly, in the initial stages of the disease, pain relieving modalities such as non-steroidal anti-inflammatory drugs (NSAIDs) and the use of a cane in the contralateral hand to offload the affected joint and reduce the net joint reactive force are appropriate. From the perspective of the young athlete, osteonecrosis of the hip is generally considered to be a contra-indication to participation in high impact sporting activities, although return to low impact activities such as swimming, biking and elliptical training devices maybe considered.

Core Decompression and Bone Grafting

The theory underpinning core decompression is that drilling of the avascular bone may permit neoangiogenesis and new bone formation in the affected region. The practice stems from the observation by initial investigators of osteonecrosis that patients obtained symptomatic relief following drilling of their femoral head performed for biopsy and manometry.

Methods for core decompression include either a single core tract, or multiple smaller holes made using a guidewire. Controversy exists as to which method is superior. In either case, biplanar imaging should be employed, and starting holes for the core decompression should be made proximal to the lesser trochanter to reduce the risk of subtrochanteric fracture. For the same reason, patients should be advised to mobilize with protected weight bearing for a minimum of 6 weeks postoperatively [3].

Stulberg et al. performed a randomized prospective study, comparing core decompression with nonoperative management in 55 hips affected by osteonecrosis. They found a 70 % clinical improvement rate with decompression in Ficat stage I, II and III hips. This compared to a 20 % improvement rate with nonoperative management with Ficat stage I, 0 % with stage II and 10 % with stage III hips [18]. The benefits of decompression were disputed by Koo et al. [19] who randomized 37 hips to core decompression or nonoperative management. They found 72 % of patients treated with decompression had radiological progression of disease, and 72 % eventually required hip arthroplasty. In contrast, 79 % of patients treated nonoperatively had radiographic signs of progression, and 69 % required hip arthroplasty. The authors thus concluded that core decompression did not improve outcomes in osteonecrosis.

There are no clear guidelines at present for selecting patients who would benefit most from core decompression. However, a literature review by Smith et al. looking at 12 studies with a total of 702 hips at an average follow up of 38 months, reported a successful outcome in 78 % Ficat stage I hips, 62 % of stage II hips and 41 % of stage III hips [20]. These results would suggest that the likelihood of successful outcome is greater the earlier the procedure is performed. There is clear evidence that the core decompression is of limited benefit once collapse of the femoral head has occurred [21]. The amount of head involvement would also appear to have a role in predicting likelihood of success following core decompression. Steinberg retrospectively reviewed 297 hips in 205 patients following core decompression with placement of cancellous graft at a minimum of 2 years [22]. Twenty-two percent of patients with Steinberg stage IA and IIA hips required total hip arthroplasty, compared with almost 40 % with stage IB, IIB or IIC hips. The author concluded that the size of the lesion as well as the stage determined the success of core decompression.

Hungerford also suggested that the decision to treat pre-collapse disease should be based on lesion size, rather than symptoms. Small and large lesions (<15 and >30 % respectively) of the femoral head should be observed, as they are unlikely to progress in the former, and unlikely to benefit from core decompression in the latter case. Decompression was therefore recommended for medium sized lesions [23].

Core decompression can be combined with bone grafting to improve results. The use of vascularised fibular grafting has been described by Urbaniak [24]. This combines core decompression with removal of the necrotic

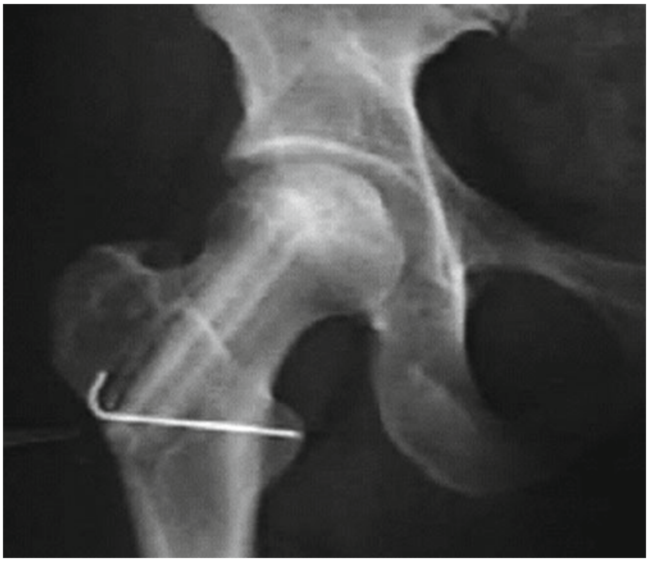

Fig. 7.5 Vascularized fibular bone grafting of the femoral head has been attempted with some success in restoring arterial supply to the avascular femoral head. The procedure is complex, and requires microvascular surgical techniques

bone, and placement of a free fibular graft to give structural support (Fig. 7.5). The fibular graft has an intact peroneal artery and veins, which are anastamosed to the ascending branches of the lateral femoral circumflex artery and vein. The aim is to revascularize the femoral head. There have been encouraging results with the procedure. Urbaniak reported on 103 patients with osteonecrosis following vascularised free fibular graft. At an average of 7 years follow up, only 30 % of hips required conversion to a total hip arthroplasty. Patients with pre-operative collapse of the femoral head fared worse [24].

Kane prospectively compared the results of core decompression alone with vascularised free fibular grafts in a group of 39 patients followed for 2–5 years [25]. Core decompression was successful in 8 (42 %) of 19 hips, whereas vascularised fibular free grafting was successful in 16 (80 %) of 20 hips. Yoo et al. retrospectively reviewed 124 hips in 110 patients who underwent vascularised fibular bone grafting for femoral head osteonecrosis at a mean follow up of 10 years. They found improved mean Harris hip scores, from 72 to 88, and improved or unchanged radiographs in 62 % of stage II hips and 60 % of stage III hips. Only 13 hips (10.5 %) failed treatment and underwent total hip arthroplasty. Graft survival was associated with the patients age and both size and location of the lesion, but not the aetiology and stages of the disease. Complications included clawing of the big toe in 17 patients, peroneal nerve palsy in two, and subtrochanteric fracture in a further two patients [26]. Although the results are promising, vascularised free fibular grafting is a laborious process, taking several hours to perform and involving two teams of surgeons using micro vascular surgical techniques. There is also a significant associated risk of complications (19 %) related to the fibular donor site [27].

Non-vascularised bone grafting is another option for management in the case of pre-collapse or early post-collapse of the femoral head when the articular cartilage remains intact. It aims to replace the necrotic segment with structurally sound bone graft, and provide osteoconductive support for in growth of new bone. Earlier approaches involved placement of autologous strut graft through a core drilled in the femoral neck and lateral cortex. Variable success rates are reported [3, 28, 29]. Contemporary methods of autologous bone graft insertion include the "lightbulb procedure", whereby a window is cut in the anterior cortex of the femoral neck and the necrotic segment is completely excised prior to insertion of cancellous bone graft from the iliac crest. This has been reported as providing complete relief in 13 out of 15 hips at a mean of 12 years follow up [30]. The "Trapdoor" technique involves surgical dislocation of the femoral head, and a direct approach to the necrotic segment through a 2 cm [2] flap cut in the articular cartilage. The necrotic bone is excised and replaced with autologous bone graft. Good to excellent results were reported in eight of nine Ficat stage III hips at a mean of 3 years post-operatively [31]. Mont looked at Bone morphogenetic protein (BMP) combined with demineralised bone matrix (DBX) and allograft bone chips as a means of avoiding donor site morbidity. Twenty-one hips were followed for a mean of 4 years, and 18 (86 %) had a clinically successful outcome [32]. Although these techniques require extensive dissection, they hold promise as a method of forestalling or avoiding total hip arthroplasty.

Osteotomy of the Hip

The theory underpinning proximal femoral osteotomy in the setting of osteonecrosis is to remove the affected necrotic or collapsing segment from underneath the weight bearing part of the hip. This is replaced with a cartilage-covered, stable portion of the femoral head. The two main types of osteotomy performed are transtrochanteric rotational osteotomies and intertrochanteric varus or valgus osteotomies which may be combined with flexion or extension as appropriate. Sugioka reported on 295 hips at a mean follow up of 11 years following a transtrochanteric rotational osteotomy in which 229 (78 %) had a successful outcome [33]. This procedure has had favourable results in several Japanese centres that have been poorly replicated in centres in the US [3].

Mont et al. reported good or excellent outcomes in 28 (76 %) of 37 hips treated by varus osteotomy combined with flexion or extension at a mean of 11.5 years follow up [34]. With either technique, the factors shown to improve the outcome of osteotomy include younger age (<45 years), small to medium sized osteonecrotic lesion, absence of joint space narrowing or acetabular involvement and no chronic use of high dose corticosteroids. Osteotomies are not generally considered a standard treatment for osteonecrosis because they can be technically difficult, carry a risk of non-union, have variable outcome, and cause technical difficulty with later conversion to total hip arthroplasty [3].

Hip Arthrodesis

Arthrodesis has generally fallen out of favour for the treatment of painful hip conditions in young adult patients, as it is associated with restricted activity, and secondary degenerative change in the lumbar spine, contralateral hip, and ipsilateral knee [35].

Total Hip Arthroplasty

Total hip arthroplasty (THA) is the most consistent means of eliminating pain in the presence of osteonecrosis. Osteonecrosis accounts for 5–12 % of total hip arthroplasties performed [3]. It is indicated for patients with osteonecrosis and associated degenerative changes in the hip joint, as well as lower demand patients with sufficient symptoms to justify replacement. It is best avoided in younger patients with osteonecrosis deemed not likely to progress (medially based disease involving <15 % of the joint surface, or where there is an option for joint preserving surgery). Due consideration should be given to patients likely to encounter problems after THA (e.g. patients with osteonecrosis secondary to alcohol excess at high risk of dislocation, and patients with osteopenia secondary to chronic steroid therapy).

Although there is evidence to suggest that patients benefit from hemiarthroplasty to cover the femoral head in the presence of osteonecrosis with intact acetabular cartilage, many investigators have reported that the results are inferior to THA [36–38] due to the late complication of acetabular wear leading to groin pain.

Concerns exist regarding the success of total hip arthroplasty in patients with osteonecrosis compared to those with osteoarthritis. Saito et al. found a significantly higher rate of complications in patients undergoing THA for osteonecrosis as compared to osteoarthritis [39]. Patients with osteonecrosis tend to be younger, and therefore have greater functional demands than patients with osteoarthritis. Poor outcomes may also be related to medical comorbidities including chronic use of corticosteroids or alcohol abuse. Brinker et al. looked at 81 hips that had THA for osteonecrosis at between 4 and 8 years of follow up. They reported good or excellent clinical results in 92.3 % of idiopathic cases, 86.7 % of alcohol-induced cases, 77.8 % of renal transplant cases, and 62.5 % of SLE cases [40]. A systematic review of the literature by Johannson et al. found that patients who received THA for osteonecrosis prior to 1990 had a cumulative revision rate of 17 %, but that this had decreased to a revision rate of 3 % for patients who had THA performed after 1990, suggesting better results with contemporary fixation methods. They reported lower revision rates in patients with idiopathic disease, SLE, and after cardiac transplant, whereas significantly higher revision rates were found in patients who had sickle cell disease, Gaucher disease and after renal failure or transplant [41].

The initial results of cemented THA in patients with osteonecrosis were inferior to those seen in patients with osteoarthritis. Kirschenbaum et al. reported an 11.5 % revision rate in 87 cemented hip arthroplasties performed for osteonecrosis at an average follow up of 5.7 years [42]. Fyda et al. retrospectively looked at 28 hips in 21 patients who had undergone cemented THA for osteonecrosis at a minimum of 10 years previously. They found the overall rate of aseptic loosening requiring revision was 13 %, with no difference in loosening rates between the acetabular and femoral components [43]. Kantor et al. reported improved outcomes with second generation cementing techniques. They followed 28 hips with osteonecrosis treated with cemented THA at a mean of 7.7 years, and reported that 83 % of patients had good or excellent clinical outcome. Cumulative probability of survival was estimated to be 85.7 % at 10 years [44]. The results improved further with the development of third generation cementing techniques; Kim et al. found no difference in outcome between cemented and uncemented stems in patients with osteonecrosis at an average duration of 9.3 years follow up [45].

With cementless components, good results have been reported in many series. Piston looked at 35 patients with cementless THA performed for osteonecrosis and found only one stem had required revision at an average of 7.5 years follow up [46]. At a mean follow up of 8.5 years, Kim found no evidence of aseptic loosening or osteolysis in 73 hips in 71 patients younger than 50 years at time of arthroplasty who had uncemented arthroplasty performed with ceramic-on-highly cross-linked polyethylene bearing for osteonecrosis. Patients had a mean Harris Hip score of 96 points at final follow up [47]. Thigh pain has been reported as a complication following cementless THA in this patient group. Katz reported a 29 % incidence of thigh pain in 14 patients undergoing cementless THA for osteonecrosis at a mean follow up of almost 4 years [48], and Lins reported a 25 % rate of the same complication in 34 THA procedures in 31 patients with the use of uncemented stems [49].

Patients with osteonecrosis are postulated to have less capsular hypertrophy of the hip joint compared to patients with osteoarthritis, thereby increasing their risk of dislocation secondary to sub-optimal soft tissue restraints. Dislocation is also a particular risk in patients with osteonecrosis secondary to substance abuse. Treatment strategies include avoidance of the posterior approach for hip arthroplasty or performing an enhanced posterior soft tissue repair, thereby reducing the risk of dislocation. Infection risk is increased in patients who are on long term steroid medication, although this should not be viewed upon as being a contraindication to surgery. Levitsky followed up five patients on chronic steroid therapy post liver transplantation, none of whom developed an infection post-operatively [50]. Patients with osteonecrosis tend not to have sclerotic subchondral acetabular bone as is found in patients with osteoarthritis. The surgeon should be aware there is thus a risk of fracture with inserting an under reamed acetabular component. There is also the potential for technical difficulty in patients who may have had previous proximal femoral osteotomy or cortical bone grafting. The use of high speed burrs for sclerotic bone, and intraoperative radiographs to check broach alignment have been recommended [3]

Hip Resurfacing

Metal-on-metal (MOM) hip resurfacing initially held great promise for individuals with osteonecrosis, as these patients tended to be younger and more active. It was believed that MOM was a more durable bearing, while larger femoral head sizes suggested an almost negligible risk of dislocation during sporting activities. Bose looked at the outcome of 96 Birmingham hip resurfacing arthroplasties performed in 71 patients with osteonecrosis of the femoral head at a mean of 5.4 years and found that all patients remained active, with only three hips requiring revision [51]. Amstutz found no difference in outcome for patients who had hip resurfacing performed for osteonecrosis compared to other underlying conditions at between 2 and 12 years follow up [52]. Recently however, there has been a decrease in the use of MOM hip resurfacing as reports are emerging of the detrimental effect that metal debris can have on periarticular tissues [53, 54]

Future Therapies

Glueck et al. showed a reduction in the progression of early stage osteonecrosis in patients treated with enoxaparin, suggesting that anticoagulant drugs may have a potential role in decreasing the intravascular thrombosis associated with the development of osteonecrosis [55].

Use of bisphosphonates, especially when used early in the development of the condition, show some promise in the management of patients with osteonecrosis. The premise is that the anti-resorptive and anti-inflammatory actions of the drugs counter the structural bone weakening caused by reparative osteocyte apoptosis. Agarwala looked at 395 hips with Ficat stage I, II, and III osteonecrosis treated with oral alendronate for 3 years. They report that 364 (92 %) had a satisfactory clinical result, and did not require surgery at a mean follow up of 4 years. Analgesia requirements were greatly reduced within months of commencing the drug, and there was a decreased rate of radiological progression of collapse and delayed need for total hip arthroplasty [56]. There is however a theoretical risk of increased technical difficulty in performing total hip arthroplasty in patients after long term bisphosphonate therapy.

Mesenchymal stem cell implantation [57] may provide some success in the management of osteonecrosis of the hip in the future, but at present it is still an experimental therapy.

Summary

Osteonecrosis of the hip is a devastating condition that can affect young adults. It is commonly associated with trauma, steroid and alcohol use, blood dyscrasias and infectious diseases but can be idiopathic in a large number of cases. It causes pain, restricts movement, and has a significant impact on sporting activities and global joint function. The majority of cases progress to collapse if left untreated, resulting in the need for total hip arthroplasty which has a successful outcome for the majority of patients. There are an as-yet a poorly defined subset of patients who may benefit from joint sparing procedures, and the success of these interventions appears to be associated with underlying comorbidities, and the location, size and stage of the osteonecrotic lesion. Further research and better understanding of the condition may result in therapies which avoid the need for surgical intervention.

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Traumatic Conditions of the Hip and Pelvis

8

Aaron Nauth, Jeremy Hall, Michael D. McKee, and Emil H. Schemitsch

Introduction

This chapter will focus on the assessment and management of fractures and dislocations around the hip and pelvis secondary to traumatic injuries sustained in the young and active population during athletic activities. Traumatic soft tissue injuries, such as labral tears, are covered in other chapters in this book. Fractures and dislocations around the hip and pelvis in young patients are most commonly seen secondary to high energy trauma, such as motor vehicle accidents (MVAs) or falls from a significant height. However, they are occasionally seen secondary to high energy athletic activities such as cycling [1], motor cross, horseback riding, alpine skiing or snowboarding [2, 3], mountain climbing [4], hockey [5], rugby [6], and American football [7]. As such, these injuries will occasionally be seen by physicians and allied health specialists covering sporting activities, and it is important to have an understanding of these injuries and their emergent management.

General principles of orthopedic trauma management should be applied in these patients and appropriate screening is necessary to rule out associated injuries. A careful physical examination should be performed focused on assessment of the injured limb, including a detailed neurovascular exam. Urgent radiographic assessment is mandatory if one of these injuries is suspected, as is urgent orthopedic surgical referral if imaging confirms a fracture or dislocation. The following sections describe individual injury patterns and their assessment and management on the basis of anatomical locations.

Proximal Femur Fractures

Fortunately, fractures of the proximal femur are rare in the young and active patient population and are more commonly seen in elderly patients with osteoporotic bone who sustain a low energy fall. When these injuries do occur in young patients they are most commonly seen secondary to MVAs and often occur in association with other significant injuries. However they are occasionally seen in young patients participating in athletic activities [8], typically secondary to a fall from a significant height.

Patients clinically present with hip pain and inability to weight-bear. Initial assessment involves physical examination to rule out other injuries. The limb is typically shortened and externally rotated. Neurovascular injuries or open injuries are rare. Radiographic assessment of the hip and femur should be performed including anteroposterior (AP) and lateral images of the hip, as well as an AP pelvis. Proximal femur fractures, once diagnosed and identified on radiographs, require prompt surgical intervention. Fractures of the proximal femur involve the femoral neck and the intertrochanteric or subtrochanteric region.

Intertrochanteric Fractures

These fractures involve the intertrochanteric region of the proximal femur between the greater and lesser trochanters. It is important to recognize specific fracture patterns radiographically as they influence the choice of implant at surgery. In contrast to elderly patients with low energy fractures, young patients with proximal femur fractures have typically sustained high energy trauma and therefore, often present with fracture comminution and unstable fracture patterns (see Fig. 8.1a). The integrity of the lateral wall of the greater trochanter has recently been highlighted as an important predictor of success when using a sliding hip screw implant (SHS) [9]. Young patients with a proximal femur fracture require careful

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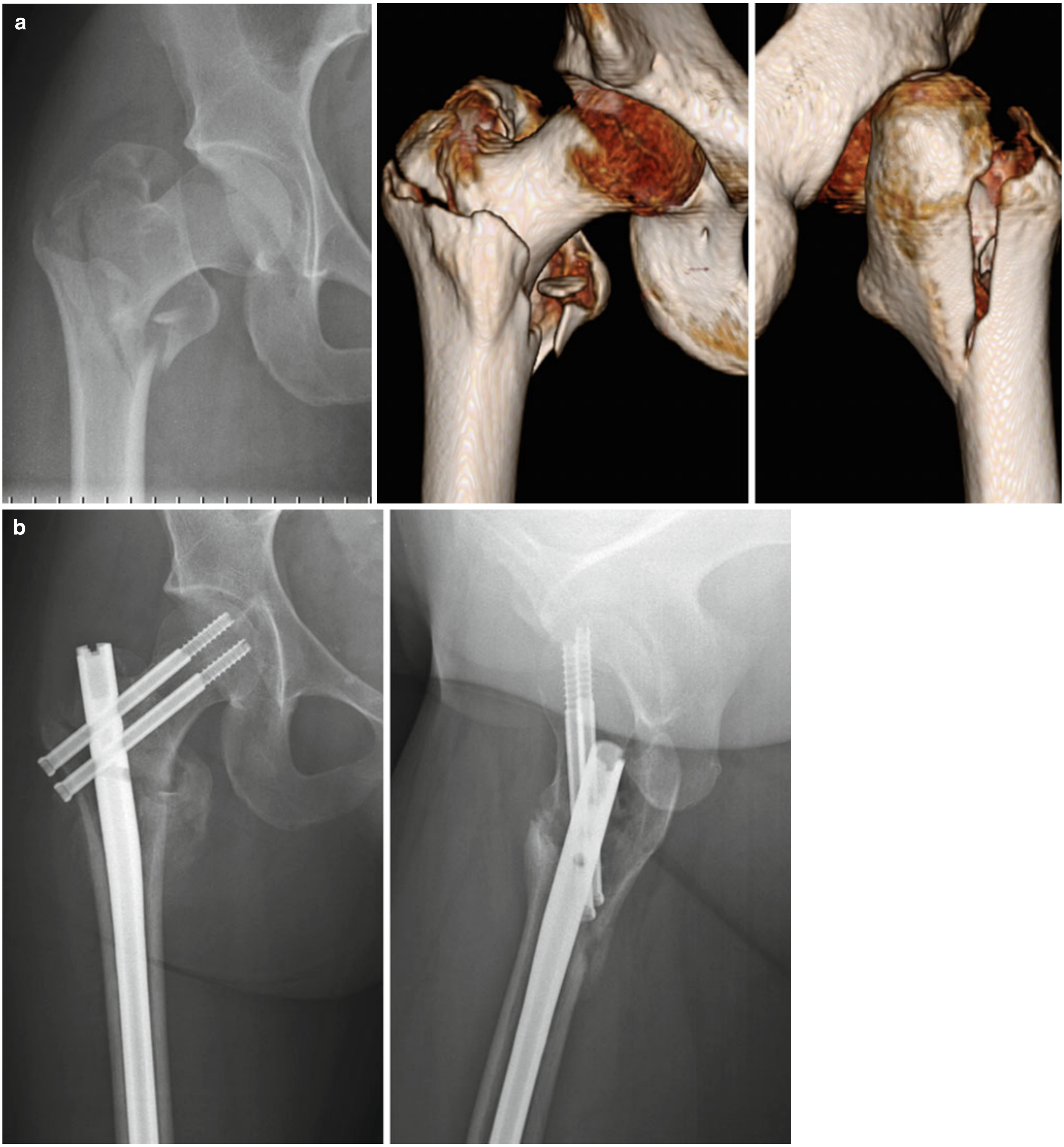

Fig. 8.1 (**a**) Pre-operative AP radiograph and three-dimensional reconstruction computed tomography (CT) images of the right hip in a 22-year-old female patient who sustained a significant fall from a height while running. The radiographs and CT images demonstrate a comminuted intertrochanteric fracture of the proximal femur with significant compromise of the lateral wall. (**b**) Six week post-operative AP and lateral radiographs of the same patient demonstrating early radiographic healing and anatomic alignment following treatment with a reconstruction type cephalomedullary nail. The patient was weight-bearing as tolerated immediately post-operatively

radiographic assessment of the lateral wall integrity. If there is any significant compromise of the lateral wall, a cephalomedullary nail is recommended (see Fig. 8.1b). A further unstable fracture pattern is the "reverse obliquity". In this fracture pattern, the fracture line extends from proximal–medial to distal–lateral. The literature suggests that this fracture pattern is also best treated with a cephalomedullary nail (see Fig. 8.2) [10].

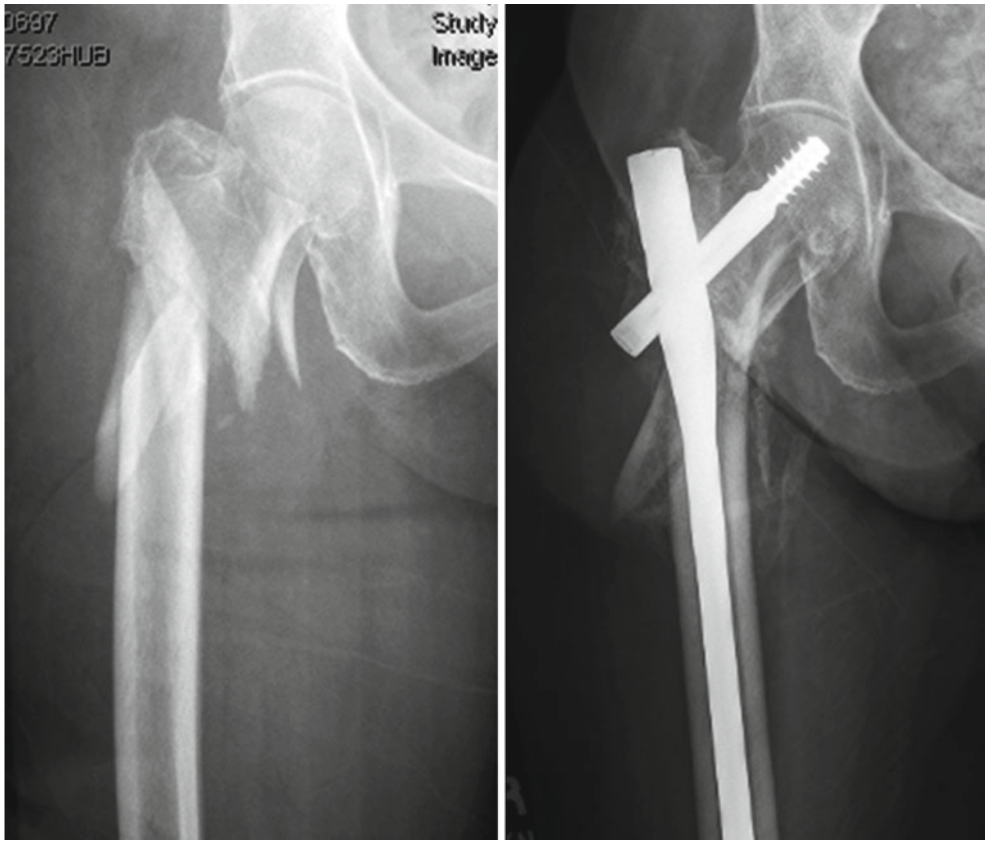

Fig. 8.2 Pre and 3 month post-operative AP radiographs of the right hip in an elderly patient with an unstable intertrochanteric fracture. The fracture pattern is similar to a reverse obliquity type, but in this case is associated with significant comminution of the lateral wall. The patient was treated with an intramedullary hip screw (IMHS) and was allowed to weight-bear as tolerated immediately. The 3 month postoperative radiograph demonstrates healing in near anatomic alignment

The authors reserve the use of sliding hip screw implants for the treatment of simple intertrochanteric fractures with an intact lateral wall. We find it rare to see this fracture pattern in young patients. For reverse obliquity fracture patterns, or those presenting with compromise of the lateral wall, the authors advocate the use of a cephalomedullary nail. In young patients, we prefer to use a reconstruction type nail with two smaller lag screws locking into the femoral head versus an intramedullary hip screw type implant, which is typically used in older patients (see Fig. 8.2). Reconstruction type cephalomedullary nails have a smaller proximal diameter (allowing less reaming of the abductor insertion), have more variability in terms of nail width, and allow easier insertion of two smaller lag screws into the hard bone of the femoral head in young patients versus the single lag screw used in intramedullary hip screw (IMHS) type nails. Both the biomechanical and clinical advantages of IM nail fixation of these fracture types are supported in the literature [11, 12]. The inappropriate use of SHS type implants in unstable fracture patterns typically leads to significant shortening at the fracture site or implant failure (see Fig. 8.3). Other authors have advocated for the use of a proximal femoral locking plate in these fracture patterns, although high-level evidence supporting their use is lacking and some series report a significant rate of failure with the use of this implant [13].

Subtrochanteric Fractures

These fractures occur in the region between the lesser trochanter and 5 cm distal to the lesser trochanter. They are subject to the deforming forces of the muscles attached to the proximal fragment, primarily the iliopsoas, the abductors, and the short external rotators. These muscle forces result in a predictable displacement of the fracture fragments with flexion, external rotation, and abduction of the proximal fragment. The correction of these deforming forces requires specific reduction maneuvers, including percutaneous clamp or reduction instrument insertion (see Fig. 8.4). The literature supports the use of small incisions to facilitate anatomic reduction, as inadequate reduction of these fractures is a common cause of implant failure and nonunion [14].The authors prefer to use reconstruction type nail devices for subtrochanteric fractures in young patients. The biomechanical and clinical advantages of treating subtrochanteric fractures with nail fixation are supported in the literature [15].

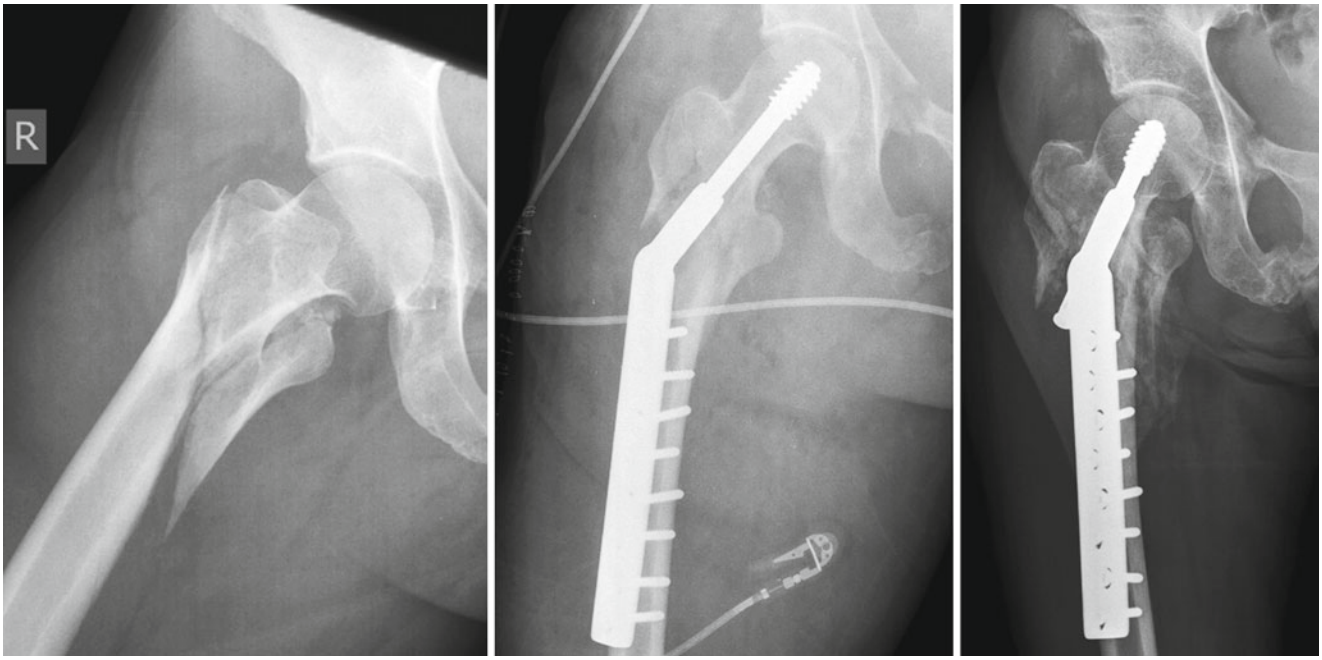

Fig. 8.3 Pre, immediate post-operative, and 3 month post-operative AP radiographs of the right hip in a 48-year-old female trauma patient who sustained a significant fall from height. The pre-operative radiograph demonstrates an unstable intertrochanteric fracture with compromise of the lateral wall and substantial subtrochanteric extension. The patient was treated with a long sliding hip screw device (SHS). The immediate post-operative radiograph demonstrates a relatively satisfactory reduction, however comminution of the lateral wall is evident. The 3 month post-operative film demonstrates that the patient has had significant shortening and medialization of the femoral shaft. This patient had a poor functional outcome

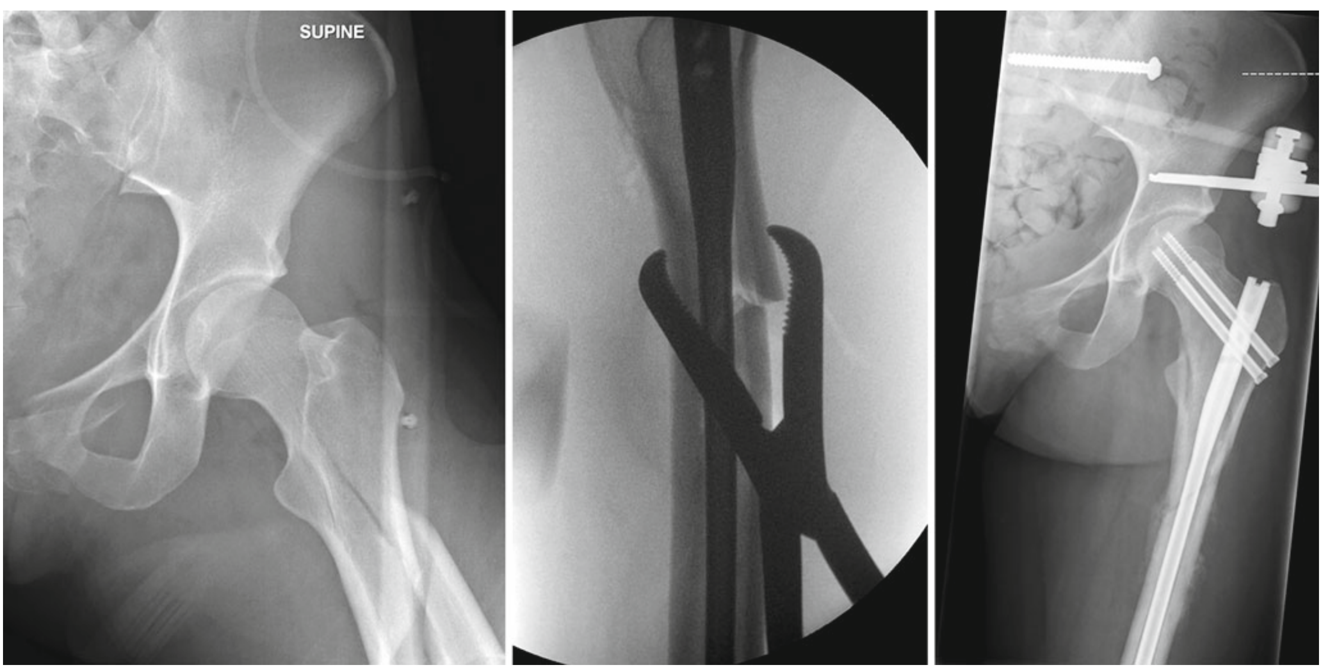

Fig. 8.4 Pre-operative, intra-operative, and post-operative radiographs of the left proximal femur of a 23-year-old female patient who sustained a significant fall from height. The preoperative radiographs demonstrate a subtrochanteric left proximal femur fracture, as well as a lateral compression fracture of the pelvis. The intra-operative radiograph demonstrates the technique for percutaneous clamp reduction of the subtrochanteric fracture. The 6 week postoperative radiograph demonstrates fixation of her subtrochanteric femur fracture with a reconstruction type cephalomedullary nail, with healing in anatomic alignment. She has also had fixation of her pelvic fracture with an anterior external fixation frame and a left sided sacroiliac (SI) screw

Femoral Neck Fractures

Similar to intertrochanteric and subtrochanteric fractures, these injuries occur with high energy trauma and fortunately, are rarely seen in sport. Patients present with hip pain and inability to weight-bear. Physical examination reveals shortening and external rotation of the limb. Radiographic assessment should include radiographs (AP pelvis and AP/lateral hip) as well as computed tomography (CT) scanning of the affected hip. CT scan images help to better define the orientation and location of the fracture, as well as demonstrate any comminution which may affect reduction.

Femoral neck fractures in young patients require urgent reduction and internal fixation, particularly if there is any displacement. Unlike intertrochanteric and subtrochanteric fractures, nonunion and avascular necrosis (AVN) of the femoral head are significant concerns in displaced femoral neck fractures. Both the quality of reduction and time to reduction have an influence on these outcomes [16–18]. Closed reduction is typically attempted on a fracture table with traction and internal rotation. Occasionally the Leadbetter maneuver of hip flexion, traction and adduction followed by internal rotation and extension of the hip back to neutral position is employed. If closed reduction is unsuccessful at obtaining an anatomic reduction, open reduction should be performed. We prefer to use a direct anterior approach (modified Smith-Petersen) to the femoral neck with a separate lateral incision for percutaneous insertion of fixation [19], although a single anterolateral approach has been advocated by some authors [20, 21].Reduction following the surgical approach often requires insertion of joystick Kirschner wires into the femoral head to correct posterior angulation and varus deformity at the fracture site. Occasionally, if there is significant comminution, a mini or small fragment plate can be used along the antero–inferior cortex to help maintain reduction (see Figs. 8.5a, b) [19]. Bone grafting of any bony defects can be carried out using autogenous graft from the iliac crest. Fixation is carried out with three cannulated screws or a sliding hip screw dependent on the fracture configuration and surgeon preference. We prefer to use three screws in an inverted triangle configuration for subcapital and transcervical fractures and a SHS implant in fractures that are more vertical and extend to the base of the neck [22].

Ipsilateral Femoral Neck and Shaft Fractures

Ipsilateral fractures of the femoral neck occur in approximately 10 % of femoral shaft fractures and are associated with high energy trauma. A specific protocol should be followed in order to identify femoral neck fractures in patients with a femoral shaft fracture, including pre-operative dedicated hip radiographs, dedicated CT scanning of the bony pelvis, and intra-operative fluoroscopic assessment of the femoral neck [23].The authors prefer to use two separate implants for the fixation of these two fractures as the literature has shown this approach to result in improved fracture reduction [24]. This typically consists of a retrograde intramedullary nail (RIMN) for the femoral shaft fracture and a SHS or three cannulated screws for the femoral neck fracture (see Figs. 8.6a, b).

Dislocations and Fracture-Dislocations of the Hip

Dislocations and fracture-dislocations of the hip most frequently occur secondary to high-energy MVAs where a posteriorly directed force is applied to a flexed hip (dashboard injury). These injuries have been reported to occur during even sports such as rugby [6], American football [25], soccer [26], and downhill skiing/snowboarding [27]. Anterior dislocation is rare and approximately 90 % of hip dislocations seen are posterior. Patients with a posterior dislocation present with severe hip pain and inability to move the hip, with the leg held in flexion, adduction, internal rotation, and a shortened position. Careful neurological examination is imperative as 10–20 % will present with a sciatic nerve injury, commonly affecting the peroneal division. Radiographic assessment with AP pelvis and AP/lateral views of the affected hip are required, and must be carefully screened for associated fractures of the acetabulum and femoral neck or head. Once a femoral neck fracture is ruled out radiographically, closed reduction under general anesthesia or conscious sedation with deep relaxation should be attempted as soon as possible, as delay to reduction greater than 6 hours has been correlated with an increased risk of developing avascular necrosis [28]. The preferred method for reduction of a posterior dislocation of the hip is in-line traction of the limb with the hip and knee flexed at 90° while an assistant stabilizes the pelvis. External rotation and adduction are gently applied until a palpable reduction of the hip is appreciated. Indications for open reduction include a failed closed reduction and an ipsilateral femoral neck fracture. Open reduction is generally performed via a posterior approach (Kocher-Langenbeck). CT scanning of the hip and pelvis is performed following closed reduction or urgently prior to proceeding with open reduction. CT scan imaging allows for evaluation of associated fractures of the femoral head or acetabulum, intra-articular fragments, and impaction of the acetabulum or femoral head.

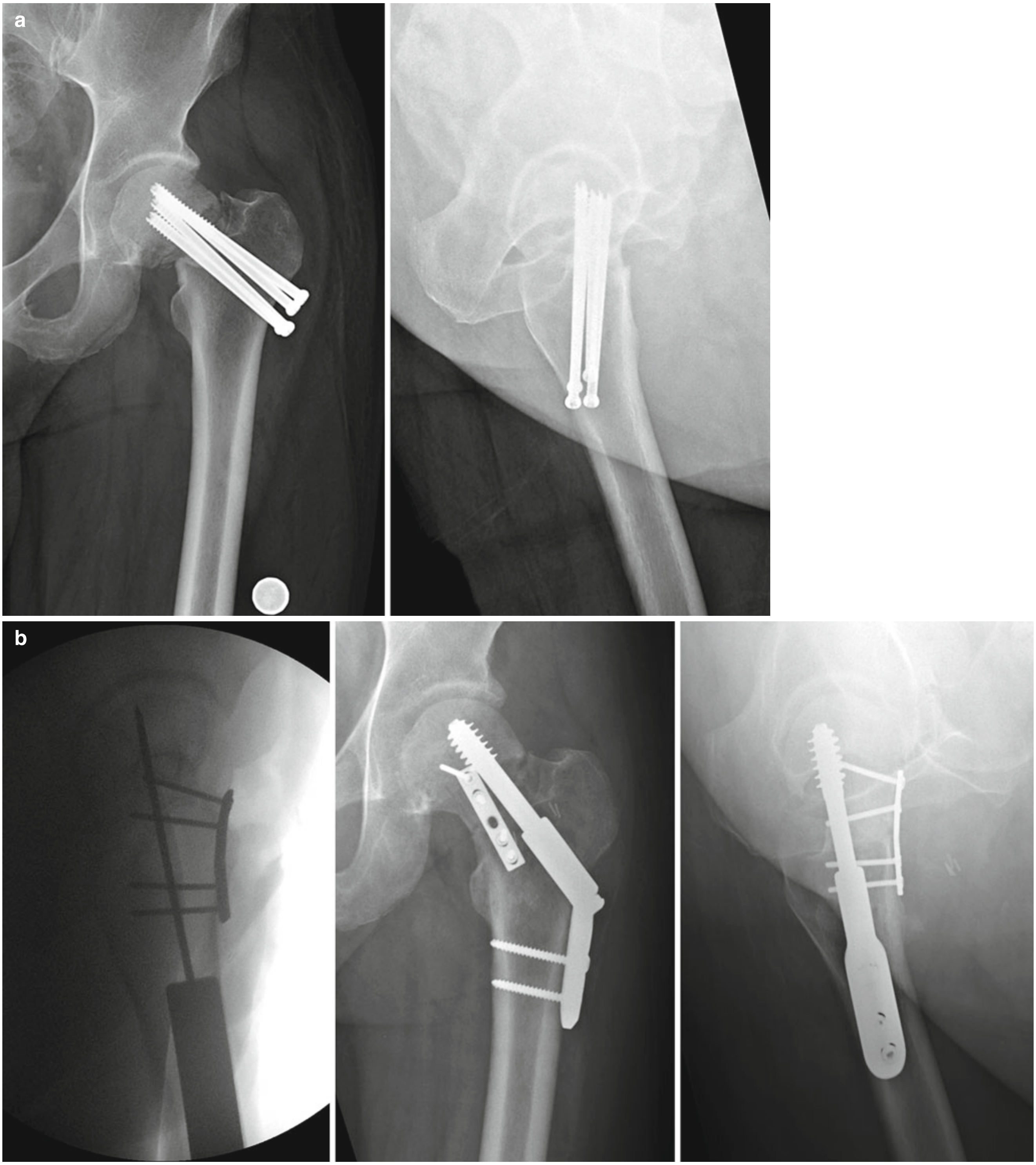

Fig. 8.5 (**a**) One week post-operative radiographs of the left hip of a 48-year-old male physician who sustained a displaced femoral neck fracture while cycling. He was treated with open reduction and cannulated screw fixation via a single anterolateral approach. His radiographs demonstrate early loss of reduction, significant shortening of the fracture, and inadequate fixation. He was referred to our institution for revision fixation. (**b**) Intra-operative and 6 week post-operative radiographs in the same patient demonstrating revision open reduction via an anterior (Modified Smith–Petersen) approach using a mini fragment plate on the antero-inferior aspect of the femoral neck and a 2 hole SHS. Bone grafting of the defect in the femoral head and neck was also performed

Fig. 8.6 (**a**) AP radiographs of the right hip and femur demonstrate ipsilateral fractures of the femoral neck and shaft in a 44 year old male patient who was struck by a car while jogging. Axial CT scan images confirm displacement of the femoral neck. (**b**) Intra-operative and 6 week post-operative radiographs of the right hip and femur demonstrate anatomic reduction, alignment, and healing of the femoral neck and shaft fractures using a sliding hip screw (SHS) and a retrograde intramedullary nail (RIMN)

Arthroscopy

Arthroscopic evaluation of the hip following hip dislocation has been described in the literature, although the indications remain undefined [29, 30]. Arthroscopy allows removal of intra-articular loose bodies and evaluation/repair of the acetabular labrum. Arthroscopic fixation of femoral head fractures has also been described [31].

Posterior Wall Fractures

Fractures of the posterior wall of the acetabulum involving greater than 30 % of the articular surface in young active patients are generally treated operatively, although non-operative treatment following confirmation of hip stability with examination under anesthesia (EUA) has been described, with good early functional and radiographic results [32]. Operative fixation is performed through a posterior approach; using plate and screw fixation (see Figs. 8.7a, b). Mitsionis et al. recently reported on the long-term results of the operative fixation of posterior wall fractures. They reported an excellent or good clinical outcome in 84 % of patients at a mean of 18.5 years post-operatively [33].

Femoral Head Fractures

Fractures of the femoral head can occur in association with traumatic dislocations of the hip and are classified according to the Pipkin classification, which is based on the location of the fracture and associated injuries involving the hip. Type I fractures involve the infra-foveal portion of the femoral head and spare the weight-bearing portion. Type II fractures extend above the fovea and into the weight-bearing portion of the femoral head. Type III and IV fractures constitute fractures of the femoral head combined with a fracture of the femoral neck or acetabulum, respectively. Initial treatment involves prompt closed reduction (except in Type III fractures) followed by CT scan evaluation. Controversy exists with regard to the surgical approach and treatment of these injuries. The authors prefer to manage Type I fractures non-operatively or with surgical excision. Type II and III fractures are managed via a modified Smith-Petersen approach with countersunk, small screw fixation of the femoral head fragment. In the case of Type IV injuries, we use a posterior approach combined with trochanteric flip osteotomy to allow both the femoral head fracture and posterior acetabular wall fracture to be addressed via a single approach [34, 35].

Pelvic Fractures

Fractures of the pelvis typically occur secondary to high energy trauma and patients presenting with such injuries require a careful evaluation to rule out associated injuries to blood vessels, urologic structures, visceral structures, and surrounding soft tissues. Patient assessment should follow Advanced Trauma Life Support (ATLS) guidelines and particular attention should be paid to the hemodynamic status of a patient presenting with a pelvic injury. Patients presenting with hemodynamic instability require prompt stabilization of the pelvis with a pelvic binder or sheet and immediate fluid resuscitation followed by the early administration of blood products if hypotension persists. These patients require multidisciplinary care and prompt referral to a Level I trauma centre is advisable. Further evaluation consists of physical examination to assess for signs of urologic injury (blood at the urethral meatus, scrotal or perineal hematoma, high-riding prostate, gross hematuria), distal neurovascular injury, and any open wounds of the rectum, vaginal wall, or perineum.

All patients suspected of having a pelvic injury should have an AP radiograph of the pelvis performed. Pelvic fractures are most commonly classified according the Young-Burgess classification system which is primarily based on the mechanism of injury. Anterior-Posterior Compression (APC) injuries present with varying degrees of an 'open-book' pelvis on radiographs (see Figs. 8.8a, b). Lateral Compression (LC) injuries occur secondary to a laterally directed force and also present with varying degrees of instability. APC and LC injuries are further subdivided into levels of 1, 2, and 3 (eg. APC-II) based on increasing degrees of instability. The final subtype is the Vertical Shear (VS) injury which presents with vertical migration of the hemipelvis.

Unstable pelvic injuries require surgical stabilization, typically with both anterior and posterior fixation, depending on the pattern and extent of injury (see Figs. 8.8a, b, 8.9a, b).

Avulsion Fractures of the Pelvis and Hip

Avulsion fractures of the pelvis or hip are occasionally seen in adolescents participating in sporting activity without major trauma, typically secondary to a forceful muscle contraction during activities such as running or jumping. These fractures

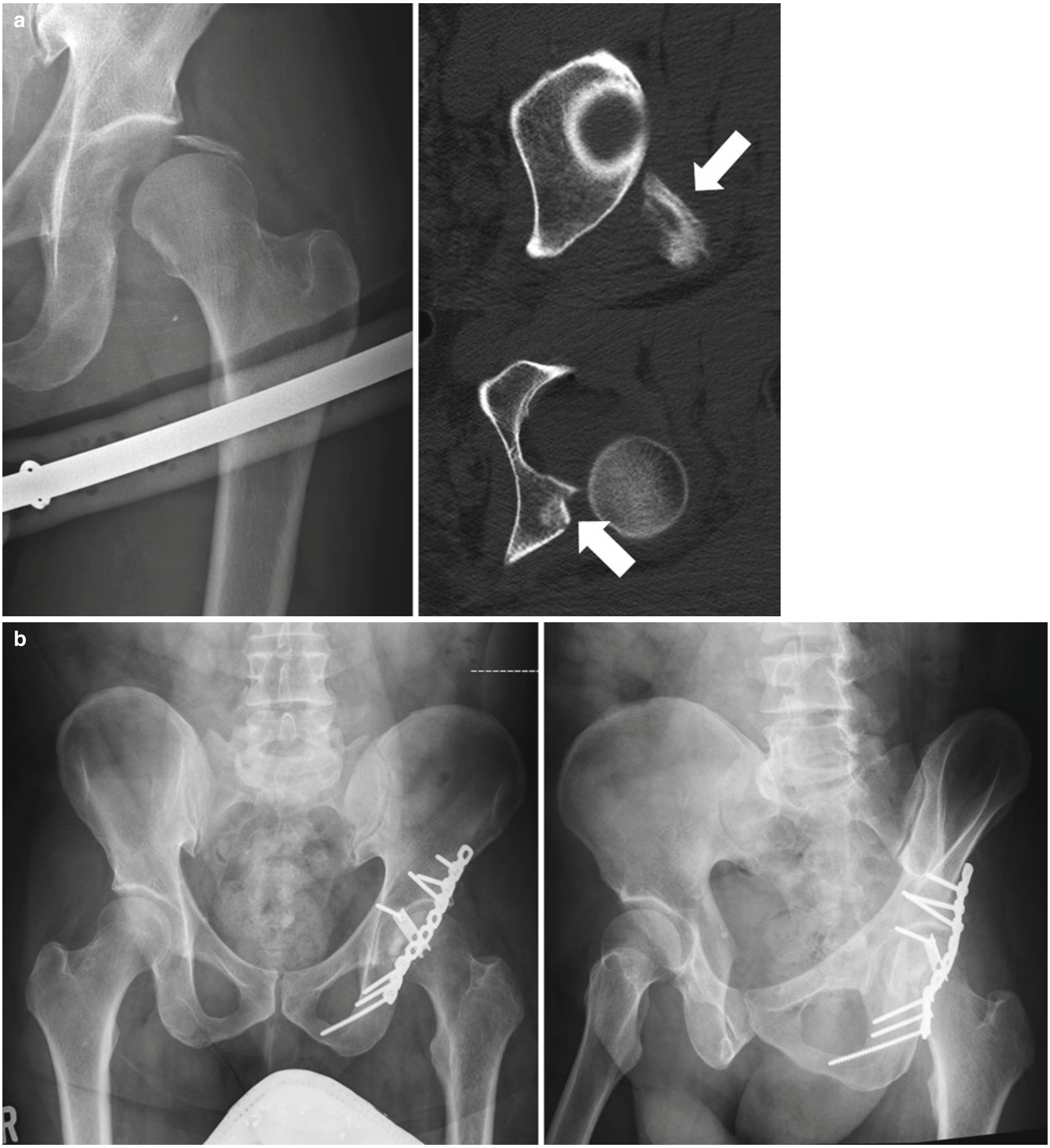

Fig. 8.7 (**a**) Radiographs and axial CT scan images of the left hip in a 41 year old male patient who sustained a fracture dislocation of his hip when he fell off his bike while participating in a triathlon. The radiographs and CT scan were obtained at an outside institution while the hip was still dislocated. *White arrows* indicate the posterior wall fragment and marginal impaction of the posterior acetabular wall. (**b**) Three month post-operative AP and Obturator Oblique radiographs demonstrate open reduction and internal fixation of his posterior wall fracture using a posterior column plate and spring plate. Calcium phosphate cement was used to fill the bone defect left when the marginal impaction was elevated

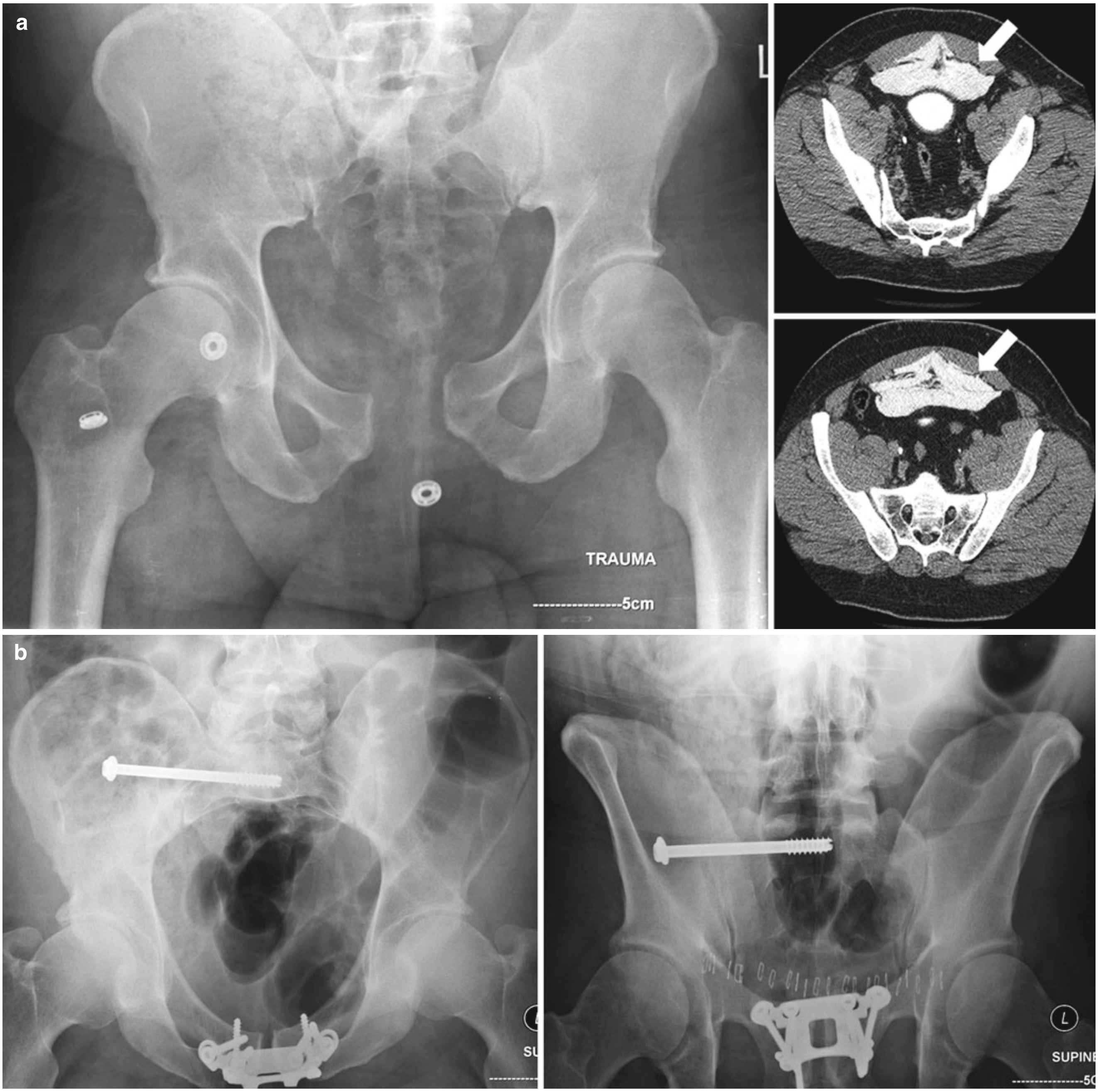

Fig. 8.8 (**a**) Pre-operative AP radiograph and axial CT cystogram images demonstrating an open book pelvic fracture (APC-II) and extra-peritoneal bladder rupture (*white arrows*) in a 49 year old male patient who was bucked off his horse. (**b**) Post-operative inlet and outlet radiographs demonstrating anatomic reduction and fixation with an anterior plate and right-sided sacroiliac (SI) screw. The patient's bladder rupture was treated non-operatively with a Foley catheter for 12 days and subsequent cystogram confirming healing of the bladder injury

occur at sites of secondary ossification (apophyses), which is why they are seen in adolescent athletes. Sites of involvement include the Anterior Superior Iliac Spine (ASIS), the Ischial Tuberosity, the Anterior Inferior Iliac Spine (AIIS), the Iliac crest, and the Lesser and Greater Trochanters. The diagnosis is suspected on history and physical examination and confirmed with radiography, or occasionally CT or Magnetic Resonance Imaging (MRI). Once one of these injuries is diagnosed, urgent referral to an orthopaedic surgeon is required. Non-operative treatment of these injuries has been described with generally good results [36]. Indications for surgical intervention include significant displacement of

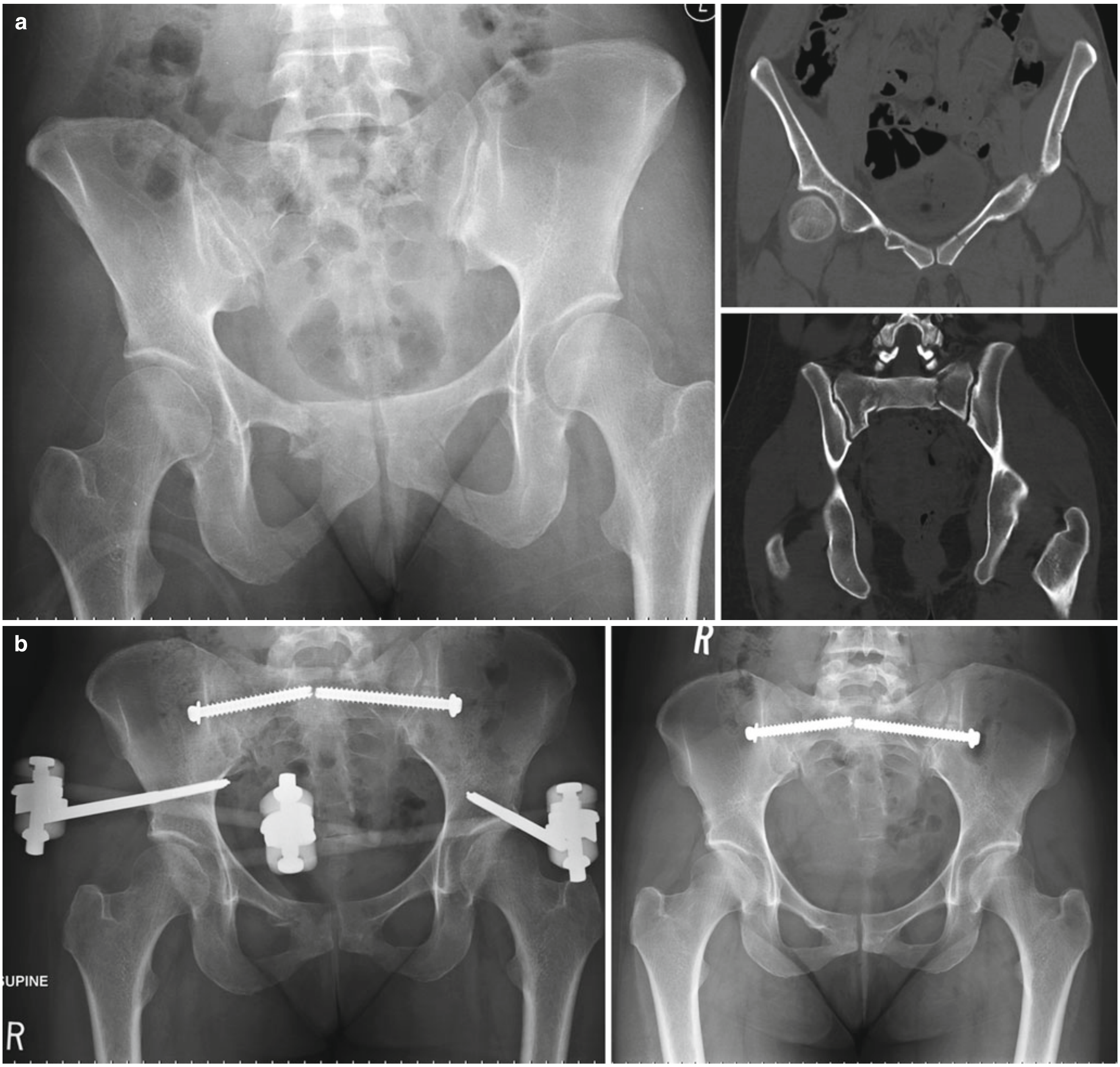

Fig. 8.9 (**a**) Pre-operative AP radiograph and coronal CT images demonstrating bilateral sacral fractures and bilateral superior and inferior pubic rami fractures in a 33 year old female patient who fell approximately 15 m while rock climbing in South America. She was transferred to our hospital 10 days after her injury and had been unable to mobilize due to pain and instability in her pelvis. Comparison with her original injury films demonstrated that her left hemipelvis had already migrated several millimeters superiorly, therefore operative intervention was recommended. (**b**) Six week and 1 year post-operative AP radiographs demonstrating initial stabilization with bilateral sacroiliac (SI) screws and an anterior external fixator (with pins placed in the Anterior Inferior Iliac Spine [AIIS]) and full healing in anatomic alignment at 1 year

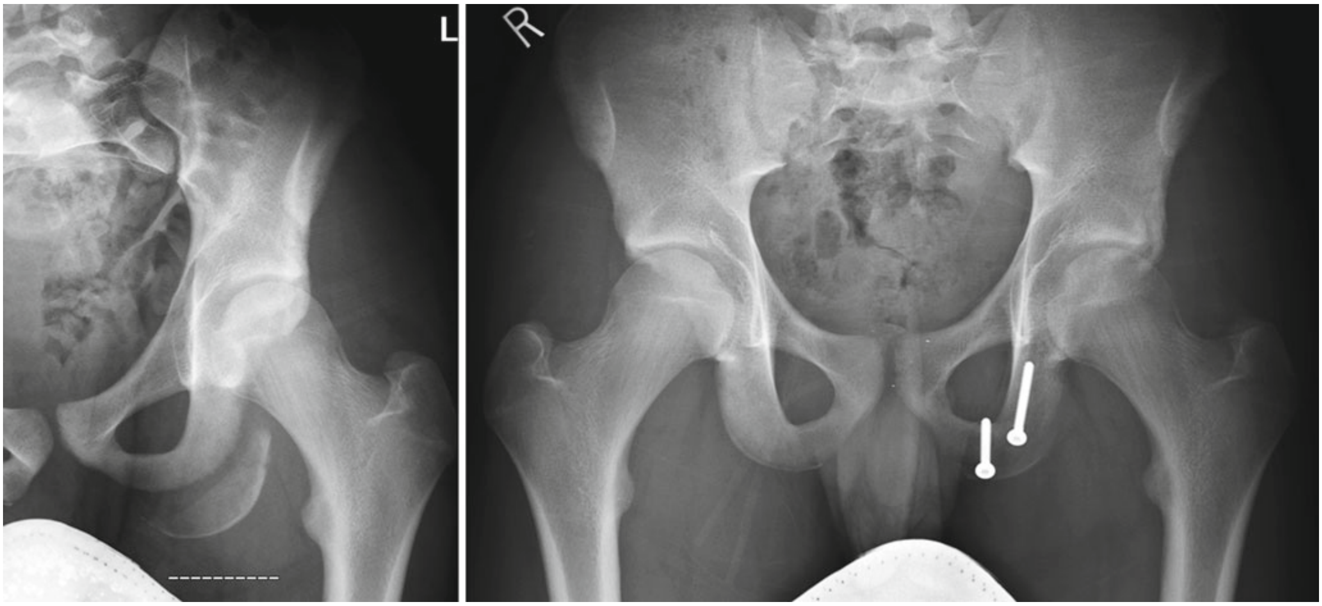

Fig. 8.10 Pre-operative and 6 week post-operative radiographs of the pelvis in a 16 year old competitive track athlete who sustained a displaced ischial tuberosity avulsion fracture. The pre-operative radiograph demonstrates significant (>2 cm) displacement of the fragment. Open reduction and internal fixation was carried out using two screws

the fragment greater than 1–2 cm (see Fig. 8.10) and nerve entrapment causing neurologic symptoms [37–39].

Conclusion

Fortunately, fractures of the hip and pelvis are rarely seen in sporting activities. However, they can be seen in association with high energy sporting activities and an understanding of these injuries and their management is beneficial. Due to their high energy, these fractures often present with associated injuries that can potentially be life threatening. Emergent referral to an orthopaedic surgeon or trauma center is mandatory if one of these injuries is diagnosed or suspected. The prompt recognition and treatment of these injuries can lead to good outcomes in the majority of cases when seen in the young, athletic population.

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9 Sports Specific Injuries of the Hip Joint

Travis Maak, Peter Fabricant, and Bryan T. Kelly

Introduction

Athletes represent a particularly challenging population with a globally increased injury risk relative to other more sedentary patients. The main categories of hip injuries in this population include: intra-articular hip injuries due to femoroacetabular impingement (FAI), hip subluxations and dislocations; soft tissue extra-articular injuries including muscle strains, tears, and contusions; overuse injuries including stress fractures and abductor failure; and snapping hip syndromes including internal and external coxa saltans. Hip instability in the hypermobile athlete represents a unique subset of hip injuries that can span the spectrum of underlying pathology from generalized ligamentous laxity to frank bony dysplasia. Hip injuries in the paediatric athlete also can represent a unique group of patients. Sports related injuries that are unique to the immature hip include apophyseal avulsion injuries, and "developmental" forms of impingement secondary to slipped capital femoral epiphyses (SCFE) and Perthes disease.

FAI has been increasingly recognized as a possible precursor to hip osteoarthritis as well as a contributor to intra-articular soft tissue injury. Contact athletes are at increased risk for FAI-related labral injury due to the increased impacts, loads, and rotational forces that are transmitted to the hip joint [1]. Hip subluxations and dislocations have been previously documented and may represent an often unrecognized cause of persistent groin pain [2, 3]. Musculotendinous strains and direct contusions are particularly frequent in this population, specifically during the early training portion of the season [4, 5]. Athletic pubalgia (also known as "Sports Hernias") are frequently related to chronic tendinopathy of the adductor and rectus abdominis tendons at their respective origin and insertions on the pubis. There has been an increased awareness of the co-existence of mechanical derangement within the hip (such as FAI) and soft-tissue overload such as adductor and rectus abdominis injury (traditional athletic pubalgia), proximal hamstring injury, hip flexor and psoas injury, and abductor injury. Feeley et al. [6] described the "sports hip triad" comprising a labral tear, adductor strain and rectus strain and attributed this pathologic combination to the increased axial and rotational loads that occur during high impact athletics.

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Femoroacetabular Impingement: Basic Principles

Femoroacetabular impingement (FAI) of the hip joint is a well documented phenomenon caused by a mismatch between the shape of the femoral head and the acetabulum leading to an abnormal dynamic abutment of the femoral head against the edge of the acetabulum. Femoral sided impingement, traditionally called cam impingement is caused by a loss of the normal sphericity of the femoral head, and leads to and "inclusion" pattern of injury to the joint primarily affecting the transition zone acetabular cartilage (Fig. 9.1a, b). These entities have been associated with injuries including labral tears, chondral delamination, and osteoarthrosis [7–10]. The young, male athlete represents the most common presentation for cam-type impingement [11, 12]. This impingement occurs with flexion and internal rotation of the hip joint, which forces the prominent femoral head-neck junction into contact with the anterolateral aspect of the acetabular chondrolabral junction. Repeated impingement in this fashion results in increased shear and direct inclusion forces leading to primary chondrolabral separation and, in more advanced phases, chondral delamination [13].

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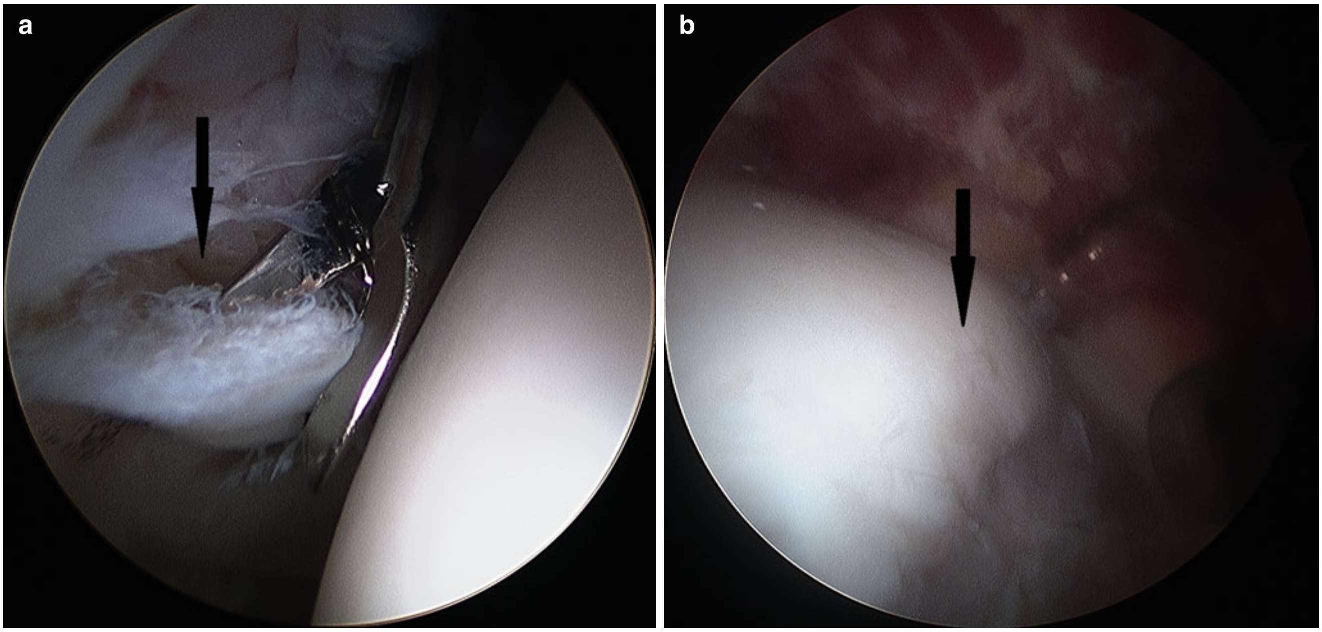

Fig. 9.1 (**a**, **b**) CAM sided "Inclusion injury pattern". (**a**) Primary injury is from the cam lesion entering the joint and leading to primary injury to the transition zone cartilage with debonding of the junction between the labral base and the transition zone (*arrow*). (**b**) Arthroscopic view of the peripheral compartment demonstrating the cam deformity (*arrow*)

Rim impingement, traditionally called "pincer" impingement, is caused by acetabular over-coverage secondary to focal over-coverage, true acetabular retroversion, of circumferential over-coverage due to profunda or protrusion deformity [7]. In contrast to cam impingement, rim impingement usually presents in the middle-aged female athlete [11, 12]. Rim impingement occurs due to increased anterolateral acetabular overcoverage that leads to a similar reduction in functional hip flexion arc and subsequent impingement on the anterolateral femoral head-neck junction [11, 12]. Direct impaction trauma to the anterior labrum leads to crushing of the acetabular labrum and subsequent posterior shearing of the femoral head leading to posteroinferior acetabular cartilage injury [11, 12] (Fig. 9.2). Additionally, a combination of mixed cam and pincer-type impingement may occur and may be the commonest type of impingement [11].

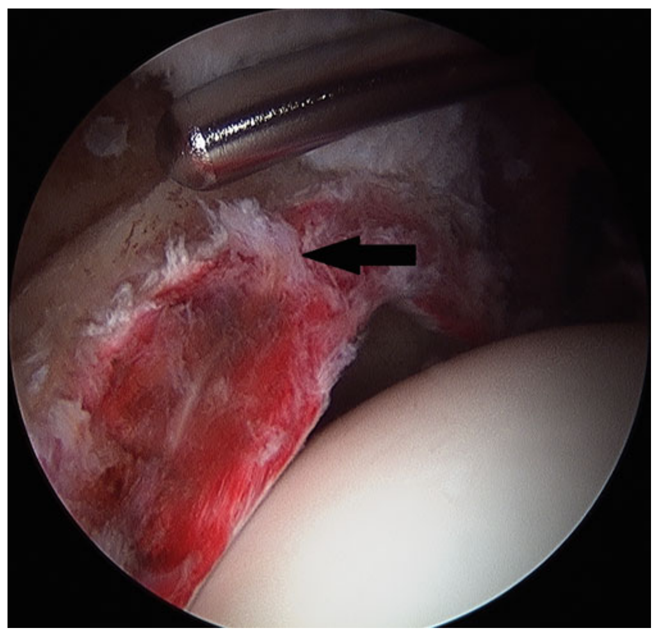

Fig. 9.2 Rim sided "Impaction injury pattern". Rim impingement leads to a primary crushing injury to the labrum secondary to focal or global over-coverage of the acetabular rim. This leads to capsular sided erythema and injury to the labrum (*arrow*)

Femoroacetabular Impingement: Assessment

Careful assessment of the patient history, physical examination and focused diagnostic evaluation is crucial to guide management decisions and optimize treatment outcomes. The typical history that is consistent with femoroacetabular impingement includes groin pain, specifically with hip hyperflexion and prolonged periods of sitting [11]. Initially, pain may be episodic and progress to a more constant presentation [12]. The pain severity can range from mild to severe; however, moderate to severe groin pain has been documented in up to 86 % of patients with FAI [14]. Functional activities of the hip may exacerbate or precipitate the groin pain, including standing from a sitting position, climbing stairs, extensive ambulation, or athletic participation [11, 12, 15, 16].

Mechanical symptoms may also exist including clicking, popping, and catching with hip motion. This complaint is particularly important and may indicate the presence of a labral tear, especially in the athlete with groin pain and normal plain radiographs [14, 17, 18].

The physical examination should begin with complete evaluation of the lumbosacral spine, hips, knees, and ankles as well as lower extremity alignment. Range of motion, strength, and stability should be tested for each joint and compared to the contralateral, asymptomatic extremity. Care should be taken to discriminate between lumbosacral and hip pathology as these can often co-exist. Particular attention should be placed on limited hip internal rotation with the hip flexed to 90°. The traditional impingement test (reproduction of pain with flexion to 90°, hip internal rotation, and adduction) is the commonest positive examination finding in the setting of traditional FAI [19]. Other provocative pain tests that should be looked at include superolateral impingement (pain with flexion and external rotation) and lateral rim impingement (pain with straight abduction). Extra-articular impingement may exist if there is abnormal contact between the greater trochanter and pelvis. Impingement induced instability may occur if premature anterior or posterior impingement results in subluxation of the hip and should be carefully tested for on examination as well.

Diagnostic evaluation for FAI should include plain anteroposterior (AP) and lateral radiographs of the lumbar spine, an AP pelvis radiograph and an elongated neck (Dunn) view of the affected hip [20]. These radiographs allow evaluation of acetabular version as well as identification of the crossover sign, in which the superolateral border of the anterior wall of the acetabulum can be seen intersecting or "crossing over" the inferomedial border of the posterior wall [21] (Fig. 9.3a). This sign suggests a degree of retroversion and increased risk of impingement. The Dunn view provides an excellent evaluation of the femoral head-neck geometry and identification of the cam-type lesion (Fig. 9.3b). An alpha angle should also be calculated on this view [22]. This measurement of potential cam-type impingement is calculated by determining the angle that is created by a line from the center of rotation of the femoral head to the anterior head-neck junction and a second line drawn from the center of rotation of the femoral head parallel to the femoral neck. An alpha angle greater than 55° suggests an increased risk of cam-type FAI [22]. The traditional Dunn view provides an assessment of the anterolateral neck of the femur at the 3 o'clock position, so may underestimate the size of the cam lesion if it is present in the commoner superolateral position (1:30). Due to this fact, 3-dimensional Computed Tomography (CT) allows for more complete analysis of the size, location and volume of the non-spherical portion of the femoral head. More advanced dynamic imaging or post processing dynamic analysis will likely lead to increasingly accurate pre-operative assessment and treatment plans in the future.

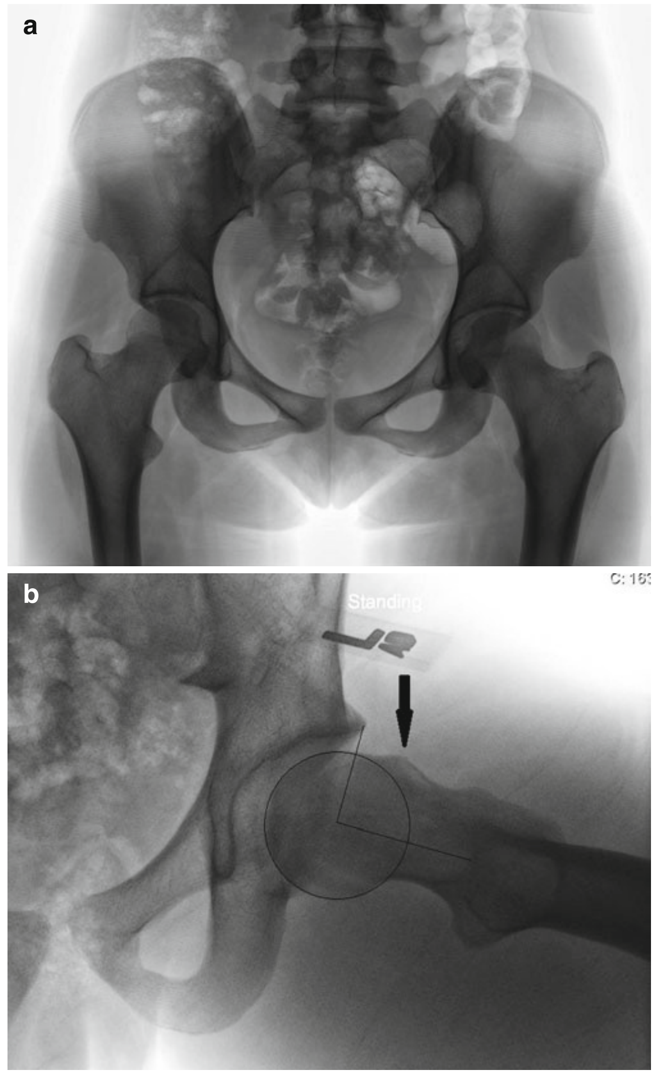

Fig. 9.3 (**a**) A properly performed AP Pelvis should have the coccyx pointed toward the center of the pubis with approximately 2–4 cm of distance between the tip of the coccyx and the pubic cleft. (**b**) Dunn lateral radiograph can clearly demonstrate the cam deformity (*arrow*). The size of the cam deformity can be estimated by measuring the alpha angle as depicted in the figure

Magnetic resonance imaging (MRI) or MR Arthrography of the affected hip will allow accurate delineation of the periarticular soft tissue structures including the femoral and acetabular chondral surface, labrum, capsule, and surrounding extra-articular tendinous insertions. The alpha angle can also be calculated using MRI axial cross-sections of the hip, best seen using radial sequencing techniques. Finally, the current authors have utilized a fluoroscopically guided intra-articular analgesic and steroid injection as both a diagnostic and therapeutic tool in the setting of the aforementioned history and physical examination. This diagnostic tool can prove extremely effective in differentiating between lumbosacral and periarticular hip pathology.

Femoroacetabular Impingement: Treatment Guidelines

Non-operative management of FAI includes oral non-steroidal anti-inflammatory medications (NSAIDs), physical therapy, and intra-articular analgesic/steroid injections. As previously mentioned, these injections may also serve as an important component of the diagnostic algorithm. Therapy should focus on trunk and hip musculature. Notably, the current authors have found non-operative management to be specifically effective in the setting of vague hip complaints in the absence of mechanical symptoms and an equivocal response to intra-articular injection. Unfortunately, non-operative management is frequently ineffective in the setting of identifiable pathology since the commonest patients with FAI are young and active and have pathology of mechanical nature [12]. In fact, physical therapy may exacerbate symptoms especially if hip hyperflexion maneuvers are utilized. Fortunately, surgical management has been particularly effective in the setting of focal groin pain, mechanical symptoms including popping and catching, radiographic evidence of a cam, pincer, or mixed-type impingement and significant symptomatic relief from intra-articular injection.

Operative treatment includes acetabuloplasty and femoral head osteoplasty, chondroplasty, labral resection and repair through both open and arthroscopic approaches. Open surgical dislocation of the hip for treatment of FAI was originally described by Ganz et al. [23]. This approach utilizes careful dissection and use of a greater trochanteric osteotomy to preserve the insertion of the vastus lateralis, hip abductors and external rotators as well as careful identification and protection of the femoral head vasculature through the deep branch of the medial femoral circumflex artery. Potential osteonecrosis of the femoral head has been documented in fewer than 1 in 1,000 cases following this approach [24]. When the approach has been accomplished with full dislocation of the femoral head from the acetabulum, all intra-articular pathology can be addressed including femoral head-neck osteoplasty, acetabuloplasty, and chondrolabral repair or debridement. Careful capsular repair should be ensured to minimize the risk of post-operative dislocation.

Arthroscopic treatment of FAI has become increasingly utilized due to the minimally invasive approach and excellent visualization that is provided by advances in current instrumentation and surgical technique. The current authors perform the arthroscopic approach with the patient in the supine position on a traction table. Both the operative extremity and contralateral limb are placed in an extended position utilizing a well padded perineal post and ankle boots to minimize iatrogenic soft tissue injury. Traction is applied to the operative leg utilizing gentle axial distraction, followed by adduction, and neutral flexion. Axial traction can be minimized by taking advantage of the levering effect of the perineal post which is approximately 12 in. in diameter. Internal rotation at the level of the ankle joint is employed in the setting of increased femoral anteversion. With femoral version less than 5°, the leg should be maintained in neutral rotation to reduce the effect of the greater trochanter blocking entry into the joint. Both traction time and force should be minimized as much as possible, as the greatest risk for iatrogenic post-operative pain is likely secondary to excessive traction time or duration. We try to limit traction to less than 60 min. If it is going to be longer than 90 min, then temporary release followed by re-application should be considered. A standard three-portal technique is employed and rim impingement and chondrolabral pathology is addressed. The current authors utilize an arthroscopic scalpel to create a sharp peri-labral capsulotomy which connects the anterior and anterolateral portals. Treatment of the rim and labral pathology depends upon the specific mechanical deformity and intra-operative damage pattern. The general principles require adequate resection of the excessive rim lesion along the circumference of the acetabulum, followed by refixation of the labrum in areas where it is unstable. This can be accomplished by primary detachment of the labrum followed by bony resection and labral refixation. An alternative, and preferred technique, is resection of the acetabular rim lesion without detachment of the labrum, followed by refixation if areas of labral instability are present at the completion of the bone resection. Characteristic cam impingement will create anterolateral chondrolabral injury. Variation in the location of the cam lesion may shift the location of this injury either anterior or lateral. Consideration should be given to microfracture or chondroplasty if grade IV lesions are identified. Unstable chondral flaps should be excised. The current authors' recommend an excision limited only to unstable chondral lesions with a focus on chondral preservation. Early grade chondral injury including softening and blistering may also be identified but in the current authors' opinion this should be preserved and should not be debrided.

After the central compartment pathology is appropriately addressed, the surgeon should remove traction, flex the operative hip to approximately 35–40°, and redirect the arthroscope into the peripheral compartment. In some cases the cam lesion can be decompressed without additional capsular cuts by retracting the capsule away from areas of impingement. In other cases the size and/or location of the impingement and additional capsular cuts can assist in visualization, assuring a complete decompression. The T-capsulotomy is made by finding the interval separating the medial and lateral limbs of the iliofemoral ligament and extending the cut down the neck of the femur at the 2 o'clock position carefully separating the iliocapsularis insertion onto the medial capsule from the gluteus minimus insertion on the lateral limb (Fig. 9.4a, b). The peripheral compartment should be fully evaluated prior to initiation of femoral head-neck osteoplasty. Careful arthroscopic

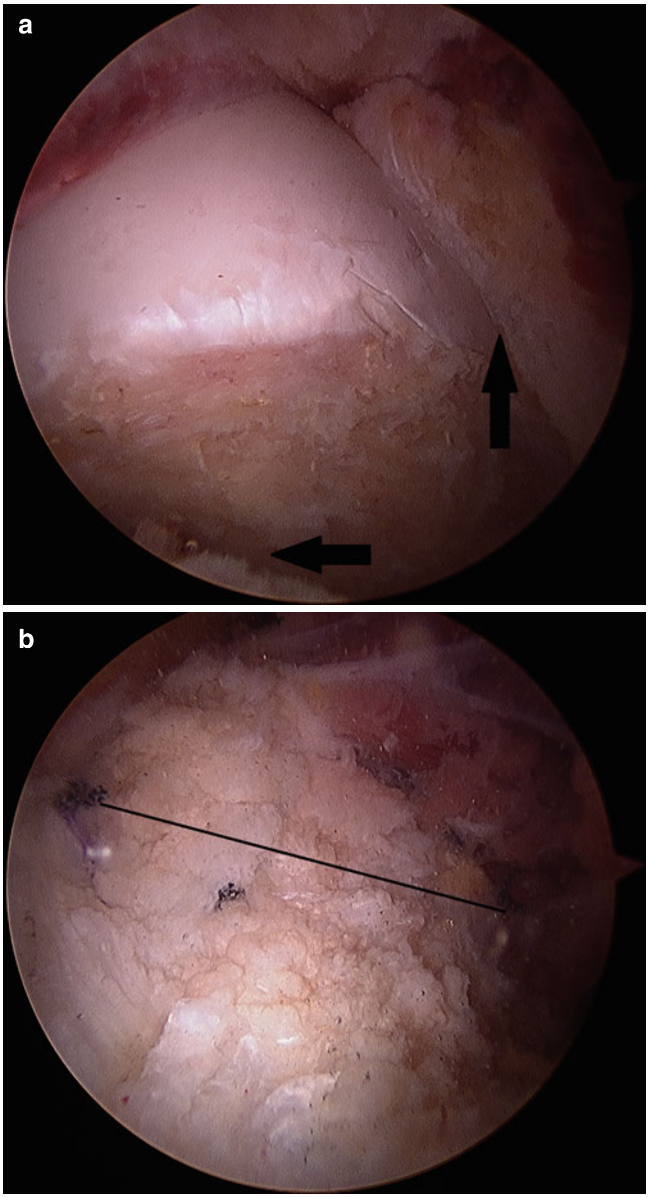

Fig. 9.4 (**a**, **b**) Clear visualization is critical for performing an adequate femoroplasty. A T-capsule cut can be performed to allow for complete visualization of the femoral sided deformity (*arrows* – **a**) while simultaneously maintaining careful protection of the capsular tissue for subsequent repair (*line* – **b**)

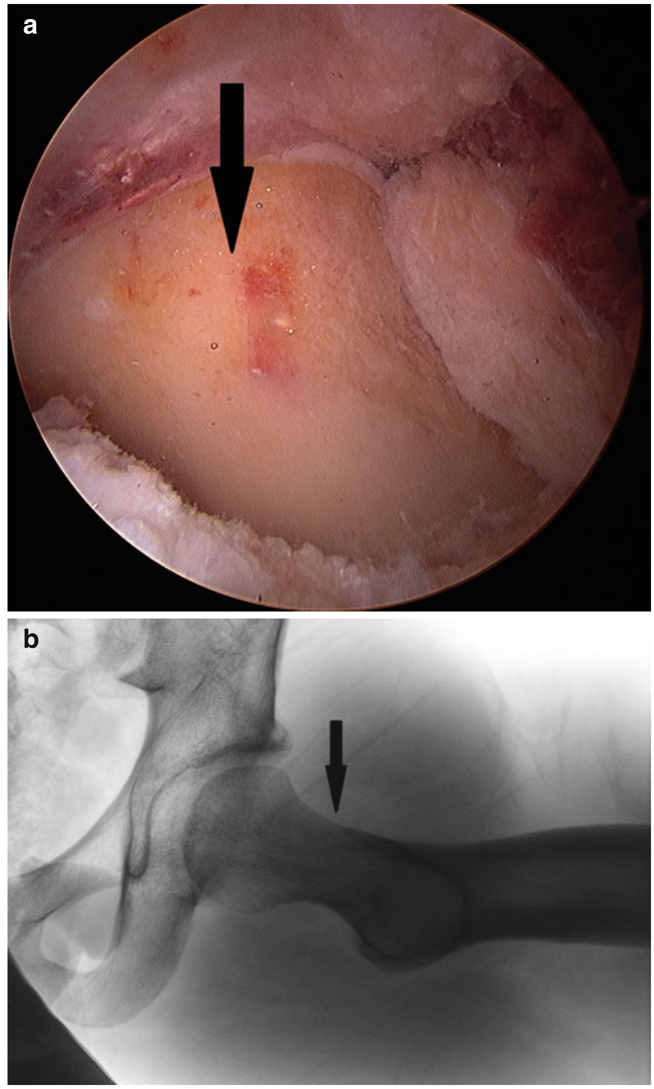

Fig. 9.5 (**a**) Arthroscopic view of a femoral sided decompression (*arrow*). (**b**) Dunn lateral view of a femoral sided decompression (*arrow*)

visualization of the cam-type impingement with passive flexion and internal rotation of the hip will provide a crucial understanding of the area and depth of osteoplasty that is necessary to sufficiently address the impingement lesion. A spherical burr is then utilized beginning at the articular head-neck junction to delineate the desired depth and length of resection. This depth should then be maintained and tapered along the femoral neck to create a smooth contour and restoration of normal anatomy (Fig. 9.5a). Fluoroscopy can be used to evaluate the relative depth of the resection, which should not extend beyond 25 % of the neck diameter (Fig. 9.5b). The retinacular vessels should be preserved at the margin of the resection and can be easily identified at the lateral synovial fold. The peripheral compartment should be extensively irrigated upon completion of the femoral head-neck osteoplasty to reduce the risk of post-operative heterotrophic ossification. At least the T-cut extension of the apsulotomy should be repaired at the completion of the decompression, and in cases of potential collagen laxity, the interportal cut should be repaired as well.

Several studies have documented excellent results following arthroscopic management of FAI [25–27]. Early data suggested that labral and acetabular rim resection produced improved results, as compared to labral resection alone [25]. Recent studies, however, have suggested that labral preservation and acetabular rim debridement may provide superior results [26]. This is the preferred method of the current authors as detailed previously. Notably, identification of associated pathology is crucial to optimize results and minimize iatrogenic injury. Care should be placed on evaluation of acetabular bony morphology, specifically acetabular dysplasia. Acetabular rim osteoplasty and labral debridement has been associated with significant iatrogenic injury in patients with acetabular dysplasia in which the labral function is crucial for hip stability and should therefore be avoided [28, 29].

Femoroacetabular Impingement: Rehabilitation and Return to Play

Focused rehabilitation following open or arthroscopic treatment of FAI will improve postoperative range of motion, strength, pain and optimize athletic return to play. This rehabilitation regimen should begin immediately following surgical management. The patient should maintain a 20 lb foot-flat weight-bearing status with crutch assistance for the first 2 weeks postoperatively following a femoral head-neck osteoplasty or 6 weeks if a chondral repair including microfracture is performed. Non-weight-bearing status has been associated with increased intra-articular hip forces and should be avoided. Isolated acetabuloplasty may initiate weight-bearing as tolerated immediately postoperatively. Despite these weight-bearing restrictions, active and passive hip range of motion should be conducted to maintain hip motion and limit postoperative stiffness. Athletic return to play is closely dependent upon the required intervention and may range from as early as 1 month post-operatively for an isolated labral debridement to up to 4–6 months in the setting of microfracture. Contact athletes should be restricted from impact activities for 4 months to allow completion of osseous remodeling, especially following femoral head-neck osteoplasty.

Subluxations and Dislocations: Basic Principles

Posterior hip subluxation or dislocation is extremely uncommon relative to the prevalence of shoulder and knee dislocations in the athlete. This injury has been previously described in professional athletics including football, rugby and soccer [2, 30, 31]. Prior data from professional football athletes documented a 28 % prevalence of hip dislocations or subluxations among all intra-articular hip injuries identified [6]. These subluxation/dislocation events resulted in the greatest amount of time removed from athletic participation. Other data from the National Football League (NFL) documented two cases of severe osteonecrosis of the hip that required subsequent total hip arthroplasty [2]. Given the significant sequelae that may occur with this specific hip injury, high suspicion should be maintained to ensure that this rare but significant injury is appropriately recognized.

Subluxations and Dislocations: Assessment

The typical presentation for an athlete that sustains a posterior hip subluxation or dislocation is a history of falling on or traumatically impacting a flexed, adducted hip [2]. Nevertheless, atraumatic hip subluxations have been described previously and should be considered [32]. In this setting, prior authors have suggested predisposing factors to hip instability including capsular redundancy or abnormal osseous hip anatomy [32, 33]. The patient history may include complaints of limited, painful hip motion in the presence or absence of resting hip pain. Unfortunately, these complaints typically localize to the groin region and may be misinterpreted as a muscle strain [32, 33]. Physical examination may be significant in the presence of an unreduced hip dislocation such that the patient will maintain a flexed, adducted and internally rotated hip that has limited passive or active motion. In this setting, immediate plain AP and lateral radiographs will confirm this diagnosis. A spontaneously reduced subluxation or dislocation, however, presents a more difficult diagnosis. This presentation may commonly maintain hip range of motion limited only by pain at the extremes. Manual muscle strength testing and a complete neurovascular examination should also be performed to identify any potential injury to the sciatic nerve.

Radiographic evaluation includes an AP pelvis and cross-table lateral of the affected hip. Oblique (Judet) plain radiographs of the pelvis may also identify concomitant posterior acetabular wall fractures in the setting of complete dislocation. If the hip is appropriately reduced, MRI should be obtained to identify chondrolabral or iliofemoral ligament injury, haemarthrosis, and retained intra-articular fragments [31, 32, 34]. In addition, acetabular fractures may be identified. Prior experience of the senior author (B.T.K.) has identified a common association between posterior hip subluxation or dislocation and anterior labral tears [6]. This injury may be due to an impact between a cam lesion and anterior acetabulum during posterior femoral head displacement [6] (Fig. 9.6).

Subluxations and Dislocations: Treatment Guidelines

Appropriate management of a posterior hip subluxation or dislocation should be specifically tailored to the aforementioned associated pathology. Clinically significant chondrolabral injury or intra-articular loose bodies can be effectively managed with hip arthroscopy as described in the previous section entitled ‘FAI treatment guidelines’ [33]. In the authors’ opinion, hip arthroscopy should be performed greater than 6 weeks following injury to minimize the risk of intrabdominal fluid extravasation due to possible capsular and acetabular injury. Additionally, the hip MRI may be repeated at the 6-week time point to identify early femoral head osteonecrosis and thereby

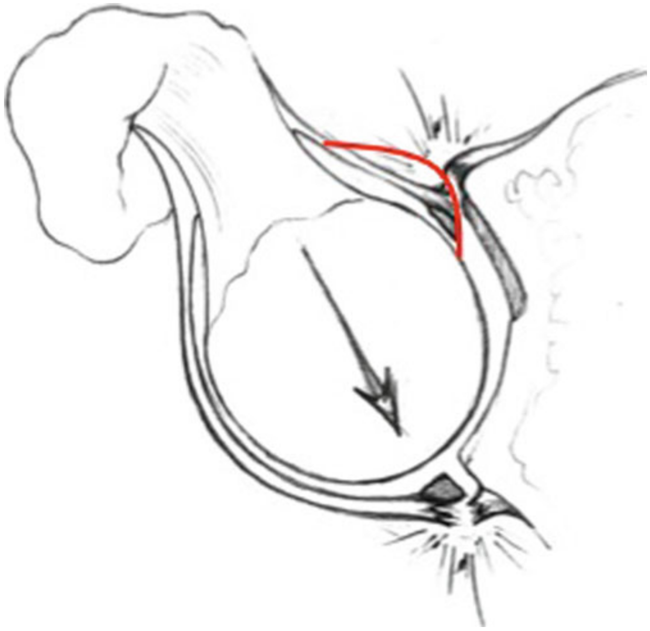

Fig. 9.6 Proposed mechanism of FAI induced instability. The anterior cam lesion leads to premature contact between the cam deformity and the anterior acetabular rim leading to limitation in hip flexion and internal rotation. With continued motion beyond the anatomic limit of the impinging hip, the femoral head will sublux or dislocate posteriorly

reduce the potential of exacerbating this pathology with applied traction during arthroscopy. Nevertheless, clinical and MRI evidence of an intra-articular loose body may be appropriately managed with acute hip arthroscopy to reduce the potential for post-traumatic hip arthritis [2, 6, 31–33]. Clinical and radiographic evidence of haemarthrosis should be acutely managed with intra-articular aspiration, toe-touch weight-bearing for 4–6 weeks, and limited hip motion [6, 32, 33]. Prior data regarding these methods of management documented a 66 % return to play at a pre-injury level of competition [2].

Subluxations and Dislocations: Rehabilitation and Return to Play

Rehabilitation following hip subluxation or dislocation is a critical component of the management algorithm. Given the requisite high energy to produce this injury, careful progression with protected weight-bearing and close clinical observation should be implemented. Rehabilitation guidelines should be tailored to the specific pathology and treatment. Chondrolabral injury and repair should maintain a rehabilitation regimen as detailed in the rehabilitation portion of the FAI section of this chapter. Additionally, patients in whom hip subluxation or dislocation is suspected should be maintained with protected toe-touch weight-bearing for 6 weeks at which time a follow-up MRI should be obtained to evaluate the potential for femoral head osteonecrosis. If this pathology is identified, the patient should maintain toe-touch weightbearing for an additional 6 weeks. If no evidence of osteonecrosis is present on the 6 week follow-up MRI, weight-bearing may be progressed as tolerated by the patient. Individuals typically return to athletic participation and full activity at approximately 3–4 months following injury.

Muscle Strains, Ruptures, and Contusions: Basic Principles

Muscle strains and contusions account for the majority of injuries that occur in the contact athlete [6]. Prior data has suggested that these injuries occur during activities including sprinting, rapid directional change and direct impact [6]. This study of professional football players in the NFL documented the greatest number (63 %) of muscle strains in the hip flexors, which resulted in a mean 8.9 days of inactivity per injury. While strains involving the hip external rotators and proximal hamstrings were less frequent, these injuries resulted in a significant increase in inactivity. In addition, muscle strains sustained while kicking resulted in a significantly prolonged period of inactivity (mean 37.8 days), as compared to other injuries. Data obtained from professional hockey players identified a high prevalence of adductor muscle strains while hip flexor strains were less frequent [35]. These authors suggested a potential contribution of poor preseason hip adductor strength as injured players had an 18 % lower strength level than uninjured players. Arnason et al. [36] evaluated professional soccer players and identified a history of groin strain or limited hip abduction as potential risk factors for hip muscle strains.

Similar to muscle strains, muscle contusions are extremely common. Fortunately, this injury resulted in a rapid return to play and only a mean 5.3 days of inactivity in professional football players. Muscle contusions are commonly sustained during contact and accounted for 53 % of contact injuries in one study, as compared to 2 % prevalence in non-contact injuries.

Muscle Strains and Contusions: Assessment

The patient history is a significant contributor to the assessment of an athlete with a potential muscle strain or contusion. The athlete may often recall the circumstance of impact in the setting of a contusion and rapid acceleration change or in direction in the case of a potential muscle strain. This history typically accompanies a clear description and localization of the pain and exacerbating movements. The physical examination begins with palpation of the identified region including the area of maximal tenderness as well as the specific enthesis. Careful palpation of proximal and distal tendon attachments of the injured muscle should also be

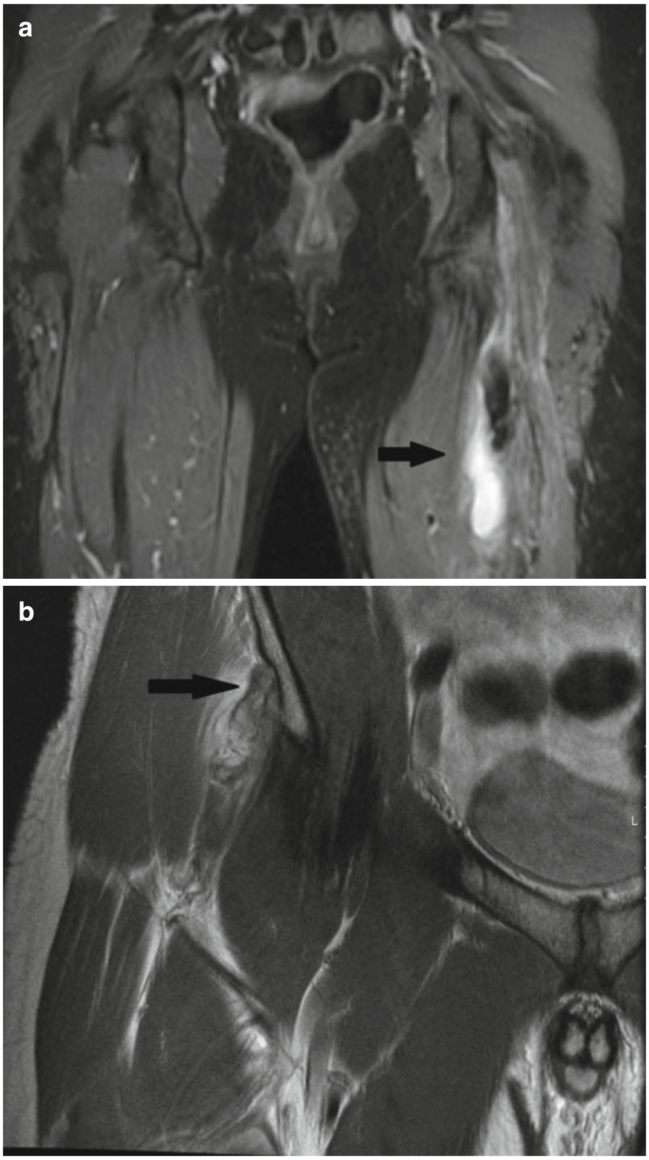

Fig. 9.7 Rupture of the proximal hamstring tendons off of the ischial tuberosity with significant retraction of the proximal tendon, and associated fluid accumulation (*arrow* – **a**). Rupture of the direct head of the rectus off of the anterior inferior iliac spine (AIIS) (*arrow* – **b**)

performed to identify possible tendon avulsion. Hip range of motion and manual muscle strength testing is assessed next. Exacerbating examination techniques may include passive stretching of the suspected muscle (e.g. hip abduction for an adductor strain). Resisted active firing of the muscle may also elicit pain (e.g. resisted active adduction for an adductor strain) [37–40]. Hamstring and hip flexor strains should be assessed with both hip and knee evaluation (Fig. 9.7a, b). Passive hip flexion and knee extension may elicit hamstring pain in the setting of a muscle strain, while passive hip extension and knee flexion may produce quadriceps pain. Similarly, resisted active hip extension with the knee extended may elicit hamstring pain and active hip flexion with the knee flexed may elicit quadriceps pain. The severity of the muscle strain may closely correlate with the degree of weakness identified by manual muscle strength testing.

Radiographic evaluation is an extremely useful tool to the treating physician in the setting of the competitive athlete with a muscle strain or contusion. While plain radiographs are rarely helpful in establishing this diagnosis, MRI fat-suppressed sequences will frequently demonstrate significant soft tissue edema patterns at the area of injury. This imaging modality may also identify tendon avulsions including the rectus femoris and proximal hamstrings.

Muscle Strains and Contusions: Treatment Guidelines

Preseason and in-season conditioning serve as the primary preventative measures to avoid muscle strains. Prior data has correlated a low pre-injury strength with increased risk of muscle strain [35]. Despite appropriate conditioning, however, muscle strains and contusions will occur. Non-operative management of muscle strains and contusions around the hip includes rest, ice, compression, and physical therapy. Acute management of muscle strains includes maintaining the injured muscle in a compressed, stretched position for at least 24 h when at rest (e.g. hip extension and knee flexion with an applied compression bandage for a quadriceps muscle strain or contusion). Immediate active motion may also be encouraged immediately following injury using an exercise bicycle with seat placement that encourages muscle stretch (e.g. low seat placement for quadriceps strain or contusion to maximize muscle stretch).

Operative management of muscle strains is extremely rare and often limited to recalcitrant proximal hamstring and iliopsoas tendonitis [37–40].

Muscle Strains and Contusions: Rehabilitation and Return to Play

A careful physical therapy regimen should be followed focusing on stretching and muscle activation to optimize edema control and minimize the potential for muscle contraction. A rehabilitation program focused on hip strengthening has been demonstrated to decrease the incidence of hip strains in high-level athletes [41]. Significant variation exists among rehabilitation programs for treatment of muscle strains and contusions; however, rest, muscular stretching and immobilization in a stretched position, ice, compression and maintenance of motion have been demonstrated to reduce haematoma formation [34]. The time required for return to play is closely dependent on the severity of the strain or contusion and may vary from a few days to multiple weeks. A progressive return to asymptomatic activity will guide the timing of return to play. Despite the seemingly benign nature of these injuries, the current authors' suggest a conservative program for return to play as an increased risk of restrain may exist if symptoms are not fully resolved prior to full athletic participation.

Athletic Pubalgia/Sports Hernia: Basic Principles

Athletic Pubalgia (Sports Hernia) is defined as exertional lower abdominal pain with or without proximal adductor related pain in athletes [42, 43].

Athletic Pubalgia/Sports Hernia: Assessment

Athletes typically present with the insidious onset of increasing exercise induced lower abdominal/adductor related pain. Physical examination often reveals tenderness to palpation above the inguinal ligament over the abdominal obliques, transversus abdominus, and at the rectus abdominus/conjoined tendon. Pain may be elicited over these structures with resisted sit-ups. Tenderness to palpation and with resisted adduction may be noted over the adductors, pectineus, and gracilis tendons as well.

Plain radiographs may be normal in the setting of athletic pubalgia or may show evidence for osteitis pubis. Although MRI studies can be inconclusive in cases of athletic pubalgia, recent studies have noted that perisymphyseal edema (Fig. 9.8a), proximal adductor/gracilis/pectineus abnormalities (Fig. 9.8b), and disruptions of the rectus abdominus/adductor apponeurosis are all consistent with athletic pubalgia [43]. In some cases both intra-articular hip pathology and athletic pubalgia can coexist and imaging studies may reveal findings consistent with femoroacetabular impingement and intra-articular labral and chondral abnormalities as well [44].

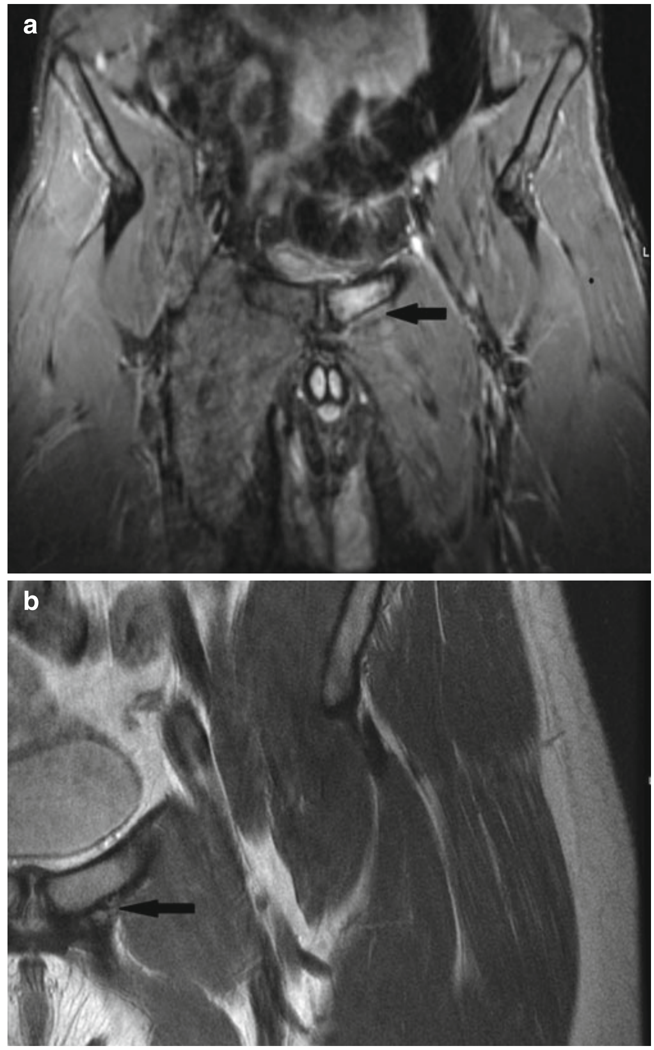

Fig. 9.8 Bone edema in the pubic symphysis (*arrow* – **a**), previously known as osteitis pubis, is often present in the setting of core muscular dysfunction involving the adductor musculature. Tendinopathy of the adductor longus (*arrow* – **b**) is frequently present in the setting of chronic athletic pubalgia symptomatology

Athletic Pubalgia/Sports Hernia: Treatment Guidelines

Initially, activity modification and a well balanced rehabilitation program focusing on core stability should be implemented. Avoidance of heavy weight, low repetition, deep hip flexion weight training and occasional corticosteroid injections into the pubic symphysis, adductor/pubic cleft, and hip joint can be helpful in some cases. When conservative measures fail, various surgical approaches for managing athletic pubalgia have been reported to result in a high return to athletic activity [42, 43]. These approaches include broad pelvic floor repairs and modified hernia repairs with or without partial or complete adductor releases [42, 43].

Athletic Pubalgia/Sports Hernia: Rehabilitation and Return to Play

Rehabilitation for athletic pubalgia involves an initial course of rest and activity modification. Oral anti-inflammatory medications may be used during the initial symptomatic period. A graduated trunk and hip strengthening program should be initiated and progressed in a symptom-free fashion. Return to play criteria includes full trunk and bilateral hip range of motion and symptom-free participation in sports-specific rehabilitation activities. Postoperative return to play typically is allowed at 3–4 months.

Association of Femoroacetabular Impingement and Athletic Pubalgia/Sports Hernia

There is increasing evidence that a subset of athletes might develop athletic pubalgia type symptoms as a result of hip joint motion limitations secondary to FAI. Studies have shown an increased incidence of chronic groin pain and osteitis pubis in athletes with limited hip internal rotation [45, 46]. One study reported that 94 % of athletes had radiographic evidence of FAI when presenting with long standing proximal adductor related pain [47]. A recent biomechanical study found increased symphyseal motion in the presence of cam-type FAI which could contribute to the development of osteitis pubis and athletic pubalgia [48]. Finally, in a series of athletes presenting with both symptomatic hip joint (FAI) and athletic pubalgia related findings, surgical management resulted in a return to sports without limitations in 50 % of athletes after isolated FAI surgery and 25 % of athletes following sports hernia surgery [44]. If both were managed surgically the rate of return to sports without limitations was 89 % [44]. It appears that the motion limitations that result from FAI can lead to extra-articular compensatory patterns resulting in athletic pubalgia in some athletes. These studies support an association between FAI and athletic pubalgia and the importance of managing both entities in select cases in order to minimize time lost from athletics and maximize outcomes.

Stress Fractures of the Femoral Neck and Pelvic Ring: Basic Principles

While insufficiency fractures are seen in elderly patients with osteoporosis due to inadequate bone mineral density and compressive and tensile strength, stress fractures in athletes are conversely the result of excessive repetitive submaximal stresses experienced by physiologically normal bone. The incidence of stress fractures ranges from approximately 1 % in the general population to as high as 20 % in long-distance runners [49]. Abrupt increases in frequency, duration or intensity of training without adequate recovery may lead to an increase in osteoclastic activity. Normal bone remodeling is disturbed such that bone formation lags in comparison to bone resorption. With continued repetitive submaximal loading, microfractures can propagate and organize into stress fractures.

Many factors may contribute to an athlete's risk of developing a stress fracture, including bone mineral density, bone vascularity, systemic factors (e.g. hormonal, dietary, collagen abnormalities, metabolic bone disorders), and type of activity. Muscular weakness or imbalance may also increase the risk for stress fracture, as excessive forces are concentrated on underlying bone. While stress fractures can affect any endurance athlete, they often present in women [50]. Female endurance athletes minimize body fat in order to maintain a high level of athletic performance. With decreased body fat, estrogen levels decrease which may lead to decreased bone mineral density and an increased risk of stress fractures. Male endurance athletes also are at risk of stress fractures due to a similar decrease in sex steroids (e.g. testosterone) [51]. This drop in testosterone results in an increased activity in osteoclasts and subsequent bone resorption. The combination of paradoxical bone resorption and repetitive excessive loading greatly increases these athletes' risk of developing stress fractures.

Proximal femoral morphology such as coxa vara and weakness of the hip musculature may also predispose an athlete to femoral neck stress fractures. With muscular weakness or imbalance, repetitive stress is further concentrated on osseous structures; when combined with the above risk factors this may also predispose endurance athletes to the development of stress fractures.

Stress Fractures of the Femoral Neck and Pelvic Ring: Assessment

The typical history from patients with femoral neck or pelvic ring stress fractures includes complaints of groin or pelvic pain exacerbated by weight-bearing or intense activity that is relieved with rest. This pain often occurs after an abrupt increase in frequency, duration or intensity of training, such as training for a marathon, triathlon, or other endurance event. Patients may present with an antalgic gait. While it is difficult to reproduce pain with palpation due to overlying soft tissue, patients complain of pain with hip internal and external rotation at the extremes of hip range of motion. With sacral insufficiency fractures, patients have pain with flexion, abduction and external rotation of the hip (FABER), and may have pelvic brim tenderness, though this finding is not sensitive due to the amount of soft tissue overlying the pelvis. If there is concern for sacral insufficiency fracture, careful neurologic examination is critical to detect any nerve impingement from callus formation within and around neural foramina.

The radiographic location of the stress fracture guides treatment, especially with regards to the femoral neck. Location of femoral neck stress fractures is classified as either tension-sided (on the superior neck), or compression-sided (on the inferior aspect of the femoral neck). Plain radiography is the first-line imaging modality, despite the fact that studies may be normal for the first 2–3 weeks after the onset of symptoms. Later films may reveal periosteal reaction, cortical lucency, sclerosis, or a fracture line. Initial views should include AP pelvis as well as an AP and lateral of the affected hip. In compression-type fractures, there is a sclerotic thickening of the inferior cortex of the femoral neck, often with a hazy radiolucent center. Careful correlation with history will differentiate this from an osteoid osteoma, which may have a similar radiographic appearance. Tension-sided fractures appear as transverse lucencies perpendicular to the superior aspect of the femoral neck. The pelvis may be evaluated for contralateral hip pathology as well as stress fractures of the pelvic ring and sacrum. Further radiography to image the pelvic ring and sacrum can include inlet and outlet views of the pelvis.

While nuclear imaging has been used in the past with success, axial imaging modalities are currently favored as the studies of choice following plain radiography [52]. Advantages of nuclear imaging include high sensitivity, ability to evaluate the entire skeleton, and lower cost, while disadvantages include invasiveness (injection of nucleotide tracer) and repeated time consuming scans. With focal symptoms such as hip and groin pain, MRI may be used to directly image the area of interest. MRI is advantageous in that it may also rule out other differential diagnoses including soft tissue abnormalities. On MRI, stress fractures appear as decreased signal intensity on T1 images and increased intensity on STIR and T2-weighted images.

The radiologic grading system by Arendt et al. [53] incorporates all three modalities – grades I and II represent low-grade lesions and high-grade lesions by grades III and IV. Grade I lesions are characterized by normal radiographs, mild unicortical uptake on bone scan and positive STIR image on MRI. Grade II stress fractures also have normal plain radiography but with moderate unicortical uptake on bone scan and positive STIR and T2-weighted images. Grade III is marked by periosteal reaction or a discrete line on X-Ray (XR), bone scan >50 % width of the bone and MRI abnormalities on T1- and T2-weighted images (Fig. 9.9). Grade IV stress fractures reveal fracture or periosteal reaction on XR, bicortical uptake on bone scan, and a fracture line on MRI.

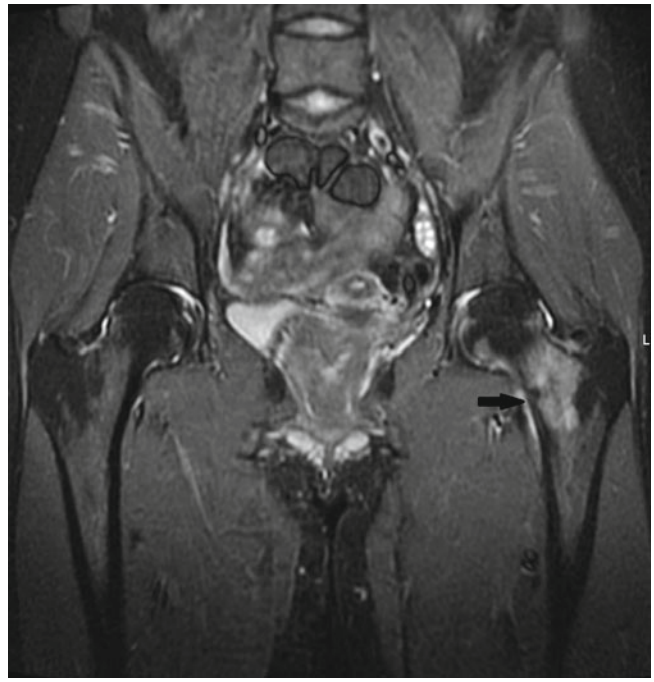

Fig. 9.9 MRI demonstrating significant increased signal intensity involving greater than 90 % of the femoral neck, with extension from the compression side toward the tension side, with apparent breach of cortical integrity on the medial cortex (*arrow*)

Stress Fractures of the Femoral Neck and Pelvic Ring: Treatment Guidelines

Prior to treating the stress fracture locally, global abnormalities must first be addressed. These include hormonal and nutritional deficiencies and evaluation for connective tissue disease if clinical suspicion warrants evaluation. Activity modification is the mainstay of treatment for stress fractures of the femoral neck and pelvis.

In compression-side stress fractures of the inferior femoral neck, the bone is inherently stable and treated non-operatively. Displacement of compression-sided femoral neck stress fractures is extremely rare. Activity modification (with or without protected weight-bearing) and expectant management are largely successful. Conversely, clinical concern should be raised when a tension-sided stress fracture is encountered. Due to the biomechanical forces causing distraction at the fracture site, there is a greater possibility for these fractures to evolve into displaced femoral neck fractures, with potentially disastrous consequences including AVN, varus mal-union, delayed union and non-union [54]. Initial management with internal fixation avoids these consequences. Any sign of radiographic displacement is indication for urgent percutaneous fixation with cannulated screws (Fig. 9.10a, b). Patients are then typically managed with protected weight-bearing for up to 12 weeks, guided by resolution of symptoms and radiographic signs of healing.

Patients with sacral and pelvic ring stress fractures are treated non-operatively in the majority of cases. Activity modification and close follow-up is the mainstay of treatment.

Stress Fractures of the Femoral Neck and Pelvic Ring: Rehabilitation and Return to Play

The patients' symptoms and radiographic signs of healing guide full return to athletic activity. In low risk stress fractures about the hip and pelvic ring (e.g. compression-side femoral neck, pelvic ring, and sacrum), activity should be titrated to a pain-free level for 4–8 weeks depending on severity of symptoms and injury. Crutches may be used for comfort but weight bearing may be as tolerated in uncomplicated cases. As symptoms improve, patients may be progressed to light low-impact physical activity and then to full activity as long as pain continues to decrease. This typically

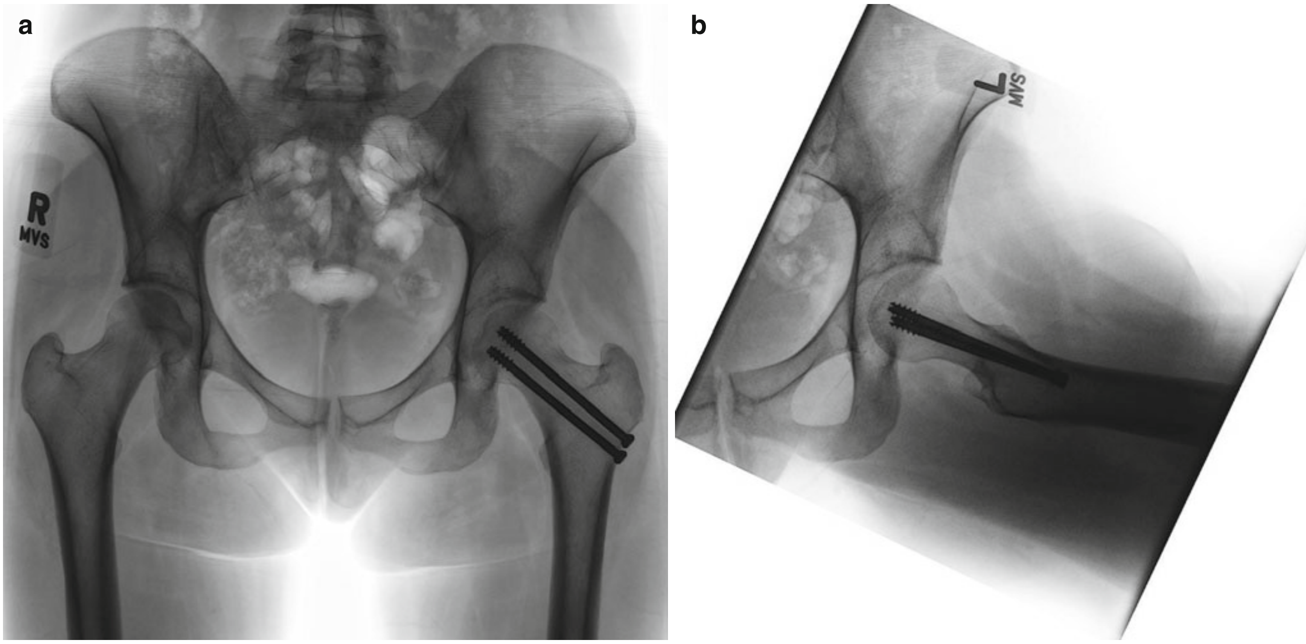

Fig. 9.10 (**a**, **b**): AP (**a**) and lateral (**b**) views of percutaneous screw fixation of tension sided femoral neck stress fracture

takes 3–6 weeks with low-grade lesions and up to 16 weeks with high-grade lesions [53].

High risk stress fractures (e.g. tension-side of femoral neck), once stabilized surgically, may return to play after symptoms have completely resolved and there is no pain with any provocative examination maneuvers nor with any activities [55]. Follow-up radiography is typically helpful to assess hardware placement and radiographic healing.

Abductor Failure: Basic Principles

Hip abductor musculature attaches to the greater trochanter of the femur in an analogous fashion to the rotator cuff of the shoulder. Therefore, acute and chronic injury to the gluteus medius and minimus may cause failure and tearing of the tendon insertions similar to a rotator cuff tear. These clinical entities, along with recalcitrant trochanteric bursitis, are referred to as greater trochanteric pain syndrome (GTPS), and peaks between the 4th and 6th decades of life. It is four times more common in females than in males. Often the initial pathology occurs in the tendinous insertions on the greater trochanter, with secondary involvement of the adjacent bursae. Bursal distension is uncommon [56, 57].

Abductor Failure: Assessment

On presentation, patients report lateral hip pain centered over the greater trochanter. Occasionally they will report a specific injury or a "pop", but this injury may also be chronic. Groin pain indicates separate pathology that should direct the clinician to evaluate for intra-articular pathology. On physical examination, patients typically report tenderness to palpation of the greater trochanter and either pain-limited or true weakness of the hip abductors depending on the size of the tear.

While plain radiography is the initial study of choice to rule out osseous pathology, diagnosis of abductor failure is largely based on MRI and ultrasound imaging. In patients with intractable GTPS, 45–50 % have demonstrated gluteus medius tendon tears by MRI or ultrasound [56, 58]. Using MRI, these tears appear as high signal intensity on T2-weighted sequences and intermediate signal on T1-weighted sequences.

Abductor Failure: Treatment Guidelines

While the vast majority of GTPS respond to conservative management, recalcitrant cases are often due to gluteus medius or minimus tendon tears. Surgical management may be considered in recalcitrant cases with failure of non-operative management for a minimum of 6 months including activity modification, physical therapy and oral NSAIDs.

Initially, open repairs were conducted with excellent results using tendon and footprint debridement followed by bone tunnels. A small series of seven patients with recalcitrant GTPS and radiographic confirmation of gluteus medius tears were managed with open repair, with results including

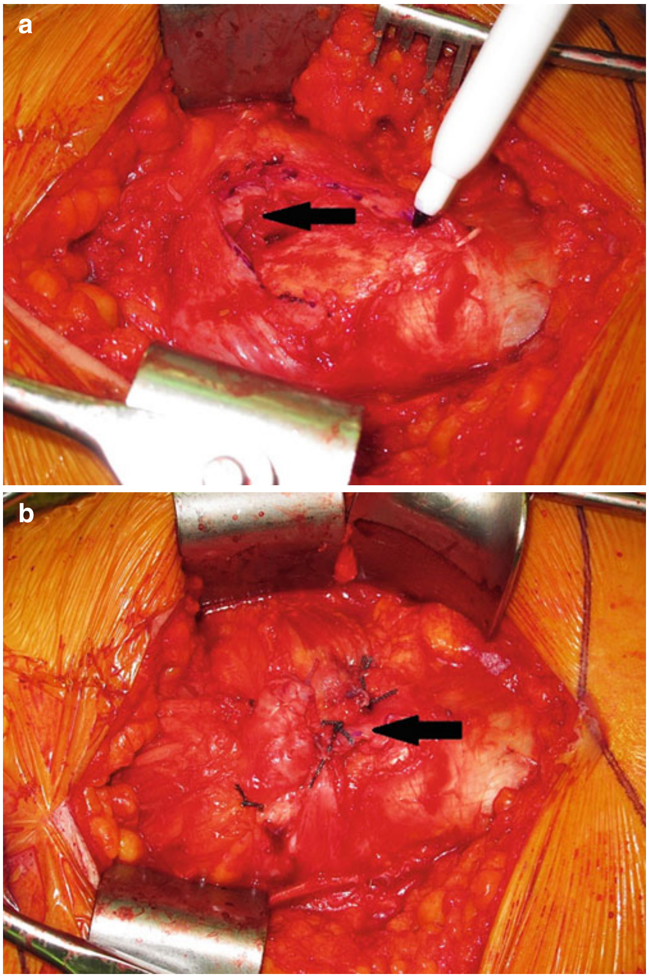

Fig. 9.11 (**a**, **b**) Abductor tear involving the gluteus medius insertion on the lateral facet (*arrow* – **a**) with open anatomic footprint repair (*arrow* – **b**)

complete pain relief at 45 months post-operatively [59]. Recent advances in hip arthroscopy have enabled an endoscopic approach through the peritrochanteric space for the repair of focal gluteus medius and minimus tears [60]. Similar to rotator cuff repair in the shoulder, the tendon and footprint insertion may be debrided and repaired using suture anchors. In a prospective study of ten patients who underwent arthroscopic abductor repair with a minimum of 2 years follow-up, all patients had complete resolution of pain in the lateral hip. Additionally, 90 % had complete return of abductor strength by manual muscle testing (one patient had 4/5 strength) and all patients' maintained full hip range of motion. At 1 year, modified Harris hip scores and hip outcome scores normalized to 92 and 93 points, respectively [16, 61, 62]. All patients reported normal or nearly normal subjective hip function [63].

Massive abductor tears with retraction are rare in this cohort and require open repair with tissue mobilization (Fig. 9.11a, b). Irreparable massive tears may be reconstructed with flap transfer of the gluteus maximus [64].

Abductor Failure: Rehabilitation and Return to Play

Postoperative rehabilitation after endoscopic repair consists of 6 weeks of crutch-protected weight-bearing with 20 lbs of pressure on the operative extremity. An abduction brace is used for 6 weeks to prevent accidental trauma and stress to the repair. Gentle passive range of motion begins 1 week postoperatively, progressing to active range of motion and abductor strengthening at 6 weeks. Twelve weeks postoperatively, strengthening continues and sport-specific activity begins at 16 weeks. Running is allowed once abductor strength becomes equal to the unaffected side, followed by a full clearance for return to play [63]. A similar algorithm can be used for open repairs once surgical wound healing is stable. Return to play after non-operative management should be guided by patients' symptomatic improvement, beginning with targeted physical therapy, strengthening, and progression of activities as tolerated.

Snapping Hip Syndromes (Coxa Saltans): Basic Principles

Coxa saltans is a clinical entity that is in fact a collection of various pathologic processes, marked by a palpable and occasionally audible "snap" or "pop" during certain hip movements. One can broadly classify this collection of pathologies as external or internal coxa saltans.

Typically, patients present with snapping hip syndromes in the second to third decades of life [65]. External coxa saltans is the most common and includes snapping of the iliotibial band or gluteus maximus tendon over the greater trochanter. Internal coxa saltans is typically caused by snapping of the psoas tendon over the iliopectineal eminence or the femoral head at the level of the labrum [66, 67]. This iliopsoas tendonitis often presents in female athletes who engage in frequent hip flexion and extension (e.g. runners, ballet dancers) [68] possibly due to a larger gynecoid pelvis creating increased tension in the iliopsoas complex. Iliopsoas tendonitis has also been noted to present along with erythematous contusion-type lesions in the anteroinferior labrum noted during hip arthroscopy; [69] patients may therefore present with labral tear-like symptoms in addition to internal coxa saltans. Intra-articular causes of snapping hip include loose bodies, labral tears and osteochondral injuries and are typically related to an episode of acute trauma [70].

Snapping Hip Syndromes (Coxa Saltans): Assessment

Unifying characteristics of both internal and external coxa saltans include the patients' description of a snap that is typically reproducible with certain movements. Lateral hip pain indicates localization to the greater trochanter and external coxa saltans while groin pain indicates internal coxa saltans or an intra-articular cause.

Physical examination of external coxa saltans typically reveals tenderness to palpation over the greater trochanter and may have a snap with hip flexion and extension that is palpable to the examiner. Ober's test for iliotibial band tightness may be positive, and is elicited by laying the patient on his or her side, with the affected side up. With the hip in extension and abduction, it is allowed to fall into adduction. The test is positive if the hip does not adduct beyond the midline [71].

Unlike external coxa saltans, in cases of internal coxa saltans soft tissue coverage precludes direct palpation of pathology. Because the sensation of internal coxa saltans is caused by the iliopsoas snapping over the iliopectineal eminence or anterior aspect of the femoral head, symptoms are reproduced with movement of the hip from a flexed, abducted, and externally rotated position into one of extension, adduction and internal rotation. Occasionally, pressure over the anterior aspect of the femoral head may prevent the tendon from snapping from lateral to medial as the hip is brought into extension. If the tendon is inflamed, there may be pain with the hip in terminal extension and external rotation, when the tendon is typically at its highest tension, and/or pain with resisted hip flexion. With concurrent labral irritation, there may be pain with terminal hip flexion, adduction and internal rotation (FADIR).

Intra-articular causes of snapping hip syndrome typically follow acute trauma and should be considered once more common causes have been ruled out. One feature differentiating intra-articular causes of snapping hip syndrome is that the snap is less reproducible than with the aforementioned pathologies.

Plain radiography should be the first study obtained in evaluation of a patient presenting with snapping hip. While unable to reveal soft tissue causes of coxa saltans, it can be useful in visualizing bony prominences on the greater trochanter or iliopectineal eminence, as well as calcified loose bodies within the joint.

Soft tissue imaging may be performed with dynamic ultrasound or MRI [72]. Dynamic ultrasonography is operator-dependent, therefore sensitivity and specificity is optimal with experienced technicians. An advantage of dynamic ultrasonography is the ability to provide guided peritendinous injections for both diagnostic and therapeutic purposes. MRI provides excellent visualization of intra- and extra-articular causes of snapping hip syndrome, soft tissue edema, labral and osseous pathology.

Snapping Hip Syndromes (Coxa Saltans): Treatment Guidelines

Non-operative treatment with physical therapy, ultrasound-guided steroid injections and activity modification is implemented initially. If conservative management fails to provide symptomatic relief, surgical treatment is employed based on the specific pathology, as described below.

Results of surgical management of external coxa saltans are mixed. The tendon may be lengthened by z-plasty [73], but patients may continue to complain of peritrochanteric pain and/or recurrence after the formation of scar tissue.

Surgical treatment of internal coxa saltans has been addressed through open [74] and arthroscopic [75] lengthening of the psoas tendon or by musculotendinous lengthening of the iliopsoas. Recent advances in hip arthroscopy have allowed surgeons to treat these patients arthroscopically with clinical outcomes comparable to open surgery [73, 75, 76]. Athletic patients have consistently achieved a full return to their preoperative level of competition in appropriately indicated cases [77]. Arthroscopic psoas tendon lengthening can be performed at either the lesser trochanter or at the level of the labrum via a transcapsular approach [78] Lengthening at the level of the labrum minimizes the rate of heterotrophic ossification compared to release off of the lesser trochanter, but may result in alteration in hip kinematics as the location of the iliopsoas tendon allows it to act as a secondary anterior stabilizer of the hip [79]. Treatment of the iliopectineal eminence-psoas conflict by arthroscopically decompressing the bone on the corresponding offending area of iliopectineal eminence is currently under investigation.

Intra-articular causes of snapping hip are often amenable to arthroscopic treatment for removal of loose bodies, repair of osteochondral lesions and/or labral repair.

Snapping Hip Syndromes (Coxa Saltans): Rehabilitation and Return to Play

Return to play after non-operative management should be guided by patients' symptomatic improvement, beginning with targeted physical therapy, strengthening, and progression of activities as tolerated. After surgical management, progression of activities is largely guided by the procedure performed and speed of the patient's recovery. Typically, after tendon lengthening for external or internal coxa saltans, physical therapy begins once the surgical wound is stable, progressing quickly from passive to active range of motion, strengthening, and sport-specific strengthening and plyometric rehabilitation. Return to full activity can be expected within 3–6 months postoperatively, depending on symptomatic relief and restoration of strength.

Dysplasia and the Unstable Hip: Basic Principles

Sports that require significant hip range of motion, including ballet and gymnastics, may increase the risk for symptomatic dysplasia and hip instability. These instability episodes occur at the extremes of motion that occur with specific coronal, sagittal and axial hip positions that occur during these sporting activities. Prior data from ballet dancers' demonstrated age-related loss of hip motion resulted in subsequent lumbosacral compensation. This compensatory motion suggests that end-range hip motions may impart increased hip joint stresses, which may increase with age [80]. Kinematic data has supported this conclusion in professional dancers by demonstrating reduced femoroacetabular translation at end-ranges of motion [81, 82]. Moreover, subtle, individual abnormalities in femoral and acetabular morphology, such as increased femoral anteversion or anterior acetabular hypoplasia may increase acetabular labral strain during external rotation and abduction [83]. Prior studies have documented increased labral strain during hip extension in dancers and gymnasts with mild acetabular dysplasia [84, 85].

Dysplasia and the Unstable Hip: Assessment

The assessment of hip pain in dance and gymnastic athletes can be particularly difficult due to the extreme ranges of motion that are required during sporting participation. Pain in these athletes is frequently due to periarticular soft tissue injury. Distinguishing between intra-articular and extra-articular injury is crucial to guide treatment and optimize outcome.

The patient history is one of the most important factors for accurate diagnosis. Careful attention should be paid to symptom location, character, exacerbating hip positions or motions and time of onset. Lateral hip pain near the greater trochanter may represent abductor overload and fatigue due to acetabular dysplasia and should not be confused with greater trochanteric bursitis. The position of the hip and specific activity in which the athlete was participating in at the time of injury are also useful. The athlete may describe mechanical symptoms including locking, catching, instability, or crepitus as well as decreased activity tolerance. Unusual symptoms which might be identified include night pain, genital pain or associated neurologic symptoms. These multiple factors should then be used to direct a focused physical examination.

A complete physical examination is conducted to not only confirm the specific inciting factors that were identified in the patient history, but also to elicit other subtle abnormalities that may be contributing to the athlete's symptoms. Palpation of superficial and deep structures should be performed to identify specific pain locations that may be due to inflamed anatomic structures. Documentation of active and passive bilateral hip range of motion in all planes may identify painful and unstable hip positions frequently at motion extremes. Careful attention should be placed on hip hyperflexion and internal rotation. Provocative positions of potential posterior instability include hyperflexion, adduction and internal rotation and anterior instability include hyperextension, abduction and external rotation. Bilateral motor strength should be assessed to identify any focal areas of weakness. Lastly, neurologic testing including sensation, reflexes and long tract signs should be performed in patients with previous neurologic complaints, as spine-related pathology may contribute to dynamic hip dysfunction [86].

Radiographic evaluation of these athletes may include plain radiographs, MRI, and/or CT scan. Evaluation of the osseous and soft tissue anatomy of the hip joint will not only identify injured areas and structures, but also allow careful evaluation of the hip joint morphology and osseous anatomic relationships. Plain radiographs allow calculation of acetabular depth-width ratio, lateral and anterior center-edge angles, cross-over and posterior wall signs and the Tönnis angle. Other suggestive radiographic signs of instability may also be identified including a high fovea, epiphyseal eversion, increased neck-shaft angle, and lateral acetabular sourcil sclerosis. CT scan may further characterize these femoroacetabular relationships. MRI evaluation may identify regions of soft tissue injury or osseous overload that present as increased intrasubstance or subchondral high signal, respectively. Gross labral or articular cartilage damage may also be identified. Ligamentum teres tears should also be identified as this pathology may suggest prior instability episodes.

Dysplasia and the Unstable Hip: Treatment Guidelines

Initial treatment of athletes with dysplasia-related instability should include activity modification with rest and avoidance of exacerbating activities. Anti-inflammatory medications may also be used in the early symptomatic period. When acceptable pain control has been accomplished, trunk and hip strengthening exercises should be initiated while avoiding extreme hip ranges of motion. Identification of painful maneuvers should direct modification of these maneuvers to minimize or completely avoid these positions. Intra-articular cortisone injections may also be considered for both diagnosis and treatment, but this modality should be used on a very limited basis to minimize the associated chondral toxicity. Surgical treatment may be considered if the athlete is refractory to these non-operative modalities.

Surgical management is designed to address the underlying mechanical factors that are contributing to the athlete's symptoms. Correction this pathology may include acetabular or femoral reorientation, acetabular or femoral osteoplasty, and capsulorrhaphy [87]. Acetabular reorientation with a periacetabular osteotomy (PAO) is most frequently used to address dysplastic instability.

Dysplasia and the Unstable Hip: Rehabilitation and Return to Play

The athlete may return to play following complete pain resolution with non-operative management or following completion of the post-operative rehabilitation protocol. Postoperative return to play is suggested at 4–6 months to ensure complete osseous and soft tissue healing as well as return of adequate muscle strength and proprioception. Abductor strength that is at least 80 % of the contralateral extremity is required prior to activity participation to reduce the potential for recurrent instability.

The Hypermobile Hip Without Dysplasia: Basic Principles

The hypermobile hip in the absence of dysplasia is poorly defined. Patients with underlying ligamentous laxity as defined by the Wynne-Davies criteria may be included in this definition when increased hip range of motion is identified [88]. These patients frequently include female athletes. Careful evaluation should be performed to eliminate other potential causes of hip pain or instability, as this the diagnosis of idiopathic hip hypermobility should be exclusionary. Associated pathology may include femoral anteversion, subtle acetabular dysplasia, trunk muscle weakness, and psoas tendonitis [89, 90].

The Hypermobile Hip Without Dysplasia: Assessment

The patient history that is consistent with a hypermobile hip without dysplasia includes an underlying diagnosis of ligamentous laxity in combination with exclusion of all other causes of instability or pain. Careful physical examination and diagnostic imaging should be obtained to eliminate any other underlying cause of the patient's symptoms. CT scan may identify more specific acetabular dysplasia or femoral or tibial torsion, and MRI can demonstrate articular cartilage and labral injury. When the diagnosis of hip hypermobility without dysplasia is suspected, confirmation of underlying connective tissue disorders such as Marfan and Ehlers-Danlos syndromes is necessary.

The Hypermobile Hip Without Dysplasia: Treatment Guidelines

Patients with this disorder frequently present with greater trochanteric bursitis and muscle weakness. Oral anti-inflammatory medications and directed steroid injections may be useful during the symptomatic stage. Physical therapy is the foundation of treatment and should include strengthening of the paraspinal, lower abdominal and pelvic brim musculature. Surgical intervention is rarely indication in these patients. However, arthroscopic treatment including a minimal capsulotomy with subsequent repair and imbrication has been used in isolated cases [91].

The Hypermobile Hip Without Dysplasia: Rehabilitation and Return to Play

Rehabilitation is focused on an initial period of rest and activity modification followed by focused strengthening of the trunk and core muscles. Return to play can be allowed following complete symptom resolution and acceptable muscle strengthening. The criteria are poorly defined, but should include symptom-free participation in sport-specific rehabilitation activities.

Pediatric Hip Injuries in Sports

Pediatric and adolescent athletic hip injuries are being seen with increasing frequency due to increased athletic participation in this cohort. Broadly, pathology may be categorized as intra-articular (e.g. healed SCFE leading to FAI), or injuries to the soft tissue envelop around the hip (e.g. apophyseal avulsion). Here we discuss both of these clinical entities, including diagnosis and treatment.

Slipped Capital Femoral Epiphysis: Basic Principles

Slipped capital femoral epiphysis (SCFE) sustained at any point throughout childhood development may heal with a prominence at the anterosuperior head-neck junction as the epiphysis falls posteriorly, thus leading to "acquired FAI". In addition to the cam lesion formed by the healed SCFE, the post-SCFE retroverted femoral head requires increased internal rotation to reproduce pre-slip hip kinematics, further accentuating the osseous conflict between the anterosuperior head-neck junction and the acetabulum. Despite similar radiographic appearance at skeletal maturity, the pathoanatomy is different. In SCFE, there is insufficiency of the upper femoral physis; hence shearing forces cause anterior translation of the metaphysis relative to the neck of the femur. The epiphysis remains normally shaped but abnormally aligned posteriorly. In contrast, a CAM-morphology likely develops slowly depending upon the morphology of the femoral epiphysis. When the trochanteric apophysis and upper femoral epiphysis are coalesced, persistent epiphyseal tissue localized to the anterolateral and lateral femoral neck form an aspherical extension of the femoral head, decreasing the normal head-neck offset [92, 93].

Slipped Capital Femoral Epiphysis: Assessment

Hip pain that is caused by femoroacetabular impingement or chronic slipped capital femoral epiphysis is usually localized

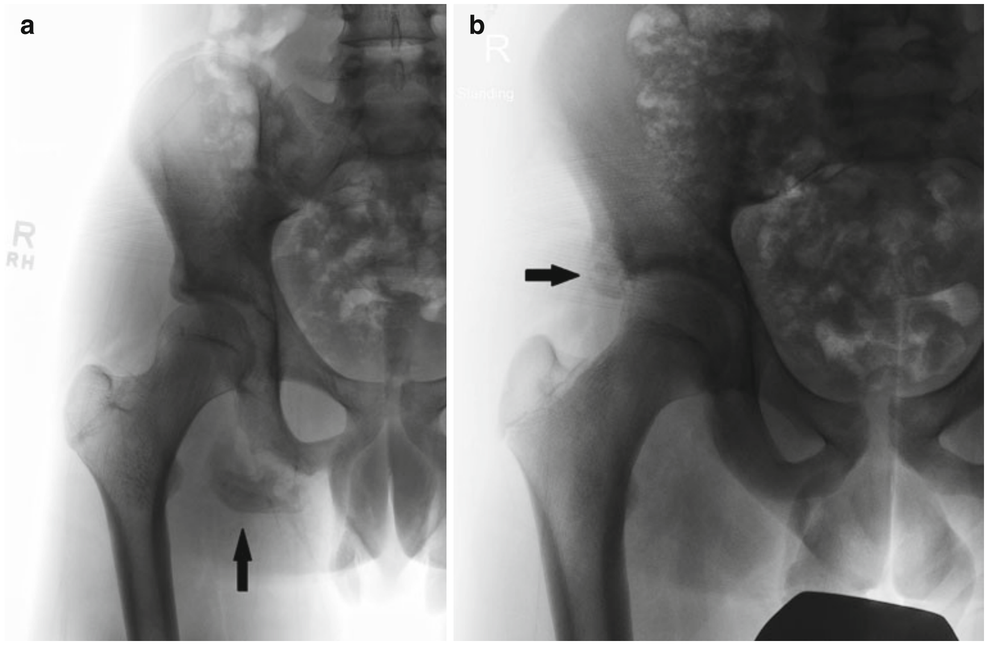

Fig. 9.12 (**a**, **b**) Apophyseal avulsion of the ischial tuberosity (**a** – *arrow*) and anterior inferior iliac spine (AIIS) (**b** – *arrow*), are seen most commonly in adolescents due to the increased stress of the tendon origins of the hamstring and rectus femoris respectively

to the groin, peritrochanteric area, buttock, or thigh, and may be associated with mechanical symptoms. Radiographic differentiation between a CAM-morphology and mild, healed chronic SCFE is best seen on the lateral radiograph, which shows anterior metaphyseal translation that is not present with a CAM-type shaped femoral neck.

Slipped Capital Femoral Epiphysis: Treatment

Treatment of FAI post-SCFE depends upon the history, degree of discomfort and MRI appearance of the articular cartilage. Surgical decision-making is dependent upon the shape and orientation of the femoral neck as well as significance of gait disturbance. Options include arthroscopic osteoplasty or an open femoral neck osteoplasty usually performed through a surgical hip dislocation. Intertrochanteric osteotomy may be required to completely address the deformity.

Slipped Capital Femoral Epiphysis: Rehabilitation and Return to Play

Patients are permitted to return to play once the hip pain is resolved. For those with excessive arthrosis who are not surgical candidates, pain is managed conservatively and participation is permitted depending upon residual symptoms. Following surgery, patients are permitted to return to sport once sufficient time has passed to permit healing and once muscle strength is normal. All patients are advised to avoid maximum hip flexion to prevent irritation of the acetabular rim.

Apophyseal Avulsions: Basic Principles

Alternatively, injuries in the soft tissue envelope of the hip are typically acute injuries. These soft tissue injuries occur due to excessive traction on developing apophyses at ligamentous attachments. Prior to skeletal maturity, these tendinous insertion sites may become destabilized by eccentric muscle contraction during competition, leading to tendon-apophyseal avulsion.

Toward the end of skeletal maturation, the femoral and pelvic apophyses become recognizable radiographically and include: lesser trochanter, greater trochanter, pubis, ischial tuberosity, iliac crest, anterior superior iliac spine (ASIS) and anterior inferior iliac spine (AIIS). The apophyseal plate is composed of columnar arranged chondrocytes located between primary and secondary sites of ossification where muscles either originate or insert. Pelvic and upper femoral avulsion injuries arise predominantly in adolescence just prior to final fusion [94]; however, they can occur until the mid-twenties at which time the iliac apophyses fuse. Generally they are brought on by an eccentric muscle contraction [95]. The ischial tuberosity (Fig. 9.12a) and the AIIS (Fig. 9.12b) are the commonest avulsed apophyses, due to avulsion of the hamstrings and direct head of the rectus femoris, respectively [96]. Severe complications following avulsion injuries are rare, with femoral head necrosis reported after greater trochanteric avulsion [97].

Apophyseal Avulsions: Assessment

The diagnosis of an avulsed apophysis is usually straightforward. Athletes experience a sudden injury, often accompanied by a popping sensation, which causes pain that interferes with weight-bearing. Physical findings include limitation of motion, swelling and tenderness at the apophyseal site. Radiographic examination is necessary in order to confirm the diagnosis of an avulsion injury and to exclude concomitant pathology, and reveals diastasis between the apophysis and neighboring pelvic footprint. Rarely, CT may be necessary to accurately gauge the degree of avulsion, however MRI is preferred to fully visualize unmineralized apophyseal tissue as well as to determine if any soft tissue pathology exists.

Apophyseal Avulsions: Treatment

Pelvic avulsion injuries are usually self-limited disorders that heal without specific orthopaedic intervention. If bearing weight is painful, crutches are prescribed. Ice and NSAID's are useful acutely to reduce pain and swelling. Rarely, significantly displaced ischial tuberosity and iliac crest avulsion injuries may require operative fixation. The decision to repair an avulsion with surgery depends upon the magnitude of avulsion and the potential to develop symptomatic weakness, a non-union, or a painful exostosis at the site of healing. Screw or suture anchor fixation may be employed depending on the size of the avulsed mineralized fragment. Short term functional bracing is typically used to prevent stress to the repair site.

Apophyseal Avulsions: Rehabilitation and Return to Play

As with other minor avulsion fractures, patients can return to sport once the injury has healed and the athlete has regained pre-injury level of flexibility and strength. In the event that operative fixation is required, adequate time must be given for bony healing (8 weeks), followed by graduated supervised physical therapy and return to play once sport-specific movements are tolerated.

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Core Muscle Injuries

10

William C. Meyers and Adam Zoga

The real magic of discovery lies not in seeking new landscapes, but in having new eyes. Marcel Proust [1].

Over the past half century, people have used a number of terms to describe the musculoskeletal injuries that affect the abdomen, pelvis and thighs of athletes. The terms reflect the various specialty disciplines of those who use them and obscure cohesive insight into the nature of these problems. In this chapter, my radiologist partner and I advise new eyes and propose nomenclature to represent new insight into the various problems. We base our request on our own clinical findings extracted from a large personal experience, coupled with some anatomical studies as well as observations of others. With respect to these injuries, we strive for the reader to embrace the above-cited Marcel Proust observation.

Historical Perspective

Dogma

The old, hard-line, dictator coach of the 1960s and 1970s (Fig. 10.1) embodies the state of our knowledge about groin injuries until recently. He knew that anyone who complained of them was *just not tough enough.* Most of us have probably had coaches like this. He was not thoughtful like Proust. He did not wonder what bothered the player, show empathy and then seek an answer. Most coaches back then were pretty powerful and just not like that. In fairness to those coaches, the fact was that most doctors in that era had no clue about this set of injuries. The pelvis remained a mysterious, forbidden area; and without a dependable fix for the injuries, there was really no purpose for a coach to think differently. He strove for team wins and most players with unfixable, disabling injuries contributed nothing to that.

Conflicts

The term "sports hernia" was around back then and deservedly had a bad name. The outcomes from hernia repair in athletes and others with inguinal pain were so predictably bad, it became verboten for general surgeons to perform repairs in the absence of demonstrable hernia. David C Sabiston, perhaps the most famous leader of American surgical training programs in that era, declared, "You shall surely fail your boards if you say you would do that" [2].

The clash between what the sports world saw as an obvious set of injuries and the medical world's failure to understand them generated a bewilderment bolstered by recent medical literature [3]. In 2006, the search terms *sports hernia* or *athletic pubalgia* yielded a total of only 12 articles using PubMed.com, while at the same time, the same key words produced over 100 articles on ESPN.com, the USA's leading sports website [4]. The same set of searches captured 15 different terms that described comparable, soft tissue sports injuries in the pelvis.

In an analogous web search in 2012, the number of terms describing these injuries grew to 50, not including 14 from the gynecologic literature. The scientific articles mushroomed to over 200. Most of the papers bundled the patients as if they had one common injury; and lacked detailed descriptions of histories and physical examinations. Several papers split out high thigh injuries from abdominal wall injuries.

Athletic Pubalgia

The multiplicity of injuries in one general location and the confusion over terms underscores the need for a unifying concept and nomenclature. The descriptive term "athletic

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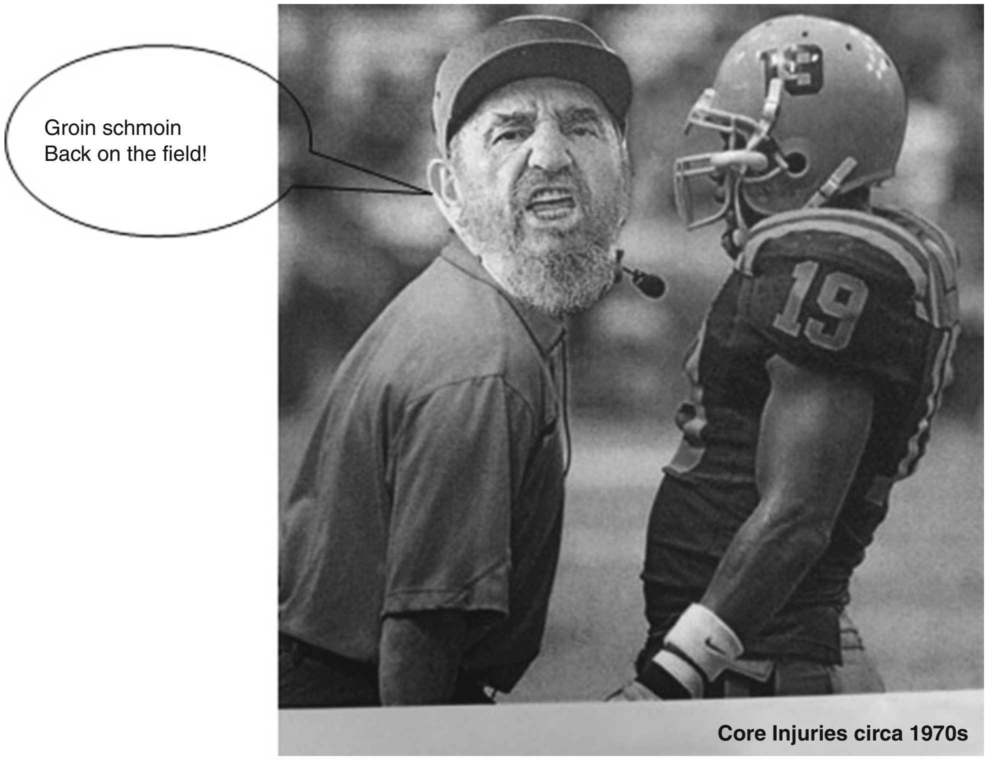
Fig. 10.1 State of knowledge about core injuries in the past



pubalgia" came from a 1991 article [5]; we sought an umbrella label without the word "hernia" for the complex pain near the pubic bone in these athletes. One specific injury could not possibly have explained the various clinical profiles of our patients. Experience over the past two decades [6] identified an even wider spectrum of pain and problems; the patients usually vaguely connected the pains. Pain occurred in a variety of muscles or muscle groups in the abdomen or thigh, often at multiple sites at the same time and with migration from one site to another over time. As encompassing as the term may be, *athletic pubalgia* does not easily roll off the English-speaking tongue so the press has not embraced the term. The French translation into a more enunciable "pubalgie" brings up a semantic issue. As accurate as the term may be, *athletic pubalgia* describes the anatomical region for these problems without connoting a unifying concept. As the reader shall see, the concept that connects the various pains and pathologies turns out to be simple.

Milestones in Recognition of a Dynamic Muscular Pathophysiology Around the Pubis

Let us summarize some of what has defrocked the myth that these are hernias. Keep in mind that the situation has grown more confusing because hernia repairs have had some success for specific injuries. Authors as far back as 1895 [7–10] speculated on a dynamic musculoskeletal nature to these injuries and on changes in the pubic bone that seemed to correlate with age and soft tissue injury. A 1924 article [10] even connects changes in the inferior aspect of the pubis to prior suprapubic injury. In 1981 Nesovic suggested a muscular imbalance in footballers in Yugoslavia [11] and subsequently devised a number of repairs for various injuries. I may have followed in suggesting this in publication [5], but Gilmore from the United Kingdom, and perhaps others, had been censuring the hernia theory years before that.

Seeking New Landscapes Versus Having New Eyes

After several early reports of successful experiences using new approaches [12–14], an outpouring of traditional hernia surgeons and then laparoscopic surgeons sought new frontiers for their tools [15–19]. Most of the reports suggested that pain rarely improved without surgery. Most of those articles provided limited follow-up; and several reported 100 % success rates – remarkable considering the wide variety of patients and absence of definitions. Consistent with those reports, in our own early experience with open and then laparoscopic hernia repair as primary treatment (circa 1988–1993), pain often improved. However, we were never satisfied with the results because athletes often persisted with some degree of pain [20, 21]. Thus, some success with hernia repair, as occurred years ago, plus an influx of hernia surgeons has brought some people back to the mistaken concept of hernia as the underlying factor.

Table 10.1 Changes in patient profiles over two decades

Patient profile	1986–1995	2003–2008
Female	Less than 1 %	15.2 %
Age (years)	24.7 (14–54)	28.6 (8–88)
Athletes	91.1 %	76.9 %
# of sports	15	32
Top sports	Soccer	Soccer, football, hockey
# of recognized syndromes	3	19 (121 different operations)
# of rehab/performance protocols	0	16

Data from Ref. [6]

Then team physicians, physical therapists, trainers, and others with experience treating players during competition wrote about the injuries [15], and some questioned the need for surgery. One paper narrowed the scope of patients to a certain type adductor injury and reported good success with a specific physical therapy regimen as primary treatment [22].

In 2008, we reported a large overall experience with these injuries characterizing the changes in the recognition and treatment over two decades (Table 10.1). The injuries were divided into a number of different categories based on the specific muscles involved, MRI and operative pathology. The pubis and its attachments were undeniably important. Not all the lesions needed surgery, and when appropriate, surgery nearly always fixed the problems. Soon afterwards, Mushawek [19] reported a minimal repair technique with 100 % "perfect satisfaction" at 4 weeks postoperatively. She described the ultrasonographic identification of an abdominal wall hernia as the common factor in the patients and at least one patient also had an adductor procedure. In 2011 Paajanen again achieved 100 % "perfect satisfaction" but this time with laparoscopic hernia surgery and at 12 months postoperatively [23]. Interestingly, Paajanen sometimes added some kind of adductor procedure to his repairs. As physicians, we are taught to challenge anything that is 100 %. On the other hand, like searching for gold, zeal comes from looking for something valuable and finding something shiny. Those startling results likely represent a combination of some success and zeal.

The literature remains confusing. The numerous articles advocate many different approaches. For example, one critical review of exercise therapy as treatment for groin pain in athletes found 468 articles on the subject, adjudged only 12 worthy of analysis, and determined that only 7 out of those 12 were reasonable in quality [24].

We found five relatively recent prospective studies (Table 10.2) [22, 23, 25–27]. Together, they reflect a lack of a unified theme. Holmich's trial [22] was randomized and prospective for two types of physical therapy for specific adductor injuries; the authors showed that an active training protocol was better. Our two studies [25, 27] were not randomized. This was not ethically possible in our patient population; plus, we chose to treat a number of patients non-surgically. In the first study, the overall two-year self-assessed success rate was 95.4 % after various types of surgery. Success was defined as at or better than pre-injury levels of play. Most in the other 4.6 % group were better but had concomitant hip or other problems not yet fully treated. The exact time frame for return to play was not assessed since many patients had surgery in the off-season. The second study [27] was on pelvic pain in women athletes. A variety of injuries separated into three categories: hip, core muscle injuries, and "other causes", and there was considerable overlap among the three groups. Surgery provided markedly superior results compared to non-operative approaches for the musculoskeletal injuries (Table 10.2). The other two prospective studies [23, 26] were randomized. Ekstrand and Ringborg [26] included 66 patients and randomized them to four different treatments, only one being surgical. The complex results are difficult to summarize, but only the surgery achieved satisfaction.

Table 10.2 Five prospective studies on groin pain in athletes

Author	Year	Study
Holmich	1999	68 patients randomized to two types of PT
Meyers	2000	157 non-randomized patients
Ekstrand	2001	66 patients randomized to four treatments
Meyers	2011	114 non-randomized women patients
Paajanen	2011	60 patients randomized to surgery vs. PT

In summary, a deluge of studies now shower the medical literature on this topic. The various authors write about a variety of injuries; and it is difficult to sort out the definitions and patient selection. Stated bluntly, the befuddling literature along with a lack of a common anatomic understanding emphasizes the urgency for new eyes.

The Old Eyes

One should not judge the above studies too harshly. They reflect the eyes of the various authors' trainings. Many of the papers touch on important observations and contribute to our having new eyes, by challenging the opacity of the pelvis and pelvic injuries.

For too many years, the pelvis has remained a mysterious anatomical region. The private nature of the pelvis has something to do with this, but the main reason is that each of us, i.e. physician, surgeon, physical therapist, athletic trainer, etc., is biased by our own training. It is difficult to see beyond that. The urologist sees the pelvis as the ureters, bladder, testicles, etc. The general and colorectal surgeons think of this region as where the colon and rectum reside as well as some protrusions called hernias. Gynecologists see other things. It is easy to list other specialists. Orthopedists are probably best equipped to deal with the mechanics of these athletic injuries as they deal with bones and joints, but they have feared misdiagnosis of, or injury to the genitourinary, gastrointestinal and gynecologic structures.

The main point is that we all must realize the limitations imposed by our training. We need to cross specialties. We need new eyes.

New Eyes

The answer to the mystery is that no one has ever taught us well what lies alongside the essential organs and vessels in the pelvis. Alongside lays some important musculoskeletal anatomy. This portion of the musculoskeleton is our transmission like a car, or our foundation like a building. This is the core of our athleticism. Consider the *new building* analogy. If the foundation is our core, perhaps then the walls are our muscles. Maybe hernia repairs have a small degree of success because the mesh fibroses and fixates the muscles with its intense foreign body reaction; and despite its intended purpose, provides a slightly firmer connection to the foundation. And perhaps the cutting of sensory nerves and slight imbrication of musculature of "minimal repair" provides a quick coat of paint that makes the building look better in the short term but not necessarily the long term, and but does not make the building much sturdier. One may carry out this analogy in several directions.

As a busy liver surgeon at Duke University in the mid-1980s, the surgeon author became curious about this anatomy. As a hobby, he helped Drs. Frank Bassett and William Garrett with the sports teams and was seeing a number of players whose careers were cut short by exertional pelvic pain. He and a medical student studied in the fresh cadaver laboratory, the anatomy depicted in Fig. 10.2. In medical school the anatomy had seemed overwhelming. Armed with the recent memory of physical examinations on athletes who could no longer play, we were determined to think about anatomic function. Most of the athletes had multiple sites of pain elicited around the pubic symphysis.

In the lab, it became obvious that the pubic bone was in the middle of all this activity. We did a stupidly simple experiment (Fig. 10.3). From above the pubis, I took a Mayo scissors and cut through about 30 % of the right rectus abdominis attachment while the medical student put her index finger behind the three adductors that attach to the pubis and on top of the anterior edge of the inferior pubic ramus which has sharp, tooth-like projections. As I cut the rectus, the adductor muscles jolted posteriorly and jammed her finger into the pubic ramus teeth and she let out a scream, depicted by the tears in the figure.

Fig. 10.2 Pelvic anatomy in a cadaver

Rather than worry whether she would ever use her finger again, we immediately made the observation that forces created by the weakened rectus abdominis were being transmitted below the pubic bone. The pubic complex was acting like a joint. We had caused instability of this pubic "joint." In further dissections, it became clear the rectus abdominis, pectineus, adductor longus and adductor brevis, were the most important structures in stabilizing the joint. Other muscles passing by the joint, such as psoas, rectus femoris and Sartorius provided additional support. A thick fibrocartilage plate lay on top of and congruent with the pubic bone connecting the muscles above and below. There was very little real tendon. The medical student's finger did recover.

Further experiments on fresh cadavers reaffirmed the dynamic nature of this region. For example, rectus abdominis divisions caused changes in either hydrostatic or strain gauge measured pressures inside the ball and socket hip joint. The cuts sometimes caused the needles to bend. In the absence of life, the precise values were not physiological. Nevertheless, the obvious changes meant that the entire region around and including the pubic bone acted in concert.

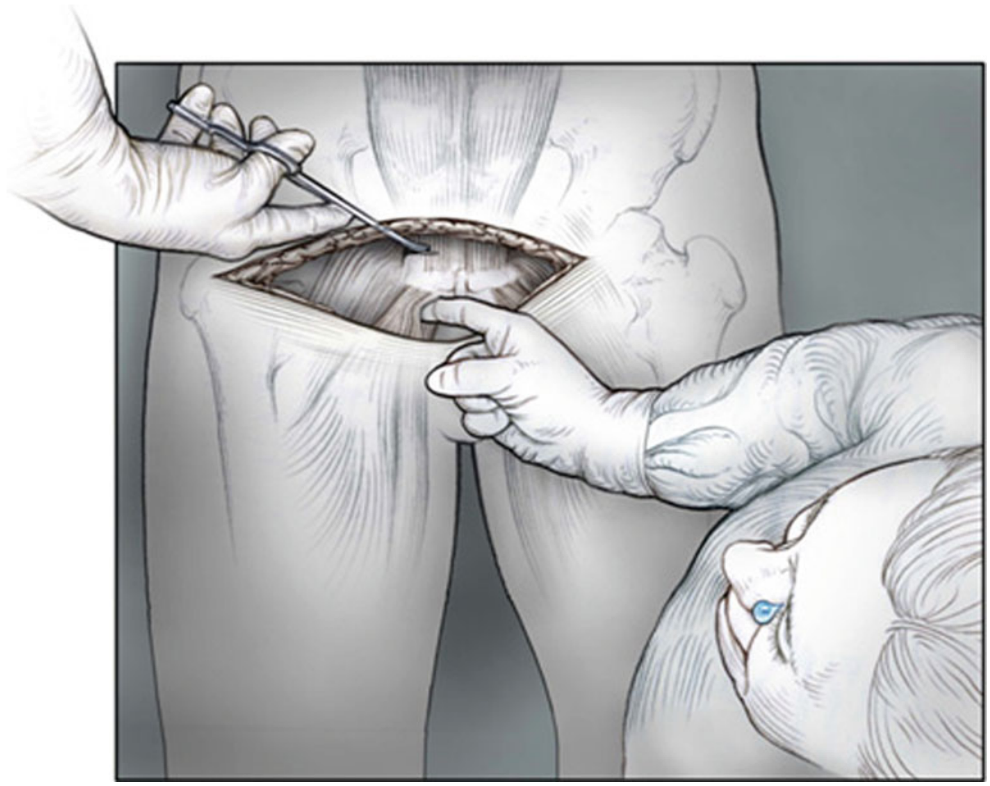


Fig. 10.3 Dissection of fresh cadaver with medical student. Note student's tears when her finger is pinched after partial rectus abdominis severance (reproduced with permission) (Artist – Rob Gordon)

Clinical Experience

These simple experiments were performed in the same era as trainers and physical therapists were recognizing more on-field, soft tissue pelvic injuries. Therefore, it seemed acceptable to perform surgical procedures on three long-injured players based on the sites of suspected pathology. Fortunately, the initial patients did well, and then more patients came.

Figure 10.4 shows the growth in patient experience. No doubt, the growth parallels an overall growth in the sports world's acknowledgement of the existence of these problems. One can notice that we were quite selective initially with respect to who underwent surgery. As we became more confident, we realized osteitis pubis was not generally a separate problem, and instead was a reaction to pubic instability; so we operated on a proportionately higher number of patients, reflected in the graph. Presently, more patients are coming with pure hip or other non-muscular causes of pain; plus we are recognizing more injuries that do not need surgery, accounting for the subsequent widening gap between surgeries and total consultations.

In a comparison of two decades of experience with these injuries [6], we chronicled a number of patterns in about 8,500 patients. While males still accounted for about 85 % of the injuries, distinct injuries became apparent in women. The median age of all diagnosed patients had increased, as well as the number of recreational athletes and sports. The paper recounted the development of 19 separate syndromes, 121 different operations, and 16 rehabilitation/performance protocols based on sites of pathology. It also documented a 15 % clinical and MRI correlation between "athletic pubalgia" and symptomatic hip pathology. We emphasize the huge diagnostic and therapeutic importance of this last observation.

History and Physical Examination

Clinical findings in the office remain our gold standard for precise diagnosis of these injuries [27]. Histories are conducted with careful attention to three sets of diagnoses: core muscle injury, hip, and other causes.

Because muscle injury results primarily from muscular disruption, the pain of core muscle injury is primarily exertional in nature. The athlete often anticipates the pain with initiation of specific forceful activities such as sprinting or changes of direction. The pain may affect normal activities such as coughing, sneezing, or rolling over in bed at night time. The pain may vary from side to side, depending on patterns of compensation, or involve multiple sites of soft tissue attachments such as the rectus abdominis, specific adductor or strap muscles. An inflammatory response of or around the pubis (osteitis pubis) sometimes accompanies the resultant instability and may cause tenderness or pain cessation of activities.

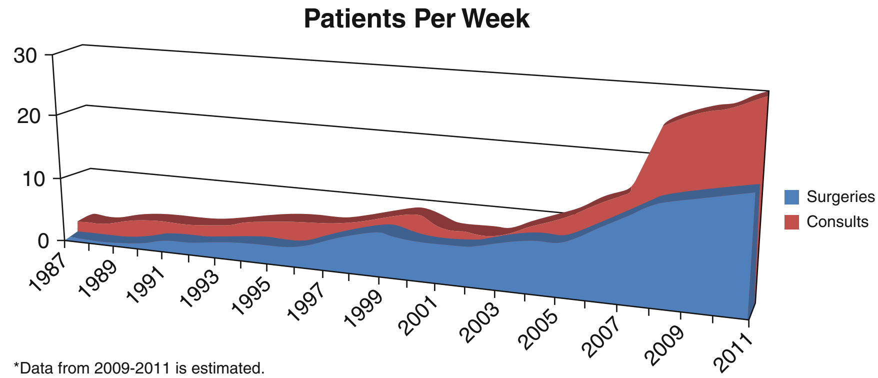


Fig. 10.4 Overall clinical experience (Data from 2009–2011 is estimated)

In contrast, patients with hip problems usually describe pain with or after minimal activity such as prolonged standing, walking or jogging, or with certain postures such as prolonged sitting, or going up and down stairs. Their pain may be more sporadic, often less predictable. Historical clues may signal the presence of both muscle and hip findings at the same time. Pains from "other causes" often have historical clues pointing to the genitourinary, gastrointestinal, gynecological symptoms or neurological systems. One's antennae should come up when the patient reports pain totally unrelated to physical activity. We cannot overstate the importance of past medical history. And one should beware that some patients with perilous other causes may have benign musculoskeletal injuries at the same time. In contrast with some other fields of medicine, the profound overlap of the three diagnostic "buckets" [6] indicates one should not necessarily be satisfied with just one diagnosis.

Physical examinations should be conducted with the same careful attention to the three categories of diagnoses. For core muscle injuries, we have developed resistance tests for each of the muscles attaching to or crossing the pubic symphysis or joint [28] (Fig. 10.5). Interpretation of each test involves three considerations: (1) Does the test cause pain? (2) Does the resultant pain correlate to the muscle being tested? And (3) Does the resultant pain re-create the pain causing the athlete's disability.

For the hip problems, the examination involves primarily range of motion tests without interference from contraction of muscles. These include the standard flexion-abduction-external rotation (FABER) and flexion-adduction-internal rotation (FADIR) tests, plus numerous other rotational or hyper flexion or hyperextension tests that could isolate anterior, posterior or lateral impingements or other pathology. Localized tenderness may sometimes help for specific diagnoses, although the tenderness form diffuse bony or soft tissue inflammation may also cause confusion.

Fig. 10.5 Pectineus test

Comprehensive physical examinations, sometimes with internal pelvic or rectal examinations, deserve particular attention for the detection of the "other causes." One must remember that other causes include both musculoskeletal problems including tumors as well as non-musculoskeletal diagnoses. It may be helpful to note that extreme pain with light touch may suggest the existence of CRPS (chronic regional pain syndrome), the more modern name for RSD (reflex sympathetic dystrophy) [29].

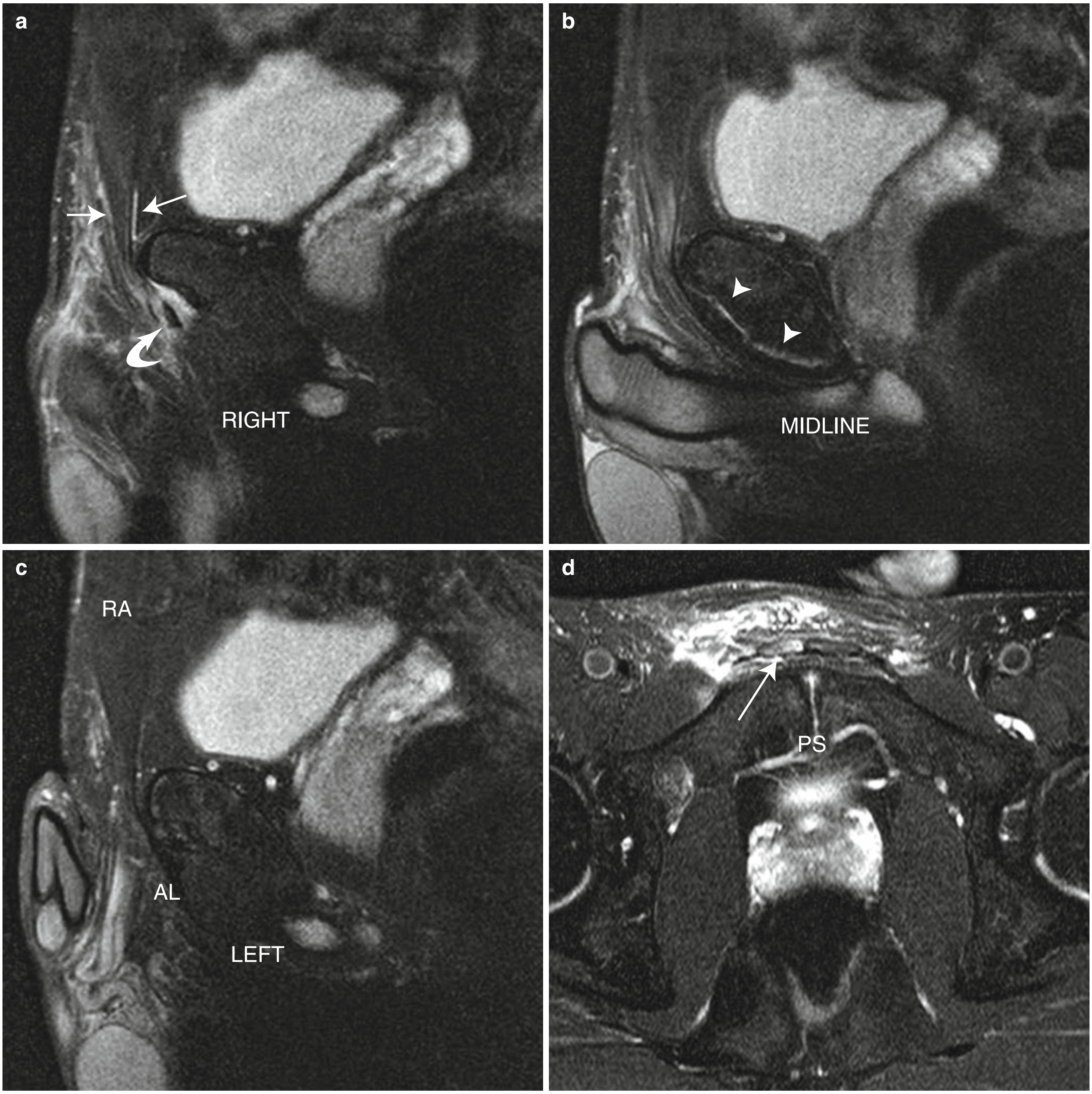


Fig. 10.6 Sequential sagittal MR images from a dedicated athletic pubalgia/core injury MRI protocol on a baseball catcher (**a**, **b**, **c**) show a detached rectus abdominis and torn adductor longus on the right (*arrows*) with an extensive midline pubic plate disruption (*arrowheads*) but normal rectus abdominis and adductor attachments on the left. An axial MR image (**d**) employing high resolution shows unilateral edema within and around the lower right rectus abdominis at the level of the pubic symphysis

Magnetic Resonance Imaging

The formulation of specific magnetic resonance imaging techniques for these injuries has opened many eyes. We initially showed a soft correlation of MRI with athletic pubalgia [30]. Then specialized pelvic MRI and MRI-hip arthrography became astoundingly accurate in demonstrating pathologic links with the histories and physical examinations [31, 32]. About 7 years ago, the radiologic co-authors designed a specialized technique for demonstrating most of these soft tissue injuries (Fig. 10.6) [33]. The technique resulted from imaging fresh cadavers, and determining the correct angles and ways to reduce bone interference so that attachments to the fibrocartilage pubic plate could be detected. The

Table 10.3 Clinical entities of core muscle injuries

Various core muscle injuries		
Syndrome	Defect	Possible indicated procedure
Unilateral RA/unilateral AD Adductor longus (AL) Adductor pectineus (AP) Adductor brevis (AB)	Tear and compartment syndrome (CS)	Repair and release
Pure AD syndromes	Normally CS	Release and/or repair
Bilateral RA/bilateral AD	Aponeurotic plate disruption; tear and CS	Repair and release
Unilateral/bilateral RA	Tear(s)	Repair
Osteitis pubis variant	Usually tears, CS, bone edema	Repair, release, steroid injection
Unilateral/bilateral	Combination tear(s) and CS	Repair(s) and release(s)
Iliopsoas variant	Impingement and bursitis	Release
Baseball pitcher hockey goalie	AD tear and muscle belly CS	Release
Spigelian and high RA	Tear	Repair
Rectus femoris variant	Impingement	Release
Female variant	Medial disruption; lateral thigh compensation	Repair and release(s)
Round ligament syndrome	Inflammation with tear	Repair and excision
Dancer's variant	Obturatorinternus/externus	Release(s)
Rower's rib syndrome	Subluxation	Excision and mesh
Avulsions	Usually acute adductor injury	Repair and/or release(s)
AD/RA calcification syndromes	Chronic avulsions	Excision, release
Midline RA variant	Tears and muscle separation	Repair
Anterior ischial tuberosity variant	Posterior perineal inflammation, gracilis, hamstrings	Release
AD contractures	Often associated with hip pathology	Release and hip repair
Other variants	E.g., gracilis, quadratus, iliotibial band	Variable

Adapted from Ref. [6]
Any of the soft tissues attached or crossing the pubic symphysis can be involved alone or in combination with other injuries. Note that a patient can have more than one variant
The above syndromes are listed in order of occurrence; highest to lowest
RA indicates rectus abdominis, *AD* adductor

technique uses surface coils and a send-receive body coil. The initially reported MRI sensitivity and specificity rates of 68 % and 100 % respectively for rectus abdominis injury and 86 and 89 % for adductor injury have improved with dedicated core muscle protocols This objective way of demonstrating injuries has provided convincing evidence of the multiplicity of soft tissue injuries as well as the overlap with ball-in-socket hip injuries. Similarly, MR arthrography has become increasingly sensitive in the diagnosis of intrinsic hip pathology, and increasingly accurate with employment of dedicated sensorcaine or lidocaine protocols.

Illustrative Cases/Studies

While we have described many distinct syndromes and procedures to repair the various injuries (Table 10.3), the main point is that many distinct injuries occur in the pelvis, involving soft tissues, bony anatomy or both. *This is not just one injury.* A pattern of injuries follows a set of forces normally symmetrically balanced around the pubis. The new eyes need to capture those dynamics. This appreciation then enables the identification of most of the problems as well as institution of appropriate therapy. Not all the diagnoses require surgery. Plus, a variety of established or alternative modalities may help treat or temporize the various problems depending on the specific injuries. When it comes to surgery, we usually perform direct repair with sutures or compartmental releases of overcompensating muscle groups, or a combination. Note that *release* to us means reducing pressure within a muscular compartment, usually with a set of epimysiotomies, and not division of muscles or tendons. We have devised a variety of compartmental decompressions depending on the particular pathologies.

The following represent several cases that portray part of the spectrum of problems:

Figure 10.7 shows a tear of the obturator externus in a professional ice hockey player during the recent playoffs. See all the edema extending into the more superficial adductor longus. The plate is spared. With steroid injection the day after injury, he was able to play 10 days after injury. The patient will likely not need surgery.

Figure 10.8 shows the imaging of what we call "baseball pitcher/hockey goalie syndrome" but in a National Football League middle linebacker. The injury is caused by fascicular disruption resulting in distal retraction of injured muscle and a compartment syndrome. This syndrome usually resolves with time, sometimes sped by a

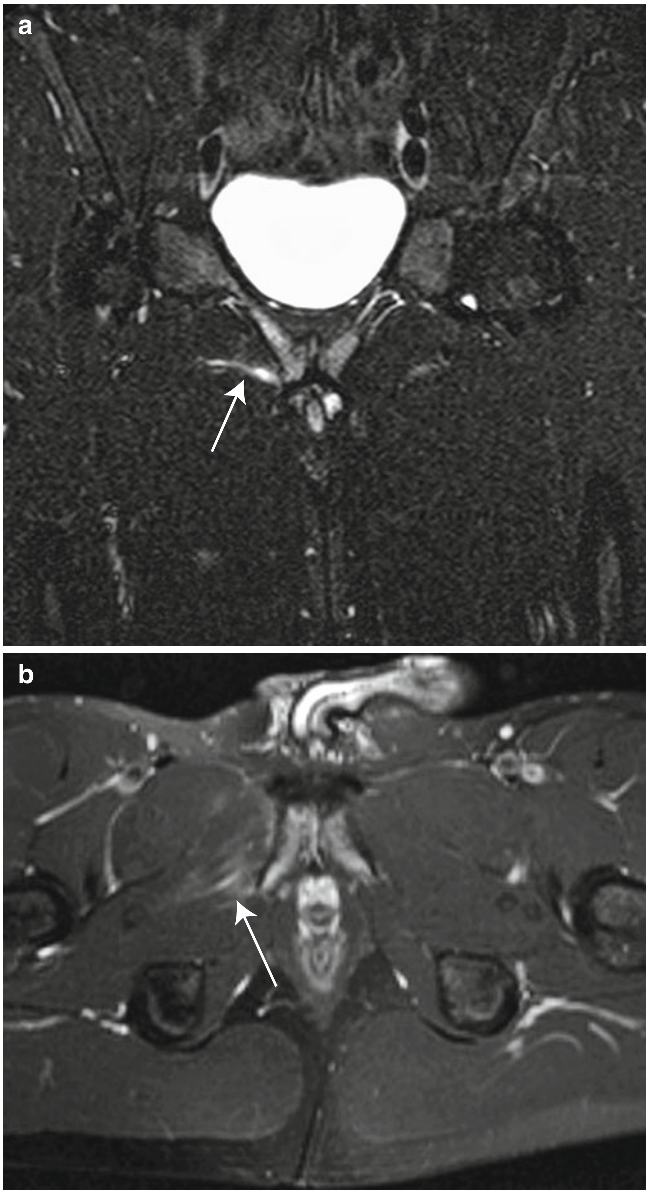


Fig. 10.7 Coronal (**a**) and axial (**b**) MR images from a hockey player show streaky edema following the distribution of the right obturatorexternus (*arrows*)

steroid injection. In this case, the pain did not resolve, and he underwent a compartmental release and nerve decompression and returned to full play 4 weeks after surgery.

Figure 10.9 shows the magnetic resonance imaging of a star soccer player who had undergone an unsuccessful hernia repair with mesh. In fact, he never had a fibrocartilage plate injury and his original pain was entirely due to an intense stress reaction in the ischiopubic aspect of the acetabulum. Fortunately, he got better with 4 months of strict non-athletic activity. In the next off-season, he did end up undergoing removal of his mesh because of the pain and stiffness from the muscular fixation and fibrosis caused by the mesh.

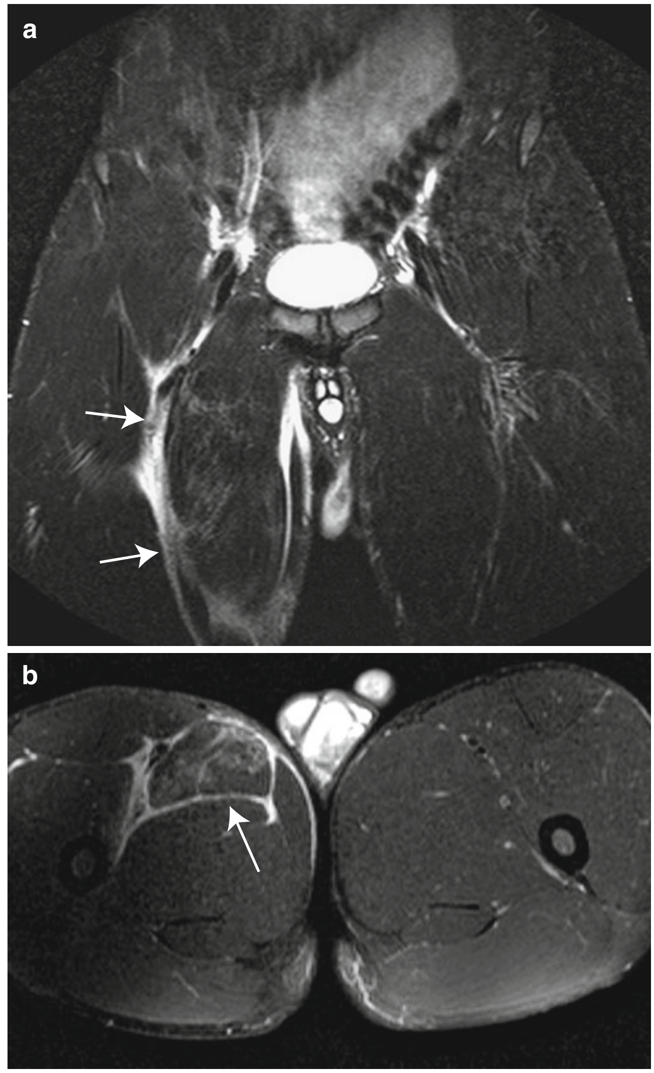


Fig. 10.8 Coronal (**a**) and axial (**b**) MR images show extensive feathery edema throughout the right adductor compartment with enlargement of the pectineus and adductor longus and perimuscular edema (*arrows*) characteristic of baseball pitcher/hockey goalie syndrome

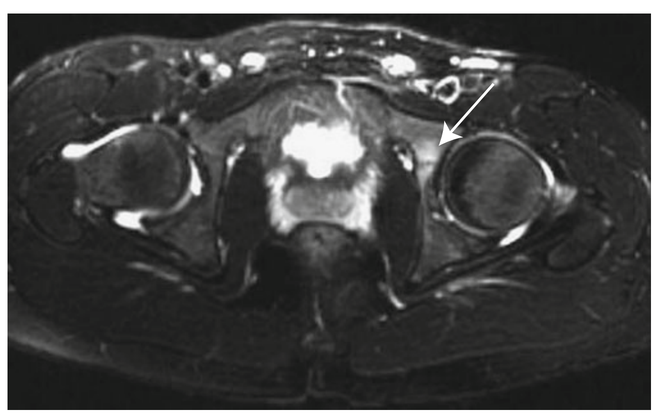


Fig. 10.9 Axial MR image from a soccer player with persistent pain after an unsuccessful mesh hernia repair shows bone marrow edema and a dark, linear lesion at the triradiate cartilage physis (*arrow*) typical for a stress fracture

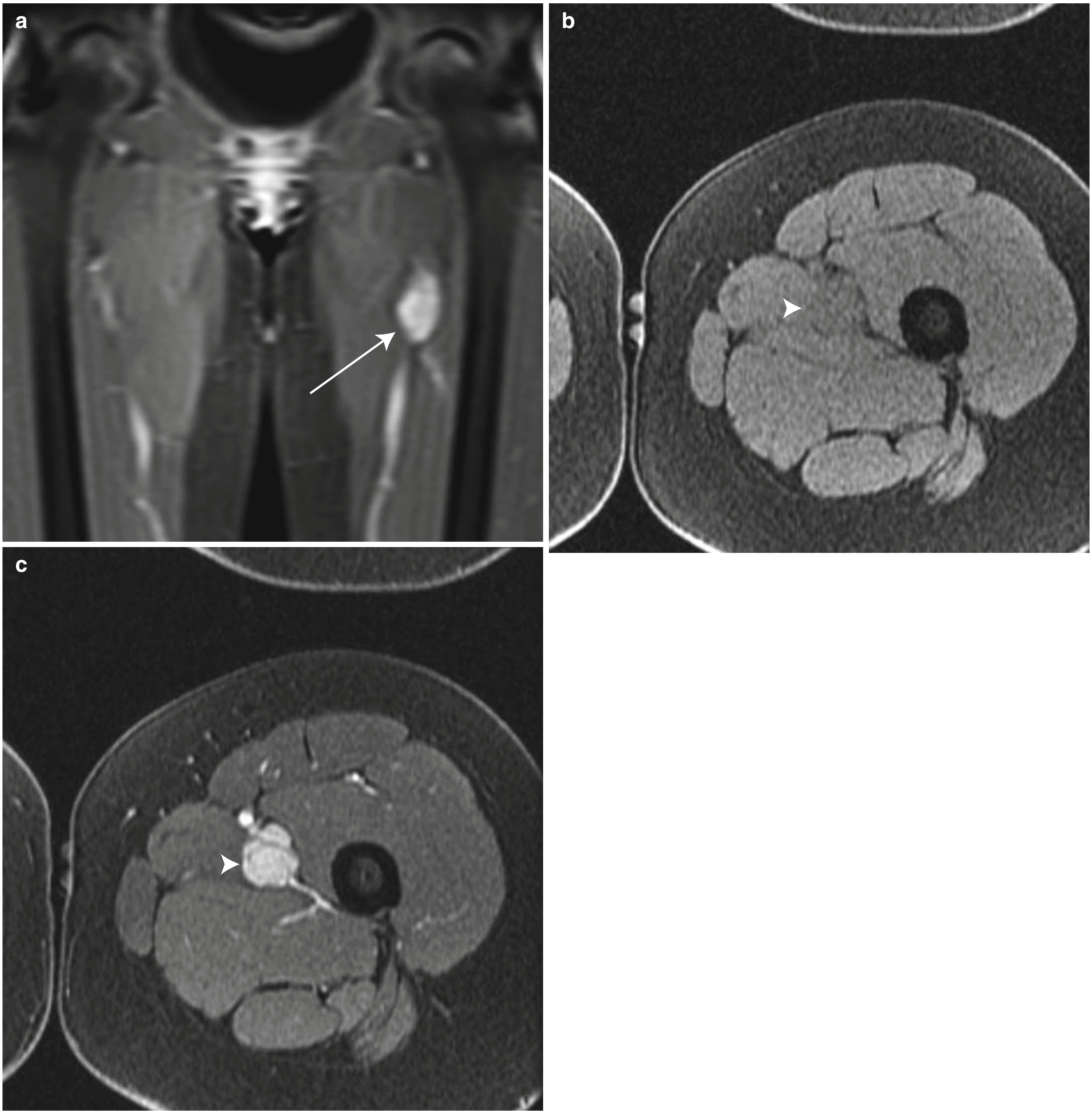


Fig. 10.10 A preliminary coronal localizer MR sequence (**a**) for a 15 year old volleyball player shows a mass within the left thigh adductor compartment (*arrow*). At this point, the MRI was altered to a soft tissue mass protocol. Pre (**b**) and post (**c**) contrast axial images of the left thigh show an enhancing intermuscular solid mass (*arrows*) with feeding vessels indicating an aggressive lesion, ultimately proven a sarcoma

Figure 10.10 is included to remind us of the scarier diagnoses that do occur in the core. This excellent volleyball player and daughter of a prominent football coach had adductor pain caused by this tumor, a usually lethal synovial cell sarcoma. Fortunately, the MRI field was widened, based on clinical examination, and the tumor was caught early. Nevertheless, it had already locally metastasized. She underwent radical resection to include femoral vein resection followed by irradiation and now healthy 6 years out and without recurrence.

Figure 10.11 illustrates what seems to be a common finding in these patients, the association of "osteitis pubis" and plate defects. This was the case in this high level basketball player's MRI. He underwent bilateral rectus abdominis repairs and plate decompression and was competing in the Olympics 6 weeks later. Most patients need surgery for this. *Osteitis pubis* is usually associated

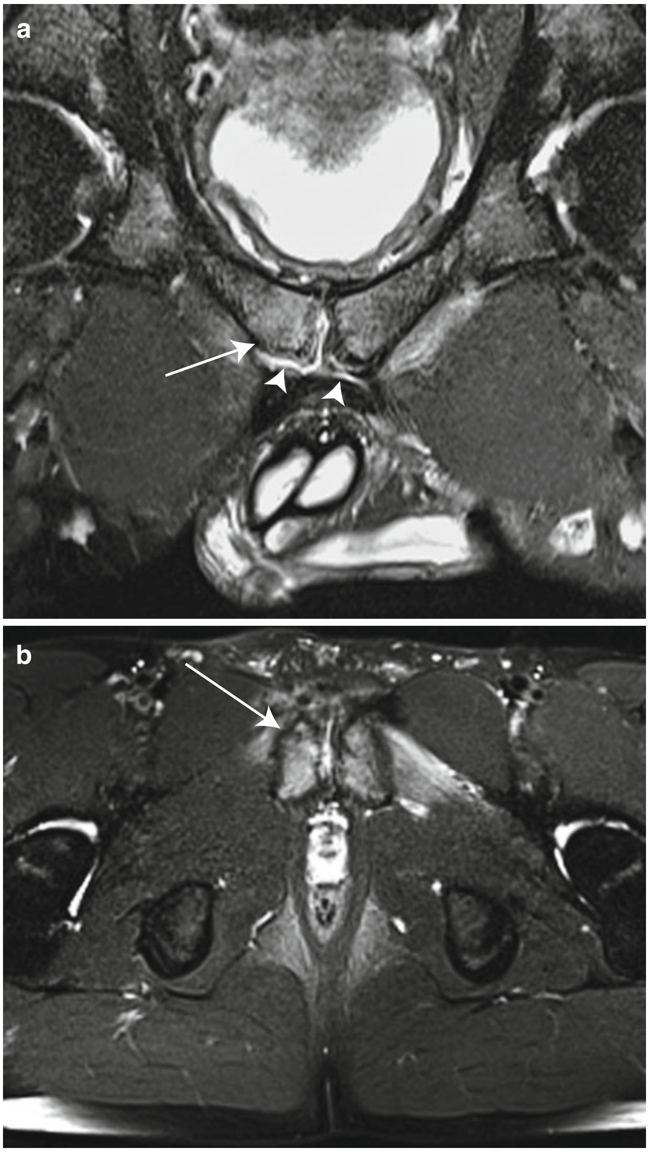


Fig. 10.11 Coronal oblique (**a**) and axial (**b**) MR images show bright bone marrow edema (*arrows*) on both sides of the pubic symphysis indicating osteitis pubis. A large detachment of the pubic plate (*arrowheads*) is also visible on the coronal oblique image

with plate disruption related to core muscle detachment. We have followed three similar patients who did not undergo surgical correction. In each, the fluid accumulation initially was entirely between the fibrocartilagenous plate and the pubic bone. With continued athletic competition, the fluid subsequently got worse, crossed the bony cortex into the marrow and formed pubic symphysis cysts. This progression of findings raises the possibility that the pubis is subject to arthritis like the ankle joint. With injury and continued pressure in the two sites, fluid accumulation and the loss of congruency seems to lead to marrow changes and arthritis.

Finally, let us illustrate two more points. As mentioned, the recently published women athlete study [27] shows nicely how the causes of pelvic pain fall nicely into three categories: hip problems, core muscle injuries and "other problems" with important overlap. The women had a markedly different set of anatomic pathologies than men, almost certainly resulting from gender differences in anatomic structure. Then, the women had combination hip and core muscle injuries all chose to undergo both or neither surgeries, possibly reflecting a more determined group of athletes. The surgical group did extraordinarily better than the non-surgical group. This constellation of observations shows how much we still have to learn about these injuries. We have only begun to understand the risk factors and best treatments.

The second point is that we are seeing an increasing number of patients with persistent or recurrent pain after either "hernia repair" or "minimal repair" (Table 10.4). Fortunately, the success rate is high after re-operation and correcting the primary defects. Unfortunately, we are also finding that many of them were originally not suffering from core muscle injury.

New Nomenclature

For clarity and hopefully facilitation of new knowledge, we recommend a new nomenclature for these injuries. As mentioned, previous terms, most notably the ones using "hernia", have led to inaccurate diagnosis, suboptimal treatment and misconceptions about pathogenesis. The recom-

Table 10.4 Re-do surgery

Type of surgery	# of patients	Subsequent surgery		
		Core muscle	Hip	Other
"Minimal repair"	99	84	12	3
Hernia repair				
Open	123			
Laparoscopic	107			
Both	17			
Total	247	218	22	7
Total	**346**	**307 (87.3 %)**[a]	**34 (9.8 %)**	**10 (2.9 %)**

[a]Overall 1 year success rate for "re-do" core muscle surgery was 93.9 %

Table 10.5 New nomenclature (See text for definitions)

Core
Core injuries
Hip joint
Core muscles
Core muscle injury
Pubic symphysis
Pubic symphyseal joint
Pubic joint or pubic bone joint
Osteitis pubis
Primary osteitis pubis
Secondary osteitis pubis

mended nomenclature (Table 10.5) hopefully encourages fresh questions concerning the physiology and biomechanical pathogenesis. The recommended terms in this section are noted in italics. The nomenclature presupposes five tenets linking the anatomy to these injuries: (1) a spectrum of injuries; (2) a dynamic musculoskeletal nature; (3) the pubis at a center of motor activity; (4) a normal musculoskeletal equilibrium among the anatomic parts; and (5) a biomechanical importance of this region in the body's athleticism.

We recommend the term *core injury* to describe any of the afore-mentioned problems. The term *core* reflects what much of the lay and scientific literature already calls the core, the large block of musculoskeleton that includes the abdomen, pelvis, hip, proximal thigh and back. *Hip joint* refers to the ball-in-socket hip joint alone with its investing capsule, thereby excluding all the muscles outside this narrowly defined hip joint. C*ore muscles* then refer to all the muscles outside the hip joint in this region, and *core muscle injury* refers injury to any of those muscles or any combination of core muscles.

Because the pubis is the center of so much activity, this bone also deserves more distinct terminology. Descriptions of the bone in classic anatomical treatises [34, 35] create considerable ambiguity. Classically, the pelvis has two pubic bones, each divided into a body and two rami. Often "body" and "symphysis" are used interchangeably; yet, the dictionary definition of symphysis "site of fusion" and the term is also used in the singular to denote the site of fusion between the right and left bodies. Most adults still have a distinctly mobile, tiny space between the two pubic bones analogous to the sterno-clavicular joint or acromio-clavicular joint. We recommend this normal mobile space be called the *symphyseal joint*. The pubic symphyseal joint is lined by fibrocartilage and includes an innermost extension of the externally investing *fibrocartilage plate* often called a "disc". The injuries to the pubis may involve either or both pubic bodies, rami, or symphyseal joint. Therefore, we recommend embracing both the plural and singular usages of *pubic symphysis* in the following context. The singular term includes both bodies and the symphyseal joint taken as a whole. In contrast, the plural *pubic symphysis* describes each central pubic body as if it were detached from the other, in which case there are two pubic symphyses: the right and the left.

In distinction from the pubic symphyseal joint, we recommend the term *pubic joint* or *pubic bone joint* to describe all the motion around the pubic symphysis. This term does not satisfy one criterion of a classical orthopedic "joint"; it does not contain two or more juxtaposed bones. Activity around the entire pubis, however, is so balanced and involves so many more degrees of freedom than even the shoulder or hip joint, it deserves a simple designation. The term(s) effectively gets across the activity theme despite the nonfulfillment of that criterion.

We also recommend *osteitis pubis* to apply to any inflammation in or around any part of the pubic bone. The user of the term then has to specify how it is being used. For example, acute or chronic inflammatory changes may be seen in part or all of the pubic bone during imaging or anatomical dissections. Any or all of this may be called osteitis pubis. We would add an additional two modifiers: *primary* versus *secondary osteitis pubis.* Secondary osteitis pubis refers to pubic inflammation when there is an obvious cause for the reaction e.g. muscular injury or obstetrical symphyseal joint disruption. Primary osteitis then refers to discernible pubic inflammation for which no cause is apparent e.g. the non-athletic patient with severe, continual chronic pubic pain, tenderness and imaging findings of pubic inflammation but no other discernible disruption. Considering the two modifiers, some patients may not easily fall into either of the two categories.

Summary and Conclusions

In this chapter we have reviewed the literature and historical and clinical aspects of injuries to the soft tissues around the pubic bone, and made some frank observations. One of the more important ones is that as specialists in medicine, we need to be aware of the limitations of our training. We also propose a new nomenclature to facilitate a common understanding and new knowledge. For *core injuries*, we need to recognize two distinctly separate areas of motion: the *hip joint* and the *core muscles* that attach to or pass by pubic bone. The two joints act together in various ways. Already a fruitful area of research, the concept of *core muscle injury* creates a paradigm shift in how we must advance this field, one that crosses multiple specialties.

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11 Nerve Entrapment

Will B.J. Rudge and Thomas P. Carlstedt

Introduction

Up to 10 % of attendances at sports medicine clinics are due to hip, buttock, or groin pain [1–4]. However, the accurate diagnosis of chronic pain can be difficult, due to the complex anatomy of the region. Nerve entrapment syndromes are a relatively rare cause of pain, yet if a precise diagnosis is made then definitive management can be instituted to good effect. Knowledge of the nerves which may be involved, their anatomy, motor and sensory functions, and the aetiology of their dysfunction, all aid the clinician to manage these complex problems.

The nerves which may be responsible for hip, buttock, or groin pain are those arising from the lumbosacral plexus and its branches (Fig. 11.1). The motor and sensory distributions of these nerves are listed in Table 11.1. Their cutaneous sensory dermatomes are also shown in (Figs. 11.2, 11.3, and 11.4). However, there is considerable overlap of their sensory distributions, as well as marked variation between individuals, and pain may be nonspecific or poorly localised. Furthermore, motor innervations are often not readily testable. It is therefore important to consider neurological causes in athletes with vague or difficult symptoms, and seek appropriate investigations if a nerve entrapment syndrome is suspected.

Investigations

Initial investigations usually involve imaging the painful area and the course of the nerve suspected of causing the symptoms. However, while imaging may have a role in detecting anatomical abnormalities, significant trauma, or tumours and space occupying lesions, the resolution is generally insufficient to allow adequate imaging of the smaller nerves of the lumbosacral plexus. Plain radiographs and computerised tomography are most appropriate for imaging bony anatomy, and magnetic resonance imaging for soft tissue anatomy including proximal nerve root lesions. Ultrasound allows for dynamic assessment, and may be useful for imaging during provocative manoeuvres.

When a specific nerve is suspected electrophysiological studies may help to localise the lesion, as well as giving an indication of the severity and prognosis. Where symptoms are brought on only with exercise it may be necessary to ask the patient to reproduce the symptoms by performing the specific activity or stretch with which symptoms are characteristically associated. Electrophysiological testing may need to be carried out before, during, or after activities, or a combination of all three, in order to obtain a clear diagnosis.

Local anaesthetic nerve blocks can also be a useful diagnostic tool, and are often used to confirm a diagnosis prior to surgical exploration and neurolysis. A careful motor and sensory examination should be carried out before and after administering the nerve block in order to assess its efficacy. Non-diagnostic blocks may be due to poor technique or an alternative diagnosis. In order to improve the usefulness of diagnostic nerve blocks they should be carried out under image guidance wherever possible.

There are also characteristic associations between certain nerves entrapments and particular sports, which may help to guide the clinician towards a likely diagnosis [5]. These are shown in (Fig. 11.5).

Treatment Principles

In the absence of a specific anatomical cause most focal entrapment neuropathies will resolve spontaneously. This usually takes a few weeks or months. During this time rest or

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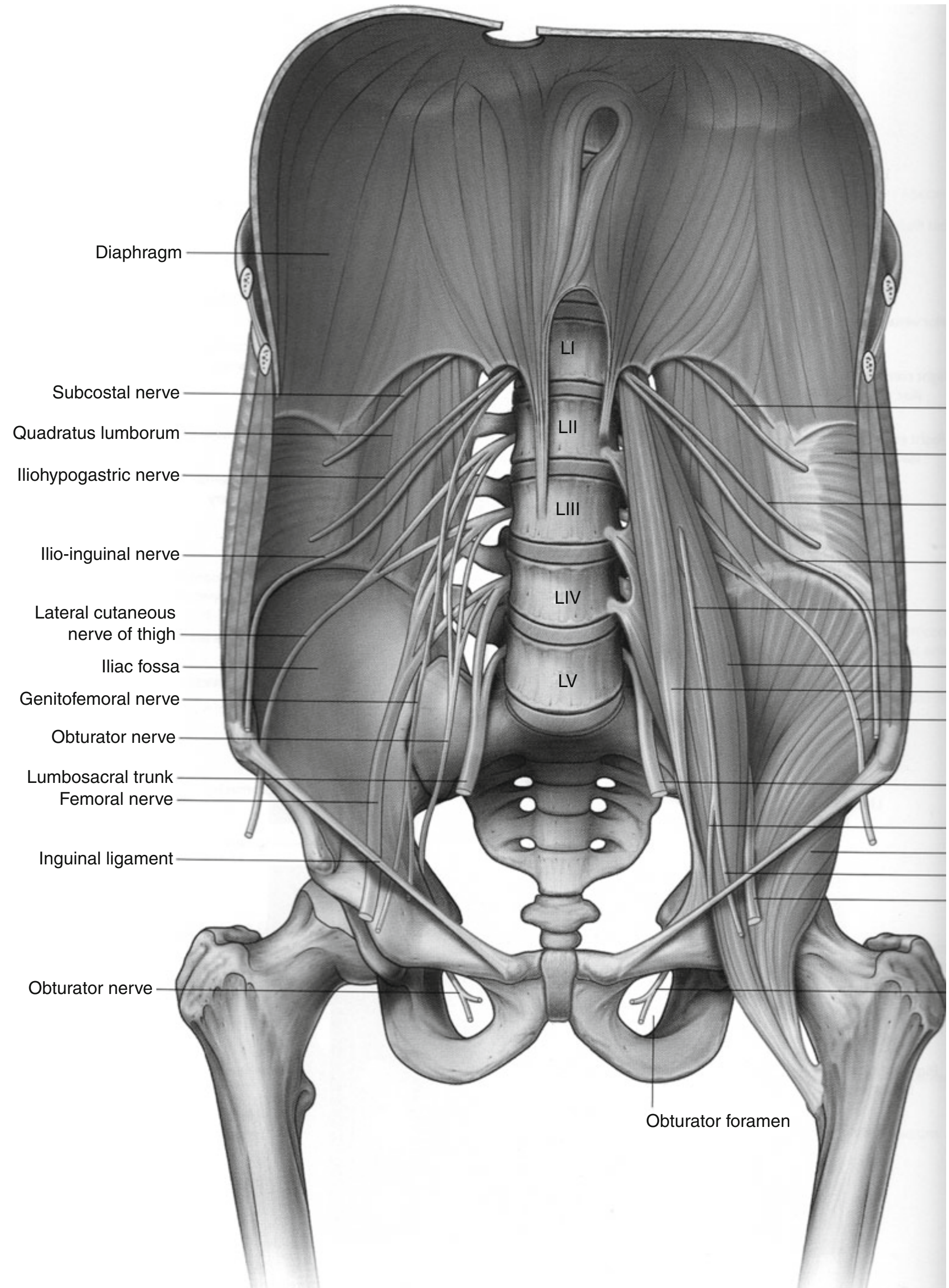

Fig. 11.1 The lumbosacral plexus (Reproduced from *Gray's Atlas of anatomy*, 1st edition)

activity modification, simple analgesics, medications for neuropathic pain, and therapeutic injections of local anaesthetic, with or without corticosteroids, may be useful. Surgical exploration should be reserved for those patients who have a clear diagnosis, severe or persistent symptoms despite adequate non-operative measures, and have evidence of a surgically accessible site of nerve entrapment, with a known or suspected cause. Treatment for each specific nerve is considered in more detail in the relevant section.

Iliohypogastric Nerve

Anatomy

The iliohypogastric nerve (IHN) is the superior branch of the ventral ramus of the L1 nerve root, with occasional contributions from T12. It traverses psoas major and emerges from its lateral border, then curving downwards anterior to quadratus lumborum and posterior to the inferior pole of the

Table 11.1 Motor and sensory distributions of the lumbosacral plexus

Peripheral nerve	Nerve roots	Motor innervation	Sensory distribution
Iliohypogastric nerve	L1	Internal oblique, transversus abdominis	Upper buttock, suprapubic area
Ilioinguinal nerve	L1	Internal oblique, transversus abdominis	Inguinal ligament, upper medial thigh, lateral scrotum or mons/labia
Genitofemoral nerve	L1-2	None	Anterior thigh, lateral scrotum or mons/labia
Lateral cutaneous nerve of the thigh	L2-3	None	Anterolateral thigh
Obturator nerve	L2-4	Adductor longus/brevis/magnus, pectineus, obturator externus	Distal medial thigh
Femoral nerve	L2-4	Quadriceps	Anterior thigh
Superior & inferior gluteal nerves	L4-S2	Gluteus medius/minimus/maximus, tensor fascia lata	None
Sciatic nerve	L4-S3	Hamstrings, all muscles below the knee	None around the hip
Posterior cutaneous nerve of the thigh	S1-3	None	Lower buttock, perineum, posterior thigh
Pudendal nerve	S2-4	External anal sphincter, external urethral sphincter, perineal muscles	Perineal skin, scrotum/labia, perianal skin

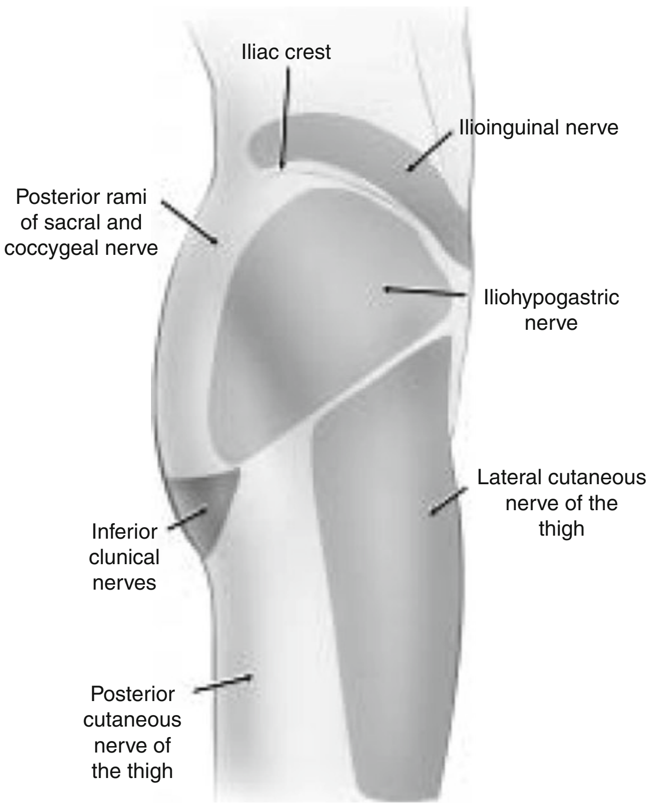

Fig. 11.2 Cutaneous sensory innervations of the hip, groin, and buttock – lateral view (Reproduced from McCrory and Bell [7])

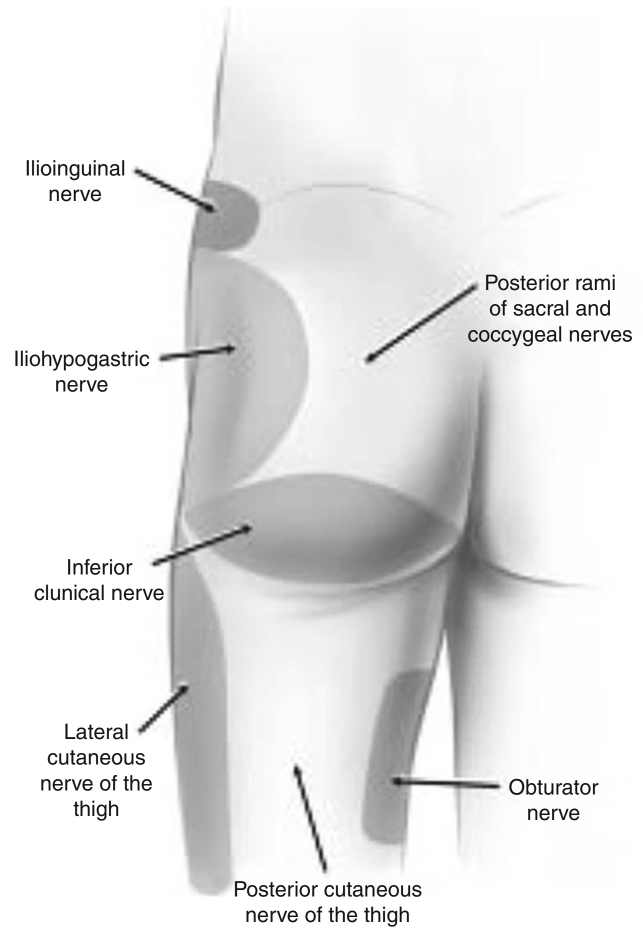

Fig. 11.3 Cutaneous sensory innervations of the hip, groin, and buttock – posterior view (Reproduced from McCrory and Bell [7])

kidney. It pierces transversus abdominis approximately halfway between the anterior superior iliac spine (ASIS) and the most superior point of the iliac crest. Here it gives off muscular branches to the lower fibres of transversus abdominis and the internal oblique muscles, before continuing to run between these two muscles and in line with the iliac crest, as lateral and anterior cutaneous branches. The lateral branch crosses the iliac crest and supplies sensation to the skin of the upper buttock. The anterior branch pierces the internal oblique muscles then becomes cutaneous through an opening in the fascial aponeurosis of the external oblique muscles, approximately 2–3 cm superior to the superficial inguinal ring, and supplies sensation to a small area of skin just superior to the pubis.

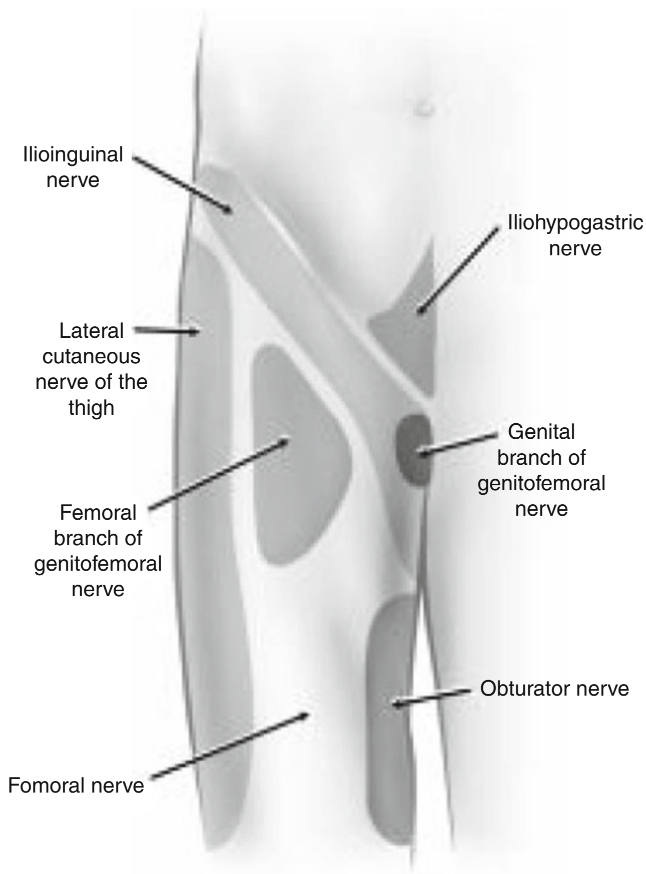

Fig. 11.4 Cutaneous sensory innervations of the hip, groin, and buttock – anterior view (Reproduced from with permission from Toth et al. [5])

Aetiology

Disorders of the IHN are uncommon. The main trunk may be damaged by retroperitoneal tumours or large surgical incisions used to approach the retroperitoneal structures, resulting in sensory disturbance, and bulging of the lower abdominal muscles. The anterior branch may also be damaged by surgical incisions, usually in the lower quadrant of the abdomen [6]. Surgery may result in direct trauma to the nerve, traction injury during retraction, or later entrapment in scar tissue. The lateral branch of the IHN is vulnerable to injury as it crosses over the iliac crest, where it may be subject to direct trauma to the lateral pelvis.

Clinical Features

Injury to the main trunk of the IHN can cause lower abdominal bulging due to paralysis of the lower fibres of transversus abdominis and the internal oblique muscles. This may play a part in the lower abdominal bulging reported with "footballer's hernia" or Gilmore's Groin [7]. Damage to the anterior branch results in only trivial sensory loss in the suprapubic area, although there may be an element of neuropathic pain. Damage to the lateral branch results in sensory disturbance of the upper buttock.

Treatment

If IHN entrapment is likely to be due to previous surgery and scarring then exploration and neurolysis of the nerve should be preformed. A neuroma in continuity may be excised, with repair of the nerve if possible, or burying of the proximal stump in muscle.

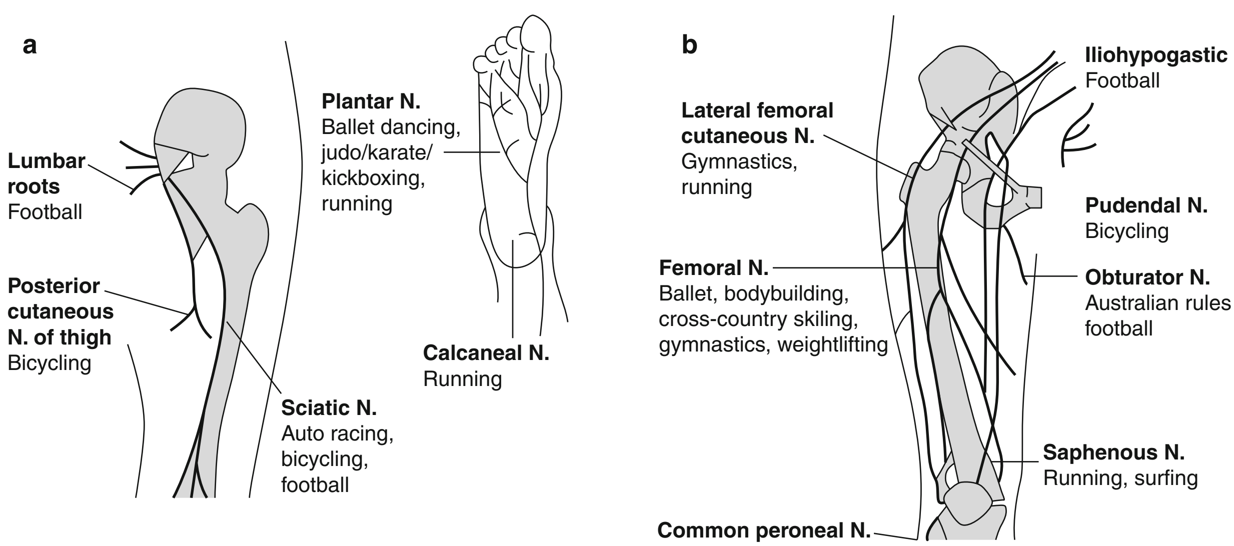

Fig. 11.5 Peripheral nerve system anatomy of (**a**) the ventral lower extremity; and (**b**) the dorsal lower extremity, showing the sports associated with lesions of each nerve (Reproduced with permission from Toth et al. [5])

Division of the nerve and burying of the proximal stump will leave the patient with a permanent sensory and motor deficit, but it may be indicated if debilitating neuropathic pain is present.

Ilioinguinal Nerve

Anatomy

The ilioinguinal nerve (IIN) is the inferior branch of the ventral ramus of the L1 nerve root, with occasional contributions from T12 and L2. Initially it follows a similar course to the IHN, emerging from the lateral border of psoas major before curving downwards anterior to quadratus lumborum and posterior to the inferior pole of the kidney. It pierces transversus abdominis near the anterior part of the iliac crest, and gives off muscular branches to the lower fibres of transversus abdominis and the internal oblique muscles. A small cutaneous branch crosses the iliac crest and supplies sensation to the skin of the upper buttock. The rest of the nerve enters the inguinal canal from the superior aspect (not through the deep inguinal ring), and travels with the spermatic cord through the superficial inguinal ring. The terminal branches supply the skin over the inguinal ligament, the upper medial thigh, and the base of the penis and upper part of the scrotum in men, or the mons pubis and labia majora in women.

Aetiology

IIN lesions are most commonly related to surgical incisions, where the damage may be due to direct injury or secondary compression in scar tissue. Procedures associated with IIN injury include the harvesting of bone graft from the iliac crest [8], appendicectomy [6], herniorrhaphy [6, 9], and procedures using a Pfannenstiel incision [6, 10]. The incidence of iatrogenic IIN injury is likely to fall with the increased use of laparoscopic techniques. Non-post-surgery IIN entrapment is rare, but may be caused by direct trauma, intense abdominal muscle training, or inflammatory conditions [11, 12]. Other causes include pregnancy, due to compression within the muscular layers caused by stretching of the abdominal wall [13], and compression within the inguinal canal due to tumours and endometriosis [14].

Clinical Features

Knockaert et al. described a clinical triad of symptoms consisting of:

1. pain in the inguinal region radiating into the genitals
2. hypo-, hyper-, or dysaesthesia in the cutaneous distribution of the nerve
3. the presence of a trigger point 2–3 cm inferior and medial to the anterior superior iliac spine [15].

The pain is characteristically muscular in nature, and is exacerbated by ambulation, exertion, hip extension, and abdominal distension, and is relieved by hip flexion or a forward inclination of the trunk [15].

Treatment

It may be difficult to distinguish between IIN and GFN lesions on clinical grounds alone, due to the overlap in their sensory distributions and lack of readily testable motor functions. It is therefore important to clarify the diagnosis using local anaesthetic blocks if surgery is being considered. If an IIN block is successful the nerve should be explored in the region of the previous incision, and neurolysis or division of the nerve should be performed. The success rate for surgical exploration of the IIN is around 90 % [16].

Genitofemoral Nerve

Anatomy

The genitofemoral nerve (GFN) arises from the ventral rami of the L1 and L2 nerve roots, passes through psoas major, and emerges on its anterior aspect at the level of L3/4. It descends retroperitoneally on the anterior surface of psoas, and then divides into genital and femoral branches near the inguinal ligament. The genital branch runs medial to the femoral branch and enters the inguinal canal through the deep inguinal ring. In males it supplies the cremaster muscle, spermatic cord, and sensation to the scrotum and a small area of the adjacent thigh. In females it provides sensation to the labia majora and adjacent thigh. The femoral branch, lateral to the genital branch, passes posterior to the inguinal ligament and enters the proximal thigh. It pierces sartorius just distal to the inguinal ligament and supplies a small area of skin on the anterior thigh, just inferior and lateral to the area supplied by the IIN.

Aetiology

GFN entrapment in sportsmen and women is almost always due to previous surgery, and no cases of spontaneous nerve entrapment have been reported [7]. The procedures which are associated with GFN injury are similar to those affecting the IIN, and include appendicectomy [17], herniorrhaphy [9], and procedures using a Pfannenstiel incision [10]. There has also been a single case report of GFN neuropathy cased by external compression from tight fitting clothing [18].

Clinical Features

The main feature of GFN injury is pain or hypoaesthesia in the cutaneous distribution of the nerve. For the genital branch this is the scrotum/labia majora and adjacent thigh, and for the femoral branch a small area of skin on the anterior thigh, just inferior and lateral to the area supplied by the IIN. The entire cutaneous innervation of the GFN lies inferior to the inguinal ligament, which may help to distinguish GFN lesions from IHN/IIN lesions.

Treatment

It can be difficult to distinguish between IIN and GFN lesions, and it is therefore important to clarify the diagnosis using local anaesthetic blocks. If an IIN block fails to improve the symptoms then a block of the L1/2 nerve roots can be performed; if this provides relief of the symptoms then the diagnosis is likely to be GFN neuropathy, and exploration and neurolysis of this nerve should be the initial surgical approach. When exploring the GFN it is necessary to identify the nerve proximally, since the branches within the inguinal region are often too small to be identified accurately. The nerve should be identified as it pierces the psoas major muscle in the retroperitoneum, and can then be either traced distally or divided at that point and buried within the psoas [7]. When the diagnosis is unclear a staged surgical exploration of both nerves may be necessary [16].

Lateral Cutaneous Nerve of the Thigh

Anatomy

The lateral cutaneous nerve of the thigh (LCNT) arises from the fusion of the dorsal divisions of the ventral rami of the L2 and L3 nerve roots. The nerve passes through psoas major and emerges from its lateral border, then crosses iliacus obliquely towards the ASIS. It passes behind the inguinal ligament then passes through a split in the lateral attachment of the ligament to the ASIS [19], before splitting into anterior and posterior branches just anterior and superior to the proximal part of sartorius. The anterior branch becomes superficial approximately 10 cm distal to the inguinal ligament, in line with the ASIS, and supplies sensation to the anterolateral thigh. The posterior branch pierces the fascia lata and supplies sensation from the greater trochanter to the midthigh.

Aetiology

Compression neuropathy of the LCNT is also known as meralgia paraesthetica, and is classically thought to be due to an expanding abdomen secondary to ascites, obesity, or pregnancy [20]. However, there is often no identifiable cause for LCNT entrapment, and it is attributed to compression or kinking of the nerve near the opening of the inguinal ligament [21]. Sports related causes of meralgia paraesthetica include jogging [22], scuba diving, due to direct pressure from the weights belt [20], seat-belt injury [23], parachute harness compression in aviation [24], and gymnastics, due to repetitive trauma on the asymmetric bars [25] or skipping [26]. Iatrogenic injuries to the LCNT can also cause meralgia paraesthetica, with harvesting of iliac crest bone graft, and prone positioning for spinal surgery both recognised as potential causes [27].

Clinical Features

The incidence of meralgia paraesthetica may be as high as 7 % in patients with leg pain referred for neurological evaluation [28], and it typically causes a burning sensation, paraesthesia, or dysaesthesia of the anterior and lateral thigh. This may be exacerbated by standing, walking, hip extension, and activities that cause further direct injury to the nerve, such as a gymnast on the asymmetric bars. Examination is often completely normal, but in some patients symptoms are reproduced by pressure medial to the ASIS, and there may be a positive Tinel's sign in this area.

Treatment

In the majority of patients symptoms will resolve spontaneously with conservative measures such as activity modification, weight loss, and local anaesthetic injections, with or without corticosteroid. There has also been a report of successful non-operative treatment using pulsed radiofrequency neuromodulation [29], although this treatment is yet to be evaluated in any larger studies. Success rates of up to 91 % have been reported for non-operative treatment [19], but if intractable pain persists despite such measures, surgery can be considered. The surgical options are neurolysis or transaction of the LCNT, although which of these should be the procedure of choice is still controversial. Transection is more likely to provide complete relief [30], but causes permanent anaesthesia of the anterolateral thigh.

Obturator Nerve

Anatomy

The obturator nerve (ON) arises from the ventral rami of the L2, 3, and 4 nerve roots, with the major contribution from L3. The rami fuse within psoas major, and the nerve then descends through the muscle and emerges from the medial border, beneath the common iliac vessels and just lateral to the sacrum. It travels along the wall of the lesser pelvis and enters the obturator foramen. Just prior to entering the thigh it divides into an anterior and a posterior branch. The anterior branch leaves the pelvis anterior to obturator internus and descends superficial to adductor brevis, but deep to pectineus and adductor longus. It supplies adductor longus and brevis, gracilis, and occasionally pectineus. It terminates with the formation of a plexus with the saphenous and femoral nerves, and via the plexus supplies sensation to the distal medial thigh. The posterior branch descends on the anterior border of adductor magnus and gives off muscular branches to adductor magnus and obturator externus. Its terminal branch descends to supply sensation to the capsule, synovial membrane, and cruciate ligaments of the knee.

Aetiology

The ON is well protected from direct injury during its retroperitoneal and intra-pelvic course, and traumatic lesions are consequently rare and usually associated with major pelvic trauma. However, the ON may be at risk from compression due to tumours, haematomas, or during childbirth, and may also be damaged by intra-pelvic cement extrusion during total hip arthroplasty [31]. As the nerve enters the thigh it is at risk from entrapment by a thick fascia overlying the adductor brevis muscle [32].

Clinical Features

Patients typically complain of exercise induced medial thigh pain, commencing around the adductor origin and radiating down the medial aspect of the thigh to the knee [32]. There may be associated paraesthesia or sensory loss in the same distribution, and symptoms are exacerbated by hip extension or abduction, which increase tension on the ON [33]. More severe cases can develop adductor weakness, and electromyography may show denervation changes within the adductor muscles [34].

Treatment

Acute ON lesions respond well to conservative management with activity modification and physiotherapy [35]. However, in patients with a delayed diagnosis, adductor weakness/EMG changes, previous trauma/surgery, severe symptoms, or failed conservative management, surgery should be considered. This should be carried out through an oblique incision 2 cm distal to the inguinal ligament, with an interval developed between pectineus laterally and adductor longus medially. The anterior branch of the ON is then identified passing over adductor brevis, and the overlying fascia is split along the entire course of the nerve. This technique has excellent results, with athletes able to return to sports within a few weeks of treatment [32].

Femoral Nerve

Anatomy

The femoral nerve (FN) arises from the fusion of the dorsal divisions of the ventral rami of the L2, 3 and 4 nerve roots. The nerve passes through psoas major and emerges from its lateral border, then passes under the iliacus fascia and descends in the intermuscular groove between iliacus and psoas major. It then passes under the inguinal ligament lateral to the femoral artery and vein. Within the femoral triangle it divides into multiple branches, with muscular branches to the quadriceps muscles and cutaneous branches to supply the skin of the anterior thigh. The terminal branch of the FN is the saphenous nerve, an entirely sensory nerve made up of fibres from the L3 and L4 nerve roots only. It descends alongside the superficial femoral artery in Hunter's canal, then exits the canal and becomes superficial by piercing the roof of the canal approximately 10 cm proximal to the medial epicondyle of the femur. It gives off an infrapatellar branch to supply the skin of the anteromedial aspect of the knee, and then continues distally accompanied by the great saphenous vein. It supplies sensation to the medial aspect of the leg, ankle, and arch of the foot.

Aetiology

The FN is vulnerable to injury from numerous causes, including surgical trauma, pelvic fractures, childbirth, and penetrating trauma [7]. There may also be femoral neuropathy secondary to diabetes [36]. In sports medicine there have been a number of reports of compression of the FN by an iliopsoas haematoma [37–39], with gymnastics being the most common cause. Sports related femoral neuropathy has also been reported in the absence of iliopsoas haematoma, including dancers who perform simultaneous hip extension and knee flexion [40], and bodybuilders [41].

Clinical Features

The symptoms of femoral neuropathy include pain in the inguinal region that may radiate to the knee, or even distal due to the knee, via the saphenous nerve (a branch of the femoral nerve in the thigh). There is also associated sensory disturbance over the anterior thigh and anteromedial leg. Symptoms are partially relieved by flexion and external rotation of the hip. In more severe cases there may be quadriceps weakness, with patients complaining of difficulty in walking and of knee buckling. On examination, patients may present with weak hip flexion (if the lesion is proximal to the inguinal region), weak knee extension, and impaired quadriceps tendon reflex, as well as a sensory deficit as described above.

Treatment

Surgical exploration of the FN is generally unrewarding unless there is an identifiable focal pathology [7], and most patients can be treated successfully with conservative measures. These include knee bracing to prevent giving way, and quadriceps strengthening. Some authors recommend early exploration and decompression in patients with an iliopsoas haematoma [42], particularly if there is an ongoing deterioration in symptoms. However, this remains controversial, with other authors reporting full recovery within 2 months in patients with iliopsoas haematomata treated conservatively [43, 44].

Superior and Inferior Gluteal Nerves

Anatomy

The superior gluteal nerve (SGN) arises from the ventral rami of the L4, 5, and S1 nerve roots. It leaves the pelvis through the greater sciatic foramen, passing above piriformis accompanied by the superior gluteal artery and vein. It supplies gluteus medius and minimus, and tensor fascia lata, but has no cutaneous sensory distribution. The inferior gluteal nerve (IGN) arises from the ventral rami of the L5, S1 and S2 nerve roots. It also leaves the pelvis through the greater sciatic foramen, but passes below piriformis. It supplies gluteus maximus, with occasional branches to medius and minimus. It has no cutaneous sensory distribution.

Aetiology

Sports related gluteal nerve palsies are rare, and are usually traumatic in nature [7]. Recognised causes are injections [45], direct blunt trauma [46], pelvic fractures [47], and surgery [48]. The SGN may also be compressed by the anterosuperior fibres of piriformis, secondary to muscle hypertrophy as the nerve exits the pelvis via the greater sciatic foramen [49, 50]. The IGN may be compressed by space occupying lesions [51].

Clinical Features

The features most commonly associated with gluteal nerve entrapment are an aching claudication-type buttock pain, weakness of abduction of the affected hip leading to a Trendelenburg gait, and tenderness to palpation in the area of the buttock superolateral to the greater sciatic notch [50]. There may also be weakness of internal rotation of the hip, but since the gluteal nerves have no cutaneous innervation entrapment syndromes do not cause any paraesthesia or other sensory symptoms.

Treatment

The diagnosis should be confirmed with electromyography or local anaesthetic blocks. As with most nerve entrapment syndromes an initial period of conservative management is recommended and good results have been reported, even in those with traumatic or postsurgical lesions [52]. In those who fail to improve with non-operative measures surgical exploration and neurolysis should be considered, with division of the piriformis muscle if this is felt to be a significant contributory factor.

Sciatic Nerve

Anatomy

The sciatic nerve is the largest nerve of the lumbosacral plexus. It arises from the ventral rami of the L4-S3 nerve roots, and consists of medial and lateral trunks. The sciatic nerve exits the pelvis through the greater sciatic foramen inferior to piriformis, but occasionally the nerve, or one of its trunks, passes through or superior to piriformis. Having exited the pelvis the nerve passes between the ischial tuberosity and the greater trochanter of the femur, deep to gluteus maximus and in close proximity to the posterior capsule of the hip joint. It then continues distally deep in the thigh, giving muscular branches to biceps femoris from the lateral trunk, and the rest of the hamstrings from the medial trunk. The trunks share a common sheath from the pelvic cavity to the popliteal fossa, where they split to form the common peroneal nerve from the lateral trunk (posterior divisions of the ventral rami of L4-S2), and the tibial nerve from the medial trunk (anterior divisions of the ventral rami of L4-S3). However, the level at which the trunks split is extremely variable, and may be as high as the pelvis. The sciatic nerve has no cutaneous sensory distribution prior to its division into the common peroneal and tibial nerves.

Aetiology

The sciatic nerve may be compressed at any level, but the most commonly encountered problem is due to compression by the piriformis muscle, known as piriformis syndrome. It is generally felt that this is either due to muscle hypertrophy, or to the high degree of anatomical variation of the piriformis muscle and its

Table 11.2 Provocative tests for piriformis syndrome

Name	Description	Reference
Freiberg	Passive internal rotation of the hip in extension reproduces buttock pain	Freiberg and Vinke [58]
Pace	The clinician provides resistance to hip abduction by holding the sitting patient's knee, reproducing pain	Pace and Nagle [59]
FAIR	Maintaining the hip in **F**lexion, **A**bduction and **I**nternal **R**otation reproduces pain	Solheim et al. [60]
Beatty	The patient holds the flexed hip in abduction against gravity whilst lying on the unaffected side, reproducing pain	Beatty [61]

relations with the sciatic nerve. In those patients in whom the sciatic nerve passes through the belly of piriformis the nerve may be "pinched" by the muscle during flexion and external rotation of the hip [53]. However, other authors of cadaveric studies have questioned this theory [54], and suggest that anatomical causes of piriformis syndrome are rare, and more common causes for a patient's symptoms should be sought. Further causes of sciatic neuropathy include blunt trauma, pelvic/hip fractures, surgery, or space occupying lesions. There have also been reports of nerve entrapment at the level of the ischial tuberosity by a fibrous aponeurotic band from the biceps femoris muscle [55].

Clinical Features

The original description of the piriformis muscle as a cause of symptoms described it as a cause of sciatica [56], although the term "piriformis syndrome" is now used more commonly to describe nonspecific buttock and hamstring pain without focal neurological signs. The symptoms usually attributed to piriformis syndrome are a cramping or aching pain in the buttock and hamstring, with a feeling that the hamstring muscle is tight or about to tear [7]. There may also be aggravation of the pain when sitting, and tenderness over the greater sciatic notch. There have been several provocative tests described to try and identify those patients with piriformis syndrome, and these are shown in Table 11.2. However, in a systematic review of the reported clinical features of piriformis syndrome none of these signs was found to be positive in any more than 74 % of patients with piriformis syndrome [57], and they are of questionable value. Focal neurological deficits are also unusual [57].

Treatment

It is important to exclude the more common causes of sciatica before making a diagnosis of piriformis syndrome, and an MRI scan of the lumbosacral spine is mandatory. If this is normal then an MRI scan of the gluteal area may be helpful, and findings of piriformis asymmetry together with sciatic nerve hyperintensity at the level of the sciatic notch have a 93 % specificity and 64 % sensitivity in identifying patients with piriformis syndrome [62]. Initial therapy should focus on activity modification, together with muscle stretching and massage. Image guided local anaesthetic injections provide relief of symptoms in over 80 % of patients, but of those who respond well to injections almost 90 % have recurrence of symptoms within 8 months [62]. If conservative measures fail then surgical exploration and neurolysis should be considered. Prior to surgery electromyography may help to identify the level of the lesion in order to aid surgical planning. If the lesion is at the level of the piriformis muscle then surgery should be carried out using a transgluteal approach, splitting the fibres of gluteus maximus to expose the sciatic nerve, PCNT, PN, and IGN beneath the surrounding fascia and fatty tissue. Any compressive lesion can be identified and addressed, and if necessary the piriformis muscle should be divided at its musculotendinous junction [60]. One series of 62 patients treated surgically reported good or excellent results in 81 %, but no benefit or worsening of symptoms in 6 % [62]. In a smaller series of 15 patients treated surgically all patients reported good or excellent results, and all returned to work and normal daily activities, at an average of 2.3 months [63]. More distal lesions related to an aponeurotic band from the biceps femoris also respond well to surgery [55].

Posterior Cutaneous Nerve of the Thigh

Anatomy

The posterior cutaneous nerve of the thigh (PCNT) arises from the ventral rami of the S1-3 nerve roots. It exits the pelvis through the greater sciatic foramen inferior to piriformis, and then descends down the back of the thigh to the knee. Initially it runs with the inferior gluteal artery deep to gluteus maximus, but inferior to this muscle it continues superficially. It is a sensory nerve only, and gives off perineal branches (the cluneal nerves) that supply the upper medial thigh, perineum, and scrotum or labia (together with the pudendal nerve and GFN). The main nerve gives off multiple small cutaneous branches to supply the lower buttock and posterior thigh.

Aetiology

Isolated lesions of the PCNT are rare. However, PCNT entrapment can be found in combination with sciatic nerve lesions and may contribute to the clinical picture of piriformis syndrome. Causes of PCNT entrapment include iatrogenic injury, blunt trauma, prolonged sitting or cycling, and space occupying lesions [7].

Clinical Features

The PCNT has no motor function, and symptoms are therefore entirely related to pain and sensory disturbance in the distribution of the nerve, and affect the lower buttock, perineum, and posterior thigh. The posterior thigh symptoms may mimic the hamstrings pain and tightness seen in piriformis syndrome.

Treatment

The nonoperative and operative management of PCNT entrapment is similar to that of sciatic nerve entrapment, as would be expected from their close anatomical relationship. Failure to improve with conservative measures should lead to consideration of surgical exploration and neurolysis, with proximal lesions treated via the same transgluteal approach as described for the piriformis syndrome. Decompression of the nerve in the upper hamstrings area requires a different approach, using an oblique skin incision just below the buttock. The lower border of gluteus maximus is identified and elevated superiorly in order to expose the region around the ischial tuberosity. The nerve can then be visualised and any local pathology dealt with accordingly [7].

Pudendal Nerve

Anatomy

The pudendal nerve (PN) arises from the ventral rami of the S2-4 nerve roots, and is the principal nerve of the perineum. It exits the pelvis through the greater sciatic foramen between piriformis and coccygeus, and then runs into the perineal area from in between the sacrotuberal and sacrospious ligaments. It has three branches, with a combination of motor and sensory functions. The first branch is the inferior rectal nerve, which is motor to the external anal sphincter and sensory to the lower anal canal and perianal skin. The second branch is the perineal nerve, which is motor to the muscles of the perineum, the external urethral sphincter, and the erectile tissue of the penis, and sensory to the perineum and scrotum or labia. The final branch is the dorsal nerve of the penis or clitoris.

Aetiology

The PN is rarely injured by direct trauma owing to its relatively protected course. However, surgical manipulation of pelvic injuries may result in pudendalneuropraxia [64], and there have also been several reports of injuries in cyclists due to prolonged compression of the nerve on narrow bicycle saddles [65, 66]. Nerve entrapment occurs between the sacrotuberous and sacrospinous ligaments [67], and may mimic urological or gynaecological conditions resulting in delayed diagnosis or unnecessary surgical intervention [68]. Some authors have suggested an elongated ischial spine as a potential cause of PN compression [67]. This may be as a consequence of high levels of athletic activities as a teenager and young adult, resulting in hypertrophy of the muscles of the pelvic floor and elongation and posterior remodelling of the ischial spine [68].

Clinical Features

Patients with PN entrapment typically present with pain in the penis, scrotum, labia, perineum, or anorectal region, and the pain is usually aggravated by sitting, relieved by standing, and absent when recumbent [68]. There are no pathognomonic imaging or electrophysiological findings, and the diagnosis is a clinical one. The following diagnostic criteria have been suggested (Table 11.3):

Treatment

In cyclists symptoms can often be improved with simple measures such as alterations in saddle position and riding technique. Image guided injections of corticosteroid and local anaesthetic provide benefit in around 75 % of patients [70]. Surgery may be beneficial in those who fail conservative management. In one series carefully selected patients undergoing surgery had good results in 70 % of cases [67]. A randomised controlled trial from the same centre showed a significant benefit of surgery over nonoperative management: at 1 year 71.4 % were improved in the surgical group compared with 13.3 % in the nonoperative group. However, at 4 years only 50 % of surgically treated patients remained improved; the nonoperative group were not followed up beyond 1 year. For a surgical treatment the PN is reached through a transgluteal approach. It is released by dividing the sacrotuberal and sacrospinous ligaments as well as followed into Alcock's canal. The surgeon should be experienced in the complex anatomy of the region.

Summary

Nerve entrapment syndromes are a rare but important cause of chronic pelvic and thigh pain in sport. A thorough understanding of the anatomy and pathology of the region, and

Table 11.3 Nantes criteria for pudendal neuralgia [69]

Essential criteria (must all be present)	
1.	Pain in the territory of the pudendal nerve: from the anus to the penis or clitoris
2.	Pain is predominantly experienced while sitting
3.	The pain does not wake the patient at night
4.	Pain with no objective sensory impairment
5.	Pain relieved by diagnostic pudendal nerve block
Complimentary criteria (may be present)	
1.	Burning, shooting, or stabbing pain
2.	Allodynia or hyperpathia
3.	Rectal or vaginal foreign body sensation
4.	Worsening of pain during the day
5.	Predominantly unilateral pain
6.	Pain triggered by defaecation
7.	Presence of exquisite tenderness on palpation of the ischial spine
8.	Clinical neurophysiology findings in men or nulliparous women
Exclusion criteria (must not be present)	
1.	Exclusively coccygeal, gluteal, pubic, or hypogastric pain
2.	Pruritus
3.	Exclusively paroxysmal pain
4.	Imaging abnormalities able to account for the pain
Associated signs not excluding the diagnosis	
1.	Buttock pain on sitting
2.	Referred sciatic pain
3.	Pain referred to the medial aspect of the thigh
4.	Suprapubic pain
5.	Urinary frequency and/or pain with a full bladder
6.	Pain occurring after ejaculation
7.	Dyspareunia
8.	Erectile dysfunction
9.	Normal clinical neurophysiology

the activities and trauma associated with different sports, will aid the clinician to manage these complex problems. A systematic approach to diagnosis and management is essential.

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Part III

Management Techniques

The Non-operative Management of Hip Disease in Young Adults

12

Noel Pollock and David Hulse

Introduction

Hip pain is a common complaint in the young adult population. Up to 10 % of patients presenting to sports medicine clinics have a primary complaint of chronic hip or groin pain [1–3]. Groin injuries account for up to 16 % of all athletic injuries in elite football players [4]. A high incidence of groin injury is also noted in ice hockey [5], American Football [6] and sports involving running, twisting or kicking [7–9]. Chronic groin injury often presents insidiously and may not always result in an abrupt cessation of sporting activity. The true mechanism of these injuries may therefore be unclear and the incidence under reported. Holmich proposed a 'clinical entities' approach to categorize groin pain as primarily adductor, psoas or rectus abdominis related [10]. However, within that report, the proportion of patients with hip pathology presenting primarily as sports-related groin pain was remarkably small. Only 3 of 207 athletes were noted to have hip joint related pain.

In a 7 year prospective study of 23 professional European football clubs, 12–16 % of injuries requiring time off from training were related to the hip and groin [11]. Adductor injuries were the most common (64 %) and 6 % of cases were diagnosed as hip joint pathology. Of the latter, the most common cause was hip joint synovitis but labral tears and chondral injuries were also noted. Only two patients were diagnosed with femoroacetabular impingement (FAI). This may be explained by the fact that only 16 plain radiographs were performed, perhaps suggesting a lack of awareness of this condition. A prospective cohort study of patients with chronic groin pain in private practice demonstrated hip pathology as the most prevalent group of conditions [12]. A 10 year retrospective study of professional American Football players reported that 3 % of all injuries were localized to the groin [13]. Of these, 5 % were intra-articular hip injuries with the majority being fractures. Only five labral tears were reported in 23,806 injuries recorded in the National Football League (NFL) between 1997 and 2006. The recent increase in utilization of MRI as an imaging modality has identified labral injuries to be a common and significant source of morbidity in the young athlete's hip [14–16].

Subtle morphological abnormalities around the hip joint are being increasingly identified in symptomatic and asymptomatic young adults [17]. Collectively termed FAI, this condition is now a recognized cause of hip pain secondary to chondrolabral dysfunction and a precursor to secondary osteoarthritis (OA) of the hip. It is therefore important for medical practitioners to have a high index of suspicion for FAI in young adults presenting with hip or groin pain. Clear management protocols are also essential to direct appropriate and timely investigations and guide treatment strategies.

Patients presenting with activity related hip pain, biomechanical dysfunction or anatomical abnormalities around the hip require a medical management plan in addition to consideration for surgical intervention. Medical management in these patients may encompass physical therapy, pharmacological interventions and intra-articular injections. Even in patients with a surgically correctable pathology of the hip, a rehabilitation plan focused on improving function and activity is critical for long term success.

The differential diagnosis of hip pain is extensive and accurately identifying the cause of hip pain on history and physical exam alone can be a challenge even for the seasoned physician. Furthermore, multiple etiologies may be present in up to 34 % of patients with chronic groin pain [10]. Normal biomechanics of the hip joint depend on well-coordinated muscle activity around a stable and congruent pelvis and proximal femur. Damage to a single structure may result in an imbalance that requires alterations in activity. These alterations can subsequently place abnormal stresses on other

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structures within the pelvis leading to secondary injury which may be detected clinically [18–20]. Iliopsoas muscle related pain was the most common secondary origin of pain in the Holmich study, consistent with its role as the major hip flexor and its importance in lumbo-pelvic function and stability.

The clinical entity of OA involves a number of different pathophysiological processes in its progression and development. Articular cartilage degradation, tissue synovitis and subchondral bone remodeling are just three examples of pathological processes which may be active in isolation or co-exist. Appropriate identification of active pathology should enable effective and targeted management strategies.

This chapter provides an overview of medical interventions aimed to assist the clinician in developing an overall management strategy for dealing with hip and groin pathology. It discusses a range of non-operative treatment options available including the role of physical therapy, oral medication, intra-articular injections and radiofrequency ablation. The potential role of these modalities in specific pathologies around the hip is discussed.

Physical Therapy

Appropriate physical therapy is a cornerstone for effective management of hip injury in the young athlete. The aim of exercise is to improve function, pain or pathology through the selection or avoidance of particular activities.

Femoroacetabular Impingement (FAI)

FAI is diagnosed when a bony abnormality exists at the proximal femur (cam type) or the acetabulum (pincer type) resulting in abnormal contact between the acetabular rim and the femoral head neck junction during hip flexion results. This results in reduction in range of movement and fissuring at the chondrolabral junction [21–23]. FAI can be painless or painful and limit athletic activity.

The prevalence of cam-type impingement in young asymptomatic individuals is around 15 % [24–26], but it is notably more common in males [25, 27, 28]. Pincer-type impingement is more common in females [29]. It is important for clinicians treating young athletes to be aware of the at risk positions of the hip joint which can increase the likelihood of impingement. Sprinters are at risk during the first few steps after the block start when the hip is in a flexed position [30] and the drive phase causes an internal rotation shear on the hip joint. In ice hockey, the initial push off requires abduction and external rotation of the hip [31, 32], a vulnerable position for the anterolateral acetabular labrum [33]. This is followed by hip flexion and internal rotation, a second at-risk position for the anterolateral labrum. As speed increases, the rate and degree of rotation of the hip joint also increases. The risk of symptomatic impingement and damage to the labrum is likely to be greater at higher velocities [34, 35]. FAI is a likely risk factor for and often misdiagnosed as groin strain [35, 36].

In athletes with recognized FAI, it may be prudent to limit the volume and intensity of the type of training which puts the hip into a vulnerable position. For a sprinting athlete this may mean less time spent doing block starts or hill sessions. The range of motion and joint position that athletes adopt during stretching and drills should also be considered. A muscle strengthening program can be devised to improve deceleration during rotation movements at the hip. Targeted strengthening to ensure optimal force attenuation through the kinetic chain will also reduce impact load on the labrum, chondral and bony surfaces during sporting activity.

The normal range of hip motion is 30–40° of internal rotation in 90° of hip flexion [37]. It has been reported that reduction in the normal range of motion is a risk factor for the subsequent development of groin pain [36]. In patients with FAI, hip internal rotation at 90° of hip flexion is limited to less than 15° [38–40]

When the usual joint range of motion for an athlete with underlying FAI is reduced, the clinician should be prompted to identify triggers and modify activity as required. It is also important to note that aggressive physiotherapy aimed at increasing range of motion is only likely to result in further micro-trauma at the labrum and is not recommended.

In addition to range of motion restriction, there have been some recent studies on FAI related kinematics which can help inform clinical decision making. Painful hip adduction and internal rotation during high intensity dynamic activities has been noted in a case report [41]. There is some good quality research on hip kinematics during walking demonstrating a reduction in hip flexion angle and reduced peak hip abduction angle [42, 43]. It is interesting to note that similar changes are seen in patients with OA and may allude to the role of FAI in the continuum of OA. This notion is supported by a recently published kinematic study which has described a reversal of these changes following FAI surgery [43, 44]. However, a significant portion of the altered biomechanics in FAI may result from hip muscle weakness. A recent study has compared hip muscle strength and EMG activity in patients with symptomatic FAI [45]. Patients with FAI were noted to have significantly reduced maximal voluntary contraction strength, in the order of around 16 %, for hip adduction, flexion, external rotation and abduction. Weakness in these muscle groups, particularly the external rotators and abductors could increase antero-medial bony contact stresses in the hip joint during dynamic activity [46]. There have been some preliminary studies which have demonstrated symptomatic and functional improvement in patients with FAI with a targeted strength and co-ordination program [46].

However, long term benefits of conservative treatment, when reported in the orthopedic literature, are usually limited [17, 47]. Unfortunately, while kinematic studies have been performed both pre and post operatively, these have not usually followed a conservative strengthening program. While the presence of a painful impingement will limit activation and rehabilitation of related muscle groups, the effects of a targeted exercise program on outcomes after FAI surgery warrant further investigation, particularly if combined with other medical strategies to reduce pain.

Labral Pathology

Labral tears of the hip joint can be a significant source of pain and dysfunction [14]. The labrum has a role in shock absorption, lubrication, stability and distribution of forces within the hip joint [33]. There is a clear association between labral tears and early onset OA [48, 49]. The occurrence of labral tears may be associated with trauma, FAI, dysplasia or capsular laxity [50]. In addition to athletes with predisposing anatomy, labral tears often occur in those who undertake repetitive rotational movements on a loaded femur [51, 52]. These movements increase stress on the capsular tissue and iliofemoral ligament. The resultant rotational instability can increase pressure on the anterior superior labrum. Activities requiring frequent external rotation of the hip such as ballet, golf and football have all been associated with labral pathology [15, 16, 53].

Exercise regimens should be based on the predisposing etiology and extremes of movement which place additional stresses on the labrum should be avoided. There is limited literature in this area and one orthopaedic review concluded that physical therapy is not recommended [54]. A therapy protocol has been described in the literature but there has been no critical assessment of its efficacy [55]. The principles of the program were strengthening of iliopsoas, hip abductors and external rotators and addressing gait dysfunction, with the aim of limiting hip hyperextension which would subsequently reduce anterior joint reaction forces [56]. However, there is no strong evidence or rationale to support conservative management and surgical intervention may well be required in athletes with symptomatic labral tears.

Early Osteoarthritis

In early OA, articular cartilage degeneration, subchondral bone remodeling and tissue synovitis can all contribute to progression of clinical symptoms. Pain is the predominant symptom and is often associated with joint stiffness, reduced range of joint motion, instability and muscle weakness. This may result in impaired global physical function and the development of compensatory movement patterns with load transfer to other musculoskeletal structures. With worsening OA symptoms, patients may experience physical and psychological disability which limits activities of daily living and impair their quality of life.

Exercise traditionally plays a role in the management of early hip OA and is specifically targeted towards improving muscle strength, range of motion, joint control and stability. The goals of exercise are to reduce pain, improve physical function and optimise participation in social and recreational pursuits. Whilst these generic goals are applicable to older patients with hip OA, they are equally relevant to the young athlete whose early functional restriction may cause significant psychosocial problems. Although exercise can provide symptomatic relief in hip OA, there is currently no evidence to suggest that it can influence underlying structural disease or modify it [57].

Findings from studies involving patients with knee OA cannot be directly extrapolated to the hip, due to differences in joint biomechanics, type of functional impairment, rapidity of progression and risk factors [57]. Recent systematic reviews have concluded that there is insufficient evidence to support the use exercise as a sole management approach in the short term, for reducing pain, or improving function and quality of life [58, 59]. However, a meta-analysis by Hernandez-Molina et al. [60] which included hydrotherapy, concluded that physical therapy was effective treatment for hip OA when supervised specialist exercises and muscle strengthening were incorporated into a program. In clinical practice exercise normally forms part of a package of care in OA. This includes analgesics, NSAIDs, structure-modifying slow-acting drugs. One feasibility study has found preliminary evidence that hip and knee OA patients can obtain health-related benefits from the combination of glucosamine sulphate and a progressive home-based walking program [61]. Furthermore, in overweight adults with knee OA, the combination of modest weight loss and exercise provided better overall improvements in self-reported outcomes and performance measures when compared to either intervention alone [62]. Clinically, the optimal mode and intensity of exercise for hip OA is unknown and few studies have compared different exercise programs [57].

Exercise regimens for hip OA should be individualized and patient-centered. They require assessment of specific impairments relative to the underlying etiology and degenerative change. In FAI with early OA, addressing strength and co-ordination of specific muscle groups, aimed at reducing anteromedial stress during activity, may improve symptoms and joint function [63]. Aerobic fitness and patient preferences will also influence the regimens used. Individualization of the exercise program to the unique requirements of the patient as well as ensuring availability of resources can be effective in maximizing compliance [57, 64]. There is also evidence that supervision may improve outcomes during an exercise program. Marked improvements in locomotor function and pain have been shown by supplementing a home-based exercise program with physiotherapist-led group sessions [65], and there is evidence from meta-analyses that increasing the number of directly supervised exercise sessions improves the treatment effect [58].

Obesity

When treating the patient with hip OA, weight-reduction strategies form an important component of the overall management strategy. Being overweight (BMI 25–30 kg m^{-1}) or obese (BMI >30 kg m^{-1}) are well-known risk factors for OA. Leptin is an adipose-derived hormone which circulates at levels proportional to body fat and is therefore overexpressed in the obese [66, 67]. It is present in the synovial fluid and, under physiological conditions, stimulates synthesis of IGF-1 and TGFβ-1 by binding to leptin receptors on articular chondrocytes [68]. These mediators are important for chondrocyte proliferation and extracellular matrix (ECM) synthesis and thus have a positive anabolic effect on the joint by increasing cartilage matrix production [69]. However, in pathological concentrations leptin mediates catabolic effects on articular cartilage [70]. Leptin enhances the synthesis of several pro-inflammatory mediators, including PGE_2, IL-6, IL-8 and nitric oxide (NO) [71]. High NO levels result in reduced production and increased degradation of ECM and chondrocyte apoptosis [72]. Leptin also induces synthesis of matrix metalloproteinases (MMP), a large family of enzymes that degrade proteoglycans and other cartilage components, leading to structural damage of cartilage.

These factors suggest that obesity, mediated by leptin, can lead to chondrocyte apoptosis and degradation of the ECM [69]. Obesity can therefore be regarded as a significant modifiable risk factor for OA both as a result of biomechanical joint overload and its adverse metabolic effects. There is therefore a rationale for exercise in OA specifically as part of a weight-reduction strategy.

Oral Medication

Paracetamol

Paracetamol is a widely used simple analgesic with antipyretic properties [73]. It does not have a particular anti-inflammatory effect but is recommended by numerous guidelines in the treatment of early OA [74–76]. It is considered safe at a maximum dose of 4 g per day. Paracetamol is hepatotoxic at higher doses and should be avoided in patients with liver disease and chronic alcohol abuse. The use of an effective analgesic in hip pathology can be of particular importance in conjunction with the overall management plan. If pain is controlled early and appropriate management instituted to address the injury, secondary consequences may be avoided.

A number of reviews and meta-analyses on the role of paracetamol in mild to moderate OA have shown that it is effective in providing early pain relief but that NSAIDs are marginally superior in improving hip and knee pain, particularly in advanced OA [77–79]. It is widely accepted that OA is an inflammatory arthropathy and it is to be expected that reducing inflammation will result in greater improvements in pain. The majority of studies have included hip and knee OA within the same group. Recent studies have noted moderate clinical heterogeneity between patients with knee or hip OA and therefore recommended that future research considers these as separate clinical conditions [80].

NSAIDs

Non-steroidal anti-inflammatory drugs (NSAIDs) are recommended for use in the management of hip OA [74, 75, 81]. NSAIDs function both centrally and peripherally, and are primarily effective in reducing inflammation and nocioceptor-mediated pain through Cyclo-Oxygenase (COX) inhibition [82]. Inhibition of COX results in a decrease in prostaglandin synthesis.

Oral NSAIDs are essentially divided into those that are selective for COX-2 inhibition and those that are nonselective for COX-1 and COX-2 [83]. COX-2-selective NSAIDs were developed to reduce the risk of gastric bleeding and ulceration since nonselective COX inhibition reduces synthesis of certain prostaglandins which protect gastric mucosa against acid attack. Significant gastro-intestinal complications such as bleeding or perforation occur in 0.2 % of patients taking COX-2-specific agents, compared with 2 % taking non-selective NSAIDs [84]. However, COX-2 inhibitors have potentially substantial cardiovascular risk [85], and as a direct result, two widely distributed COX-2 inhibitors (rofecoxib and valdecoxib) were recently withdrawn from the market. NSAIDs can also adversely affect renal function and both NSAIDs and COX-2 inhibitors can adversely effects bone and tendon healing [86–88].

NSAIDs are routinely recommended in OA if paracetamol alone cannot control symptoms or if there are signs of clinical inflammation [74, 75, 81]. They should be used at the lowest effective dose and consideration should be given to the concomitant use of a gastro-protective agent such as a proton pump inhibitor or misoprostol in patients with increased gastrointestinal risk. One systematic review found NSAIDs to be slightly more effective than paracetamol in patients with hip OA [80].

In non-arthritic hip conditions, the rationale for using NSAIDs should be based on the presence of concomitant inflammation. In labral injury or FAI, the clinical presentation can include episodes of joint synovitis which may respond to short-term use of NSAIDs. OA has not previously been synonymous with inflammatory arthropathy, though we now know that inflammatory mediators are expressed in the cartilage and synovial tissues in the early stages of OA and that they are involved in cartilage degeneration [69]. NSAIDs in early OA may have a disease-modifying role.

Codeine Based Medication

Opioids have been shown to be of some benefit for the treatment of pain associated with arthropathy [89, 90]. However, their use may be associated with adverse events, particularly nausea, dizziness and constipation. This may limit their role in the treatment of the young adult hip. They may be helpful for short term pain relief but should not be used regularly as a long term treatment option.

Glucosamine and Omega-3 Fatty Acids

Articular cartilage has limited ability to regenerate or adapt to altered mechanics. It is avascular and receives nutrients by diffusion from surrounding tissues and joint fluid. Chondrocytes maintain composition and organization of the ECM which consists of a network of collagen and elastin within a proteoglycan gel [69]. Proteoglycans have a net negative charge and hold a large amount of water within the cartilage. They confer resilience and elasticity to cartilage and aid in lubrication of the joint system. Proteoglycans are large molecular complexes, composed of a central hyaluronic acid (HA) filament, to which aggrecan molecules composed of chondroitin sulfate and keratan sulfate are attached. In OA, the balance between catabolic and anabolic processes within articular cartilage is disturbed and chondrocytes are unable to compensate for the loss of collagen type II fibers and proteoglycans despite increased synthesis [91].

The amino-monosaccharide glucosamine is an essential component of proteoglycan synthesis. The availability of glucosamine, synthesized from glucose in human tissues, is one of the rate-limiting steps in proteoglycan production [69]. As a dietary supplement, glucosamine may overcome this rate limitation and support joint health as suggested by numerous in vitro studies [92–94]. Glucosamine enhances production of aggrecan, collagen type II, and HA [93]. It may prevent collagen degeneration in chondrocytes by inhibiting lipoxidation reactions and protein oxidation. It may also inhibit the predominant cleavage enzymes in cartilage (MMP and aggrecanases) and hence prevent proteoglycan degradation [94, 95].

Inflammation in OA is not simply a secondary event [96, 97]. Inflammatory mediators are expressed in cartilage and synovium in early OA in response to mechanical overload, trauma, and obesity. Benito et al. [98]. have found that expression of both inflammatory mediators and transcription factors from the inflammatory cascade is significantly higher in the earlier stages of OA. A combination of inflammation and oxidative stresses leads to cartilage degeneration and chondrocyte apoptosis. Glucosamine has been shown to act in a number of ways to modulate the inflammatory cascade and exert an anti-oxidant effect. In particular, glucosamine may suppress the IL-1 induced expression of COX-2 and NO [99], two mediators which trigger inflammation and are implicated in chondrocyte apoptosis.

In clinical trials, glucosamine has been shown to delay progression of knee OA. Similar effects have not been demonstrated in hip OA, for reasons that are unclear. There are a number of contentions why this may be so. The anatomy, vascular supply and cartilage loading within the hip are very different to that in the knee. Nevertheless, in evaluating the evidence from available clinical trials, meta-analyses and reviews in knee OA, authors have concluded that long term treatment with glucosamine reduces pain, improves function and mobility of the joint, reduces disease progression and reduces risk of total joint replacement [100, 101]. These conclusions have also been applied to recommendations for hip OA despite the limited clinical evidence. Glucosamine sulphate is taken as a daily dose of 1,500 mg and most trials have demonstrated tolerance of this dose at least the same as placebo and better than for NSAIDs. There has been conflicting evidence on the effect of glucosamine from both clinical trials and meta-analyses, with high placebo effect, subject heterogeneity and bias due to industry funding all cited as potential confounding factors. A network meta-analysis by Wandel et al. [102]. in the British Medical Journal concluded that "compared with placebo, glucosamine, chondroitin, and their combination do not reduce joint pain or have an impact on narrowing of joint space". Furthermore, they recommended that patients on these supplements may continue their use based on good safety and perceived benefit, but that new prescriptions should be discouraged given the lack of putative clinical relevance. However, Bruyere [103] has challenged their trial selection, high study heterogeneity and the use of a complex Bayesian analysis. Glucosamine supplementation is recommended by European and international guidelines on the treatment of OA and there is a wealth of data from in vitro studies and clinical trials and reviews which provides a sound rationale for its use in chondropathic conditions [101, 104–106].

Chondroitin sulphate is a natural glycosaminoglycan and an important component of the extracellular matrix. The European League Against Rheumatism recommendations regarding knee OA gave chondroitin sulphate the highest evidence grade and recommend that effects may be noticeable within 3 weeks [107]. In addition to its role as constituent of the ECM it can increase hyaluronan production and stimulate further anabolic effects [108, 109]. There are some clinical and in vitro studies which suggest that chondroitin and glucosamine may have synergistic effects [110, 111].

The role of glucosamine and chondroitin in the synthesis and composition of large proteoglycans, such as aggrecan, has led some researchers to question their use in patients with tendinopathy [87]. In reactive tendinopathy which is characterized by tendon swelling and aggrecan production [112, 113], an increase in proteoglycan synthesis may be detrimental. Although tendon pathologies around the hip are usually inflammatory in nature, it may be prudent to avoid the use of glucosamine in iliopsoas or gluteal tendinopathy especially in patients with concomitant reactive patellar or Achilles tendinopathy.

Omega-3 polyunsaturated fatty acids are known to have anti-inflammatory and antioxidant effects and have been used as dietary supplements in rheumatologic conditions. Polyunsaturated Fatty Acids (PUFAs) are also important components of dietary therapy in OA. Reactive oxygen species are generated in OA and have been shown to be involved in cartilage degradation [114, 115]. A recent study has demonstrated a synergistic effect between glucosamine and omega-3 fatty acids s in markedly reducing morning stiffness and pain in hip and knee pain OA [116]. The anti-inflammatory effects of omega-3 PUFAs have been shown in several studies [117–119] and they may be useful in inflammatory hip disease.

Vitamins and Minerals

There is limited clinical evidence demonstrating increased oxidative stress and reduced total antioxidant capacity in patients with OA [120]. Vitamin C and E are antioxidants which may stimulate collagen and proteoglycan synthesis [121, 122]. The role of Vitamin D in muscle strength is well established and a few small studies have noted that low levels of Vitamin D can increase progression of OA [123]. Selenium, Zinc, Manganese and Copper all have theoretical beneficial effects on proteoglycan synthesis and chondropathy but clinical evidence is currently limited and they cannot be strongly recommended.

Calcitonin

Calcitonin is produced by parafollicular C cells in the thyroid. It has a key role in calcium and phosphate regulation through increasing the effect of Parathyroid Hormone (PTH) and limiting calcium mobilization from bone. It is a weak inhibitor of osteoclasts and has also shown to inhibit MMP and block collagen degradation in chondrocytes [124]. In animal studies, calcitonin has been shown to be a disease modifying agent [125, 126]. A small clinical study has also noted improved functional scores in patients with knee OA using calcitonin [127]. It is recognized that subchondral bone changes and remodeling are involved in the initiation and progression of early OA. They are also usually a concomitant feature of acute intra-articular pathology. The precise nature of the interaction between articular cartilage and subchondral bone is not completely clear. It has been proposed that subchondral bone changes precede the development of cartilage degradation [128] and that bone produces a number of cytokines and eicosanoids that can induce these cartilage changes [129, 130]. Other studies suggest that subchondral bone changes occur secondary to cartilage degradation and subsequent microfissuring [131–133]. Regardless of the timing of these events, it would appear that the relationship between subchondral bone and cartilage is a key factor in both joint health and pathology [134]. With improvements in MRI scanning it is possible to observe bone marrow activity at subchondral sites [135–137]. While clinical studies are still awaited, treatments targeted at subchondral bone such as calcitonin and strontium may prove to be effective in improving subchondral bone homeostasis and subsequent intra-articular health.

Intra-articular Injections

Corticosteroids

Corticosteroids are strong anti-inflammatory agents that limit the inflammatory cascade through a reduction in vascular permeability and inhibition of leucocyte activation. They also inhibit inflammatory mediators such as prostaglandins, MMPs and interleukins [138–140]. MMPs are catabolic enzymes that are implicated in cartilage matrix degradation. Interleukins 1 and 6, amongst others, are associated with the synovitis that is present in inflammatory and degenerative joint disease and implicated in cartilage breakdown early in the pathological progression of OA [141, 142].

There are notable consequences of repeated intra-articular corticosteroid injections (IACSI). Corticosteroids inhibit fibroblasts and collagen production. Inhibition of osteoblastic and osteoclastic function limits bone remodeling. Cartilage breakdown has been reported following IACSI [143, 144] Cystic lesions and thinning of articular cartilage have been noted in weight bearing joints injected with corticosteroids. There is also a marked reduction in the elasticity of articular cartilage following IACS due to a degradation of the cartilage matrix [145–147]. Corticosteroid, particularly if combined with local anaesthetic is chondrocyte toxic [148–150]. With repeated injections and subsequent chondrocyte death, cartilage may be unable to regain its natural physical properties [151]. The injection of corticosteroids into the joints of young patients should therefore be considered carefully. An early return to running following steroid injection is more detrimental to cartilage. It may be preferable, to inject into the inflamed synovium rather than the joint fluid.

The most common and significant local adverse effect of IACSI is pericapsular or intracapsular calcification [139, 152]. These calcifications, composed of hydroxyapatite, may become inflamed and interfere with normal joint mechanics. Atrophy of the adjacent soft tissues is also a possibility. The psoas muscle lies directly anterior to the hip joint. Degeneration and atrophy of psoas fibres is certainly a possibility following injections into the hip joint. This can be minimized by guiding needle placement into the joint before attaching the syringe containing steroid and by avoiding injecting steroid during needle withdrawal. Avascular necrosis is a recognized complication, and usually follows several injections within a short time frame. Rapid destruction of the femoral head has been described in women with unilateral hip OA [153]. On microscopic assessment, total necrosis of the underlying trabecular bone is noted and it is recommended to consider avoidance of IACSI in severe chondral disease with underlying bone marrow edema and microfissuring into the subchondral bone. Joint infection is another serious complication and it is essential that an appropriate antiseptic and no-touch technique is performed. It is recommended that all injections of the hip are performed under radiographic guidance and after joint aspiration if an effusion is present.

A number of expert opinion studies have suggested a role for corticosteroids in therapeutic pain relief and in patients who are not candidates for total hip arthroplasty due to co-morbidity or young age [154, 155]. Clinical guidelines for the use of corticosteroids in OA are generally based on studies performed on knee OA patients [74, 75]. The evidence suggests some short term benefit in pain over the course of 4–6 weeks but this is not maintained and improvements in function and stiffness are minimal [156]. Predictors of improvement in some studies were the presence of synovitis and successful joint aspiration prior to injection [139, 157]. A prospective cohort study on hip OA has shown improvements in pain and stiffness at 6 and 12 weeks [158]. In young athletic patients with active synovitis, bursal inflammation, intact cartilage surfaces and normal subchondral bone requiring short term pain relief or reduction in inflammation after an acute incident (e.g. a labral injury), IACSI may be an appropriate option. It can provide short term relief in patients with FAI and associated peri-articular inflammation. This may be particularly useful during certain stages of an athletic season. However, if limited mobility rather than pain is the most significant presenting feature, short term improvement with intra-articular HA may be more appropriate, prior to surgical consideration.

Viscosupplementation

Viscosupplementation is the intra-articular injection of HA and was first presented as a therapeutic option over 20 years ago [159, 160]. The rationale for its use is based on the importance of HA in synovial joints. HA is a polysaccharide produced by chondrocytes and synovial cells [161] with a molecular weight of around 1×10^7 Da. It is the major constituent of synovial fluid and a component of the ECM of cartilage and the superficial synovial membrane. It has an important role in directly maintaining the structural and functional integrity of cartilage and indirectly in enabling normal joint mobility and effective shock absorption. The viscoelastic properties of HA can increase viscosity to provide lubrication during low shear movements and, alternatively, it may provide shock absorption by reducing viscosity and increasing elastic properties during high shear and faster movements [162, 163]. In OA the composition of synovial fluid changes with reductions in viscosity and elasticity [164] thereby increasing susceptibility to injury. The average molecular weight of HA in OA is also reduced to around 2×10^5 Da.

In addition, to its role in joint mobility and cartilage health, HA has an important function in maintaining joint homeostasis through modulation of the inflammatory response. HA can inhibit the release of arachadonic acid and Interleukin-1 (IL-1) [161, 165]. IL-1 is an pro-inflammatory cytokine which may induce cartilage degradation in culture models [166] and can be detected in inflamed synovial tissue [142]. IL-1 also stimulates the production of prostaglandin E2 (PGE2), a pro-inflammatory factor present in early OA [98].

HA preparations differ in their origin, molecular weight, biological characteristics and pharmacodynamics [167]. A number of proposed mechanisms exist for improved outcomes following intra-articular HA injections. HA injection may immediately reduce the activity of nociceptive afferents [168] and provide short term pain relief. Additionally, HA can modulate an anti-inflammatory effect through the reduction of PGE2, IL-1 and other inflammatory cytokines [165, 169]. This provides the rationale and supportive evidence [170, 171] for effective initial reduction in pain following intra-articular HA injection to a painful, inflamed joint with potential advantages for future cartilage preservation. However, a number of large meta-analysis and systemic reviews on knee OA have generally found delays in efficacy of around 4 weeks [172, 173].

HA injection is effective in stimulating synovial cells to synthesize endogenous HA [174–176]. This may be one potential mechanism for long term effects following injection since retention within the joint is only short-term [177]. Intra-articular retention may be increased to several weeks by the use of high molecular weight preparations. There is, however, conflicting evidence regarding clinical efficacy of high molecular weight HA (HMWHA) relative to low molecular weight HA (LMW HA). Some studies have identified that HMWHA is more effective in pain relief for knee OA [178], proposing that higher viscoelastic properties improve efficacy [160]. Other studies have found no difference in clinical efficacy between different molecular weight

HA injections in hip and knee OA [179, 180]. While HMWHA is more biologically active and similar to endogenous HA, there is some evidence that it may be less effective in penetrating the synovial ECM and reducing synovial inflammation [181]. A rational interpretation of the currently conflicting literature on the differences between various preparations may be that HMWHA is more appropriate for the functional restoration of joint mobility and that LMWHA more appropriate to target active synovitis.

The ability of intra-articular HA to directly preserve or improve cartilage structural integrity is currently unclear [182]. It has been reported that HA may improve chondrocyte density and articular cartilage reconstitution in vitro [183]. Cartilage preservation has been also identified in experimentally induced models of knee OA [184]. However, in clinical studies HA has not been shown to be a long term disease modifying agent [185].

The most comprehensive systematic review assessing intra-articular HA is a 2006 Cochrane review on knee OA [167]. There was support for a small reduction in pain over 3 months with maximal efficacy at 5–8 weeks following injection. In comparison, a recent meta-analysis identified greater pain relief following corticosteroid injection at 2 weeks but not at 4 weeks and greater benefit of HA at 8–26 weeks [186]. It is difficult to extrapolate the evidence for HA in the knee joint to the hip. The hip is clearly a very different joint biomechanically and anatomically. It should be recognized that in a significant number of patients there is a communication between the hip joint and iliopsoas bursa [187, 188] with the potential consequences of dispersal of injection from the joint.

In hip OA, there have been a number of recent studies of generally poor methodological quality. Migliore [189] performed a prospective non controlled study on the symptomatic effects of HA, using Hylan G-F20. They noted improvement in pain, functional scores and NSAID consumption. A number of other studies have shown similar improvements with a variety of HA preparations and no differences between preparations [179, 190]. A more recent study in 120 patients noted significant improvements in hip pain, mobility and function with 6 monthly HA injections [191]. The same study group also reports a 6-month RCT comparison of HA to Mepivicaine and noted a reduction in pain and improved function following HA injection [192]. While there have been no high quality long term studies of the efficacy of HA in hip OA the available evidence, albeit with a possible positive publication bias, does point to a role for HA in hip joint OA. From the previous discussion regarding the mechanism of action of HA it is possible to rationalize that this would be most effective in hip joint synovitis, early chondropathy and synovial restrictions in hip joint range. In early chondropathic states, the cartilage is likely to be more responsive to a normalized synovial fluid environment. It is likely to be less helpful in restriction due to bony impingement or in advanced chondropathic or subchondral bone disease.

Most studies investigating HA injection into the hip have commented on the importance of ultrasound or fluoroscopic guidance [193, 194]. The hip is a difficult joint to inject without guidance [195] and there is a high risk of adverse events. It is our recommendation not to inject intra-articular local anaesthetic during the intervention, due to the chondrotoxicity of local anaesthetic [150]. The anterior approach is recommended due to the large target area between the femoral head and neck within the anterior recess of the anterior capsule. This approach also prevents damage to the labrum or articular cartilage from the needle tip. If an effusion is present, this should be aspirated prior to HA injection to prevent dilution. Injection of HA into the hip joint appears to be safe and well tolerated and reported complications in the literature are rare [196, 197]. The most commonly reported side effect is a transient increase in minor localized pain, within the first week following injection [191, 198].

Platelet Rich Therapies

Growth factors (GF) are essential for the repair of injured tissue through the stimulation of various aspects of tissue healing. Platelets contain growth factors, such as insulin-like growth factor, transforming growth (TGF) and vascular endothelial growth factor (VEGF) in their α-granules. These are released at the site of injury and aid repair. This theory has led to the development of a variety of therapies based on delivering more platelets (and therefore GFs) to the site of injury. Platelet therapies, including platelet rich plasma (PRP), have been used for more than 20 years in the fields of dentistry and maxillofacial surgery and more recently in the treatment of musculoskeletal injury [199, 200]. In the context of intra-articular hip pathology, TGF β and platelet derived GF are known to have important roles in cartilage regeneration [201–203]. Laboratory studies have also shown the efficacy of platelet rich therapies in reduction of the inflammatory effects of IL-1 on human chondrocytes [204]. While these basic science studies are encouraging, there have been limited clinical studies in hip pathology to date. A number of pilot studies on patients with knee and hip OA [205–207] have shown encouraging results particularly in young patients with early chondropathic changes. Further research in this area is needed.

Radiofrequency Ablation

The hip joint capsule is innervated by sensory branches of the obturator, femoral and superior gluteal nerves [208]. The groin and medial thigh pain which is often present with hip pathology is usually mediated by the articular branches of the obturator nerve. It is recognized that minor pathology in the groin can have numerous secondary effects on the function of other structures, particularly the iliopsoas and adductor musculature. In the young athlete with hip pain arising from an acute synovitis or FAI, the secondary effects on pelvic function may be more debilitating on athletic performance than the pathology itself. Assuming that the overall management plan can address the underlying biomechanical or structural problems, a short term pain relieving procedure may be particularly effective for athletic performance and minimizing secondary dysfunction.

Radiofrequency ablation can effectively block nociceptive conduction. Continuous radiofrequency (CRF) of sensory articular branches of the hip can provide long term relief of joint pain [209–211]. However, as CRF works through thermal coagulation of nerves, it may be complicated by neuroma formation [212]. Pulsed radiofrequency (PRF) has been described as an alternative technique which effectively blocks nociceptive signals through the application of an electric field but does not induce structural nerve injury [213–215]. It is also associated with less post-procedure neuro-inflammation and is not complicated by loss of sensation. There are a number of case studies which have produced promising effects in patients with hip and groin pain [215, 216]. There are insufficient high quality studies to draw conclusions about the efficacy of this intervention at present but if appropriately targeted, it appears promising for the future.

Conclusion

Hip and groin injuries in young adults are a common presentation in sports medicine and orthopaedic outpatient clinics. A small but significant proportion of these patients will have an intra-articular pathology which must be thoroughly investigated. Physicians should have a low threshold for early MRI in patients where the diagnosis is uncertain and when symptoms are refractory. An accurate diagnosis based on functional and anatomical hip abnormality is critical to directing appropriate treatment. FAI is being increasingly recognized as a cause of hip pain and restriction of movement in young adults and can potentially lead to chondrolabral damage and early hip OA. Although surgical intervention may well be needed in a proportion of patients with structural abnormalities around the hip, the role of medical treatment is well recognized, both as an adjuvant to surgery as well as to delay progression of irreversible joint damage and the subsequent need for early arthroplasty in relatively young patients.

In athletes with symptomatic labral tears, 'early' surgical intervention may be required.

Physical therapy may provide symptom relief in hip OA and is especially effective when supervised by trained specialists and incorporated into a formal training program. Obesity is a significant modifiable risk factor for hip OA and the role of leptin in obesity-related chondrocyte damage is well established. Supervised exercise appears to have a number of benefits in hip OA; it improves muscle strength, locomotor function and aids weight loss.

NSAIDs in addition to paracetamol are routinely recommended in OA especially if concomitant signs of inflammation are present. Glucosamine taken orally has been shown to reduce pain and improve knee joint function and may therefore also have a role in hip OA. Further clinical studies are needed to assess the effects of treatments targeted at subchondral bone such as calcitonin and strontium.

Intra-articular joint injections of corticosteroids, HA and platelet rich therapies have all been described in hip OA. Radiographic guidance during injection is recommended as routine. The effects of intra-articular corticosteroids and HA are short lived and their long term use is generally not recommended. The use of intra-articular platelet rich therapies and pulsed radiofrequency has shown promising results in reducing inflammation around the hip joint and this is a potential area for future research.

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Hip Injections and Arthrography

13

Christopher Rees Gooding and Aresh Hashemi-Nejad

Introduction

Before considering any surgical intervention a thorough understanding of the patients' pathology is of paramount importance. In this chapter we will consider how fluoroscopic assessment and MRI arthrography can help those with an interest in hip preserving surgery. We will also consider the contribution of hip injections in the diagnosis and management of hip pain.

Clohisy et al. [1] concluded in their very instructive paper that despite their attempts to define several standard diagnostic criteria to diagnose structural hip abnormalities, there was limited reliability in radiographic diagnosis. They urged caution in basing surgical treatment options on isolated radiographic findings and highlighted the importance of understanding the mechanical pathology of individual patients, particularly in femoro-acetabular impingement (FAI) to avoid relying solely on static radiographic findings.

As emphasized by Bedi et al. [2], impingement is a dynamic problem and therefore is best investigated dynamically. For this reason a dynamic fluoroscopic arthrogram is essential very useful tool.

Dynamic arthrograms can be obtained under fluoroscopic control and ideally should be undertaken by the surgeon who will be performing the definitive surgery. MRI arthrograms can give additional information regarding the integrity of the articular cartilage as well as labral damage and extra-articular pathology. In a static position an arthrogram can be used in conjunction with a CT and MRI to outline the bony structure of the joint surfaces and soft tissues including the labrum and chondral surfaces. With advances in the contrast agents used in MRI arthrograms such as 'delayed Gadolinium Enhanced MRI of Cartilage' (dGEMRIC), information regarding the quality of the articular cartilage can also be obtained.

As well as injecting contrast into the hip joint, other topics to be discussed will include the symphysis pubis arthrogram, the psoasogram and injection of the trochanteric bursa, all of which can be useful therapeutic modalities in patients with extra-articular causes for their pain.

Fluoroscopic, Dynamic Hip Arthrograms

An arthrogram is an investigation where a radio-opaque dye is injected into the joint to try to outline the joint surfaces. As mentioned it can be a dynamic investigation which is done preferably by the operating surgeon where the joint is moved under imaging to assess congruence, instability and position of best fit. It can be used for therapeutic and diagnostic intervention.

Technique

It is our practice, having obtained appropriate consent from the patient, to perform the procedure in the operating theatre under a short general anaesthetic. An image intensifier is placed on the contra-lateral side to the hip which allows an unobstructed AP view of the hip of interest to be taken and allows movement of the hip so that lateral views as well as views in rotation and varus/valgus alignment can also be made. Fluoroscopic pictures are taken before injection of contrast as an AP view with the femur in neutral (patella pointing to the ceiling), the Dunn view to assess the anterior aspects of the femoral head and superior impingement as well as the frog lateral. A 22 gauge spinal needle is inserted under fluoroscopic control into the hip joint. In the adult, the authors' preference is for the anterior approach, aiming the

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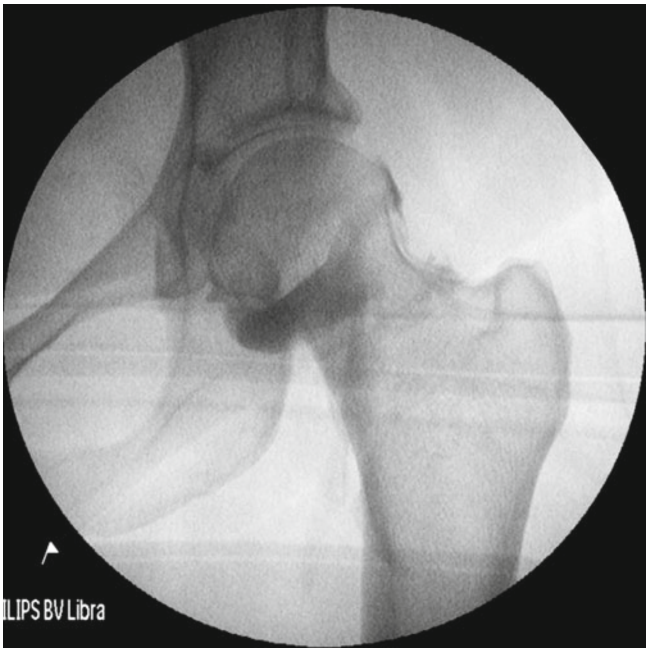

Fig. 13.1 AP fluoroscopic image of a normal hip arthrogram

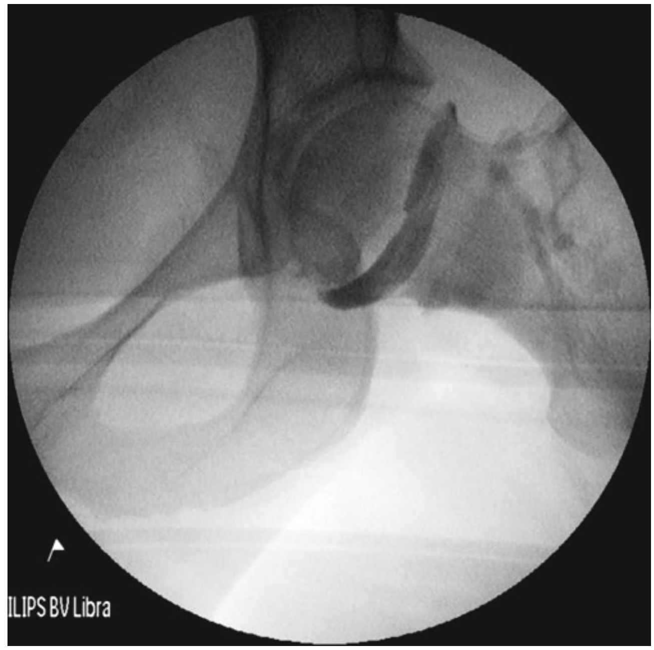

Fig. 13.2 Dunn view fluoroscopic image demonstarting a normal congruent hip

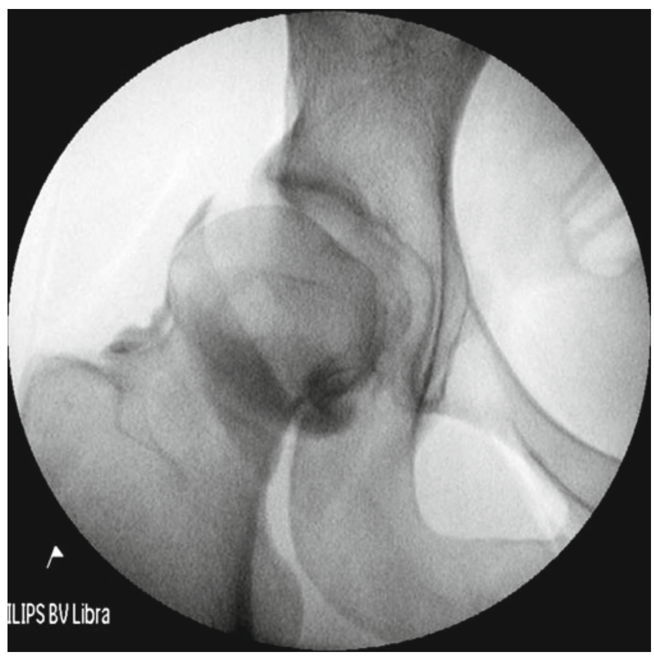

Fig. 13.3 AP fluoroscopic image showing disruption of Shenton's line in a dysplastic hip

needle at the base of the femoral head directly onto the proximal femoral neck and attempting to insert the needle tip into the sulcus formed as the hip capsule is elevated off the femoral neck. A medial approach is reserved for the paediatric patient group. Once the desired position is reached, the hip can be gently rotated. If the needle is lodged in the periosteum of the femoral neck it will rotate in the same direction as the hip, however, if it is within the capsule but not lodged in soft tissue it will rotate in the opposite direction to the rotation of the hip. A radio-opaque contrast (Omnipaque®, GE Healthcare) is then injected through intravenous tubing into the hip joint. We usually instill approximately 2 ml's of dye so the joint capsule is not over distended. Further injection of local anaesthetic and steroid (approximately 5 ml's) 0.5 % chirocaine or marcaine and 40 mg of triamcinolone (Kenalog®-40, Bristol-Myers Squibb) is effected. We try to avoid injecting large volumes that may cause distension and discomfort. It is important to avoid extravasation of the contrast particularly in the supero-lateral aspect of the joint so that the arthrogram yields the best possible information for the surgical plan. The needle is then removed and the hip is circumducted to allow for dispersal of the contrast over the entire femoral head. Having injected the dye the hip is screened dynamically in flexion, then internal and external rotation, abduction and adduction to assess congruence, stability and position of best fit. The hip is then classified into the following five groups:

1. The hip is congruent in all movements. There is no pooling of the dye and there is a round head within the round socket as shown in Figs. 13.1 and 13.2. Shenton's line is maintained in flexion, abduction, adduction, internal and external rotation.
2. The hip shows reducible subluxation. There is a disrupted Shenton's line on the AP neutral view shown in Fig. 13.3 which on flexion and internal or abduction of the hip is congruent with no pooling of the dye shown in Fig. 13.4.

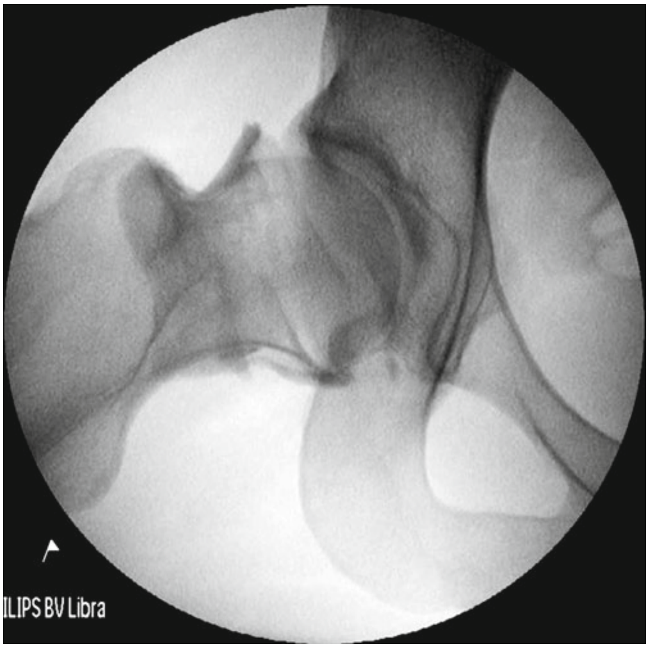

Fig. 13.4 AP fluoroscopic image of a dysplastic hip in abduction with no pooling and showing good joint congruency

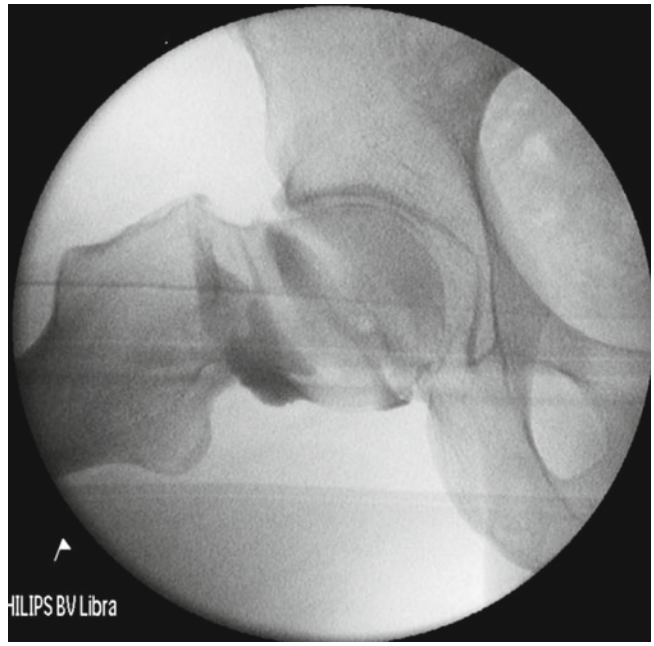

Fig. 13.5 AP fluoroscopic image of a hip with cam impingement showing impingement of the femoral head on the labrum at the supero-lateral aspect of the acetabulum

3. The hip shows irreducible subluxation. The Shenton's line will not restore in any position and therefore a false socket has been created.
4. There is evidence of hinge abduction in extension where the superior aspect of the femoral head impinges on the labrum edge of the acetabulum and the centre of rotation moves out in abduction on dynamic testing and pooling of the dye occurs in abduction shown in Fig. 13.5.
5. There is evidence of impingement anteriorly and superiorly in the Dunn view shown in Fig. 13.6, as the hip is flexed in abduction and internal rotation and again an unstable movement is noted as the hip is flexed and pooling of the dye medially.

While the dynamic movement occurs, a position of best fit, that is, the most congruent is assessed. In a congruent hip this is usually in abduction or internal rotation and in an incongruent hip it may be in adduction of the femur. While the position of best fit is assessed, attention is paid to the position of the greater trochanter in relation to the centre of rotation and acetabular coverage as this will allow for planning of any acetabular surgery. These static images are taken as a record but the dynamic test allows for the feel of the hip and the planning of any intervention.

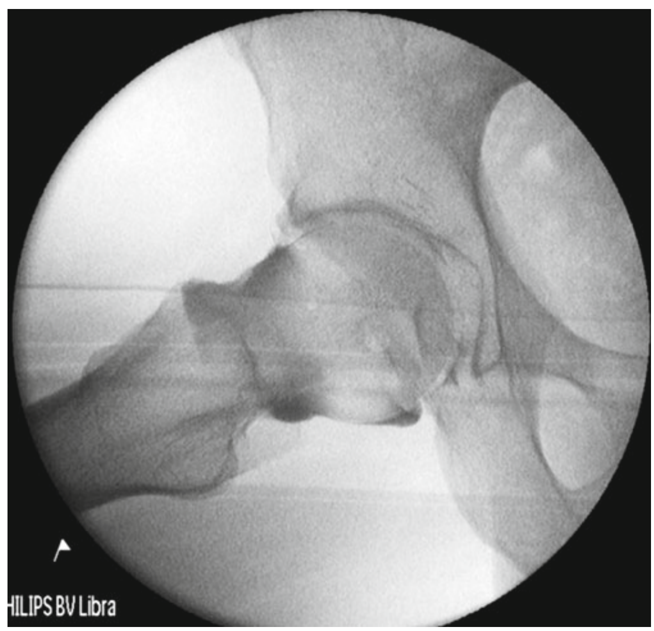

Fig. 13.6 Dunn view fluoroscopic image showing impingement anteriorly and superiorly

The injection of local anaesthetic and steroid will give some temporary block to the hip pain and is a useful diagnostic tool in eliminating extra-articular causes of pain that may present as hip pain. The injection can also be used as a therapeutic tool to give some pain relief while a decision is made regarding intervention. The use of CT allows assessment of the bony structures and delineation of the articular cartilage. The use of the MRI allows assessment of the chondral surfaces and of the labrum/chondrolabral junction and soft tissue structures which may also be a source of pain. The dGEMRIC technique allows biochemical assessment of the articular cartilage rather than the standard present methods which better identify

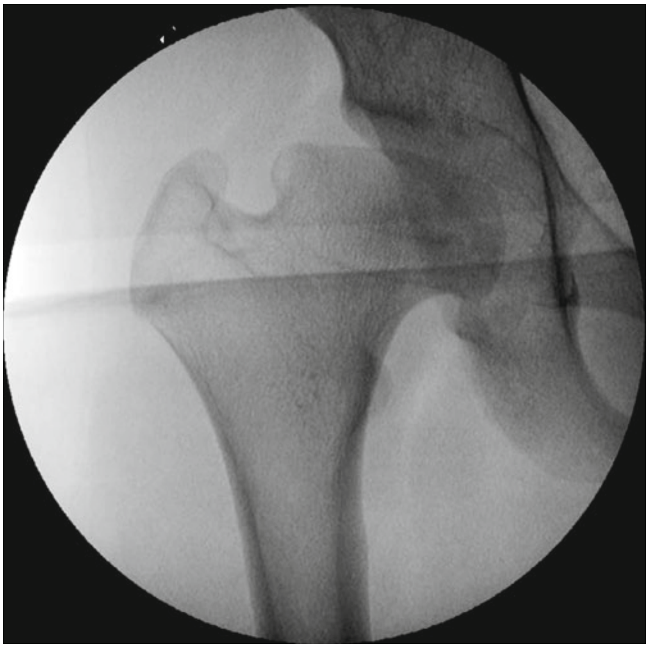

Fig. 13.7 AP fluoroscopic image of a right hip (Perthes)

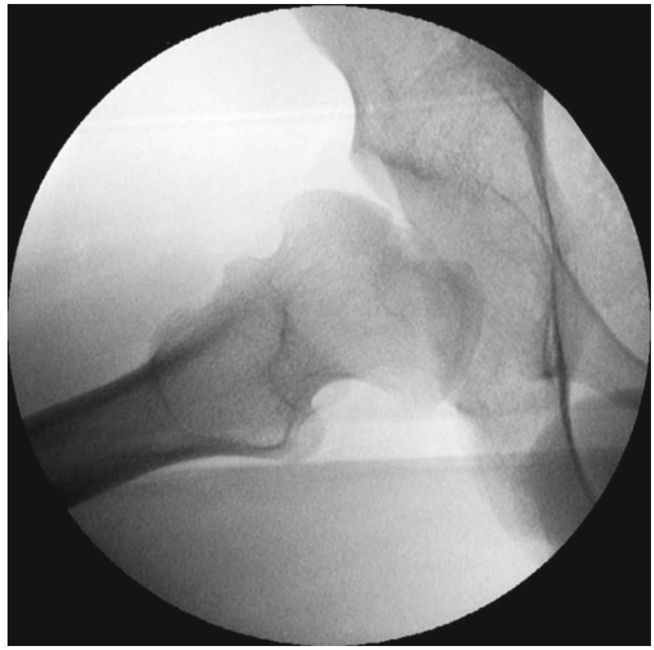

Fig. 13.8 Dunn view fluoroscopic image of a right hip (Perthes)

anatomical structures. It is important to be aware of the presence of degenerative changes as this would influence the outcome/prognosis of hip preserving surgery.

Examples of Hip Arthrogram Findings

Perthes in the Adult Hip

Figure 13.7 demonstrates an AP fluoroscopic image of a right hip. The typical appearance of a flattened femoral head with a hanging rope sign can be seen and is further illustrated by the Dunn view shown in Fig. 13.8. Figure 13.9 shows an AP fluoroscopic image after injection of contrast into the joint. The intact labrum can be seen as a filling defect sitting on top of the superolateral aspect of the femoral head. Figure 13.10 shows the same view but as an MRI arthrogram confirming that the filling defect is the hypertrophied labrum. Figure 13.11 shows an AP fluoroscopic image with the hip abducted demonstrating medial pooling of the contrast caused by the hinge abduction of the lateral aspect of the femoral head on the lateral aspect of the acetabulum. That is to say, the femoral head does not move concentrically within the acetabulum but levers on the edge of the acetabulum in abduction. Figure 13.12 shows an AP fluoroscopic image with the hip adducted. This shows obliteration of the medial pooling of the contrast and the 'best fit' of the femoral head within the acetabulum. The joint is concentric in this position and the outline of the labrum can be seen to be down sloping. The shape of the femoral head roughly represents a broad based cone with the acetabulum a reciprocally similar shape, making concentric movement difficult. This can be demonstrated with live screening of the hip. Once the femoral head hinge abducts on the lateral aspect of the acetabulum, any further abduction is achieved with tilting of the pelvis and not from movement of the femoral head within the acetabulum. The surgical options can be

Fig. 13.9 AP fluoroscopic image of a right hip (Perthes) with contrast

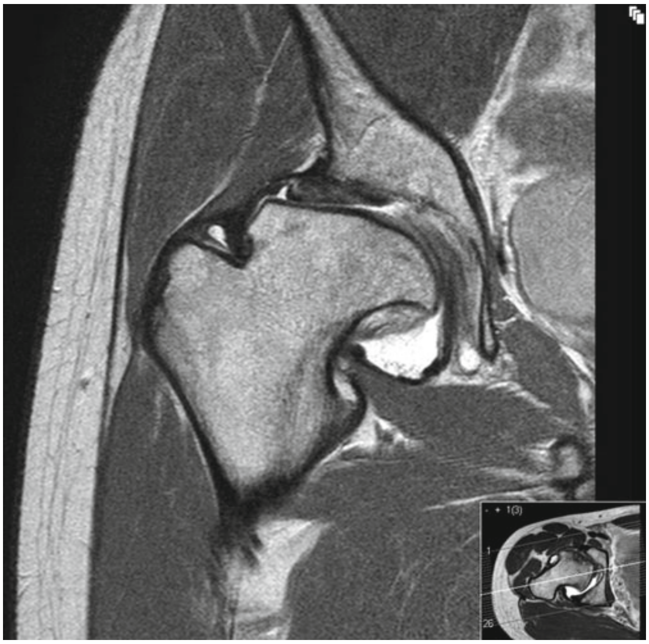

Fig. 13.10 Coronal MRI arthrogram right hip (Perthes)

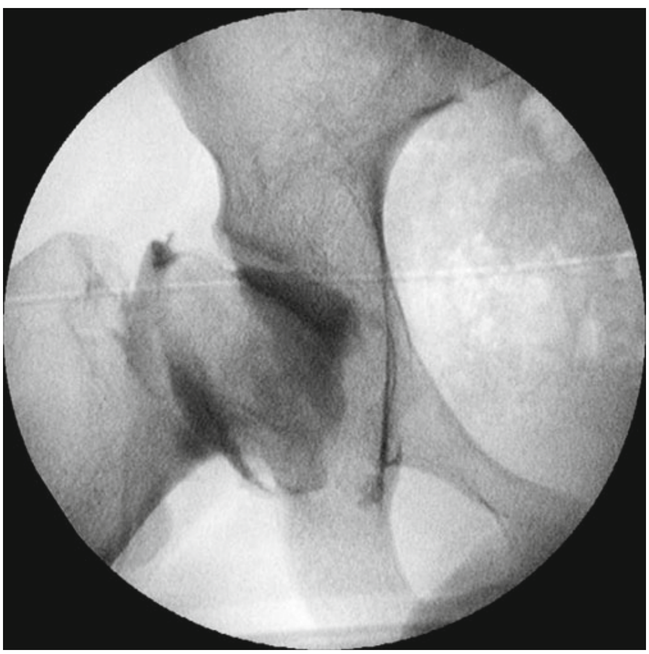

Fig. 13.11 AP fluoroscopic image with right hip (Perthes) abducted with contrast

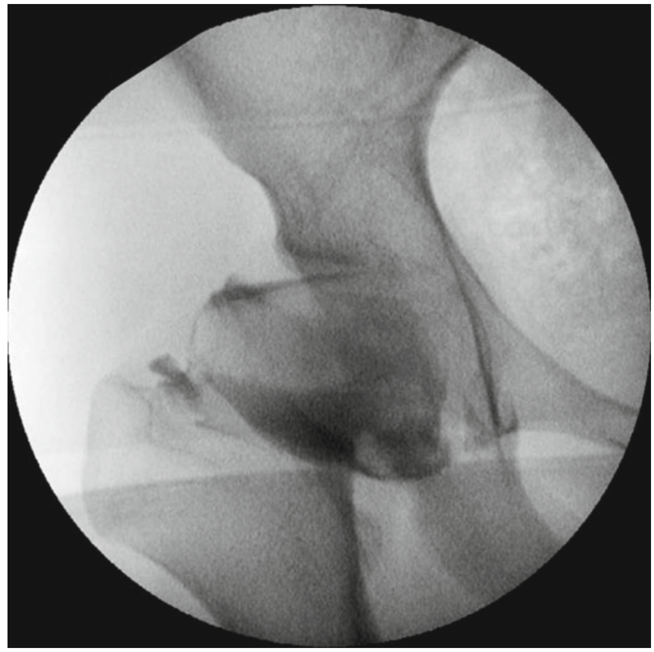

Fig. 13.12 AP fluoroscopic image with right hip (Perthes) adducted with contrast

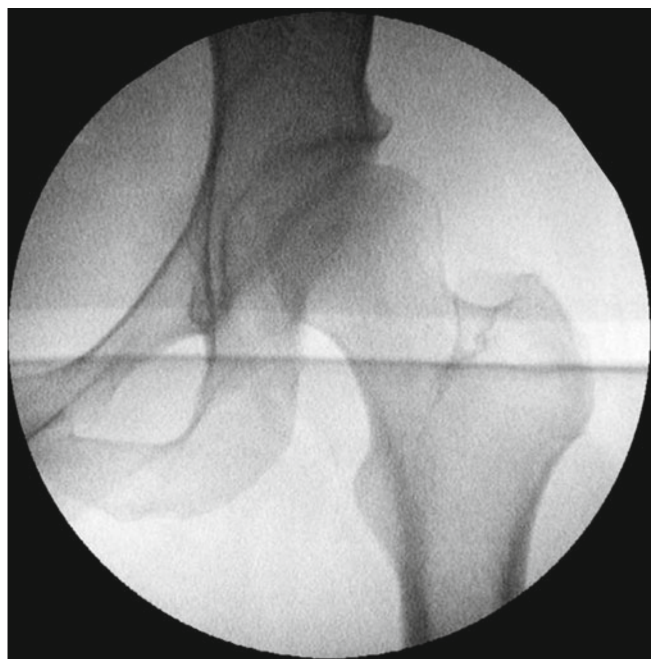

Fig. 13.13 AP fluoroscopic image of the left hip (Dysplasia)

difficult in this situation. In this particular case the patient was very symptomatic and was 15 years old. In this situation a valgus osteotomy can be performed with a head-neck debridement, however the patient should be adequately counselled regarding the realistic expectations of this procedure to succeed. They should be warned that they may require a hip arthroplasty as a young adult.

Dysplasia in the Adult

Figure 13.13 shows an AP fluoroscopic image of a dysplastic hip with a centre edge angle of 17° and a sourcil angle of 12°. Figure 13.14 shows a fluoroscopic image after the hip has been injected with contrast. With the hip in 20° abduction, the femoral head has good lateral coverage and the labrum which

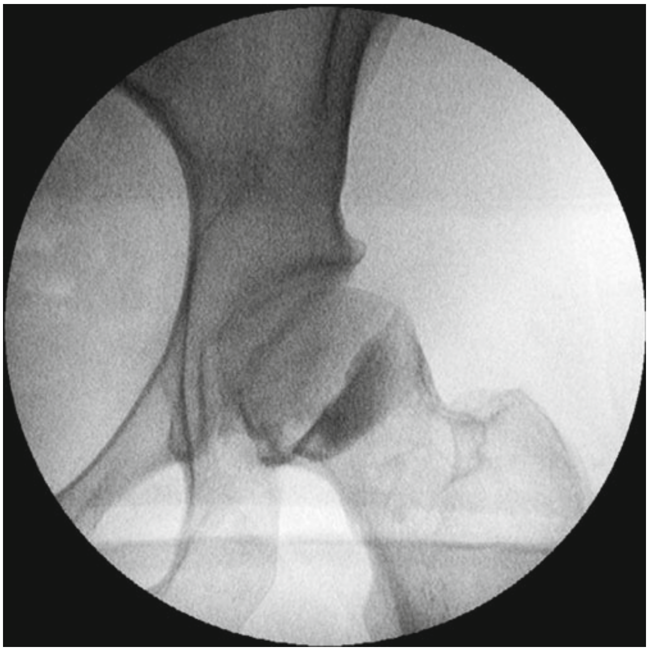

Fig. 13.14 AP fluoroscopic image of the left hip (Dysplasia) with contrast

Fig. 13.15 AP fluoroscopic image of the left hip (Dysplasia) abducted with contrast

is outlined by the contrast, is horizontal. In this position the joint is congruent and represents the best position of the hip as shown in Fig. 13.15. This is the expected position of the hip following a successful peri-acetabular osteotomy. During the dynamic screening of the hip, careful attention should be paid to the Dunn view ensuring that there is no co-existent cam lesion. A static Dunn view is shown in Fig. 13.16.

Fig. 13.16 Dunn view fluoroscopic image of the left hip (Dysplasia) with contrast

Patients with dysplasia may not have any symptoms or signs of impingement pre-operatively but following correction of their dysplasia with an osteotomy, a cam lesion may become symptomatic particularly if the socket is retroverted.

MRI Arthrogram

If labral pathology is suspected then MR arthrography is the investigation of choice. Czerny et al. [3] confirmed that the sensitivity and specificity of MR arthrography in the diagnosis of labral tears and detachments was 90 % and 91 % respectively and in MRI's without contrast these figures dropped to 30 and 36 %. Standard MR arthrography can also show articular cartilage thinning and cartilage defects, but cannot give any information regarding the quality of the articular cartilage. More recent techniques can be used to identify the characteristics of the cartilage itself.

These techniques involve the injection of a contrast such as Gadolinium-DTPA^{2-} (Diethylene Triamine Penta-Acetic Acid) which is an ionic agent that has a negative charge that is able to penetrate cartilage. This contrast agent works since the glycosaminoglycans (GAG's) found within articular cartilage also have a negative charge so areas within cartilage that have a high GAG content will have low concentration of Gd-DTPA^{2-} and areas with a low GAG content will have a high concentration of Gd- DTPA^{2-}. From the distribution of Gd- DTPA^{2-}, areas of high and low GAG concentration can be determined. This technique is called 'delayed Gadolinium Enhanced MRI of Cartilage' (dGEMERIC) and is illustrated

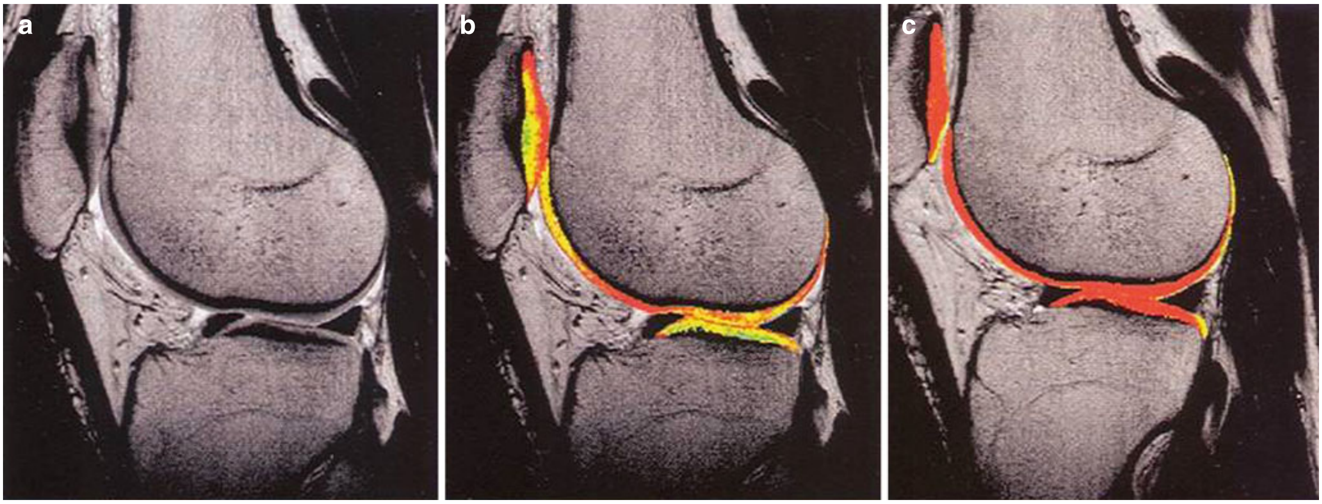

Fig. 13.17 This sequence of magnetic resonance images illustrates how dGEMERIC imaging can visualize the glycosaminoglycan composition of articular cartilage. (**a**) Shows a proton density image of articular cartilage. (**b**) Following administration of a charged ionic contrast agent (Gd-DTPA^{2-}), the distribution of which is dependent on the concentration of glycoaminoglycans (GAG's). Areas of high concentration of GAG's take up less of the contrast due to there negative charge and areas of relatively low GAG content will take up more of the contrast. (**c**) When the same patient is given a nonionic agent Gd(HPDO3A) the cartilage appears homogenous. This suggests that the selective uptake of the ionic contrast agent seen in 11b is due to charge and hence indicates the GAG distribution [32] (Courtesy of the *American Journal of Bone and Joint Surgery*)

in Fig. 13.17. The results of this technique are encouraging when compared to the 'gold standard' of estimating GAG content biochemically and histologically [4]. This agent also appears to increase the detection rate of defects as opposed to using an MRI with a non-ionic contrast such as Prohance (Bracco Diagnostics, Princeton, New Jersey) [5]. Using the dGEMERIC technique it is not possible to measure the absolute amount of GAG content, but it is able to provide a baseline with which disease progression and therapeutic measures can be monitored.

Some studies have also suggested that the technique can be successfully used in the selection of suitable patients for hip arthroscopy over the more traditional methods of assessment of degenerative disease [6–8]. In an interesting study looking at cam impingement, Pollard et al. [8] reviewed the dGEMRIC images of hips in patients who were asymptomatic and who were subdivided into one of two subgroups depending on the presence of a cam deformity and a positive impingement test. The authors showed that there was evidence of localized cartilage damage in patients who were asymptomatic with a cam deformity and had no evidence of joint space narrowing based on their plain radiographic assessment. In these patients the dGEMRIC technique was able to identify reduced GAG content in the anterosuperior region of the acetabular articular cartilage. The remainder of the joint had a similar GAG content to the hips with a normal head-neck morphology and physical examination. This could suggest that the difference in GAG content is related to the cam impingement. This conclusion is consistent with other studies [6, 7] that dGEMRIC is able to provide objective evidence of disease progression in the absence of any measureable change in the joint space. Additionally, the severity of the cartilage damage has been shown to be proportional to the severity of the cam deformity [8]. However as pointed out in other studies [7], a cam deformity does not inevitably result in progressive osteoarthritis, other factors such as age, activity level, acetabular morphology and the durability of the chondrolabral junction also play a significant role.

In the age of increasing financial pressures where the use of a novel and expensive technique such as dGEMRIC may be limited, patients who are at the upper age limit for hip preservation surgery (≥35 years) may benefit the most from such a technique as age has been shown to be a significant prognostic factor for early failure [9–14].

Symphysis Pubis Arthrogram

Osteitis pubis is a relatively rare pathology in the general orthopaedic clinic but has been quoted to be as high as 7 % in the general athletic population [15–17]. The majority of the reports to date describe the condition affecting athletes who participate in sports involving kicking such as football, although it has also been reported in basketball players and long distance runners [16, 18]. Symptoms can include pain when kicking or during the swing phase of the gait cycle when the hip is flexed. Pain is classically localized over the symphysis pubis and parasymphyseal bone but can also occur

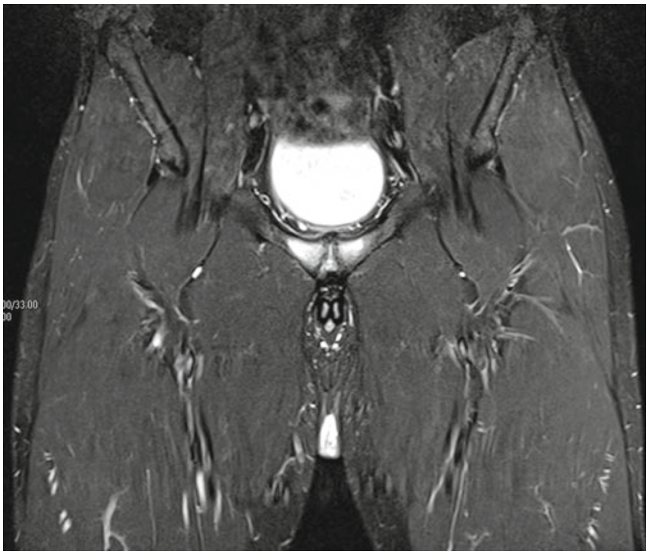

Fig. 13.18 Coronal T2 MRI of the pelvis illustrating oedema adjacent to the symphysis pubis

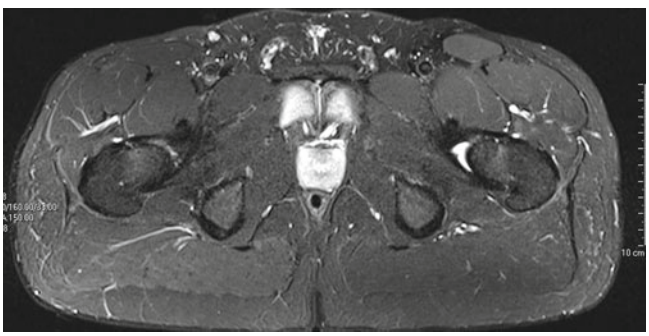

Fig. 13.19 Axial T2 MRI of the pelvis illustrating oedema adjacent to the symphysis pubis

within the lower aspect of the abdominal muscles. Clinical evaluation may reveal tenderness over the adductors particularly over the musculotendinous attachments. Painful symptoms can be reproduced with passive and resisted muscle tests of the adductor and abdominal muscles. A Technetium Tc 99 m pubic bone scan has been classically used to detect increased uptake in the pubic symphysis area [19–21]. However, the degree of uptake is poorly correlated with the duration and the severity of symptoms [20] and currently the MRI has become the diagnostic modality of choice shown in Figs. 13.18 and 13.19 [22–25]. Although this condition can be treated non-operatively with anti-inflammatories and rest, resistant cases can be treated with an injection of contrast under fluoroscopic control to first confirm the location of the symphysis pubis joint followed by an injection of steroid and local anaesthetic. There are a number of case series reporting favourable results with patients being able to return to sport after injection of steroid into the symphyseal cleft and surrounding tissues [26–28].

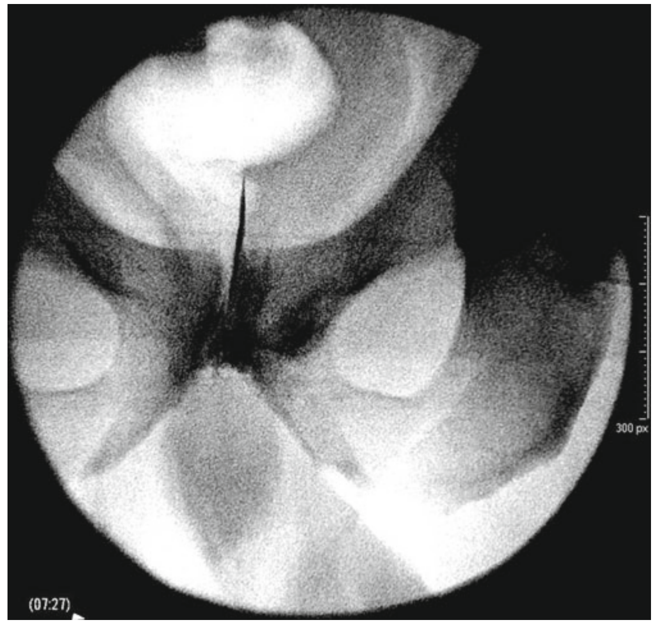

Fig. 13.20 AP fluoroscopic image of the pelvis after infiltration of contrast into the symphysis pubis

In O'Connell et al.s [28] description of the technique under fluoroscopic control they introduced a 22 gauge needle into the symphyseal cleft halfway between the upper and lower margins of the symphysis. The needle was advanced into the cleft and 1 ml of non-ionic contrast was injected to confirm the needle position and outlining the fibrocartilaginous disc. In O'Connell's study a radiographic image was then taken to record the appearance of the disc. Then an aqueous suspension of 20 mg of methylprednisolone acetate and 1 ml of 0.5 % bupivacaine hydrochloride was injected into the cleft as shown in Fig. 13.20. Of the 16 patients who had confirmed osteitis pubis in O'Connell's study 14 experienced immediate relief of their symptoms and were able to resume athletic activities 48 h after the procedure. One patient had complete resolution of symptoms at their 6 month follow up following a period of rest and one patient had ongoing symptoms. There were no complications reported. The authors concluded that particularly in athletes a symphyseal cleft injection can confirm the diagnosis and give short-term relief enabling return to sport.

Injection of the Trochanteric Bursa

Trochanteric bursitis is a relatively common problem in the hip clinic and although it can be successfully treated with conservative interventions in the majority of patients [29] recurrence can be a problem. There are both direct and indirect causes for this condition but in most patients the etiology is multifactorial and can affect patients of all ages. There are a number of non-operative options that can be administered either independently or in combination. Such methods include activity modification, physiotherapy, weight loss non-steroidal anti-inflammatories (NSAIDS) or a corticosteroid injection. Currently the most widely used treatment modality is an injection performed with ultrasound guidance. Furia et al. [30] found from their results following a course of rest, physiotherapy, ultrasound, steroid injection, ice as well as heat that 66 % of patients were able to return to sport and 83 % to jobs that involved a lot of manual labour after 3 months.

In summary, a single steroid injection can be effective in treating patients with trochanteric bursitis but some patients may benefit from a multimodal approach and some recalcitrant cases may require surgery.

Psoasogram

Iliopsoas bursitis and tendinitis are interrelated conditions, in that inflammation of one will inevitably result in inflammation of the other, due to their close proximity. Therefore these conditions can be considered as essentially identical with respect to their presentation, aetiology and treatment. Acute or chronic occupational trauma and sports injuries are thought to be responsible for the majority of iliopsoas bursitis [31] with rheumatoid arthritis being an additional cause.

Initial treatment has classically included rest with targeted physiotherapy consisting of stretching and strengthening exercises along with a course of oral anti-inflammatory medications. However, not all patients respond well to this treatment and as a result may proceed to an injection. Commonly this is performed under ultrasound guidance. In the majority of patients this intervention is able to provide temporary or permanent symptom relief to allow return to activities and may postpone or avoid future surgical intervention.

To conclude, arthrograms and hip injections can be extremely useful to the surgeon with an interest in hip preserving surgery. The dynamic arthrogram should not be underestimated in its usefulness in managing patients with an atypical presentation of hip pain and inconclusive static imaging.

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14 The Current Status of Hip Arthroscopy: The Central Compartment

Giles H. Stafford and Richard N. Villar

Introduction

In 1931, Michael Burman wrote that 'visualisation of the hip joint is limited to the intracapsular part of the joint. It is manifestly impossible to insert a needle between the head of the femur and acetabulum' [1]. This was following extensive cadaver experimentation using an early arthroscope design. He did not, however, attempt to distract the hip, and also states that 'we have found it difficult to move the joint because of rigor mortis fixing the joint solidly'. Despite this statement, arthroscopic access to the central compartment of the hip, otherwise known as the part of the hip medial to the acetabular labrum and including the acetabulum and articular surface of the femoral head has been practiced since the late-1970s [2].

It is difficult to pinpoint who was the first surgeon to achieve arthroscopic access to the central compartment, as at least two surgeons, working independently of each other and in different parts of the world, were experimenting with the arthroscope in this fashion at approximately the same time. These two pioneers were Dr. Lanny Johnson in the United States and Professor Ejnar Eriksson in Sweden. This is not to say that these two were the first to place an arthroscope in the hip, however. French rheumatologists had been routinely taking synovial biopsies from the peripheral compartment for some time. The first publication describing this was in 1976 [3].

The first symposium on hip arthroscopy was held in Michigan in 1976, with Lanny Johnson as course convener. Dr. Johnson had discovered that by placing a needle into the hip and injecting fluid, less force was needed to obtain the distraction necessary for safe arthroscopic access to the central compartment. Using this method he was able to visualise the labrum and ligamentum teres. Through a second portal he also performed basic procedures such as loose body removal (personal communication, 2013).

Dr. Johnson did not publish on this topic however until 1981, when he described his technique for hip arthroscopy in his book titled 'Diagnostic and Surgical Arthroscopy of the Knee and other joints' [4]. The first publication in the literature describing arthroscopy of the central compartment was, in fact, by Richard Gross in 1977, describing hip arthroscopy in children [5]. (Gross was an attendee at Johnson's symposium). In 1980, there were two case reports of arthroscopy of hip arthroplasty; both describing removal of loose bodies from the acetabular component [6, 7]. Following this, Holgersson also published a series of 15 cases of hip arthroscopy in children with juvenile chronic arthritis [8]. He used the arthroscope mainly for diagnostic purposes and assessing the articular surfaces of the hip.

Dorfmann and Boyer, both French rheumatologists, also started to extend their hip arthroscopies of the peripheral compartment to include the central around 1983 [9]. It was, in fact, they who coined the expressions 'central and peripheral compartments'.

Following Johnson's discovery of injecting fluid into the hip to aid distraction, Eriksson went on to describe the 'suction seal' of the acetabular labrum. Eriksson studied the amount of traction necessary to distract the hip in both conscious and anesthetised patient and also discussed the pros and cons of gas over fluid media for hip arthroscopy in his series [10]. Both Eriksson and Johnson performed hip arthroscopy with the patient in the supine position. In 1987, James Glick published a series of hip arthroscopies performed with the patients in the lateral decubitus position [11]. The conditions addressed in his series were arthritic change, loose bodies and avascular necrosis. He performed debridement where necessary using motorised shavers and burrs. Also in 1987, Goldman described the arthroscopic removal of a bullet from the femoral head

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[12]. Hip arthroscopy began to gather momentum with Hawkins publishing a further series of cases, and Dvorak describing arthroscopic anatomy in the late 1980s [13, 14]. Richard Villar authored the first textbook dedicated to hip arthroscopy in 1992 [15].

This chapter aims to describe the current status of hip arthroscopy as it pertains to the structures found in the central compartment of the hip. This will be viewed initially from a historical perspective, but will bring the reader through to the current state-of-the-art techniques, giving a comprehensive overview of the topic.

Basic Anatomy of the Central Compartment of the Hip

The hip has been broadly likened to a 'ball and socket', and cadaver studies have shown this to be true [16]. The femoral head (the ball) sits inside the acetabulum (the socket), and is enveloped by the acetabular labrum, and inferiorly the transverse ligament. The acetabular morphology is similar to an inverted horseshoe. The articular surface is lined with hyaline cartilage. Around its edge is the labrum, which merges with the transverse ligament inferiorly, and passes between the inferior limbs of the horseshoe. At the centre of the horseshoe, is the cotyloid fossa, which contains the origin of the ligamentum teres, and the haversian fat pad. The femoral head is covered by hyaline cartilage. Inferior to its polar margin, the ligamentum teres inserts at a depression termed the fovea. Ilizaliturri et al. have divided the acetabulum and femoral head into six descriptive zones each for arthroscopic purposes [17].

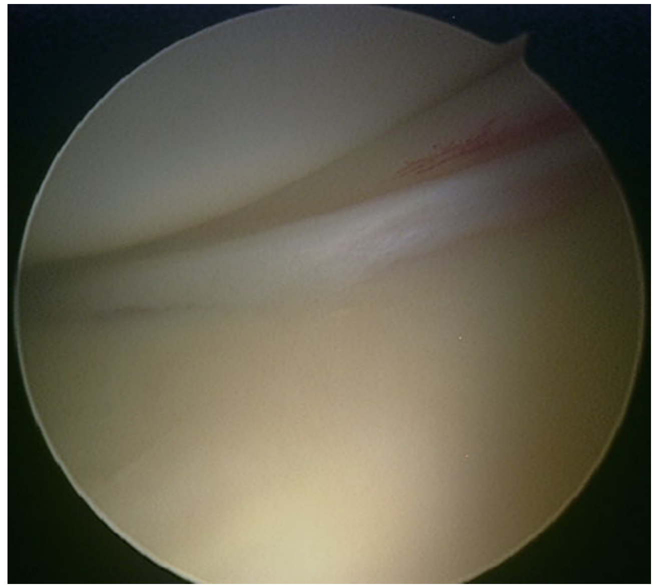

Fig. 14.1 The normal appearance of the anterior labrum

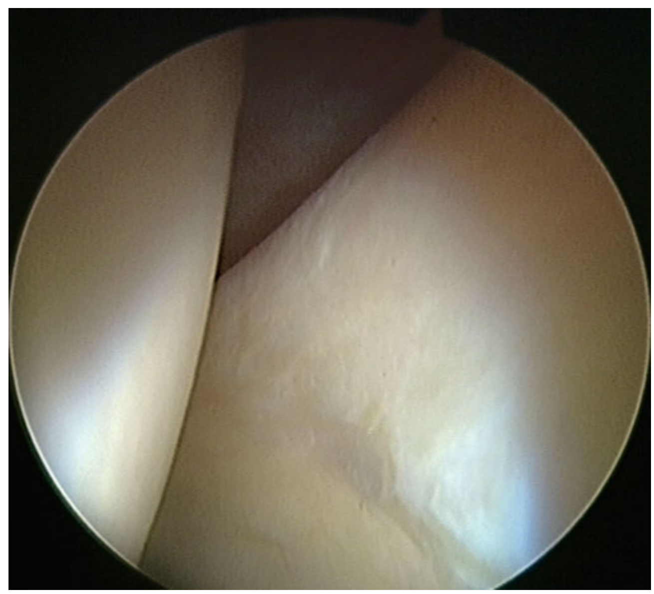

Fig. 14.2 The normal labrum at the anterosuperior margin

The Labrum

The arthroscopic appearance of the labrum varies as it is followed around the acetabular rim. Anteriorly, the labrum may be seen inverted to the acetabular rim (See Fig. 14.1). This has been described as an embryological remnant and is normal [18]. As the labrum passes more superiorly, it blends with the acetabular cartilage so that in the normal hip, the join between the acetabular cartilage and labrum is hard to define (See Fig. 14.2). Occasionally, there may be a sulcus seen, which could be mistaken for a labral tear. This sulcus is, however, much more commonly seen posteriorly (See Fig. 14.3).

The labrum is continuous with the hyaline cartilage of the acetabulum, blending with the transverse ligament inferiorly. Therefore, the combination of the labrum and transverse ligament form a circumferential seal to the femoral head. The labrum is formed of fibrocartilage and in cross section forms a wedge shape [19]. The labrum acts to increase the surface area of the hip socket by approximately 27 % [20]. The collagen fibres run parallel to the acetabular margin anteriorly, which slowly changes to perpendicular posteriorly [18, 21]. The labrum is thickest superiorly, and widest anteriorly [22]. A bifid posterior labrum is an interesting normal anatomical variant [23].

The chondrolabral junction is not, in fact, at the edge of the osseous margin of the acetabulum. The labrum wraps around the acetabular margin by 1 or 2 mm, its inferior margin blending with the hyaline cartilage of the

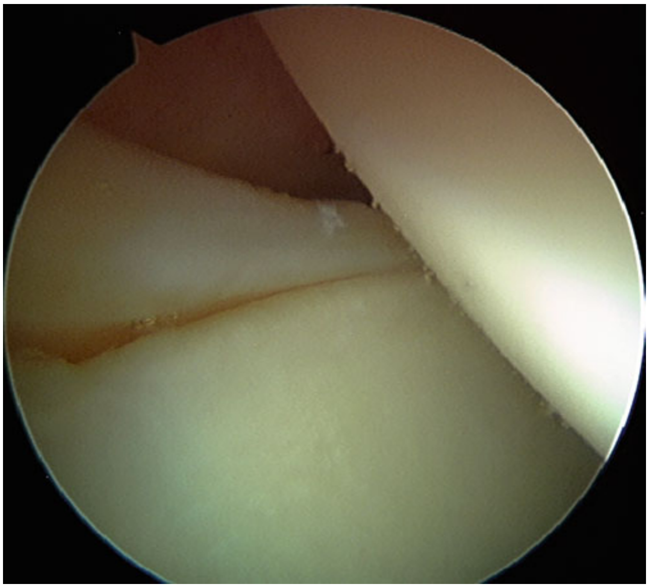

Fig. 14.3 The normal posterior labrum, note the appearance of a labral separation from the acetabular rim

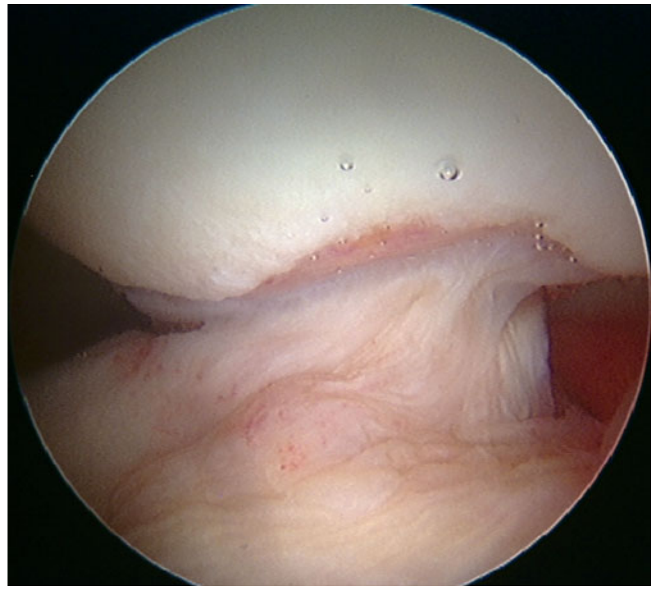

Fig. 14.4 A normal ligamentum teres

acetabulum, also known as the 'transition zone' [18]. The intra-acetabular part of the labrum is attached to the underlying bone by a layer of calcified cartilage. However, labrum outside of the acetabulum is attached directly to the underlying bone. This extra-articular part has been shown to contain blood and nerve vessels, explaining why a torn labrum may be painful [24–26].

The labrum is thought to have two separate functions, to enhance of hip stability and as a synovial fluid seal [27, 28]. It has been shown that the labrum acts to keep synovial fluid inside the central compartment, and that resection increases the frictional forces between the articular surfaces, leading to degenerative change [21, 29]. The fluid biodynamics of the hip have also been demonstrated, showing that synovial fluid is pumped from the inferomedial joint capsule to the central compartment as the joint moves [30]. The zona obicularis has been postulated to be integral to this pumping action.

The Ligamentum Teres

The ligamentum teres passes between the floor of the acetabulum and the femoral head. In the immature skeleton, this carries a nutrient vessel from the obturator artery to the femoral head. The ligamentum has a double-bundle structure, similar to that of the anterior cruciate ligament [31] (See Fig. 14.4). The ligamentum teres has, for many years, been thought of as a vestigial conduit which serves no purpose. However, recent interest in the ligamentum teres has increased understanding of the structure, and it is now beginning to be thought of as integral to the stability and function of the normal hip [32, 33].

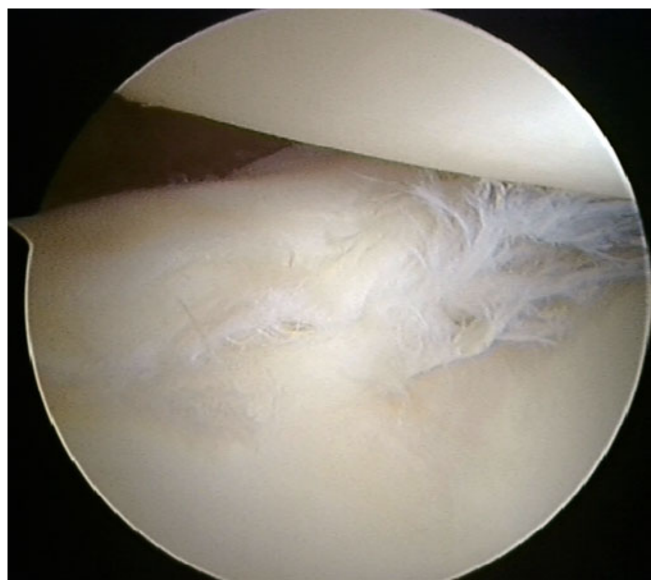

Fig. 14.5 An anterosuperior labral tear

Labral Tears

Disorders of the acetabular labrum have been associated with pain and cartilage degeneration since the late 1970s and early 1980s [34–36] (See Fig. 14.5). It was postulated that a labral tear was a predisposing factor to developing osteoarthritis. Labral tears as a painful entity were first to described in 1984 [36]. Ikeda et al. subsequently described arthroscopic debridement of labral tears with reasonable early results in a small case series [27]. Lage, Patel and Villar proposed an arthroscopic classification system for labral tears in 1996

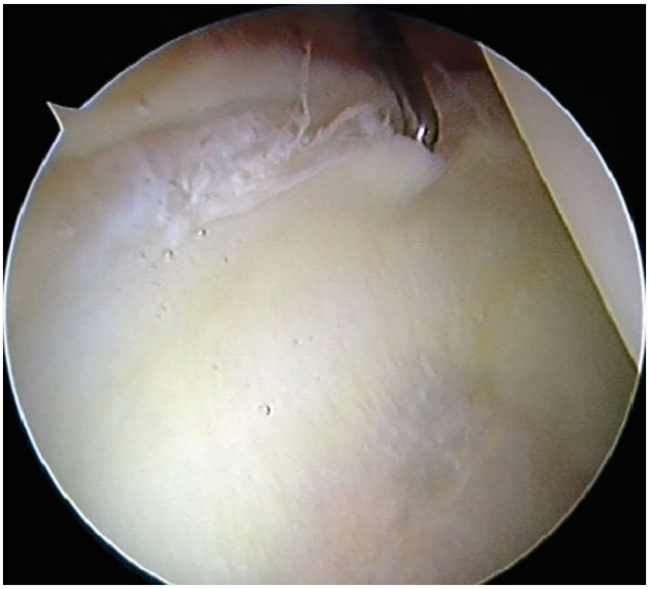

Fig. 14.6 Early chondrolabral separation

[37]. Subsequently, in 2001, McCarthy was awarded the Otto E. Aufranc Award for his work on the role of labral lesions in the development of early arthritis [38].

Labral tears have been known to be associated with acetabular dysplasia, but the description of femoroacetabular impingement (FAI) in 2001 highlighted the significance of possible labral pathology in what was previously thought of as a normal hip [39–41]. With this, improvements in imaging techniques meant that labral tears and the underlying associated pathology could be more readily identified [42–44].

Theories of how the labrum could be damaged have been classified into three main categories; cam-type FAI, pincer-type FAI or dysplasia. However, it has been shown that patients may suffer from not only one, but also perhaps a combination of these morphological abnormalities at one time [45]. Of course, isolated trauma could still be responsible, but this appears to be becoming a rare entity since these developmental abnormalities are further understood. However, certain sports such as ice hockey appear to be associated with higher incidences of labral injury [46, 47]. Capsular laxity and psoas impingement have also been suggested to be causes of labral tears [48].

The mechanism of developing a labral tear, and therefore its pattern, depends upon the underlying pathology [49]. In cam-type femoroacetabular impingement, the labrum is squashed between the abnormal femoral neck and the acetabular rim during flexion, adduction and internal rotation. This causes a shearing force at the chondrolabral junction and the labrum is forced outward [45]. Damage begins with a chondrolabral separation, but may progress to full detachment from the acetabular margin (See Fig. 14.6). The most common area for labral tears is at the anterosuperior margin of the acetabulum. The cartilage at the chondrolabral junction may then become damaged as a result of the shearing forces, leading to degenerative change.

Pincer-type impingement, where there is over-coverage of the femoral head by the acetabulum, subjects the labrum to more linear compressive forces [45]. This phenomenon is usually at the anterosuperior margin of the acetabulum, but not exclusively. The pattern of damage causes repeated microtrauma to the labrum, in the form of fissuring and cyst formation. The labrum may slowly ossify as a result, worsening the pincer impingement by deepening the socket further. Occasionally, small fractures of the acetabular rim may occur, described as an ‘os acetabuli’ [50]. Os acetabuli are not, however, exclusive to pincer impingement, and may be seen in all forms of morphological abnormalities associated with acetabular edge loading.

In the dysplastic socket, the labrum may be a weight-bearing structure [39]. Tears of the labrum in the presence of dysplasia tend to be more degenerate in nature, and have been likened to a torn meniscus in an arthritic knee. They are also most commonly seen at the weight-bearing anterosuperior margin [51, 52]. However, once the congruity of the chondrolabral junction is lost, cartilaginous degenerative changes may progress [51–53]. This is because of uncovering of the femoral head and ‘point loading’ of the acetabular margin. Again, rim fractures, or os acetabuli, are also commonly seen in the presence of dysplasia.

Debridement/Repair/Reconstruction

Acetabular labral tears have been identified as a cause of pain and implicated in early cartilage degeneration for over 30 years [34]. The treatment at that time was simple open excision, giving good immediate relief of symptoms. The first description of arthroscopic diagnosis of labral tears was published from Japan in 1986 [54]. Two years later, the satisfactory early results of arthroscopic labral debridement were published [27]. A larger series of patients following arthroscopically debrided labral tears was published in 1995 [55]. Following this, further small series reported satisfactory short-term results of arthroscopic partial labrectomy [56–59]. Byrd and Jones have since reported good outcomes for 26 patients at 10 years following partial labrectomy, suggesting that this is a satisfactory method of treating labral tears [60].

However, because of the increasing understanding of the function of the labrum, surgeons have more recently sought to repair the labrum if possible, rather than resect it. Marc Philippon developed a labral repair technique based on that used in the shoulder. He started using this technique in 2002, and subsequently the excellent early results were reported in 2005 [61]. The labral repair involves using bone anchors

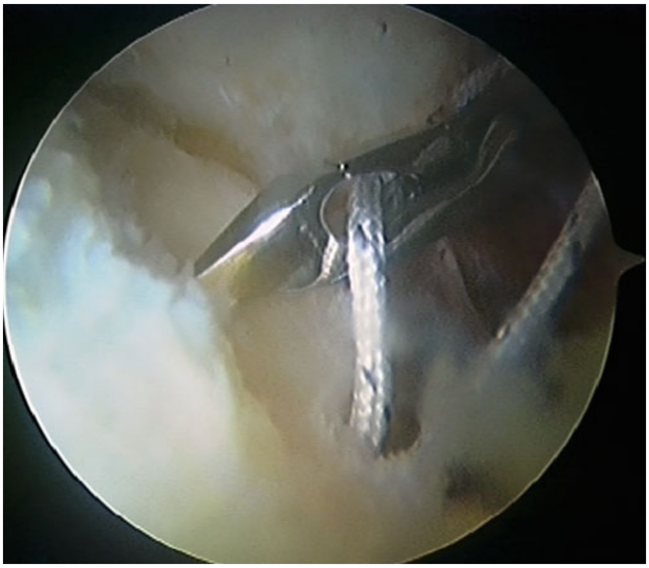

Fig. 14.7 A labral anchor placed in the bony acetabular rim

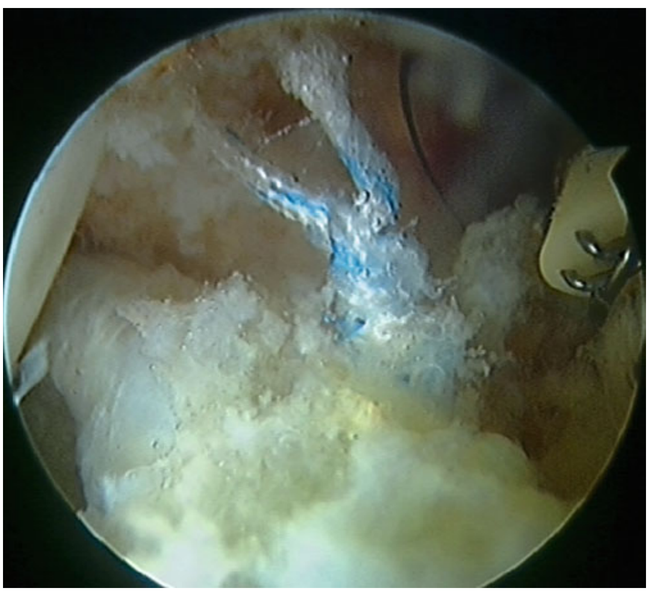

Fig. 14.8 After labral refixation; the labrum is now firmly held against the acetabular margin

with sutures attached to stabilise the torn labrum against the acetabular rim (See Figs. 14.7 and 14.8). There have been three further studies comparing the results of labral debridement over refixation in the literature, which all report superior early results over labral debridement [62–64]. To provide further scientific weight to this technique, Philippon, Arnoczky and Torrie performed a study on sheep, proving that healing can occur post labral refixation using his technique [65]. Further studies from the same group reports excellent results following labral refixation in professional sportsmen at a mean of 2 years [46]. Of note, a recent study of 156 hips by Schilders et al. shows favourable results of labral refixation over debridement at a minimum of 2 years [64]. Haviv and O'Donnell also report good functional returns following labral repair at a mean of 3 years, in the absence of bony impingement or dysplasia [66].

However, the minority labral tears associated with femoroacetabular impingement are full-thickness detachments from the labral rim. A significant proportion of labral tears seen, especially in the presence of cam-type impingement, are partial thickness detachments at the chondrolabral junction [22, 67]. To further detach the labrum to perform a labral repair does risk compromise of the labral blood supply [25]. Therefore, in this situation, the senior author performs labral reattachment by using the radiofrequency probe, termed 'chondrolabral sealing'. This has also been described as 'spot-welding' by John O'Donnell, but results of this technique have yet to be published.

Although the initial results of labral repair appear encouraging, not all torn labra are repairable. This has led some surgeons to experiment with labral grafts, substituting irreparable labral tissue with that harvested from either elsewhere in the same patient (autograft), or from donated tissue (allograft) [68]. The first to publish this technique was Sierra and Trousdale, who used the ligamentum teres as a labral graft in five cases [69]. This was not, however, done arthroscopically, but via a surgical dislocation approach. Philippon et al. have since described an arthroscopic technique of labral grafting using a harvested strip of iliotibial band [70]. The results of both these techniques are promising, but further long-term studies are needed to prove their efficacy. The use of allograft has been published as a case report [68]. The authors are also aware of gracilis being used in a similar fashion to the iliotibial band, being harvested with a tendon stripper such as those used for arthroscopic anterior cruciate ligament reconstruction (personal communication).

Acetabular and Femoral Cartilage Lesions

The Acetabulum

McCarthy et al. showed a high correlation between labral injury and acetabular joint degeneration, and are part of a continuum of the progression of arthritis [38]. It is very common during hip arthroscopy to encounter acetabular cartilage lesions adjacent to labral pathology [24, 45]. The pattern and nature of the acetabular cartilage injury naturally, to an extent, determines the options open to the surgeon for addressing them.

Regarding cam-type femoroacetabular impingement, a frequently seen appearance is that of anterosuperior acetabular chondral delamination, or damage at the area of impingement [71]. This has been described as the 'wave' or 'carpet' sign, and its severity recently classified [45, 72] (See Fig. 14.9).

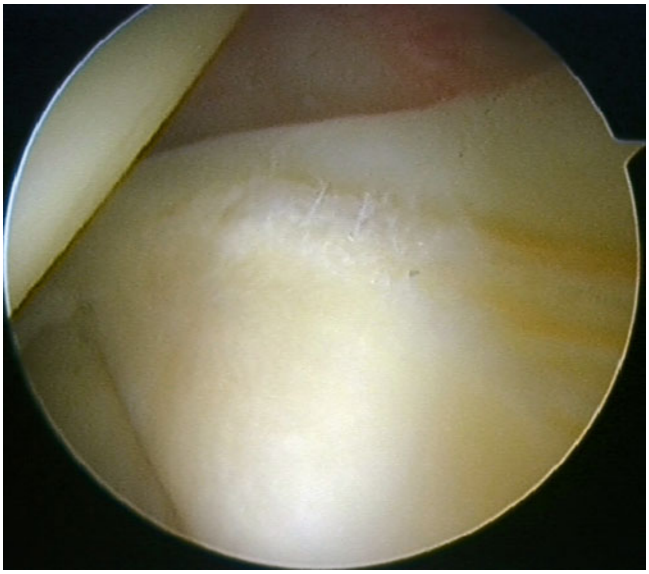

Fig. 14.9 A large 'wave' or 'carpet' sign of chondral delamination from the underlying subchondral bone, but with an intact chondrolabral junction

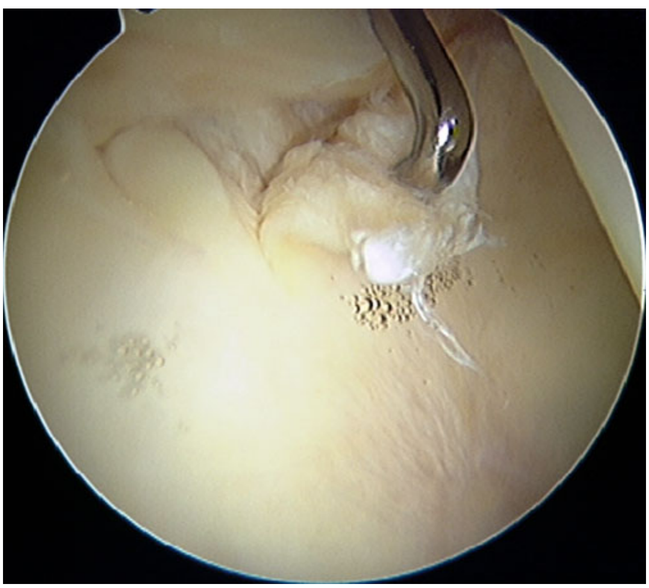

Fig. 14.10 Chondral delamination with an associated labral tear

This debonding of the cartilage from the subchondral bone is thought to be due to shear stresses at the chondrolabral junction, where the labrum is forced outwards, and the cartilage compressed medially. The delaminated cartilage becomes increasingly unstable with continued insult, and may degenerate and progress to frank arthritic changes (See Fig. 14.10).

The strategies available to the surgeon when faced with this are reasonably limited. In the presence of arthritic changes, simple smoothing of the remaining fibrillated cartilage surfaces, termed chondroplasty, is all that can be reasonably offered [73]. The results of this are mixed, and it is

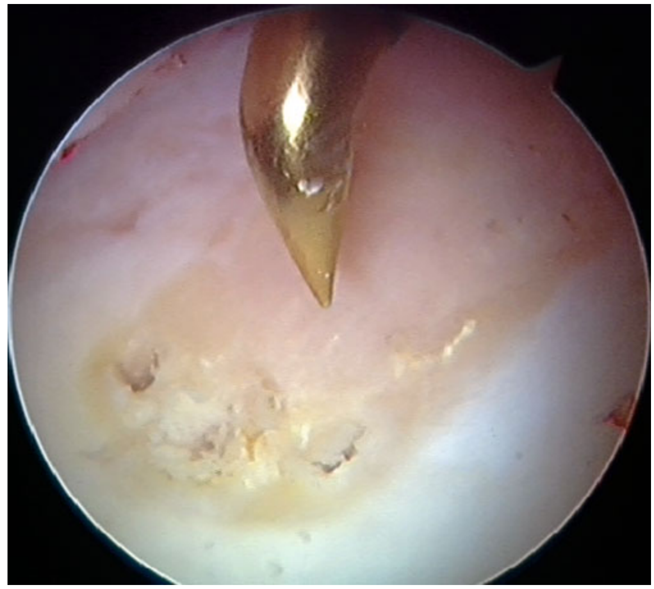

Fig. 14.11 Acetabular microfracture underway

generally considered that these patients' symptoms will inevitably progress [74–76]. However, the presence of a wave sign, where the cartilage macroscopically appears in reasonable condition, a few options have been described. The most commonly used technique in this situation is resection of the unstable cartilage flap, and subsequent microfracture of the subchondral bone. This technique is adopted from that initially developed for the treatment of chondral injuries in the knee. The technique for its use in the hip was published in 2006 [77]. The microfracture principal is based upon allowing mesenchymal stem cells from the bone marrow to populate the area of chondral deficiency, stimulating them to differentiate to form layers of healing fibrocartilage in place of the lost articular hyaline cartilage. Punching small holes in the subchondral bone with a specially designed awl allows this (See Figs. 14.11 and 14.12). Early results of this technique are encouraging [77, 78].

A further method to address cartilage delamination has been developed by Richard Villar, which aims to preserve the articular hyaline cartilage [79]. This uses a combination of the microfracture technique and fibrin adhesive to attempt to rebond the delaminated cartilage to the underlying subchondral bone. The principal is that delaminated cartilage may still contain viable chondrocytes, and that as they gain nutrition from the synovial fluid, not the subchondral bone, that the cartilage may be preserved and continue to function. Exposure to mesenchymal stem cells may promote healing of the delaminated cartilage to the underlying bone. Early results for this technique are very good, although histological studies have not been performed [79, 80].

An innovation recently described by Richard Field, is arthroscopic assisted grafting of isolated acetabular subchondral cysts [81]. This uses plugs of bone substitute, which

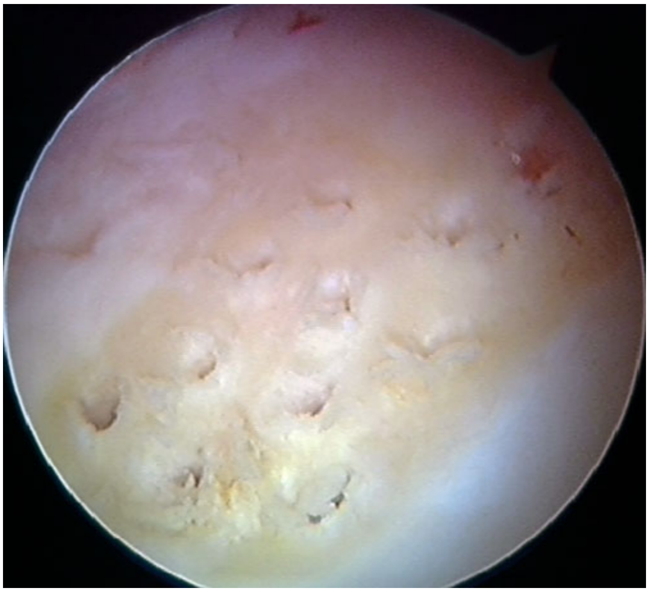

Fig. 14.12 The appearance after microfracture

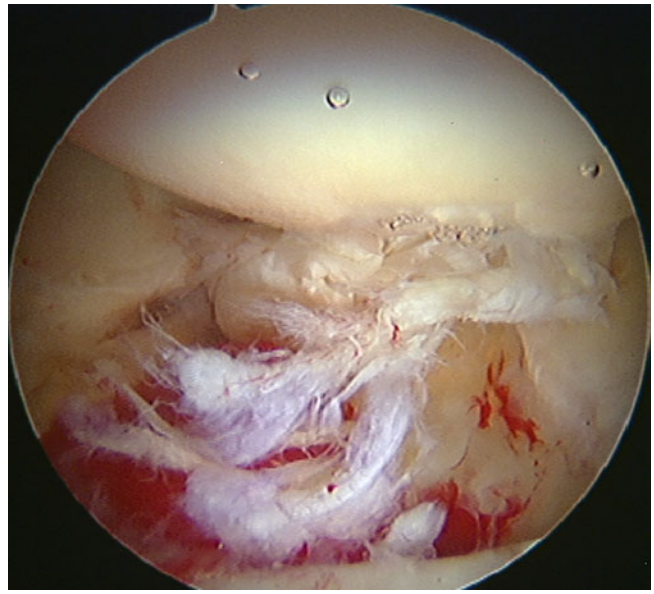

Fig. 14.13 A torn and degenerate ligamentum teres

are delivered 'outside in' using a modified ACL-type guide. Other techniques have also been described 'all inside' [82]. The 12-month results are hopeful. Further techniques that are being developed involve chondrocyte grafting to isolated cartilage defects [83].

The Femoral Head

Osteochondral injuries to the femoral head are not as common as those affecting the acetabulum. Arthroscopically, iatrogenic injuries to the femoral head are unfortunately probably the most commonly seen [84]. However, injuries can occur as a result of trauma such as dislocation, or other high-impact accidents. Arthroscopic treatment of these are similar to those used in the acetabulum, such as debridement, chondroplasty, microfracture and occasionally cartilage grafting [85].

Arthroscopically assisted treatment of avascular necrosis of the femoral head has been described [86–88]. The mainstay of treatment in this scenario is debridement, chondroplasty and removal of loose bodies. However, instrumentation has been developed to allow for arthroscopically assisted drilling of subchondral avascular areas 'outside in', and this has been used by the senior author (See Fig. 14.10). A technique for grafting of femoral head cysts has also been described [82].

Ligamentum Teres Injury

Ligamentum teres injuries are now a rare but well recognised cause of hip pain in the adult [89–96] (See Figs. 14.7 and 14.8). Historically thought of as a vestige of embryological development, the ligamentum is now considered an important stabiliser of the hip joint [33, 97]. Gray and Villar classified tears of the ligamentum teres into three grades; complete rupture, partial rupture or degenerate [89] (See Fig. 14.13). Botser et al. recently refined this, aiming to be more descriptive regarding the amount of tearing [96].

The treatment for ligamentum teres tears is ill defined. The mainstay of arthroscopic treatment is debridement, using either a motorised shaver or radiofrequency probe [98]. Partial tears and degenerate ligamenta may be debrided, as may full thickness tears [66]. If incompetent but still intact, such as in patients with dysplasia, the radiofrequency probe may be used to 'shrink' the ligamentum, tightening it thus possibly inferring more lateral stability [32] (See Fig. 14.9). Ligamentum teres incompetence or injury is also more commonly seen in patients with hyperlaxity, or those who subject themselves to extremes of movement, such as ballet dancers [31, 66]. It has been noted that the ligamentum teres may have the capacity to heal itself [99]. However, if this is not the case, a technique for ligamentum teres reconstruction has been developed, and has been performed by a handful of surgeons world-wide, with promising results [100].

Further Applications of Hip Arthroscopy in the Central Compartment

One of the first applications of hip arthroscopy was removal of loose bodies from the central compartment [101, 102]. This remains one of the most efficacious arthroscopic manoeuvres in the hip, with numerous reports of satisfactory outcome [103, 104]. The arthroscope has also been used following trauma to ensure non-penetration of femoral neck screws [105]. Matsuda has described fixation of a femoral head fracture following traumatic dislocation [106]. Following this, Yang, Chouhan and Oh have described arthroscopically assisted acetabular fracture fixation [107]. Arthroscopically assisted fracture fixation may well be in its infancy, but the future may well show it has a useful role to play.

Hip arthroscopy at the same sitting as a rotational periacetabular osteotomy for dysplasia has also recently been described, aiming to address intra-articular pathology at the same time as improving hip mechanics and coverage [108].

Conclusion

Hip arthroscopy of the central compartment has come a long way since its inception in the 1970s. This is, of course, mainly due to the increasing understanding of intra-articular hip pathologies and advances in their treatments. This chapter aims to give an overview of the current status of the techniques currently being used and those under development. This is a rapidly evolving field with huge scope for innovative ideas and high quality research. There are only a few long-term studies currently in the literature, but this is mainly due to the ever changing nature of the techniques. Only time will tell what the future holds and where the boundaries lie.

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Hip Arthroscopy: The Peripheral Compartment

15

Emmanuel Illical and Paul E. Beaulé

Introduction

When performing hip arthroscopy, the hip can be divided into three compartments: central, peripheral, and peritrochanteric. The central compartment is intra-articular, and is made up of the acetabular fossa and lunate cartilage, ligamentum teres, and the loaded articular surface of the femoral head. The peripheral compartment of the hip is separated from the central compartment by the labrum. The peripheral compartment is extra-articular yet intra-capsular, and consists of the femoral head's unloaded cartilage, femoral neck with synovial folds (anterior, medial, and lateral), and the articular capsule of the hip joint. The zona orbicularis, also known as ligament of Weibrecht, is a thickening of the hip joint capsule which wraps around the femoral neck, forming a ring around the neck's circumference, and is the narrowest area within the capsule [1]. It is thought to enhance hip stability with distraction and is an important landmark in peripheral compartment arthroscopy. There are also four capsular-ligamentous complexes (iliofemoral, quadrupedal, ischiofemoral, posterior) that contribute to hip stability, that have ill-defined borders [2]. The peritrochanteric compartment lies between the iliotibial band and the proximal femur providing access to the insertion of the gluteus medius and minimus.

Arthroscopic evaluation of the hip joint must include both the central and peripheral compartments to properly diagnose and address pathology. In regards to labral refixation techniques, due to its attachment to the bony rim of the acetabulum, one might consider the base of the labrum to be part of the peripheral compartment but in order to pass sutures it is necessary to visualize the central compartment.

Arthroscopy of the peripheral compartment is performed without traction, with the hip flexed between 30° and 45°, unlike the central compartment and is used to address the following pathology:

- femoral head-neck junction pathology
  - loss of femoral offset (CAM type femoroacetabular impingement)
  - impinging osteophytes of the femoral head-neck junction
  - hypertrophy of femoral neck synovial folds
- synovial pathology and tumors
  - primary or reactive synovitis
  - synovial chondromatosis
  - pigmented villonodular synovitis
  - chodromas/osetochondromas
- peri-articular structures
  - psoas tendon sheath

Pre-operative diagnostic imaging is imperative to properly evaluate the extent of bony deformities as well as rule out other possible pathologies. This includes a full set of standardized radiographs to assess acetabular depth, femoral head coverage, head sphericity and offset, as well as the degree of degenerative changes. At our institution, this includes an AP pelvis, false profile views of both hips, and Dunn views of both hips (Fig. 15.1). On the anteroposterior radiograph, the center edge of Wiberg, Tonnis angle, presence of cross-over sign or ischial spine sign are evaluated. Magnetic resonance imaging (MRI)is then used to further evaluate labral pathology and peri-articular soft tissues as well as ruling out other diagnoses such as stress fracture, osteonecrosis or a neoplasm (Fig. 15.2). By carefully evaluating the pre-operative diagnostic imaging, the surgeon can plan for either a solely arthroscopic treatment, combination of arthroscopic and mini-open anterior approach, or surgical hip dislocation.

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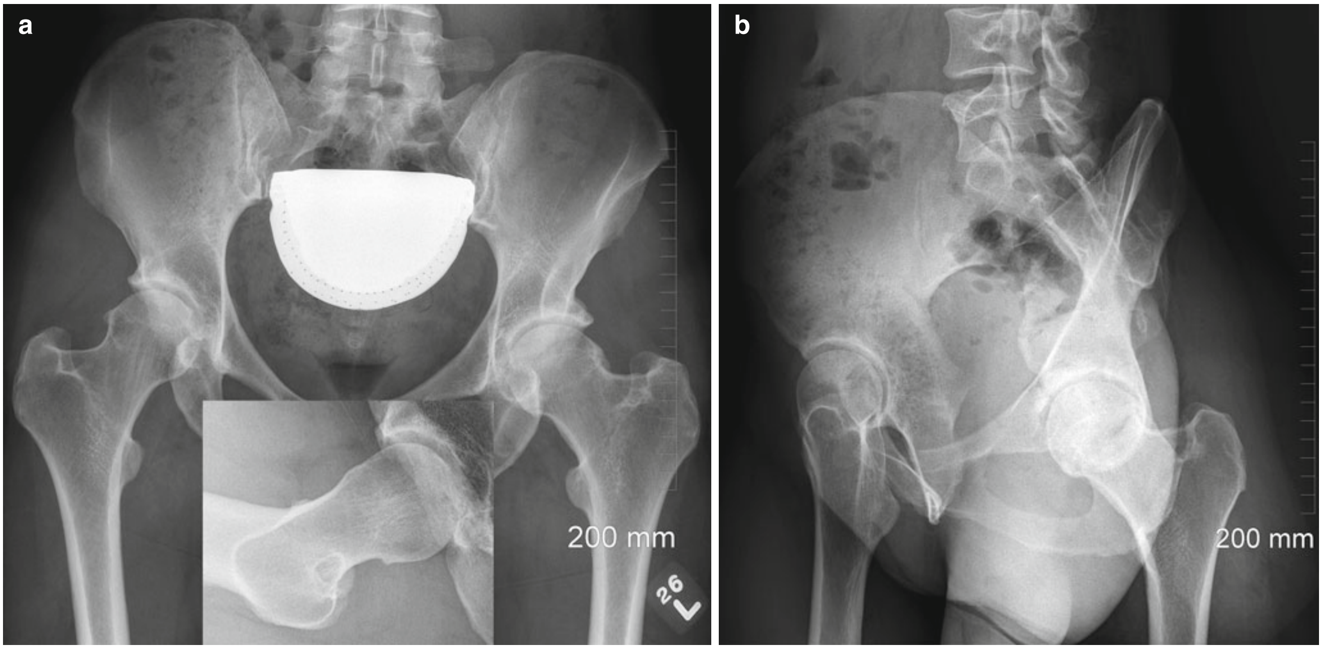

Fig. 15.1 Healthy 35 year old female who presented with bilateral hip pain, right worse than the left hindering her activities of daily living and recreational activities. Physical examination was consistent with hip impingement signs bilaterally, right worse than left. (**a**) Pre-operative AP pelvis and Dunn view (*inset*) of the right hip consistent with cam type impingement. (**b**) False profile view of the right hip demonstrating adequate coverage and good posterior joint space

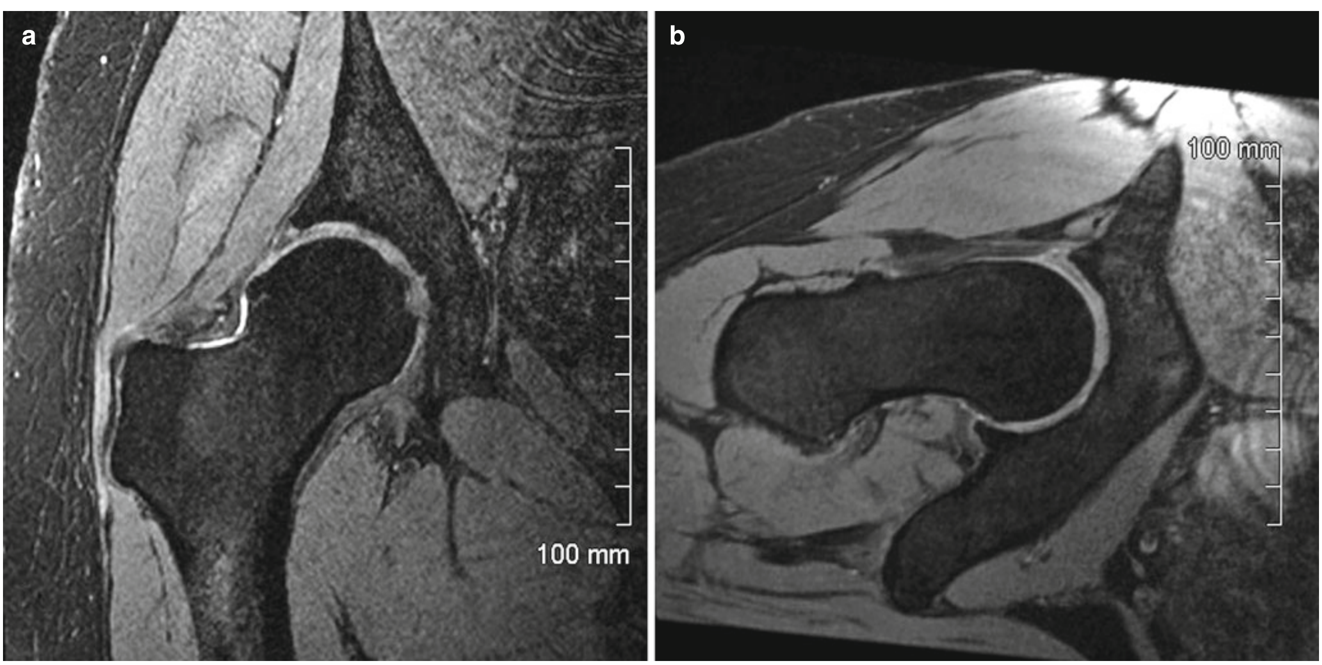

Fig. 15.2 Healthy 35 year old female patient with clinical and radiographic CAM type FAI whose radiographs are shown in Fig. 15.1. Selected cuts from coronal (**a**) and radial (**b**) MR imaging of the patient's right hip further delineate her CAM lesion and labral pathology

Surgical Technique

Positioning and Set-Up

Performing hip arthroscopy in the lateral decubitus or supine position is well accepted and is based on surgeon preference. At our institution, we use the supine approach on a positioning table. Although peripheral compartment hip arthroscopy is performed without traction, the traction table gives the flexibility of switching between the peripheral and central compartment. Furthermore, at our institution we perform the central compartment hip arthroscopy first. The foot is kept in the traction boot and an unscrubbed assistant provides or releases traction as necessary and is able to move the hip into flexion and extension by moving the traction boot along the extension bar. This is necessary to move between compartments and also properly visualize all aspects of the femoral head neck junction. The patient is positioned on the operating room table with a well-padded perineal post placed as far lateral as possible on the operative hip, resting against the medial thigh, to provide an optimal vector for distraction once traction is applied. Counter traction on the non surgical limb is critical. We prefer the patient to be under general anaesthetic with full muscle paralysis to ensure that the hip can be distracted with the minimal amount of traction. Arthroscopic monitor and towers and C-arm image intensifier are positioned on the opposite side of the surgical hip. The fluoroscopy monitor is placed at the foot of the bed on the opposite side of the surgical hip. After adequate distraction is confirmed using fluoroscopy (combination of traction first then adduction of the operative extremity), the extension bar is locked and the operative hip is prepped and draped widely to allow for proper portal placement.

Portals and Capsular Release

A standard anterolateral portal (laterally over the superior margin of the greater trochanter at its anterior border) is established first with the use of fluoroscopy with the hip distracted. Great care is taken not to penetrate the labrum. To minimize the risk of penetrating the labrum, once the spinal needle is inserted, normal saline is injected to further distract the joint and then re-inserted as close as possible to the femoral head. An anterior or mid-anterior portal is then made under direct arthroscopic visualization through the anterolateral portal. The anterior portal is placed as described by Byrd; at the site of intersection of a line drawn distally from the anterior superior iliac spine and line drawn transversely across from the tip of the greater trochanter [3]. The mid-anterior portal is placed distal and lateral to the anterior portal placement site at an intersection of approximately 45° from the anterolateral and anterior portal sites [4, 5]. We have tended to use the mid-anterior portal in the majority of cases where the central and peripheral compartments were both visualised, as this portal gives us a better angle for both labral repair and femoral head neck osteochondroplasty. A more anterior portal can be used if labral debridement or resection is planned or for access to the medial recess. To facilitate the essential working space required for peripheral compartment work, a partial capsular release between the anterolateral and mid-anterior portal is made using an arthroscopic blade along the acetabular rim from medial to lateral. The proximal to distal placement of the capsulotomy i.e. distance from acetabular rim, will aid visualization of either the labral-capsular recess (more proximal) or femoral head/neck junction (distal) as required. Some have advocated the use of T-shape extension for the capsulotomy but this may pose more difficulties in regards to proper healing and/or repair of the hip capsule.

Once inspection and management of the central compartment is complete, access to the peripheral compartment is further facilitated by performing a more extensive anterolateral capsulotomy. The 70° arthroscope is placed in the anterolateral portal to visualize both the central compartment and peripheral compartment. Subsequently an unscrubbed assistant releases traction, gradually moving the hip into flexion and slight abduction, with the foot remaining in the traction boot. As traction is released and the femoral head is visualized reducing within the acetabular fossa, a capsulotomy usually needs to be performed with a shaver and/or a radiofrequency ablation device through the anterior or mid-anterior portal to ensure full visualization of the femoral head neck junction. Further synovectomy is also performed to adequately visualize the femoral head neck junction. Once this is completed, one should be able to move easily between the two portals providing a complete visualization of the femoral head/neck junction. The extent of the capsulotomy can be limited if the hip is flexed, thereby reducing tension of the anterior capsule and ligaments and allowing easier mobility of instrumentation. However, in some patients who have "tight" hip joints (narrow compartments, significant loss of rotation), a more extensive capsulotomy and even partial capsulectomy is performed to include not only the zona orbicularis, but the iliofemoral ligament as well. Care must be taken, however, not to resect the posterolateral synovial fold, as this carries branches of the posterior femoral circumflex vessels, which supply the femoral head. This process is further aided with the use of fluoroscopy to confirm the location of the entire CAM deformity (Fig. 15.3).

Proximal or distal accessory portals can also be made to further visualize the peripheral compartment. A proximal anterolateral portal is known to give a comprehensive view of the peripheral compartment. This portal is established

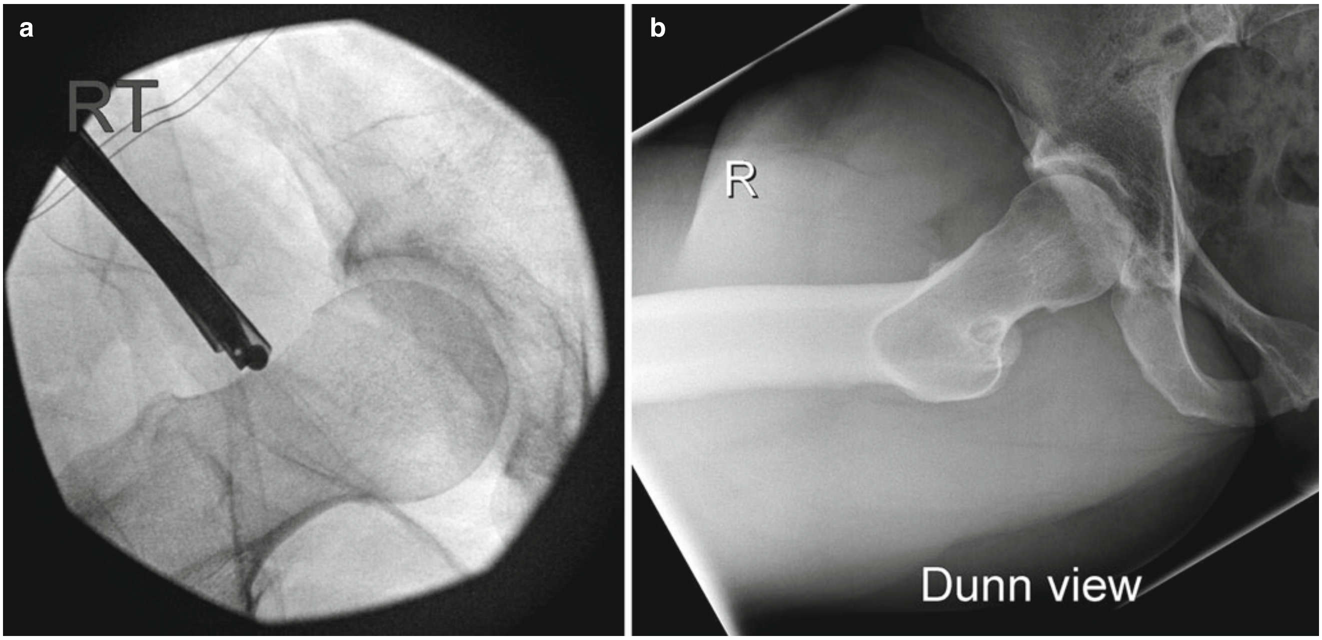

Fig. 15.3 Healthy 35 year old female patient with clinical and radiographic CAM type FAI whose pre-operative radiographs and selected MRI images are shown in Figs. 15.1 and 15.2. (**a**) Intra-operative fluoroscopic Dunn view of the right hip confirming position of the arthroscopic shaver on the femoral head neck CAM lesion. (**b**) Post-operative Dunn view of the right hip confirming resection of the CAM lesion

approximately 3–4 cm proximal to the standard anterolateral portal in the same line. That being said, there is a risk associated with this portal placement of damaging the branch of the superior gluteal nerve which supplies the tensor fascia muscle. Other authors have described it as the "soft spot" one third of the distance along the line drawn from the ASIS to the tip of the greater trochanter [6]. A similar proximal mid-anterior portal can also be made in the same line as the mid-anterior portal. Furthermore, a distal anterolateral portal can also be established 4–7 cm distal to the anterolateral portal as an access portal [4]. Each of these portals can be used as either a visualization or working portal to allow adequate visualization of the peripheral compartment or to address pathology (e.g. performing a femoral head neck osteochondroplasty).

We only use the posterolateral portal (placed along the inferior margin of the greater trochanter or at its posterior border under direct arthroscopic visualization), during work in the central compartment and acetabular rim.

Diagnostic Arthroscopy of Peripheral Compartment

A systematic approach to viewing the peripheral compartment must be developed to accurately diagnose all pathology. Dienst et al. published a sequence of systematically viewing the peripheral compartment by dividing the compartment into seven areas: anterior neck, medial neck, medial head, anterior head, lateral head, lateral neck, and posterior [6]. The authors noted that the peripheral compartment could be best viewed starting from the anteromedial surface of the femoral neck where the zona orbicularis and anterior and medial synovial folds could be seen. Similarly, Bond et al. describe a systematic approach to the peripheral compartment starting from the medial femoral neck but ending at the anterior femoral neck and anterior synovial fold [7]. Regardless of which approach is taken, the important aspect is applying a systematic routine and identifying common landmarks. The zona orbicularis and medial synovial fold are landmarks to gain access to the psoas tendon. The medial synovial fold serves to approximately mark the 6 o'clock position of the femoral head neck junction, and is usually the medial extent of a CAM lesion. Similarly, the lateral synovial fold can be used to roughly mark the 12 o'clock position, and as mentioned, is important not to resect to avoid iatrogenic injury to the retinacular blood vessels supplying the femoral head.

During the diagnostic arthroscopy of the peripheral compartment, each of the areas is inspected thoroughly and any synovial pathology or tumors (i.e. chondromas/osteochondromas) are treated.

Arthroscopic Femoral Head Neck Osteochondroplasty

Treating CAM lesions arthroscopically requires addressing both the central and peripheral compartment pathology. We first address the central compartment pathology performing chondroplasty for loose chondral flaps, microfracture for any chondral changes equal to or greater than Outerbridge four and labral debridement or restabilization for tears. Once this is complete, attention is turned to the peripheral compartment. Access is gained as described previously. Once the femoral head-neck junction is visualized, especially anterolaterally where the majority of CAM lesions occur, the hip can be flexed, abducted or adducted, and rotated to demonstrate the area of impingement arthroscopically and confirmed using fluoroscopy. Occasionally, the area of impingement is well demarcated at the osteochondral junction found at the base of femoral head and proximal aspect of the femoral neck and the articular cartilage and bone may have irregular discoloration [8]. It is important to have an idea of where the patient's CAM lesion is located, based on pre-operative diagnostic imaging, as each patient has a slightly different location of the lesion. Therefore, the amount of femoral head neck osteochondroplasty required must be tailored to each individual patient. The use of three-dimensional computer tomography imaging may be useful in helping to determine the area of resection.

The goal is to restore the "normal" anatomy and offset for the patient. Determining the "ideal" amount of bone to resect has not been definitively established in the literature. It is important not to over resect as this may result in loss of the seal effect between the labrum and femoral head [9]. Furthermore, early clinical outcomes of decompression of the CAM lesion do not correlate with the ability to restore a normal alpha angle [10, 11]. It must be noted that the alpha angle does not represent the full extent of the cam pathology, as it only measures the loss of anterior concavity, whereas clinically, can appear either laterally, anteriorly, or a combination of the both**.** As a result, resection should be started between 7 and 10 mm from the labral edge and continued distally to ensure that all of the offending impinging area is addressed. Similarly, the medial to lateral resection should do the same, keeping in mind the medial and lateral extents mentioned above (medial and lateral synovial folds). The depth of resection is also another area of debate with a general guidelines suggestion of 1 cm [5, 12]. Using a cadaveric model, Mardones et al. determined that resection of greater than 30 % of the femoral head-neck junction diameter significantly decreased the amount of energy required to produce a femoral neck fracture [13]. At our institution we use a combination of fluoroscopy and dynamic hip range of motion during arthroscopy to ensure that an adequate resection of the CAM lesion is achieved (Fig. 15.3).

Post-operative rehabilitation is completely variable in the literature after arthroscopic management of CAM type FAI. At our institution, the patient is kept 50 % weight bearing on the operative extremity with crutches. The patient is also given heterotopic ossification prophylaxis in the form of indomethacin for 1 month (25 mg dose three times daily). Hip range of motion is started immediately as tolerated with simple exercises that the patient does individually. Formal physiotherapy for progressive hip range of motion, stretching, and strengthening, starts at the 2 week follow up visit.

Psoas Tendon Release

The psoas is located directly anterior to the anterosuperior capsulolabral complex at the 2–3 o'clock position [14]. The psoas tendon lies anterior to the hip joint capsule, in line and anterior with the medial synovial fold, between the anterior zona orbicularis and the anterior labrum proximally. Depending on the thickness of the capsule, the psoas tendon may be visible. Furthermore, there is a direct connection between the hip joint and the iliopsoas bursa in approximately 15 % of patients [15].

Arthroscopic release of the iliopsoas tendon for the treatment of internal snapping hip syndrome has been performed either at the level of its insertion on the lesser trochanter or at the level of the hip joint via a transcapsular approach [16–18]. The transcapsular approach can be performed from either the central or peripheral compartment. Regardless of approach, treatment seems to be effective and results reproducible [19].

Access to the psoas tendon via the peripheral compartment can be made using the existing portals described and by making accessory portals distal to the anterior or mid-anterior portals (with the aid of fluoroscopy to ensure that the portals are directed towards the lesser trochanter). A capsulectomy is performed at this level to gain access to the iliopsoas bursa and tendon, and synovial tissue around the tissue is resected using a shaver. Once the tendinous portion of the iliopsoas is identified, it is released with a radiofrequency hook probe, ensuring that the underlying iliacus muscle fibers remain intact. Wettstein et al. have also described psoas tendon tenotomy through a peripheral hip arthroscopy, without traction and using a proximal anterolateral portal for visualization [18].

Complications

The largest series in the literature report complication rate following hip arthroscopy anywhere from 0.4 to 1.4 % [20, 21]. In the largest and most recent series, the authors describe that complication rate declined from 15 % over the first 60 cases to6.2 % over the next 500 cases, and 0.5 % over the last 500 cases, citing that safe traction and experience helped reduce the complication rate [21].

Neuropraxias are the most prevalent complication (0.4–2 %) with injury to the pudendal (most common), sciatic, peroneal and femoral nerve all being reported. Nearly all neuropraxias in the literature have been transient [20, 21]. Other rare traction complications such as perineal hematomas and vaginal/labial tears have also been reported [20, 22]. Although these traction related complications should not be a factor with peripheral compartment arthroscopy, given the fact that most hip arthroscopies will involve visualizing both the central and peripheral compartments, traction related complications can be avoided by minimizing the traction time (common recommendation is less than 2 h although there is no good evidence to support this), minimizing the traction force (e.g. ensuring that the patient is adequately paralyzed), and carefully positioning a large well-padded perineal post laterally.

Inaccurate portal placement can also lead to nearby neurovascular structural damage. The standard anterolateral and proximal anterolateral portals are within the safest zones during hip arthroscopy [4]. The anterior portal is close to branches of the lateral femoral cutaneous nerve, and using a mid-anterior portal can decrease the chance of injury to this nerve. Portal bleeding and hematoma are rare complications [20].

Iatrogenic damage of the acetabular cartilage and labrum as well as the femoral head weight-bearing cartilage is usually not an issue during peripheral compartment arthroscopy as long as the instruments are not too close the joint space. Moving the hip joint during peripheral arthroscopy so that the femoral head cartilage is hidden underneath the labrum in the acetabular fossa will also prevent inadvertent damage to the cartilage. Sampson reported three cases out of 1,001 which had significant femoral head scuffing because of inadequate distraction [21]. The author also states that most hip arthroscopies will result in minor scuffing from needle placement and instrument maneuvering. In the 1054 cases reported by Clarke et al., 30 cases could not be entered with the arthroscope but there was no mention of iatrogenic damage [20]. Both of these reports imply that the incidence of iatrogenic damage to the femoral head and labrum is under reported in the literature.

Theoretically, arthroscopic CAM resection could compromise femoral head blood supply if the deep branch of the medial femoral circumflex artery is damaged as it enters the hip capsule. As mentioned, keeping the osteochondroplasty limited to areas medial to the lateral synovial fold will also help protect the femoral head blood supply. To date, there have been no reports of femoral head osteonecrosis following arthroscopic CAM resections. However, there have been two reports in the literature of avascular necrosis following hip arthroscopy. Sampson reported only one case in a cohort of 1001 hip arthroscopies [21]. The author speculates that the one case may have been at risk of osteonecrosis secondary to the trauma the patient suffered prior to the surgery, and that distraction and partial capsulectomy performed at the time of hip arthroscopy may have contributed to the development of AVN. Scher et al. reported on one case that that did not have any significant underlying factors other than a traction of 10 mm was held for 90 min intra-operatively [23].

Extravasation of irrigation fluid into the abdominal and/or retroperitoneal compartments causing cardiac arrest and intra-abdominal compartment syndrome has also been described [24]. Fluid may track along the psoas tendon if there is damage to the sheath allowing for fluid to pass into the retroperitoneal space. Fluid extravasation can also significantly decrease the space in the peripheral compartment. Minimizing capsular resection and performing work that requires capsular resection at the end of procedures can help limit the amount of fluid extravasation that occurs. Careful attention to the pump and outflow during predictably long cases or extra-articular cases will further reduce this problem. Sampson also reports that changing to an outflow dependent pump nearly eliminated extravasations in their institution [21].

Infection has been an extremely rare complication, only reported in one study [20]. Similarly complications such as myositis ossificans [25], trochanteric bursitis [20] and reflex sympathetic dystrophy [22] are also just as rare. Femoral neck fracture after arthroscopic management of CAM lesions has also been reported [20]. Limiting the amount of femoral neck resection [13] and modifying weight bearing status postoperatively can help prevent this serious complication [26].

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Hip Arthroscopy: The Use of Computer Assistance

16

Danyal H. Nawabi and Anil S. Ranawat

Introduction

Computer assisted surgery (CAS) continues to redefine the specialty of orthopedic surgery, as it has previously done in urology and general surgery. CAS has successfully been applied to lower limb arthroplasty, trauma reconstruction and spine surgery over the last two decades. In these procedures, CAS has resulted in more precise and reproducible results, and importantly, a reduction in the surgical learning curve [1–3].

Efforts are now being made to translate the benefits of CAS to the challenging technique of hip arthroscopy, and specifically the treatment of femoroacetabular impingement (FAI). FAI is a biomechanical entity arising from the presence of an osseous anatomical abnormality of the femur and/or acetabulum combined with certain hip movements, that can cause premature hip joint failure [4]. It is characterized by repetitive contact, typically of the anterosuperior femoral head-neck junction and the acetabular rim during flexion-internal rotation of the hip, manifesting as decreased range of motion (ROM) and pain. This results in labral damage, chondral degeneration and secondary osteoarthritis of the hip joint [5]. Three distinct types of FAI have been described. On the femoral side, a misshapen femoral head-neck junction, typified by a loss of sphericity and a reduced femoral head-neck offset is known as 'cam' impingement. On the acetabular side, an excessively deep or maloriented socket is known as 'pincer' impingement. A combination of these two abnormalities is known as 'mixed' impingement.

Clinical studies have shown that surgical correction of the osseous abnormalities that cause impingement improves function and relieves pain [6–9]. As with other areas of joint preservation surgery, the surgical treatment of FAI has inevitably progressed towards the use of less-invasive techniques such as hip arthroscopy. This procedure remains technically demanding with a significant learning curve [10]. A common reason for failure after arthroscopic FAI surgery is inaccurate resection, either under or over-resection, which is perhaps not surprising as the surgeon is treating complex 3-dimensional (3D) 'cam' and 'pincer' deformities through a 2D arthroscope [11, 12]. This problem has, in part, fueled the drive towards computer-assisted solutions.

Computer-assisted hip arthroscopy encompasses three broad categories: preoperative assessment tools, intraoperative navigation programs, and robotic-assisted surgery. Preoperative tools provide the surgeon a patient-specific reconstruction of osseous anatomy in 3D. Depending on the software, a virtual bony resection can then be performed based on strict anatomic or kinematic parameters in order to minimize impingement and improve ROM. Intraoperative navigation, on the other hand, allows the visualization of the surgeon's instruments in relation to a virtual reconstruction of the patient, which can then guide the surgeon intraoperatively in a precise manner. Navigation may or may not have a preoperative assessment tool and requires an intraoperative registration process. Robotic-assisted surgery moves one step beyond preoperative planning and navigation with even greater accuracy [13]. It combines both preoperative assessment and intraoperative navigation tools with a 'guided' intraoperative cutting device that is automated based on a preoperative plan.

This review outlines the various surgical techniques used to treat FAI and addresses their current limitations. It will focus on the evolution of CAS to address the limitations of both open as well as arthroscopic hip impingement surgery. The most current research and the latest technology of computer-assisted techniques for preoperative planning, intraoperative navigation, and robotic-assisted execution in impingement surgery will be presented.

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Limitations of FAI Surgery

FAI surgery can be performed open or arthroscopically. Irrespective of the approach, there are multiple factors which contribute to a successful outcome following FAI surgery. These include patient selection, patient expectations, indications for surgery, appropriate imaging, preoperative planning, patient positioning, visualization of the lesion, localization of the deformity and treatment of primary bony abnormalities and secondary lesions. In addition, rehabilitation is incredibly important. In this section, we will discuss the limitations unique to both open and arthroscopic approaches, while focusing primarily on proper visualization and correction of the osseous lesions.

Open surgical hip dislocation is the historical gold-standard treatment for FAI. Good to excellent results at mid-term follow-up range between 70 and 80 % [8, 9, 14, 15]. The open approach allows for circumferential visualization of the hip joint. Femoral, rim and chondral pathologies can be treated and the zone of impingement can be assessed dynamically. Open surgical hip dislocation is currently the best option for the precise treatment of complex bony abnormalities including extra-articular impingement, global FAI and femoral version anomalies. However, there are disadvantages with this technique, which include trochanteric nonunion and pain, potential risk of avascular necrosis and increased inpatient stays and rehabilitation periods. In an effort to minimize these disadvantages, mini-open approaches have been used, such as the Heuter approach, which provides good visualization of the anterior femoral head-neck junction without surgical dislocation [16]. However, the potential for assessment of lateral and posterior pathology as well as the chondral surfaces is limited. These limitations with open techniques coupled with new advances in hip arthroscopy marked a gradual shift among FAI surgeons to less invasive arthroscopic techniques.

In the early days of hip arthroscopy, the technique provided an effective option to deal with intra-articular pathology, including chondral lesions, loose bodies, labral tears, synovial disorders and infection. With improvement in instrumentation and increased surgical experience, femoral osteochondroplasties, acetabular rim resections and labral repairs can now be easily performed [17]. Arthroscopy has the advantages of being minimally invasive, avoiding the morbidity of a surgical hip dislocation and trochanteric osteotomy, and allowing for faster rehabilitation [18]. Cadaveric studies have shown that arthroscopic osteochondroplasties are comparable in accuracy and precision to open techniques [19]. Clinical studies have also shown that arthroscopic techniques have yielded outcomes that are not inferior to open surgical dislocation [18, 20, 21]. A recent radiographic outcomes study has shown that hip arthroscopy has comparable efficacy to open surgical dislocation in restoring head-neck offset and achieving an adequate amount of osseous resection for anterosuperior cam impingement [22]. Presently, most femoral cam deformities are effectively treated by arthroscopic approaches.

Although arthroscopic hip surgery continues to increase in popularity, it has its own unique set of challenges. First, it remains technically demanding with a steep surgical learning curve [10, 18]. Second, a dynamic assessment of the zone of impingement is difficult to perform with the hip fixed in a traction device. Third, the relative inflexibility of small portals being used to maneuver instruments within a thick capsule limits visualization, can cause iatrogenic injury, and increases operative time, which may cause neurovascular injury secondary to prolonged traction. Finally, poor visualization may make appropriate osseous resection difficult. Osseous abnormalities are commonly under-resected and this is a common cause for revision surgery, accounting for up to 78–90 % of all failed arthroscopic hip surgery [11, 12]. Over-resection, on the other hand may lead to fracture, hip instability, and dislocation [23–25].

The intraoperative assessment of an adequate resection is limited in both open and arthroscopic surgery. The open surgeon uses spherometer gauges and fluoroscopy for guidance while the arthroscopic surgeon combines fluoroscopy with arthroscopy. For the arthroscopic surgeon however, the problem remains that 2D modalities are being utilized to define a 3D morphology. Furthermore, the difficulty in judging the adequacy of resection is compounded by the lack of appropriate preoperative planning tools. The combination of a complex decision-making process in defining a 3D problem, while performing technically demanding surgery, has resulted in the recent research into computer-assisted preoperative planning solutions.

Preoperative Planning in FAI Surgery

CAS has been gaining popularity in FAI surgery to minimize the limitations outlined in the previous sections but specifically to address the issues of accurate and precise osseous resections. Preoperative planning software has been designed to perform virtual bony resections to minimize impingement and improve ROM [26, 27]. Although these tools have been shown to be helpful in predicting postoperative ROM and have been validated, they also raise as many questions as they answer. Specifically, what parameter does one use to define adequacy of osseous resection? Convention is to use anatomic parameters such as the alpha angle [28]. An alternative concept is to use a pure kinematic plan or collision detection algorithm to show improved motion, especially flexion combined with internal rotation.

The anatomical abnormality in cam impingement is reduced anterior femoral head-neck offset, which is currently quantified by the alpha angle [28]. This angle is drawn on

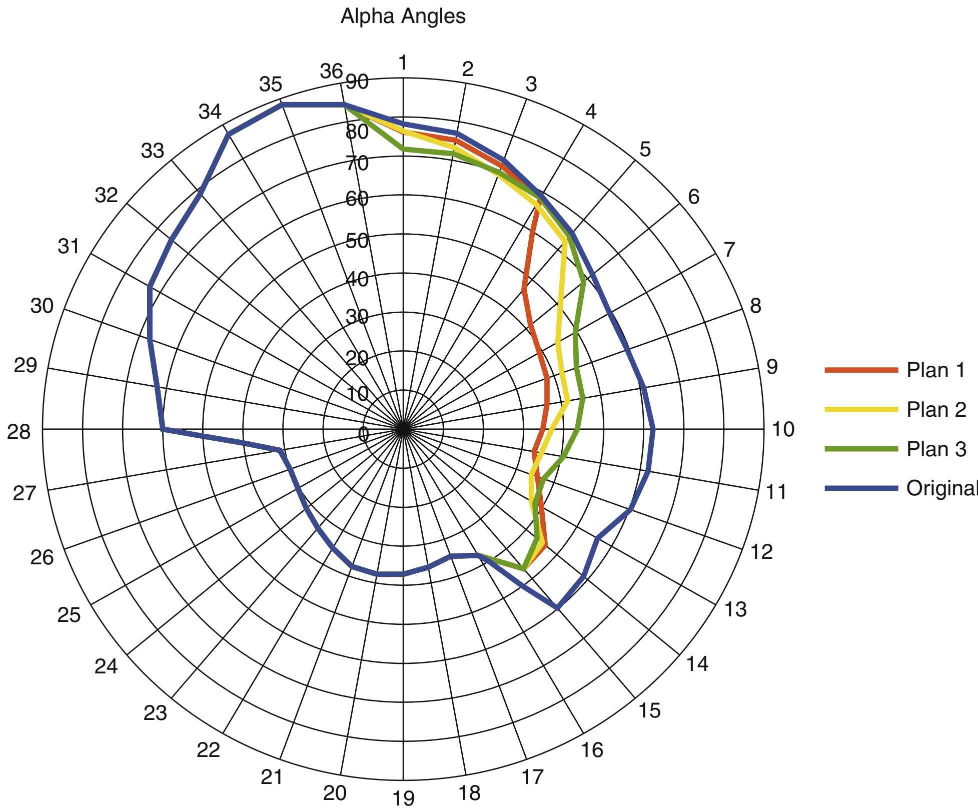

Fig. 16.1 A 'spider plot' illustrating the 360° alpha angles in 10° increments for three different preoperative resection plans. Note how the alpha angle changes at different locations on the clockface (Reprinted with permission from Ecker et al. [36], Fig. 3)

MRI cuts parallel to the axis of the neck and passing through the center of the head and is defined by the axis of the femoral neck and a line connecting the center of the femoral head to the anterior extent of the concavity of the femoral neck [28]. An angle of less than 50° is defined as normal. In cam FAI, Stahelin et al. have recommended that an alpha angle less than 50°, or a reduction of the alpha angle by 20° (in cases of very large alpha angles), will result in satisfactory restoration of femoral head-neck offset [6].

The alpha angle however does have its limitations. It does not take into account the length of the cam lesion. If the 'bump' is long, the resection may have to be advanced into the trochanteric fossa. Several authors have noted that the maximal loss of head-neck offset may be present at different locations in different patients and thus a single value is limited in the information it provides [29]. Others argue what is truly a pathological value of the alpha angle. Clohisy et al. evaluated the alpha angle in patients with FAI and asymptomatic controls and found a comparable range of normal and abnormal alpha angles in the two groups [30]. They could not define an alpha angle threshold beyond which a pathological diagnosis can be considered. Furthermore, it has been shown that the alpha angle does not reliably correlate with the clinical range of motion with one study reporting that patients with insufficient offset correction showed a slightly better internal rotation than patients with satisfactory offset restoration [31].

A more recent trend in anatomic planning software is to use a 3D alpha angle or volume. This concept takes into account several alpha angles at different locations on the clockface (Fig. 16.1). It also takes length and area into account thereby identifying a true zone of impingement.

Due to the inherent problems in pure anatomic planning programs, Tannast et al. designed the first comprehensive preoperative assessment tools in 2005, utilizing "HipMotion" software (Bern, Switzerland) to perform a CT-based 3D kinematics analysis of the hip joint [26]. This software uses a kinematic plan to define zones of impingement and then predict improvement in ROM after a virtual resection. It therefore addresses the need for an accurate kinematic preoperative plan but also gives enhanced visual guidance to the surgeon in executing the plan precisely. The software reconstructs a 3D model of the pelvis and femur which is digitized and orientated to the anterior pelvic plane (APP). After localization of the hip center, the native preoperative ROM is calculated using collision algorithms which determine ROM based on points at which contact (i.e. impingement) occurs (Fig. 16.2). Hence, a zone of impingement is identified. A virtual surgical acetabular and femoral resection is then performed to delay impingement until later in the motion cycle (Fig. 16.3a, b). Virtual postoperative ROM is simulated by reconstructing the hip joint using the new parameters, to assess the efficacy of the planned procedure (Fig. 16.3c, d).

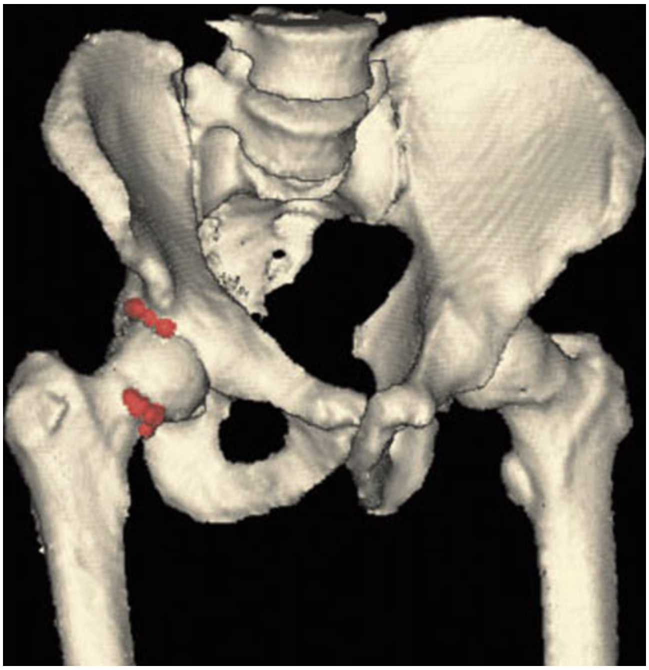

Fig. 16.2 Image from HipMotion software of the pelvis and both hips. The acetabular and femoral location of impingement is identified for the right hip (Reprinted with permission from Tannast et al. [26], Fig. 1)

This program was validated by the authors by integrating it with the imageless BrainLAB (Feldkirchen, Germany) software and comparing virtual with real ROM. The accuracy of HipMotion was 0.7° ± 3.1° in a plastic bone setup, and −5.0° ± 5.6° in a cadaveric setup. Perhaps the most encouraging aspect of HipMotion is that it calculates the volume of resection based on a desirable postoperative ROM rather than a postoperative alpha angle. The limitations of the program is that it assumes the hip joint has a perfect center of rotation, thereby not accounting for the translation which occurs with weight-bearing, hip motion, and muscular activation. This issue is now being debated and more accurate models are being proposed [27].

HipMotion was also used in a clinical pilot study by the same authors to compare the ROM in 28 hips with anterior FAI to a control group of 33 normal hips [32]. The hips with FAI had decreased flexion, internal rotation, abduction, and internal rotation in 90° of flexion. The zones of impingement were found anterosuperiorly and were similar in the two groups. The virtual postoperative ROM improved in all subgroups of FAI, with the biggest improvement (15.7°) seen in mixed impingement. Another company known as A[2] Surgical (St Pierre d'Allevard, France) are producing innovative solutions

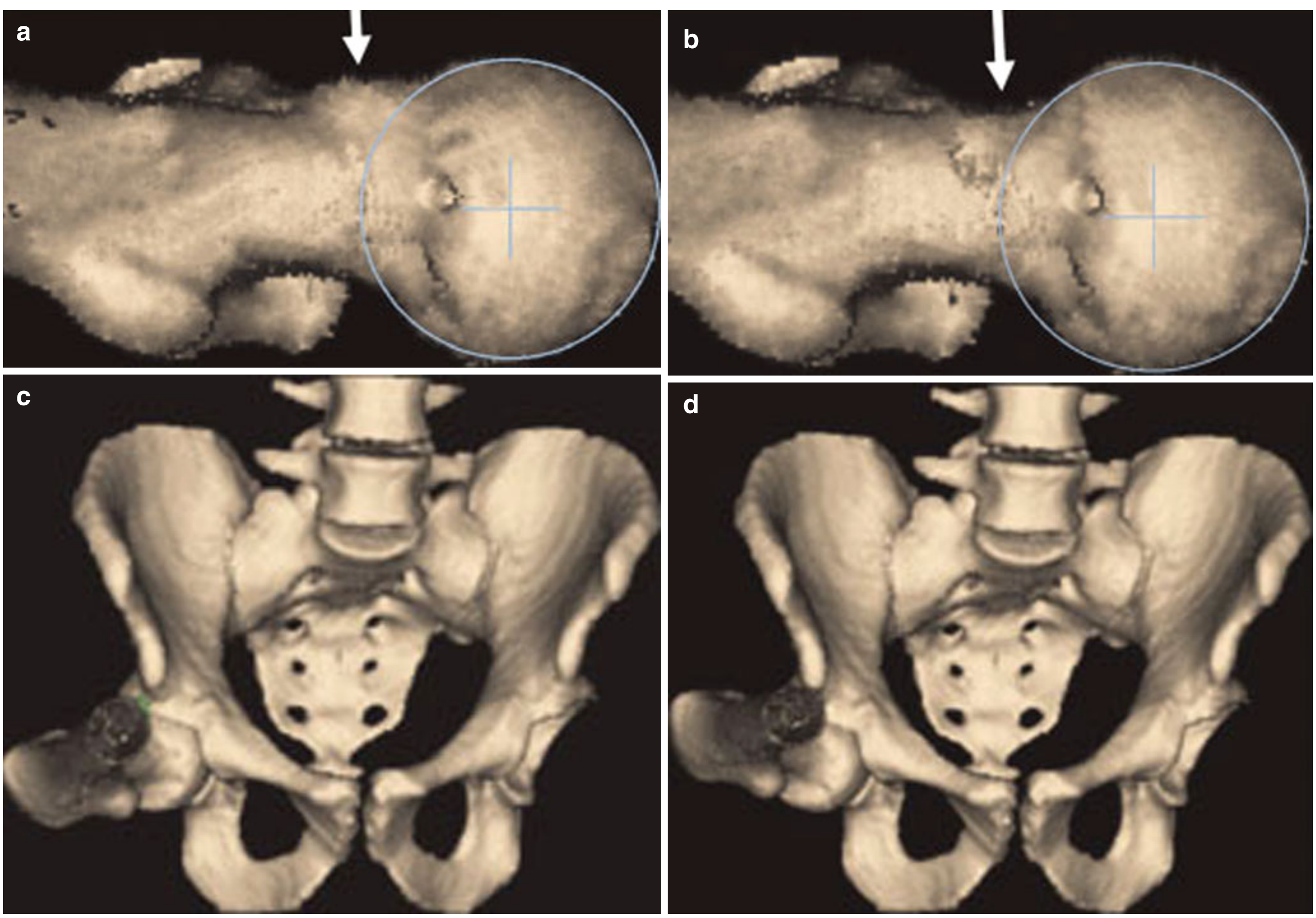

Fig. 16.3 (**a, b**): HipMotion software planning a virtual resection with pre (**a**) and post (**b**) resection images being shown (Reprinted with permission from Tannast et al. [26], Fig. 2 A and D). (**c**, **d**): HipMotion 3D ROM analysis showing the beneficial effect of a virtual femoral osteochondroplasty. A native internal rotation of 11° in 90° of flexion (**c**) is increased to 37° (**d**) after the virtual offset creation (Reprinted with permission from Tannast et al. [26], Fig. 2 C and F)

that also use preoperative CT scans to plan impingement scenarios. This product is currently not on the market. It is based on an anatomic plan, using alpha angles in various planes, thus allowing for accurate resection in targeted areas. In summary, there are various noninvasive preoperative software programs available which help the surgeon localize the zone of impingement and then confidently plan and quantify the volume of resection and predict postoperative ROM using both anatomic and kinematic data.

Navigation in FAI Surgery

Navigation programs guide the surgeon intraoperatively to precisely reproduce preoperative plans. Navigation can be image-based, imageless or fluoroscopically-guided. Image-based navigation obtains registration of anatomical landmarks with the use of osseous pins. With the pelvis, for example, pins are inserted into the anterior superior iliac spines and pubic tubercles. These pins allow the digitization of the pelvis in virtual space, align it to the APP, and match it to preoperative 3D MR or CT data. Imageless navigation achieves registration by the use of optical infrared trackers mounted on the pelvis, coupled with a calibrated optical pointer to register the anterior superior iliac spine and pubic tubercle. Fluoroscopically-guided navigation uses a calibrated tracker on a specially designed C-arm which takes a series of images in multiple planes to establish registration. The intraoperative images are then matched with preoperative data. Due to the complex 3D osseous morphology in FAI, most navigation programs use 3D CT based technology with either direct bony registration or 3D to 2D registration with specialized fluoroscopy.

Navigated orthopaedic surgery can be simplified into three steps: digitization, registration, and tracking. Digitization requires a reconstruction of a patient's 3D bony anatomy by using either magnetic resonance (MR) imaging or computed tomography (CT). Markers are then placed intraoperatively on specific bony landmarks to register the computer to the orientation of the patient on the surgical table. Once this is done, the instruments can link the patient's osseous anatomy to the image data, allowing the visualization and real time tracking of the surgical instrumentation in relation to the virtual representation of the patient as defined by the preoperative imaging. This process allows the surgeon to determine precisely what areas to resect.

One of the first groups to intraoperatively track instruments during hip arthroscopy was from Pittsburgh (USA), who developed an encoder linkage system to track surgical instruments [33]. This eliminates the problem of occlusion with standard optical tracking systems. An encoder is a device which captures tool motion and orientation. The setup consists of a chain of rotational encoders connecting a surgical instrument to a reference point on the patient's pelvis. A similar chain is attached between the arthroscope and the pelvis (Fig. 16.4). The encoder linkages are calibrated with preoperative, patient-specific 3D CT or MR imaging data so the position of the surgical tools can be verified with respect to patient anatomy. This system is unique in that it incorporates soft tissue as well as bony anatomy and therefore also serves as a useful aid for safe portal placement. The software therefore can warn a surgeon when a surgical instrument has moved too close to a neurovascular structure for example (Fig. 16.5). The positional information from the arthroscope is integrated in real time to the visualization software to provide virtual arthroscopic views of the hip joint in addition to the view from the camera itself. This system has been tested by performing a user study where ten participants completed a simple navigation task with and without the aid of the system. The computer-aided system resulted in a 38 % reduction in operative time and 78 % reduction in tool path-length [34]. Once the clinical feasibility of this system has been assessed, it offers a promising alternative to optical tracking systems.

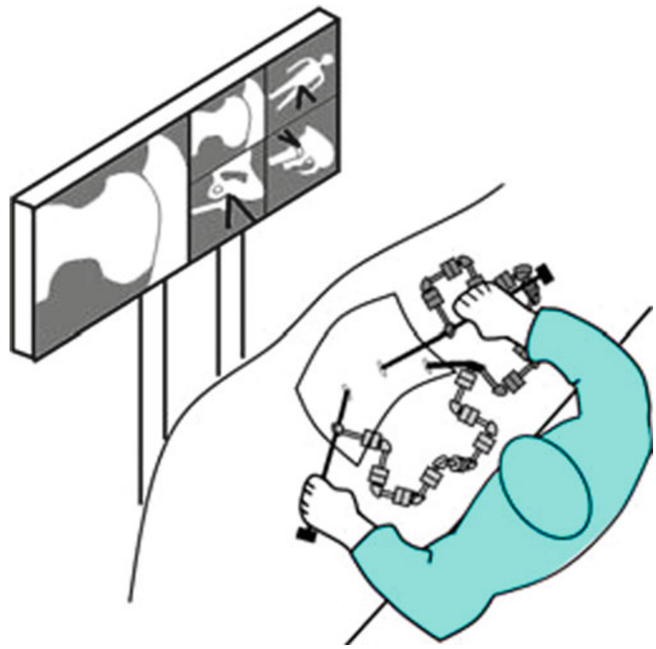

Fig. 16.4 The encoder-linkage system attached to an arthroscope and pelvis model, tracking tool position and quantifying movement (Reprinted with permission from Monahan et al. [33] Fig. 1)

The best navigation paper to date was by Brunner et al. who performed a prospective study looking at the clinical outcomes and head-neck offset correction in patients with cam impingement in both navigated and non-navigated groups [31]. Fifty patients were included in the study and were randomly assigned to receive navigated or 'freehand' arthroscopic cam decompression. They used a 3D-CT based navigation system which uploads a preoperative CT scan of the pelvis and crossmatches this with intraoperative fluoroscopy

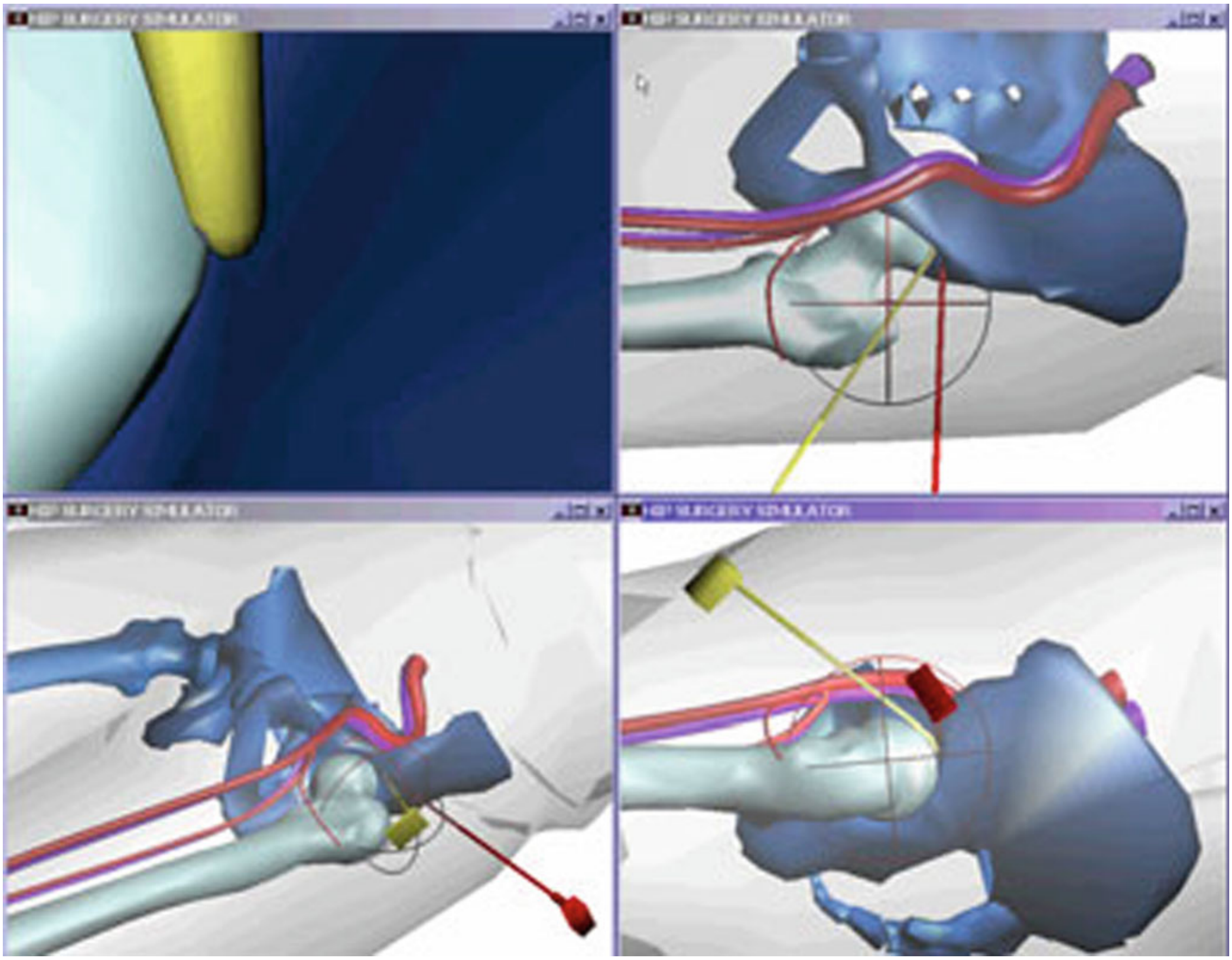

Fig. 16.5 A computer generated view of the hip joint showing the important vascular anatomy, generated by the encoder linkage system. The *circle* denotes a 'safe-zone' whereby the arthroscope can be maneuvered without danger to the nearby vascular structures (Reprinted with permission from Monahan et al. [33] Fig. 2)

(Fig. 16.6). This system gives the surgeon real time information about the position of the surgical instruments in relation to the femoral neck (Fig. 16.7). It does not however allow for preoperative planning, delineate the zone of impingement, or display the amount of resected bone as the surgery progresses. The study found no significant difference in femoral offset correction with 24 % of subjects in both the navigated and non-navigated groups having an inadequate reduction of the alpha angle. Both groups showed significant improvements in ROM and non-arthritic hip scores, but with no demonstrable difference between the groups. Interestingly, those patients with insufficient femoral offset correction did not display adverse clinical outcomes. The authors concluded that the presented navigation system did not improve the accuracy of femoral offset restoration and that another study is underway utilizing an updated version which allows 3D virtual simulation of the impingement process, preoperative planning of location and quantity of femoral resection and intraoperative tracking of the extent of bony resection. This study once again illustrates the limitations of using the alpha angle as an outcome measure and emphasizes the importance of measuring clinical outcomes.

The third group to investigate intraoperative tracking is an Ottawa-based group that used an improved version of Brunner et al.s software [35]. They tracked bony resection for cam impingement and assessed the adequacy of resection when comparing surgeons of varying experience and when comparing open versus navigated arthroscopic resection. Twelve sawbone femurs with anterosuperior cam deformities were divided into four groups. In the first three groups, correction was performed with a navigated technique using a mini-open arthrotomy model. The experience of the surgeons in the three groups varied as follows: (1) Experienced surgeon specializing in surgical correction

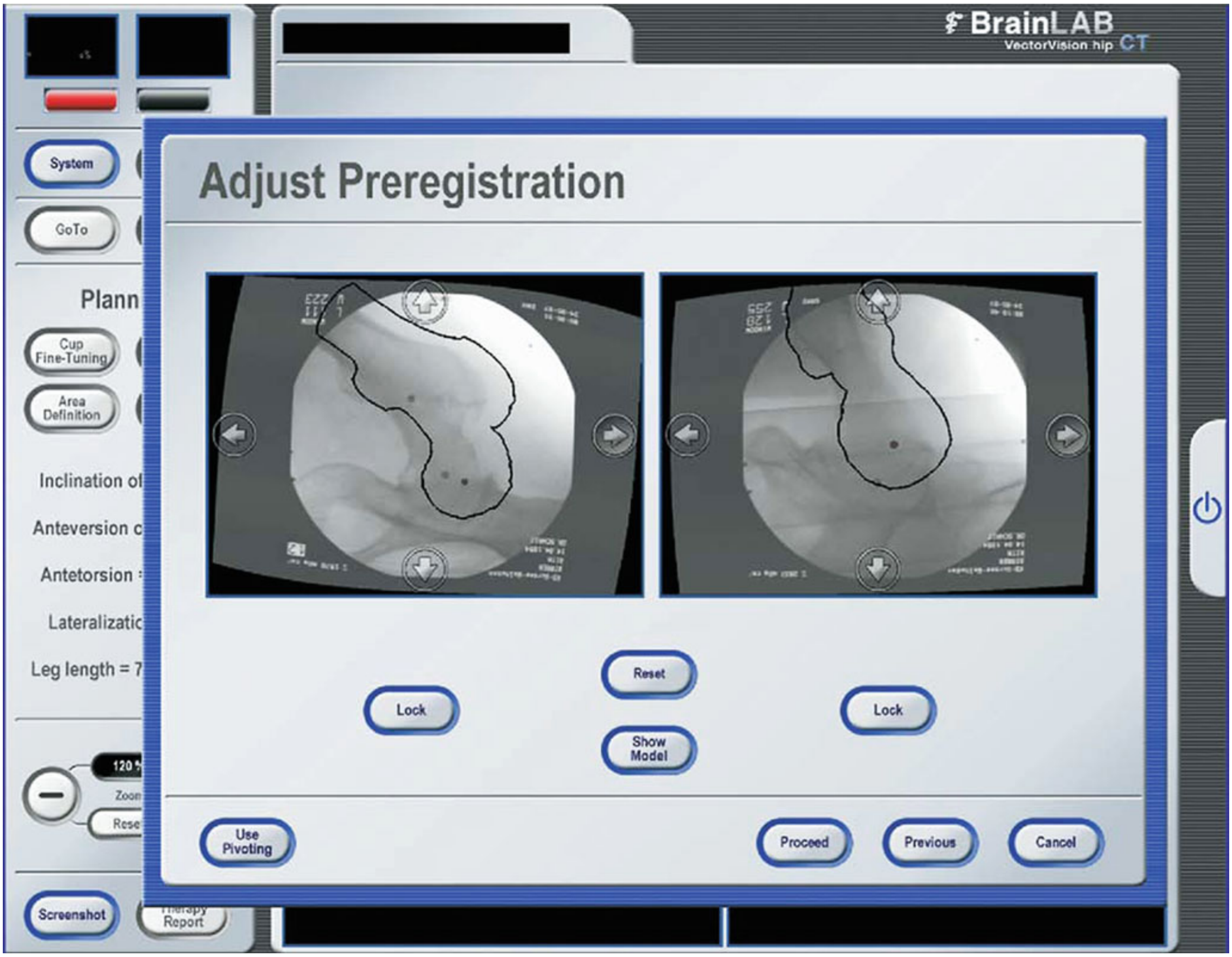

Fig. 16.6 Fluoroscopically-guided navigation using 'cross-matching' of online fluoroscopy and preoperative computed tomography data (Reprinted with permission from Brunner et al. [31], Fig. 1)

of FAI deformities, (2) Experienced surgeon not specializing in surgical correction of FAI deformities, and (3) Fellow in adult reconstruction. The fourth group was operated on by the same surgeon used in Group 1, but the correction was performed with an open technique using femoral head spherometer gauges.

A preoperative plan was generated for all cases from CT scans and the BrainLAB navigation system (Feldkirchen, Germany). A sawbone model was then inserted into a foam block to simulate a mini-open anterior approach. Registration was performed with a BrainLAB marker array attached to the distal femur and biplanar fluoroscopic images of the proximal femur. An alpha angle of 45° was selected as an indicator of adequate resection. The navigation software highlighted in red the bone that was to be resected and real time tracking could be performed by the surgeon using a pointer with marker arrays to ensure the area highlighted in red was appropriately resected. Postoperative CT scans were performed and alpha angles were determined at both the one-thirty and three-o'clock planes of rotation in order to identify the differences between the different groups. Similar post-resection alpha angles were observed between all three surgeons in both the one-thirty and three-o' clock planes. This nicely demonstrated how CAS could minimize the learning curve in FAI surgery and permit the less-experienced surgeon to perform bony resections equivalent to an experienced surgeon. Interestingly, surgical navigation yielded significantly higher post-resection alpha angles compared to open surgery with spherometer gauges at the one-thirty position. No difference however was found at the three-o'clock position. The authors attribute this difference to the difficulty in properly visualizing the anterolateral femoral head-neck junction and the perception that this area is too lateral to be perceived as an area of impingement. In addition, limitations in the accuracy of the osseous registration step were highlighted as a source of error.

Fig. 16.7 Typical view of a navigation screen showing the position of an optical tracking device in relation to the femoral neck (Reprinted with permission from Brunner et al. [31], Fig. 4)

Most recently, Tannast's group have published the follow-up paper to their previous paper on ROM analysis in FAI [36]. Their current software combines their previous collision detection and ROM analysis technology [26] with a color-coded intraoperative map to guide resection in real time. The navigation application is based on the MARVIN application framework [37] where a 3D model of the patient's pelvis is derived from MR or CT. Preoperative ROM analysis is performed to define a zone of impingement. This is followed by a virtual cam decompression according to the preoperative plan to ensure an improved postoperative ROM without impingement. A superimposed translucent sphere prevents excessive resection, ensures sphericity, and depicts pre and postoperative femoral morphology. The operation begins with registration of the 3D virtual model to the patient's anatomy using a dynamic reference base (DRB) attached to the femur. The reaming device is then calibrated with another DRB. The preplanned resection area is highlighted on the screen as color-coded distance map with a red color indicating the prereamed state and a change to green when the reamer is within 1 mm of the resection goal (Fig. 16.8). Reaming is commenced and the surgeon is guided to the preplanned goal by real time tracking of the reaming device and color changes on the map indicating depth of resection.

The feasibility and accuracy of this navigation device was tested using 3D models of 18 identical sawbone femurs. Postoperative models were created to compare with preoperative plans. Two surgeons performed three different osteochondroplasties on three occasions, resulting in nine operations per surgeon. The results demonstrated excellent intraobserver and interobserver agreement with the mean distance between planned and actual reamed surface at the femoral neck of 0.41 mm. The discrepancy between planned and actual reaming was consistently less than 1 mm in all 18 sawbone operations. The planned alpha angle was reamed with an accuracy of $0.1° \pm 0.6°$. These results show beyond

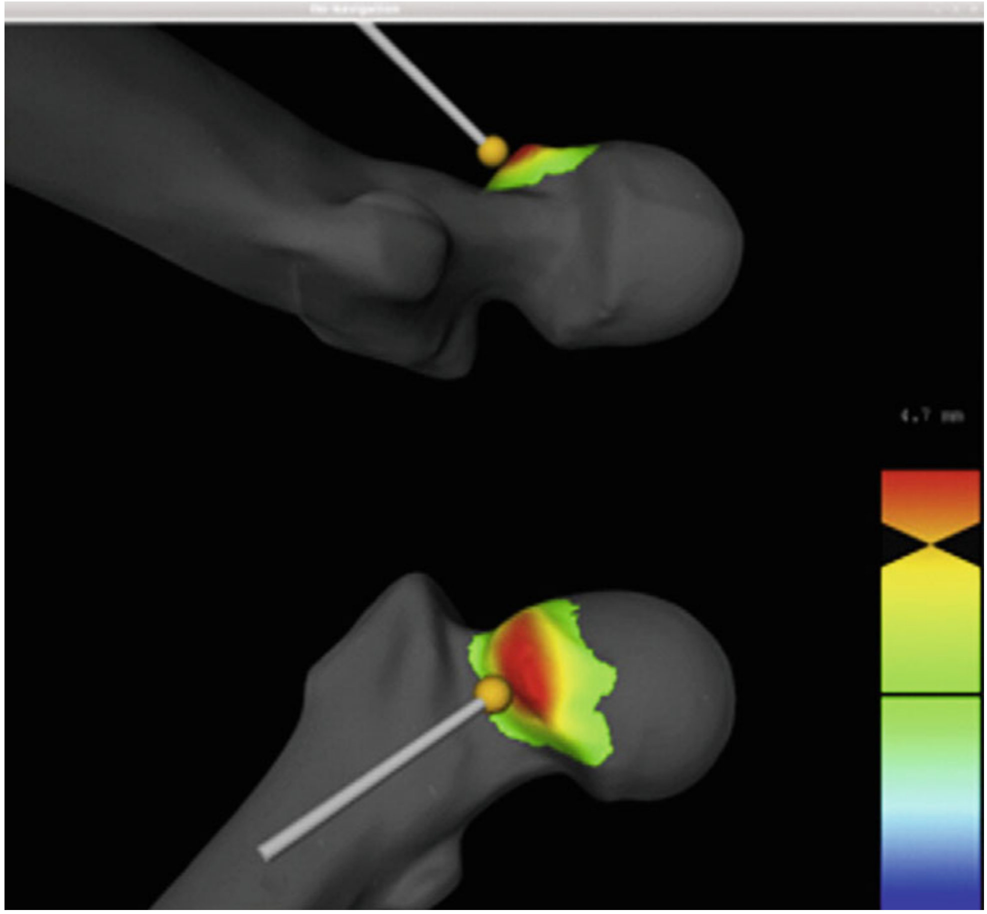

Fig. 16.8 The volume of resection is highlighted as a *color-coded* distance map according to the preoperative collision detection and ROM analysis. The burr is tracked in real time and color changes on the map indicate the proximity of the depth of resection to the pre-planned goal (Reprinted with permission from Ecker et al. [36], Fig. 2)

doubt the accuracy of this planning and tracking system. It seems to address the limitations of all the previous applications presented. The next test is going to be its applicability to an actual intraoperative arthroscopic setting.

Large orthopaedics companies like Stryker (Kalamazoo, MI) have also made an effort to produce navigation systems for use in surgeries to treat cam type impingements. One of their newer products, OrthoMap 3D, is based on their previous OrthoMap Hip Navigation Software that is currently in use for total hip arthroplasties. OrthoMap 3D provides surgeons with visualization of the proximal femoral region, thus providing localization of the cam lesion and real time instrument positioning. However, to date there has been no published data on this system.

Robotic-Assistance in FAI Surgery

Navigated CAS allows the formulation of an accurate preoperative plan that can be virtually assessed and tracked intraoperatively. The missing link is precise surgical execution. Robotic surgery is the most recent development in CAS and translates the quantitative assessment produced by navigation into an automated mechanical action. Surgical instruments are mounted on a robotic arm which may partially or completely automate the entire surgical procedure. Robotic surgery provides a greater level of dexterity and precision, and even allows for unmanned or remote surgery [38].

The most widely used robotic surgical system in use today is the "da Vinci" tele-robotic platform. It was licensed in 2001 for urological procedures and in 2005 for gynecological procedures by the US Food and Drug Administration. This system allows the surgeon to sit remotely at a console and control the movements of several robotic arms while viewing the operative site in three dimensions using stereotactic cameras. The surgeon's hand movements are scaled and translated to surgical instruments mounted on the robotic arms. Currently, it is being used in procedures such as hysterectomies, prostatectomies, gastric bypass, and treatment of mitral valve prolapse.

There has been a preliminary attempt to apply the "da Vinci" surgical system to hip arthroscopy. By only using the instrumentation available to them, Kather et al. attempted to perform a hip arthroscopy on two fresh frozen cadavers [39]. They were able to resect the acetabular labrum with a hook knife and scissors. However, they had difficulty accessing the posterior or postero-inferior labrum, and the medial and posteromedial femoral head. This would currently limit the

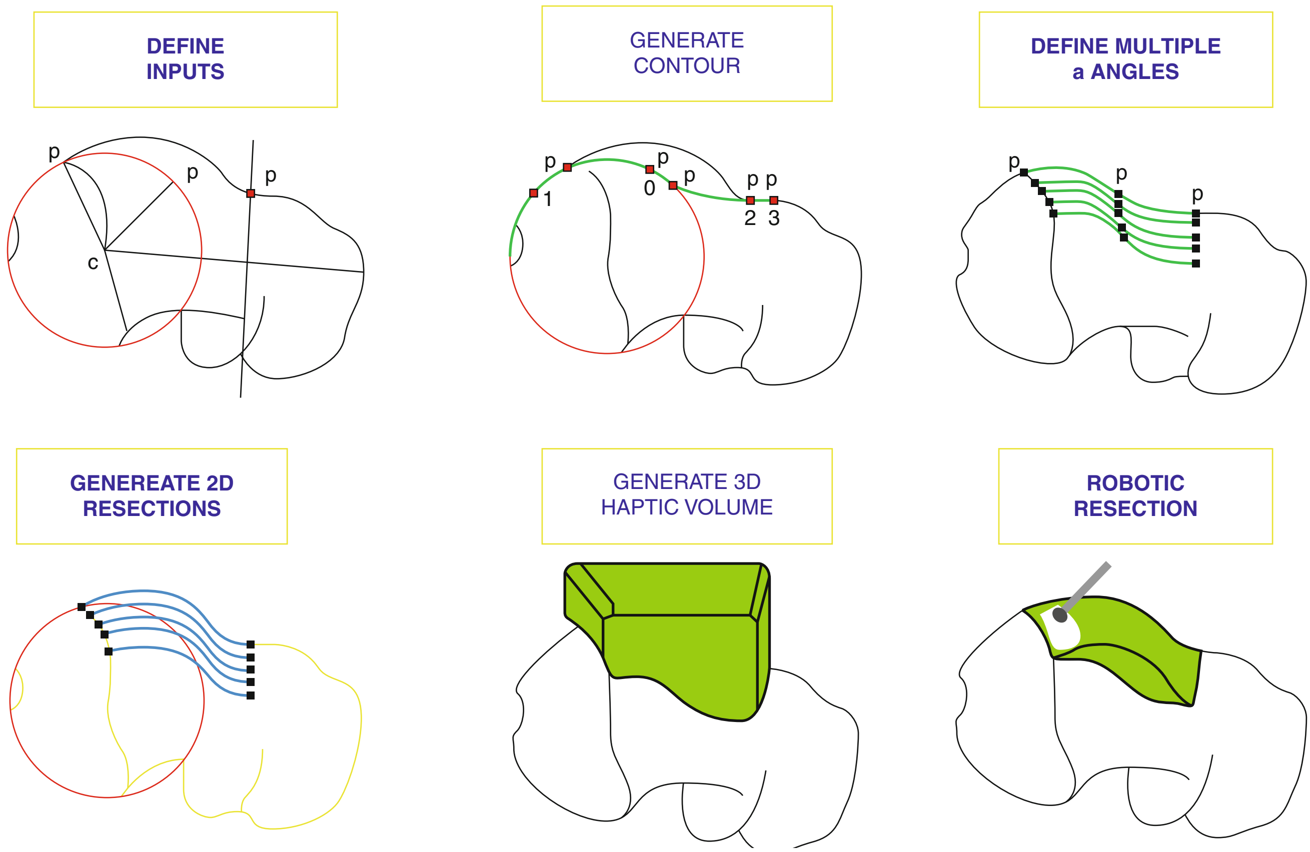

Fig. 16.9 An anatomic plan can be generated by defining the volume of resection in 3D using collision detection and ROM analysis data. The anatomic plan then generates a 3D Haptic volume which is accurately resected with robotic-assistance

"da Vinci" system's applicability to FAI surgery although it must be noted that the instrumentation being used was not specialized for the demands of arthroscopic surgery. This study shows that remote robotic hip arthroscopy is in its infancy but with time and appropriate instrumentation, robotic technology has the potential to allow orthopaedic surgeons to perform complex procedures in very restricted spaces from a remote location.

There are already a number of robotic surgery systems in use in orthopaedic surgery, especially in total hip and knee arthroplasty. The "Brigit" Bone Resection Instrument Guide applies preoperatively defined cutting limits to an intraoperative rigid multislot guide, to assist the surgeon in accurate tool positioning. An advancement of this principle is the use of 'Haptic' technology. 'Haptics' is a tactile feedback technology that utilizes a preoperative plan to control the operator's movement and sense of touch by applying forces and vibrations. A haptically guided semiactive robot can therefore add virtual safety barriers based on patient-specific templates or preoperative plans to control the movements of the surgeon and his/her instruments. Haptically guided robotic technology has already demonstrated success in orthopaedics. Cobb et al's group in London, UK have used the Acrobot haptic-guided unicondylar knee replacement system (Acrobot, London, UK) to improve implant-positioning precision [40]. In a prospective randomized controlled trial of 28 knees, they found that the tibiofemoral alignment of all the robotically assisted knees was within 2° of the planned position whereas only 40 % of the conventional group achieved this accuracy.

A system similar to the Acrobot has been developed in the United States: The Tactile Guidance System (MAKO Surgical, Fort Lauderdale, FL). This system is currently being used to perform partial knee replacement (medial unicondylar, lateral unicondylar and patellofemoral) and total hip arthroplasty. The senior author of this review has conducted a study on robotic-assisted femoral osteochondroplasty for FAI [41]. Sixteen identical sawbone models with a cam deformity were treated by a single surgeon simulating an open FAI procedure. Eight of the procedures were performed using a free-hand technique and eight were performed using robotic-assistance with the MAKO system. For the models that used robotic-assistance, a 3D haptic volume was defined by the desired post-operative morphology (Fig. 16.9). After resection, all the sawbones were scanned, and post-resection measurements of the arc of resection, volume of bone removed and resection depth were obtained

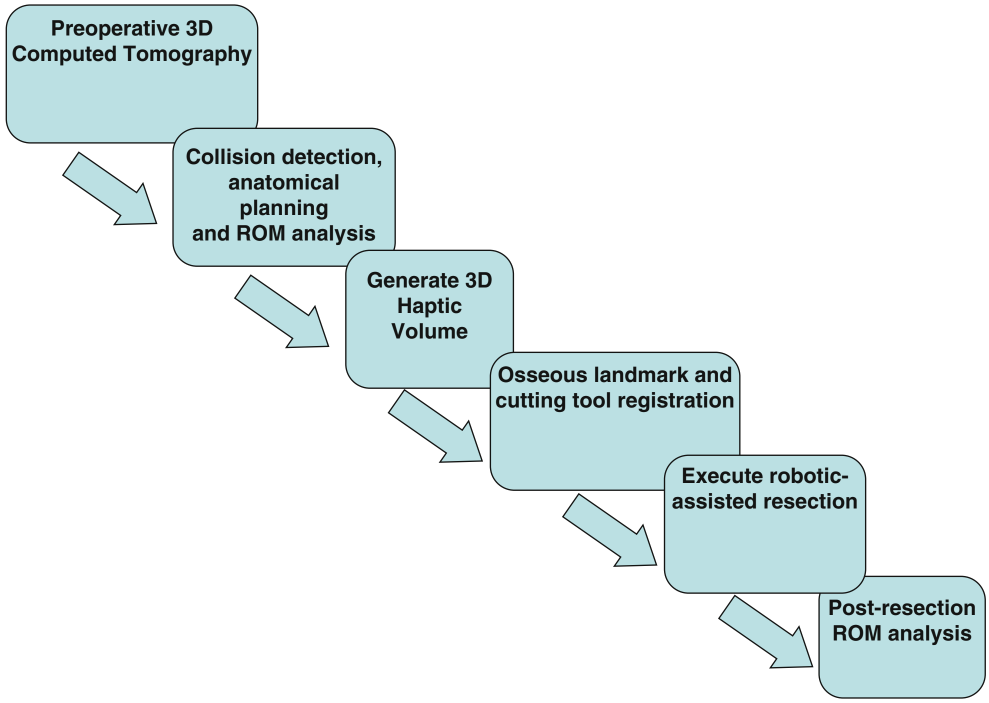

Fig. 16.10 Surgical strategy flow diagram – Preoperative 3D CT, Collision detection and ROM analysis, Virtual resection, Assess virtual ROM ensuring that it is impingement-free, generate haptic 3D volume, place portals, bony landmark and cutting tool registration, execute robotic resection

and compared to the pre-operative plan. The desired arc of resection was 117.7° starting at −1.8° and ending at 115.9°. The models resected using a free-hand technique produced an average arc resection error of 42.0° ± 8.5°. Those that were resected using robotic-assistance produced an average arc resection error of 1.2° ± 0.7° which was significantly lower than the free-hand group ($p<0.0001$). Furthermore, every manual resection resulted in over-resection with an average volume error of 758.3 mm^3 ± 477.1 mm^3 as compared to the robotic group which produced an average volume error of 31.3 mm^3 ± 200.7 mm^3 with four over-resected and four under-resected. Again, this was significantly less than the free-hand group ($p<0.01$). The average cutting time for a robotic-assisted resection was 210 s which was significantly less than 303 s seen in the free-hand group ($p<0.001$). This study shows that robotic-assistance is significantly more accurate and precise than free-hand techniques.

Using all currently available technology, a surgical strategy for future robotic-assisted FAI surgery can be proposed (Fig. 16.10). A preoperative 3D CT would be obtained to define the morphology of a cam lesion (e.g. alpha angle) or a pincer lesion (e.g. lateral center-edge angle). The pelvic and femoral orientation would be registered. A preoperative assessment of virtual ROM using collision-based algorithms would plan the resection volume to achieve impingement-free postoperative ROM [26, 42]. The calculated arc and depth of resection may be represented on a clock face on the femoral head. A robotic-guided cutting tool and arthroscope would be co-registered with bony tracking to enhance intraoperative visualization and allow real time tracking. A robotic-guided arm with 6 degrees of freedom would then haptically guide the surgeon around the calculated resection volume with virtual walls ensuring an accurate bony resection and preventing iatrogenic damage to bone and surrounding soft tissue. Finally, a dynamic intraoperative real time assessment will be permitted to assess the adequacy of resection.

Conclusion

Arthroscopic techniques for treating FAI are becoming the standard of care for many common deformities. However, inaccurate and inadequate resection continues to plague the hip arthroscopist, due to the technical difficulty of the procedure combined with the limitations in preoperative planning, visualization, and intraoperative judgement of the adequacy of resection. The majority of revision hip arthroscopies are currently being performed for inadequate resection and unless the quality of the surgery improves, clinical results are likely to decline. CAS is an attractive proposition for improving the accuracy and precision of arthroscopic FAI surgery. The prototypes discussed in this review have shown encouraging results in vitro, but clinical success and commercial viability is yet to be demonstrated. With regard to cam impingement, the current literature supports the measurement of a virtually simulated ROM to help plan any resection as opposed to using the alpha angle. Using this principle, the ideal CAS solution would define the zone of impingement preoperatively, plan the bony resection based on a virtual impingement-free ROM, track arthroscope and instrument movement intraoperatively, guide the surgeon towards accurate resection with haptic barriers, and facilitate dynamic intraoperative assessment of ROM to ensure adequacy and precision of resection. Ultimately, only by improving clinical outcomes, reducing technical difficulty, decreasing operative time, and minimizing cost, will such a system become the standard of care. Although this ideal system is currently not available, the latest research would suggest that it is attainable.

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17 Hip Arthroscopy: Recent Progress and Future Directions

Marc J. Philippon, Diana Patterson, Teddy Fagrelius, and Karen K. Briggs

Introduction

The earliest mention of arthroscopic surgery on the hip joint was in a 1931 publication by Burman, a cadaver study in which he utilized arthroscopic techniques to examine interior of the joints of the human body. However, at the time, he stated that it was impossible to "insert a needle between the head of the femur and the acetabulum" [1]. This sentiment limited the use of hip arthroscopy to the peripheral compartment and significantly slowed its growth in popularity. In North America, it was essentially rediscovered in 1977 when Gross reported on usage of hip arthroscopy to treat congenically dislocated hips [2]. Then, in 1986, Eriksson published an overview of hip arthroscopy in which he concluded that it was possible to remove loose bodies from the joint and perform a partial synovectomy with an arthroscopic shaver, and that arthroscopy enabled shorter hospitalizations and rehabilitation [3]. In the 10 years following this publication, the use of and research done with hip arthroscopy expanded. Today, it has become the treatment modality of choice to address most intra-articular pathologies, such as FAI, labral tears, chondral injuries, capsular laxity, avascular necrosis and synovial chondromatosis, to name a few.

The development of arthroscopic techniques for the hip has progressed much slower than those for the shoulder or knee. This is potentially due to two major factors. First, as intimated by Burman, the hip is a difficult joint to access arthroscopically, as the femoral head is deeply and firmly established in the bony confines of the acetabulum and the supporting soft tissues are stiff and strong. Second, hip arthroscopy is now being used regularly to treat conditions that were previously rarely diagnosed. In the past, physicians did not treat femoroacetabular impingement, labral tears or chondral lesions, or their pathologic sequelae [4]. Now, improved physical exam and diagnosis techniques have improved our diagnostic capabilities. Enhanced patient positioning and portal placement, flexible scopes a wide variety of instruments that have been specifically designed for the unique anatomy of the hip has opened up the world of hip arthroscopy. The options available to the surgeon and patient range from capsular tightening procedures to complex reconstructions of the labrum or ligamentum teres. Usage of platelet-rich plasma and other suspensions are exciting in their potential to augment and speed recovery. Hip arthroscopy is now, more than ever before, allowing people from all walks of life, both the weekend warrior and the professional athlete, to return to their prior level of activity and with improved quality of life.

Progress and Future Directions on Diagnosis of Hip Pathology

The ability to diagnose hip pain has greatly improved over the last 10 years. The diagnosis of FAI is the most common diagnosis seen in most practices with young active adults. The physical exam to diagnose hip pathology includes an assessment of gait, neuromuscular status, inspection and palpitation of all involved structures, full range of motion and special maneuvers. Range-of-motion is often restricted in patients with FAI and a labral tear [5]. Special maneuvers performed to isolate a diagnoses of FAI, labral tear or instability include the anterior impingement test, the FABER test and the dial (or log roll) test. The anterior impingement test is positive when flexion-adduction-internal rotation elicits anterior groin pain. The FABER test measures restrictions in flexion-abduction-external rotation by measuring the distance between the lateral aspect of the knee and the exam table with the lower leg is crossed and

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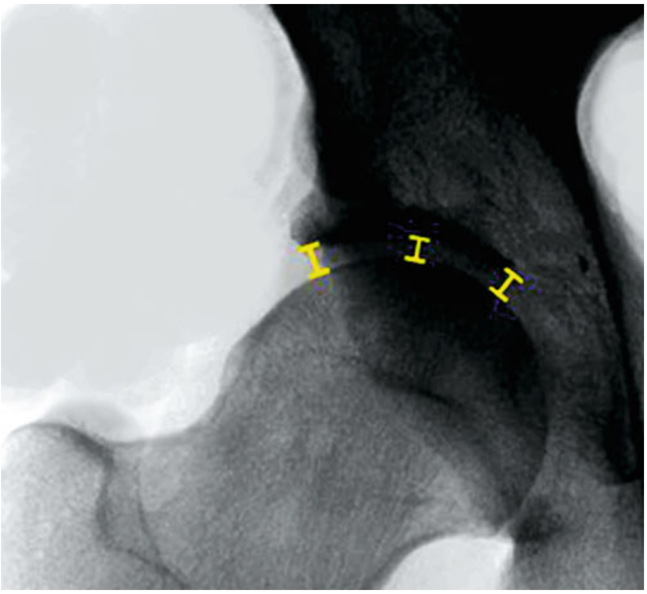

Fig. 17.1 Joint space at the level of the sourcil is measured at 3 points on the AP radiograph

placed on top of the contralateral knee [6]. The log roll, or dial, test consists of holding the foot, internally rotating the limb and then releasing to allow natural external rotation. A positive test is defined as excessive external rotation (>45° from vertical) and no mechanical endpoint compared to the asymptomatic side [7]. An intra-articular lidocaine injection can help differentiate between intra and extra-articular pathology. If the pathology is in the surrounding soft tissue, it is less likely to be relieved with an intra-articular injection. One study found that therapeutic alleviation of symptoms in response to an intra-articular injection of anesthetic was 90 % accurate in predicting intra-articular pathology [8].

Diagnostic imaging for intra-articular hip pathologies continues to improve in quality and accuracy. Our radiographic studies routinely include AP pelvic, cross table lateral, false profile and tunnel view radiographs. The joint space at the level of the sourcil, measured at 3 points (Fig. 17.1), the center edge and Sharp's angles and head-neck offset are measured on the AP pelvic views; this AP image is also utilized to evaluate for acetabular overcoverage as determined by a cross over sign or posterior wall sign. The alpha angle, which has been correlated with presence and extent of labral and chondral lesions [9], is measured from the cross table lateral image, and the tunnel view assesses the varus or valgus neck shaft angle. In addition to radiographs, we perform an MRI get a clearer view of the FAI lesions, labral tear and other intra-articular and soft-tissue pathology. Future uses of MRI will include T2 mapping of the articular cartilage to best detect the presence and size of lesions in the articular cartilage preoperatively, to noninvasively assess the overall health of the articular surface and potentially predict or monitor early osteoarthritis before it is clinical appreciated.

Progress and Future Directions in Surgical Set-Up

As the number of hip arthroscopies has increased, many changes have been seen in surgical set-up. Keys to successful surgical set-up include positioning, anesthesia and muscle relaxation, joint distraction and access to the hip joint. Hip arthroscopy can be performed with the patient in the supine or lateral position, based on the surgeon's preference. The surgeon must be able to achieve sufficient distraction of the femoral head from the acetabulum to fully visualize the articular surfaces and safely work within the joint [10]. General or spinal anesthesia, or both, can be used, to maintain complete relaxation of skeletal muscles and thus minimize the amount of force necessary for joint distraction [10]. Our current protocol is the patient in a modified supine position on a standard fracture table (Fig. 17.2). The operative hip is placed 10° flexion, 15° internal rotation, 10° lateral tilt and neutral abduction. An extra-wide and padded peroneal post prevents iatrogenic injury to the perineum or pudendal nerve. First, traction is applied with the leg in slight abduction to break the vacuum seal of the joint, and then the capsule is further released with adduction over the peroneal post to force the femoral head laterally. Using fluoroscopy to monitor distraction, traction is applied until 8–10 mm joint distraction is achieved, providing enough space to work in the joint and avoid iatrogenic chondral damage from the instruments. Approximately 40–50 lbs of traction are required to achieve this amount of distraction [10, 11]. Gentle countertraction is applied to the contralateral limb to avoid angulation of the pelvis around the peroneal post [10].

Over the years, the number and placement of portals has changed. Accurate portal placement is critical to optimal visualization of all intra-articular structures, safe access to and maneuverability within the joint, and success of the procedure. Misplaced portals can cause neurovascular injury or other surgical complications, and increase the morbidity of surgery. In the past, hip arthroscopy has been performed through three, or more, incisions. However, with advances in technique, only two portals, the anterolateral and midanterior, are necessary to visualize and address pathology in the central and peripheral compartments [12]. The position of our lateral portal has remained mostly unchanged, but we moved the midanterior to reduce the risk to the rectus muscles and lateral cutaneous nerve of the thigh.

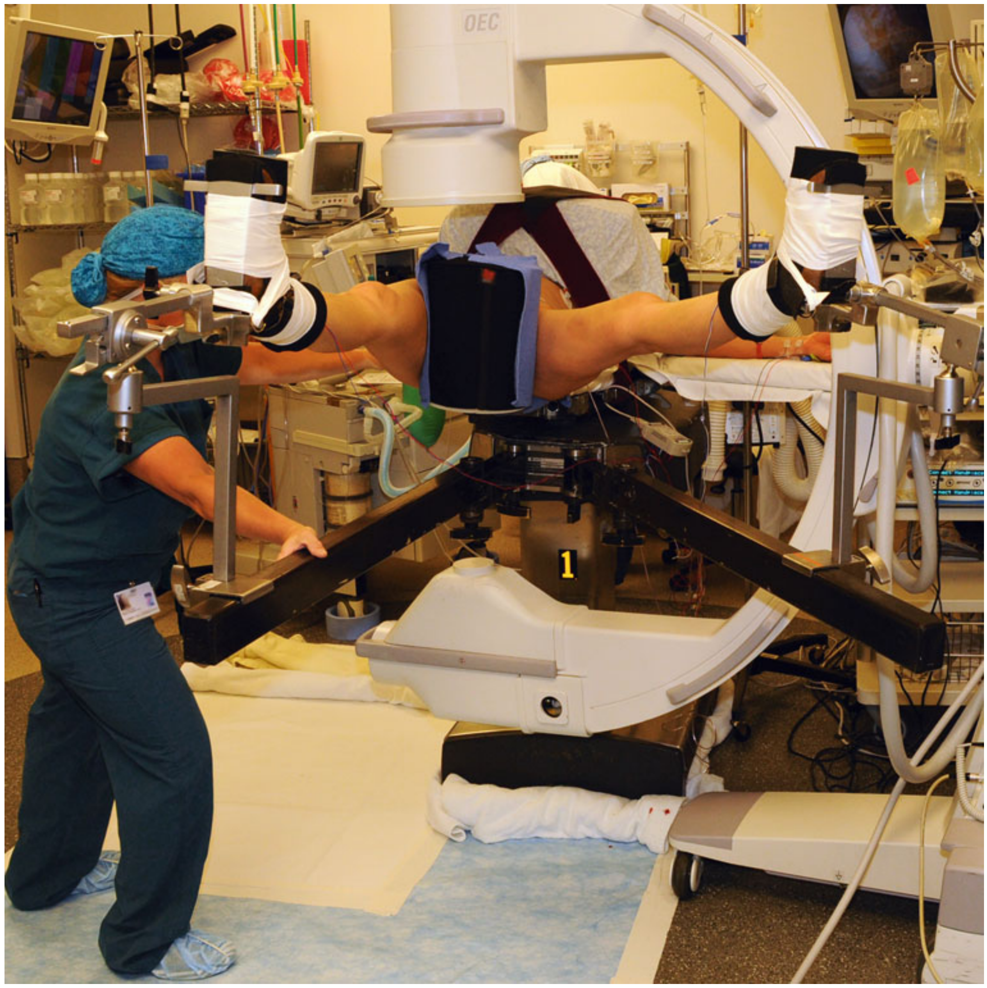

Fig. 17.2 Patient in a modified supine position on a standard fracture table

Technical Advances in Hip Arthroscopy

Femoroacetabular Impingement

Improved diagnostic capabilities have contributed to the increase in the incidence of FAI. Athletes, both amateur and elite, with hip pain that was misdiagnosed and incompletely treated in the past now have the option of minimally invasive surgical procedure that treats both the acute injury and the underlying pathology and allows return to play. A study of 2-year outcomes following arthroscopy for FAI indicated good longevity of the repair and return to pain-free daily life [13]. Additionally, as FAI has been implicated as a precursor to hip osteoarthritis [14], the possibility of slowing progression of OA and protecting patients from premature total hip arthroplasty is one of great potential.

It is crucial to address any FAI at the time of a labral repair. If the cam and/or pincer lesions are not decompressed, labral damage and delamination of the cartilage will continue or recur. To further the prevent recurrence we take care to perform a complete intra-operative dynamic exam to ensure complete resolution of the impingement. After the labrum is reattached and the cam lesion decompressed, the hip is slowly moved through its range of motion under direct arthroscopic visualization, paying particular attention to the movements specific to that patients' sport, if pertinent. The resected region of the femoral head-neck junction is observed for any residual impingement. As the most common cause of revision arthroscopy is incomplete resection or recurrent labral tears, this dynamic exam is crucial.

As pediatric and adolescent patients are participating in high level athletics at younger ages than ever before, FAI is being seen with increased frequency in these age groups as well. Arthroscopy has had good results for FAI in the pediatric patient. One theory is that when the open femoral physis of the adolescent patient is submitted to high stresses in competitive, it may be prone to the development of a cam deformity. This hypothesis raises concerns about youth participation in sports. It is estimated that 30–45 million adolescents between the ages of 6 and 18 years old are involved in sports. To protect this large population which may be at risk of developing FAI, further research is needed on screening and prevention programs. A study we performed on asymptomatic youth hockey players showed that FAI and labral tears were already prevalent at a young age in this population. Additionally, the older and more experienced players had, on average, more physical exam findings and higher alpha angles and more extensive labral and chondral damage on imaging than younger players [15]. A related study showed that certain moments in the ice skating stride placed the hip in positions that at particularly risk for impingement lesions to cause damage [16]. This indicated that perhaps limiting certain activities, such as squatting or repetitive motions, during critical growth periods may prevent the development of the cam deformity. Additionally, when patients do develop symptoms, this age group may be ideal to intervene, as the deformity is not fully established and chondral damage has not occurred (Philippon et al. unpublished data).

With the rise in FAI across all age groups, and the improvement in diagnosis via patient history, physical exam, and imaging, we are becoming able to diagnose "silent", or asymptomatic, FAI. With research showing the connection between FAI and the development to osteoarthritis necessitating total hip replacement, the debate of prophylactic treatment for FAI is emerging. Future research to best equip us to address this question should include an algorithm to identify those patients who are at-risk to develop symptoms or OA from their FAI.

Labral Repair

Some of the earliest reports in the literature described labral debridement. As techniques have advanced, labral repair and preserving the labrum are the goals of treating the injured labrum. The reports of clinical success with labral repair have led it to become the treatment of choice for the majority of labral tears [10, 17]. In repairing a labrum, a surgeon can preserve as much of the natural labral tissue as possible to optimize joint congruence, evenly distribute loads and prevent further cartilage degeneration [18, 19]. If an identifiable cause, such as FAI, is observed, it should be resolved during the surgery to prevent premature failure of the repair. Tear size does not disqualify a patient from repair, but it is important to recognize when the tissue is irreparable.

In repairing a tear of the labrum off the acetabular rim, the bony rim is shaved to a bleeding bed with a motorized burr to provide a solid base for the healing labrum [19]. However, the anatomy of the acetabular rim differs between patients, and the safety margin for inserting suture anchors was previously unknown. Using the acetabular rim angle, an anatomic measurement that quantifies the angle between the subchondral margin and outer cortex of the acetabulum, we determined the margin for safe anchor placement, as well as factors that altered it [20]. Location on the acetabular clock face, drill depth and rim trimming for pincer impingement all significantly affected the acetabular rim angle. Shorter drill depth and more extensive rim trimming resulted in greater rim angles, and thus a larger safety margin for anchor insertion. We found that the safety angle was largest at the 2-o'clock position and smallest at the 3-o'clock position. Thus, surgeons must take extra care when inserting anchors at the 3-o'clock position, and potentially use smaller anchors due to the thinner bone [20].

The type of suture repair is also advancing. We practice two versions of suture placement. In both, the knots are tied on the capsular side of the labrum to prevent iatrogenic injury to the articular surface. A limb of the suture can either be looped around the whole labrum or be passed through the substance of the labrum via a sharpened suture passer. The latter method pulls the tissue closer to the rim and brings the lateral edge of thick labrum in contact with the femoral head [19]. Sutures looped around the labrum tend to slightly evert it while intra-substance sutures invert it. These characteristics can be manipulated to best reapproximate the labral suction seal in a specific patient. To ensure recreation of the seal, traction is released and the hip moved through its complete range of motion under direct visualization.

Labral Reconstruction

Preserving native labral tissue is not always a feasible option. If the arthroscopic exam shows an irreparable complex tear, a segmental deficiency or a severely hypotrophic labrum (less than 3 mm in width) [21], suture repair will not be successful. We have developed a technique of arthroscopic labral reconstruction an iliotibial band (ITB) autograft. Acetabular rim preparation to create a bleeding cancellous bed necessary for vascular in-growth of the graft [19] and debridement of unhealthy labral tissue are performed using a motorized shaver and bur as in a labral repair. A 5.5 mm burr is used to measure the size of the labral defect, and a bioabsorbable suture anchor is placed at each end of the defect. The leg is released from traction and internally rotated to access the ITB. A longitudinal incision is made over the greater trochanter and a rectangle of tissue is taken from the junction of the anterior two-thirds and posterior one-third of the ITB. The graft should be approximately 15–20 mm in width, and measure 130–140 % of the length of the labral defect, usually about 5–7 mm. All muscular and fatty tissue is cleaned off its surface and it is tubularized with absorbable sutures. The end result should be a tubular structure of about 7 mm in diameter and long enough to fill the defect

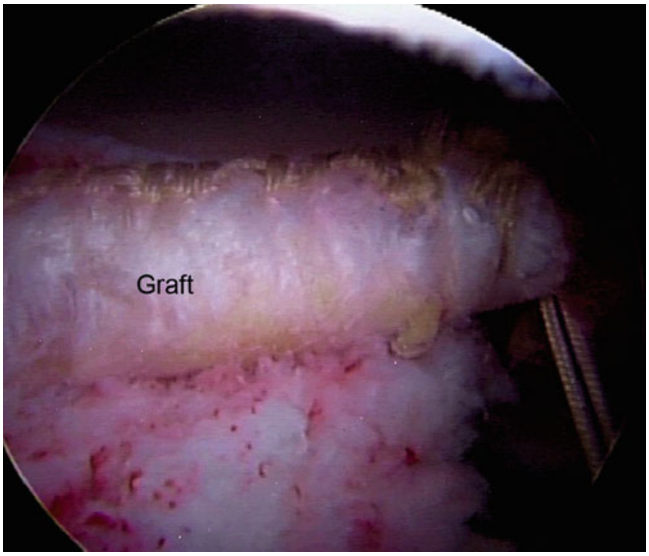

Fig. 17.3 The graft for labral reconstruction resembles a tubular structure and is placed on the acetabular rim

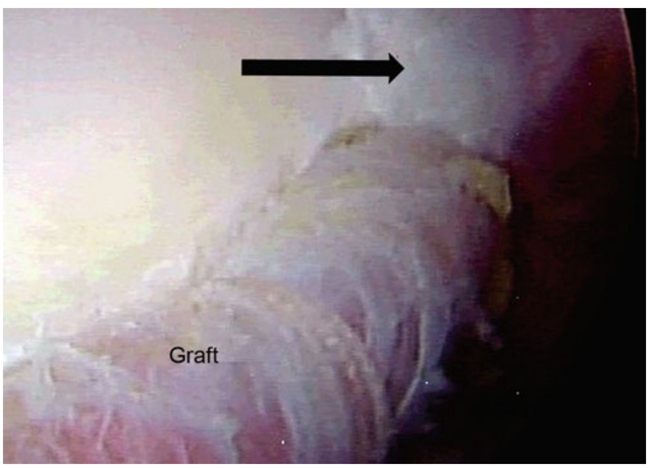

Fig. 17.4 When completed, the reconstruction provides a seal with the femoral head resembles the native labrum (*arrow*)

(Fig. 17.3). Resistant sutures are placed on each end to tension it, and an additional loop suture is placed at the thicker end, which will become the proximal, posterior end of the graft. The graft is also bathed in platelet-rich plasma.

The leg is put back into traction, and the graft is inserted through the mid-lateral portal and attached via one of the previously placed suture anchors anteromedially along the acetabulum. This step is repeated to anchor the posterior end of the graft to the other previously placed suture anchor. Further anchors are placed sequentially along the graft, with one limb of each being looped around the tissue to fix it against the acetabular rim. Depending on the fit of the graft into the defect, sutures can be used to attach the graft to the remaining native labrum and create a side-to-side anastamosis. When completed, the graft should resemble the native labrum (Fig. 17.4). Traction on the leg is released and the reconstruction is evaluated for stability and physiologic function in all planes of movement [19, 21, 22].

Early results following this labral reconstruction procedure were promising. A group of 37 patients, average age 37 years old and with an average time from injury to surgery of 36 months had significant increases in their Modified Harris Hip Scores (MHHS) and excellent patient satisfaction at 18 months follow-up. The mean improvement in MHHS was 23 points, and all but two patients had improvement in their MHHS. Independent predictors of patient satisfaction that were identified included age under 30; patients who had evidence of joint space narrowing to less than 2 mm at surgery had poorer outcomes. Four patients progressed to total hip arthroplasty. However, the mean age of these four was 49 (range 39–54), which was significantly older than the mean age of patients who did not progress to THA [21].

Hip Instability and Capsular Laxity

The hip is inherently stable due to the deep recess of the acetabular socket and naturally strong ligamentous support. However, in recent years more patients have reported instability in the hip joint. Idiopathic instability can be caused by conditions of generalized ligamentous laxity, such as Ehlers-Danlos, while developmental dysplasia of the hip places more stress on the ligamentous supports of the joint in normal motion. Traumatic instability is usually the result of a single dislocation or subluxation event, which the patient is usually able to recount. Overuse leading to capsular laxity and, consequently, hip instability, is increasingly common as elite athletes compete at higher levels of skill and practice for more hours at a younger age in a single sport. The focal, rotational instability felt by these athletes is often one secondary to the repetitive microtrauma caused by the moments when the capsular ligaments are stressed and stretched, especially rotation with axial loading.

Hip instability, especially that in elite athletes, often coexists with a labral tear. This tear may be caused by the excessive translation of a normally shaped femoral head allowed by an overstretched iliofemoral ligament or a femoroacetabular impingement lesion allowing shearing off of the labrum. The labral tear may be the direct cause of the sensation of hip instability, or it may lead to less restricted hip movement, thereby allowing extra stretch to the iliofemoral and ischiofemoral ligaments, and, consequently, instability. Research has indicated that labral excision results in increased vertical and lateral translation at the femoroacetabular joint, and that sectioning of the labrum in a cadaveric model leads to elongation of the iliofemoral ligament [23–25].

Arthroscopic thermal capsulorrhaphy and capsular plication to repair capsular laxity have had positive results. In a series of professional athletes who underwent thermal capsulorrhaphy, each athlete returned to their prior level of competition and had no symptoms of recurrence 6 years following the procedure [22]. Intra-operatively, the capsular ligaments are probed to determine the areas of most significant tissue redundancy. A flexible monopolar radiofrequency probe is moved across the tissue in a striped pattern. The tissue can be seen to shrink, flatten and turn yellow. Care is taken to leave sufficient healthy tissue between the stripes to encourage regeneration of fibroblasts. Motion is restricted for the first few 4–6 weeks postoperatively to prevent stretching of the repaired tissue and recurrence [26, 27].

A capsular plication may be performed to tighten the capsule as well, either alone or in combination with thermal treatment. A plication suture is passed through the redundant tissue and tied down to tighten it. These sutures can be placed in either the anterior or posterior capsule, depending on where the most lax tissue is observed. Sutures can continue to be added to the capsule until adequate stability is observed on intra-operative hip exam.

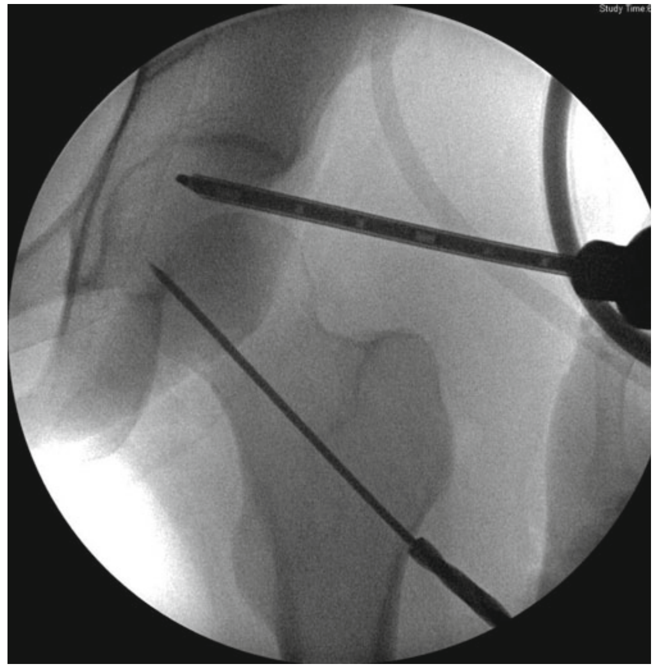

Fig. 17.5 A guidewire, under fluoroscopic guidance, is placed up the femoral neck and exits through the center of the fovea capitis

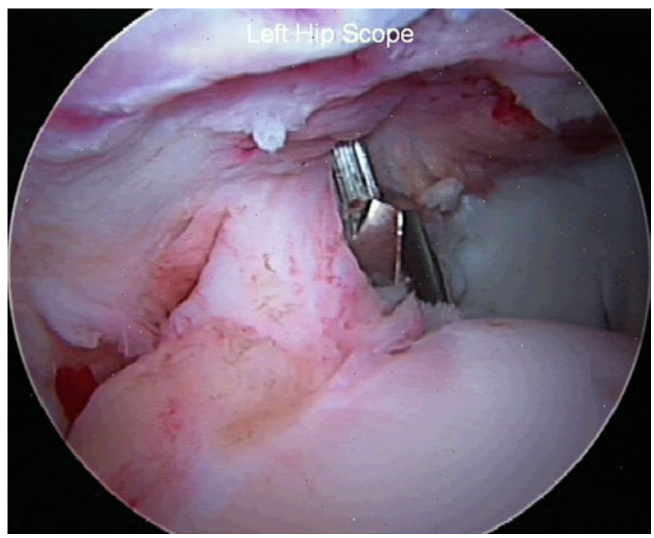

Fig. 17.6 The femoral tunnel is drilled and placement is verified with arthroscopy

Ligamentum Teres Reconstruction

Tears of the ligamentum teres may be an under diagnosed cause of hip pain and instability, especially in those patients with persistent or recurring symptoms after other more common etiologies are addressed. Injury to the ligamentum teres has been identified as the third most prevalent cause of hip pain in athletes, and rupture of the ligamentum teres has been discovered on 4–15 % of hip arthroscopy patients [28, 29]. In a small subset of patients surgical repair of the capsule and/or labrum does not resolve pain and instability. For these appropriately selected patients, we have designed a novel procedure of arthroscopic ligamentum teres reconstruction. In a small sample size, we have had good results in symptoms resolution and return to activity in these patients [30].

A ligamentum teres reconstruction is performed with fluoroscopic guidance. On arthroscopic exam of the joint, any labral or capsular pathology that could be the source of instability is repaired first. If instability is still seen on dynamic exam, we perform the reconstruction. We harvest the graft from the junction of the posterior one-third and anterior two-thirds of the iliotibial band (ITB) through an incision over the greater trochanter. The graft should be approximately 50 mm by 15 mm and, as in a labrum reconstruction, the graft is tubularized with sutures and tagged at one end with an additional non absorbable suture.

To place the graft, we drill a 2.0 mm guidewire in a retrograde direction under fluoroscopic guidance up the femoral neck and exiting through the center of the fovea capitis (Fig. 17.5). Correct placement of this guidewire is confirmed through the arthroscope. We create the femoral tunnel with an 8 mm drill (Fig. 17.6) and the acetabular bed is prepared by debridement of all the soft tissue in the cotyloid fossa. We use an absorbable suture anchor placed into the footprint of the ligament bed to anchor the graft, being careful not to recess it too far into the acetabulum and retrieving the sutures through the midanterior portal. The ends of the sutures are fed through the proximal portion of the graft, and then the prepared graft is fed into the midanterior portal with the sutures as guides. It is secured into its bed on the cotyloid fossa and then the distal end of the graft is fed back into the femoral tunnel via the whip stitch. We leave 2.5 cm of graft visible within the joint when the hip is placed in external rotation and extension. The distal end of the graft is fastened with a bioabsorbable interference screw.

In the postoperative period, all patients receive 2 weeks of indomethacin, unless medically contraindicated, to prevent heterotopic ossification. Patients are limited to 20 lbs of foot-flat weight-bearing for the first few weeks, and spend 4–6 h per day for the initial 2 weeks on a CPM machine to prevent development of capsular adhesions. Patients are also instructed to use a hip abduction brace that prevents excessive abduction and extension for these first 2 weeks.

Cartilage Injuries

Chondral injuries in the hip are commonly associated with other intra-articular hip pathologies, such as acetabular labral tears, FAI or degenerative joint disease. In cam-type FAI, the abnormally shaped femoral head creates excessive shear forces on the cartilage in the anterior quadrant of the acetabulum [31, 32]. Hips with a deficient labral tissue are also subject to increased friction as the femur is translated superiorly and anteriorly into the acetabulum instead of being held in place. Microfracture techniques have been used extensively in the knee and now in the hip with successful outcomes in properly selected patients.

Osteochondral defects of the hip are rare clinical entities with limited therapeutic options. It is estimated the lesions of the femoral head account for 2 % of all osteochondritis dissecans [33], though another recent study estimated prevalence as high as 18 % in asymptomatic professional hockey players [34]. Osteochondritis dissecans, often seen as an incidental finding on routine X-rays, is a condition of unknown etiology that leads to defects in the articular cartilage of a joint surface. In adults, its development is usually secondary to an occult traumatic or ischemic event, such as a hip dislocation. In pediatric patients, it has been associated with Legg-Calves-Perthes disease. Current treatment options have been drawn from techniques used in the knee, such as arthroscopic osteochondral autograft transfer.

We have performed several repairs of osteochondral defects of the femoral head using osteochondral autograft transfer. Osteochondral plugs harvested from the femoral head-neck junction ranged in size from 6 by 10 mm to 8 by 12 mm. The recipient sites were prepared, and the donor plugs were impacted into the defects. Several microfractures were created around the recipient sites to supplement cartilage regeneration and graft success (Fig. 17.7). Associated hip pathology seen on arthroscopy was addressed after the osteochondral plug was in place. Patients were limited to foot-flat weight bearing for 2 weeks and a continuous passive motion machine for 6 weeks. Platelet-rich plasma

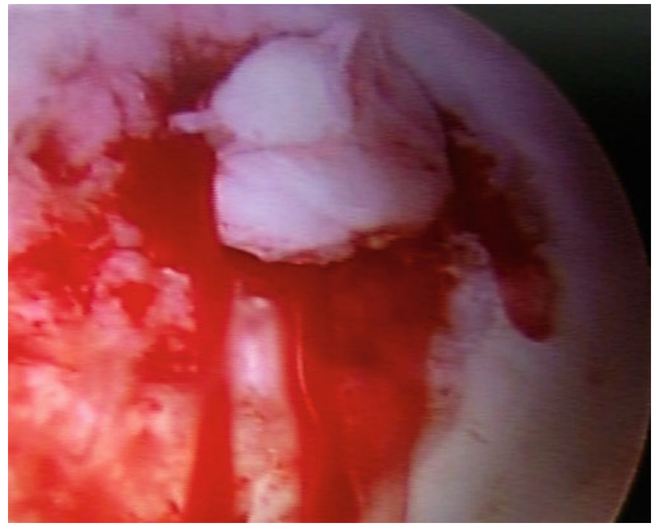

Fig. 17.7 Microfracturesare created around the recipient sites to supplement cartilage regeneration and graft success

(PRP), was either as a plug over the recipient site or injected into the joint once the capsule was closed.

Improve Healing

Platelet-rich plasma was initially developed in the 1970s, but its potential clinical uses are only just beginning to be realized. PRP has been used successfully in plastic surgery to improve the function of fat grafts placed in reconstructive surgery, hemithyroidectomy to reduce postoperative drainage, and diabetic foot ulcers to accelerate chronic skin ulcer reepithelialization [35, 36]. Its uses in orthopedic surgery are expanding rapidly. Thus far, its use, and relative success, has been documented in chronic tendinopathies, such as in the elbow, acute ligamentous injuries, muscle strains and tears, and intraoperatively for healing augmentation [37]. In orthopedic surgical procedures, PRP aids control of homeostasis, decreases pain, promotes the healing response, and potentially, decreases the formation of adhesions and promotes a faster return to sports activities.

The PRP mixture contains up to five times more growth factors, such as Platelet-Derived Growth Factor (PDGF), Transforming Growth Factor-b (TGFb), Insulin-like Growth Factor (IGF), Epidermal Growth Factor (EGF) and Vascular Endothelial Growth Factor(VEGF), than physiologic plasma, as well as histamine, serotonin, cell adhesion mediators and other bioactive factors which may have a critical role in the healing process, especially that of articular cartilage [38]. Research has shown that activated platelets can form an osteoclast-like formation which may stimulate cellular proliferation and result in enhanced bone formation. In ACL reconstruction, grafts treated with PRP matured in 109 days, as compared to 363 days without intra-operative PRP [39]. Use of PRP was shown to decrease pain and improve outcomes in the osteoarthritic knee in comparison to hyaluronic acid supplementation. In articular cartilage, which has weak replication and healing potential *in-vivo*, chondrocytes may proliferate in response to PRP. In vivo studies using PRP in microfracture lesions in the human knee and osteochondral defects in rabbits showed increased osteochondral formation and enhanced healing in the presence of PRP [40]. In a 2010 consensus study, the International Olympic Committee stated that there is significant anecdotal evidence that the use of PRP for the treatment of musculoskeletal injuries has increased in recent times, though it is still considered a drug or therapeutic substance. It encouraged extensive further study into the preparation and healing properties of PRP, but deleted intramuscular injections of PRP from the 2011 Prohibited List for Olympic athlete usage [41]. Longer follow-up data from these and different preparations and applications of PRP are needed to best evaluate its benefit in procedures necessitating regeneration of articular cartilage for lasting clinical success.

Progress and Future in Outcome Assessment

Early reports of outcomes following hip arthroscopy reported the modified Harris hip score and the Non-Arthritic hip score. The Non-arthritic Hip Score (NAHS) was introduced in 2003 and designed specifically for 20- to 40-year-old patients with hip pain but no obvious pathology on plain radiographs. The modified Harris hip score is currently the most commonly used score in publication. The Modified Harris Hip Score is a patient-administered variation of the original Harris Hip Score that came into use in the mid 1990s. It has seven questions which cover patient symptoms and function. The questionnaire is easy for patients to understand and easy to score. This has led to its wide use in tracking outcomes following hip arthroscopy.

Introduced in 2006, the Hip Outcome Score (HOS) was developed to assess the treatment effect of hip arthroscopy in young, active patients. It includes both activities of daily living and sports subscales for more complete outcomes assessment. It has shown to be valid, reliable, and responsive for patients undergoing hip arthroscopy in a small population. It received a negative rating for content validity and an indeterminate rating for internal consistency; however, Thorborg et al. concluded that the HOS is the "best available questionnaire for evaluating hip arthroscopy" [42].

As hip arthroscopy has grown, so has the number of scores being reported and new scores being developed. The HOOS, WOMAC, HAGOS, Merle d'Aubigne Score have all been used in hip outcome studies. We are currently developing a hip score based on responses from over 1,000 hip patients. The score consists of ten questions that are easy for the patient to understand and easy to score. The score underwent strong psychometric testing and has proven to be reliable, valid and responsive. The score was tested in the young adult athlete, the professional athlete, and the older athlete to ensure its quality over a cross section of patients. It was specifically tested in patients who underwent hip arthroscopy to show it was applicable to this population.

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The Management of Chondral Defects in the Hip

18

Lisa M. Tibor, Florian D. Naal, and Michael Leunig

Introduction

The results following treatment of focal cartilage lesions in the hip were generally poor prior to the description of the surgical hip dislocation by Ganz and colleagues [1]. These were confounded by the risk of avascular necrosis associated with the surgical approach and surgeries that were frequently performed for avascular necrosis [2, 3].

To date, most of the literature, experience, and techniques for treating focal cartilage defects have been for lesions in the knee [4, 5]. Thus, the recommendations in this chapter are based on the current understanding of hip biomechanics in combination with what is known about cartilage biology from the experience in the knee. These recommendations have the potential to change as the understanding of hip biomechanics and focal cartilage lesions in the hip improves.

The joint preservation techniques described here are for the treatment of focal, full-thickness cartilage lesions, not generalized osteoarthritis. The treatment goals for these patients are: resolution of pain, restoration of function, and return to activity. Although it has yet to be definitively proven, early treatment of a focal cartilage lesion may also help to prevent the progression of cartilage degeneration and osteoarthrosis. These techniques are contraindicated if the patient is unable or unwilling to comply with postoperative rehabilitation and weight-bearing protocols, if arthritis is due to a systemic inflammatory disorder, or if the arthritis is significantly advanced, involving the majority of both the femur and acetabulum. In these cases the patient may be a better candidate for joint replacement surgery.

Basic Science

One of the principles of cartilage biomechanics is that mechanical stress on the cartilage causes chondrocyte death and damage to the extracellular matrix [6]. In a focal cartilage defect, there is increased strain and shear stress at the rim of the lesion, with a change in the fluid mechanics around the rim [7]. Thus, the lesion has the potential to degenerate further due to the increased stress on the chondrocytes on the rim. In addition, there appears to be a threshold effect to lesion size. Below a certain size, the surrounding tissue can absorb the increased load caused by the cartilage defect (Fig. 18.1). Above this size, the rim stress around the lesion increases and is detrimental to the surrounding cartilage. In a cadaveric knee model, the threshold size of the lesion was 10 mm and the meniscus was able to absorb the load created by smaller defects [8]. In similar finite element studies, the threshold size of a cartilage lesion became smaller if the meniscus was removed, because the meniscus could not absorb the increased load (Fig. 18.1) [9].

Cartilage Science in the Hip

The cartilage in the hip is thinner than in the knee [10], with an average cartilage thickness that varies from 1.08 to 2.4 mm on the femoral head [10, 11] and from 1.24 to 2.25 mm on the acetabulum [10, 11]. There does appear to be some correlation of cartilage thickness to the size and weight of the person, with taller and heavier people having thicker cartilage [10].

Studies comparing the cartilage thickness between joints of the same cadaveric specimen have lead to the hypothesis that congruent joints like the hip and ankle have thinner cartilage than incongruent joints—namely, the knee [10, 12].

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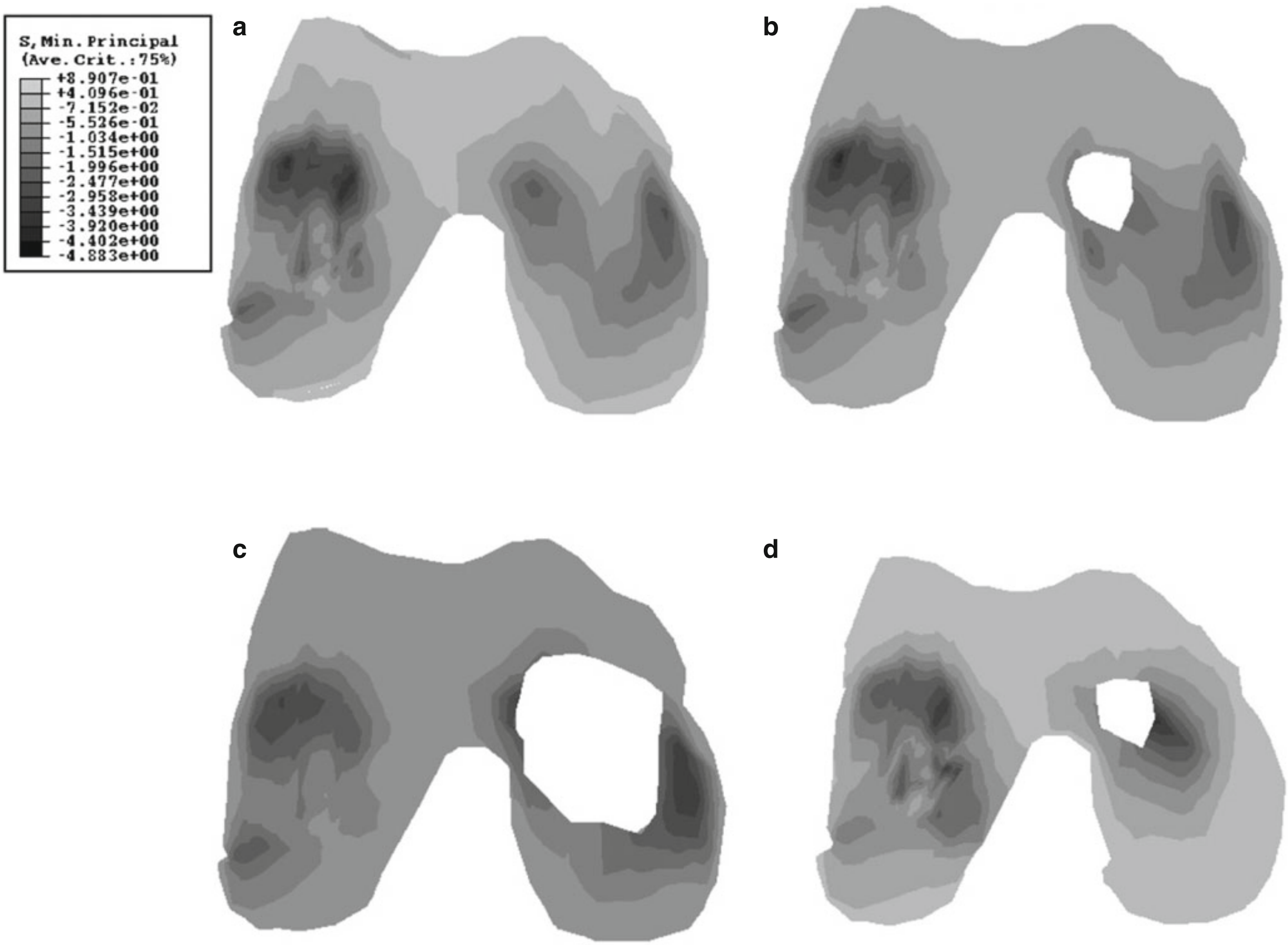


Fig. 18.1 Both lesion size and menisectomy influence the stress on cartilage surrounding a focal defect. In this finite element model of the knee, the threshold size of the lesion was 0.78 cm^2 (**b**). Even though the lesion is located in a high-load area, the stress on the surrounding cartilage is the same as in the normal knee (**a**). A larger lesion (**c**, 3.14 cm^2) causes significantly increased stress in the adjacent cartilage. A menisectomy (**d**) also decreases the threshold size because the meniscus is unable to take up the increased mechanical load from the defect (Adapted from Peña [9], Reprinted with permission)

The rationale for this is that in a congruent joint the cartilage deforms only a small amount but that the much larger area of contact between the opposing cartilage surfaces is able to distribute the load and maintain an appropriate level of stress. For an incongruent joint with thicker cartilage, the greater degree of cartilage deformation increases the contact area between joint surfaces to decrease the stress to an acceptable level [12].

Although the hip is generally considered to be a congruent joint, it is actually slightly incongruent. The slight incongruency of the femoral head and acetabulum enables the formation of a pressurized fluid layer between the cartilage surfaces, resulting in more efficient load bearing [13]. Contact between the acetabulum and femur is first established at the labrum and chondrolabral junction at the periphery of the joint. The load is then transmitted to the pressurized fluid layer [13, 14].

The area of contact between the acetabular and femoral cartilage varies with the load and phase of the gait cycle [14]. Based on this finding, the cartilage surfaces in the hip can be described by four different types of contact:

- Habitual contact: Surfaces that make contact at the lowest loads. This occurs at the anterior and posterior portions of the acetabulum and femoral head.
- Position-dependent contact: Contact depends on the position of the hip, but can occur at low loads. This occurs at the anterior and posterior aspects of the inferior femoral head.
- Load-dependent contact: Contact occurs at higher loads, not at low loads, and is independent of hip position. The contact between the acetabular dome and femoral head is load-dependent.
- Habitual non-contact: No contact at any position or load. This is true of the periphery, perifoveal, and inframedial portions of the femoral head.

The cartilage in the hip is stiffer and less permeable than cartilage in the knee [11]. The stiffness varies somewhat in the hip such that the cartilage at the inferior aspect of the femoral head is the softest, while the stiffest cartilage is at the superomedial and posteromedial femoral head [11]. Interestingly, there is some stiffness mismatch between the cartilage that is in contact during particular motions. When seated, the anterior acetabulum and inferior femoral head cartilage contact each other; however, cartilage in the anterior acetabulum is stiffer than the corresponding cartilage on the inferior femoral head [11]. It is not yet known if this contributes to the patterns of degenerative arthrosis seen in the hip.

Studies of the labrum and finite element modeling of the cartilage and labrum have provided further insights. Finite element studies and a cadaveric model suggest that the labral seal is important for maintenance of the pressurized fluid layer between the acetabulum and femur [15–17]. Thus, loss of the labral seal increases the cartilage load and the potential for degenerative changes. Correspondingly, an MRI study of cartilage strain found that strain decreased after labral repair as compared to labral resection [18].

Because the hip is more constrained than the knee, the combination of size and location of a cartilage defect may be important. For example, the stress on the adjacent cartilage may be different if the entire rim of the defect is within the contact area and is loaded as compared to a partially loaded defect with an area of focal stress on the rim [7]. Thus, the effect of lesion size may be different in the hip as compared to the knee. Because cartilage contact first occurs at the periphery of the hip, the threshold size may be different for lesions near the labrum or the adjacent area on the femoral head. In addition, if the labrum is not intact or functioning normally, the congruency of the joint and the fluid layer change. An abnormal labrum may decrease the threshold size of a cartilage defect. On some MR arthrograms performed for patients with FAI, the femoral head was observed to settle into an anterosuperior acetabular cartilage defect [19]. During open surgical dislocation, the defect was found to be substantial, ranging from one-third to one-half of the cartilage width. All of these cartilage defects were associated with labral lesions. This suggests that, in addition to the threshold size of a cartilage defect, there is also an interaction between defect size, location, and associated labral lesions.

In the hip, the percent of the involved cartilage surface area is likely more important than the absolute size of the lesion. Thus, a cartilage lesion in a female patient with a smaller femoral head may be much worse than the same size lesion in a male with a larger femoral head, because the defect takes up a larger portion of the femoral head surface area. Another important and unanswered question is the influence of the concavity or convexity of the surface. For example, would a focal cartilage defect on the acetabulum be less likely to progress than one of the same size on the femur? The acetabulum is a concave surface and the edges of a lesion face relatively inward as compared to convex surface of the femur where the edges of a cartilage lesion would be relatively outward facing. In addition, the quality of the subchondral bone is different between the acetabulum (relatively harder) and the femoral head (relatively softer). The relevance of this to the likelihood of defect progression or for potential therapy has not yet been investigated.

Clinical Evaluation

General Considerations

The treatment goals for a patient with a focal cartilage lesion are resolution of pain, restoration of function, and return to activity. There are some general considerations and important factors that influence the treatment protocol, the specific technique used for the cartilage lesion, and the overall prognosis.

Three different classification schemes are commonly used for cartilage lesions in the hip (Table 18.1). The Outerbridge classification was originally described for lesions of the patellofemoral joint [20], but is widely used for cartilage lesions in other joints as well. The Outerbridge grade helps to characterize lesions that have a better prognosis (Grade I or II lesions) as compared to lesions with a poorer prognosis (Grade III or IV lesions) [21]. The ICRS grading system is similar to the Outerbridge system and is part of the overall evaluation in patients undergoing cartilage repair [22]. The Beck classification of cartilage damage was originally described for patients undergoing surgical dislocation for FAI, but is also useful for grading of hip cartilage lesions due to other causes [19].

The location of the lesion is important. Clinically, acetabular defects may have a better prognosis than femoral head lesions. On long-term follow up of hip arthroscopy patients, lesions on the femoral head had worse prognoses than acetabular lesions [21]. In theory, lesions on the non-weightbearing portion of the femoral head could be treated conservatively, similar to the treatment for a Pipkin I femoral head fracture; however, there is no discussion of this in the literature.

For more advanced cartilage restoration techniques, the diameter of the femoral head, the size of the lesion, and the quality of the adjacent subchondral bone are important factors that may dictate treatment options. Finally, any associated bony pathology should also be addressed, either concomitantly or in a staged manner to prevent further damage to the reconstructed area. Thus, this may include treatment of associated osteochondral fractures due to an acute dislocation or subluxation event; arthroscopic or open management of FAI; osteotomy for acetabular dysplasia, Perthes or rotational malalignment; or recognition of avascular necrosis and potential for femoral head collapse.

Table 18.1 Cartilage classification systems

Grade	Criteria	
Outerbridge classification [20]		
I	Cartilage swelling or softening	
II	Cartilage fragmentation or fissuring, <0.5 in diameter	
III	Cartilage fragmentation or fissuring, >0.5 in diameter	
IV	Cartilage erosion to bone	
Stage	**Description**	**Criteria**
ICRS classification [22]		
0	Normal	Normal cartilage
1	Nearly normal	Superficial lesions; soft indentation, superficial fissures or cracks
2	Abnormal	Lesions extending down to <50 % of cartilage depth
3	Severely abnormal	Defects extending >50 % of cartilage depth as well as to the calcified cartilage, but not through subchondral bone. Includes cartilage blistering.
4	Severely abnormal	Cartilage defect that extends into the subchondral bone
Beck Classification [19]		
0	Normal	Macroscopically sound cartilage
1	Malacia	Roughening of surface, fibrillation
2	Pitting malacia	Roughening, partial thinning and full-thickness defects or deep fissuring to bone
3	Debonding	Loss of fixation to the subchondral bone, macroscopically sound cartilage, carpet phenomenon
4	Cleavage	Loss of fixation to the subchondral bone, frayed edges, thinning of the cartilage
5	Defect	Full-thickness defect

History and Physical Exam

The treatment plan should be individualized for each patient and developed from a collective assessment of the injury mechanism, symptoms, physical exam, radiographic findings, and the result of an intraarticular diagnostic injection with local anaesthetics. The time course of symptom onset is important. Symptoms that began with a relatively minor trauma or the insidious onset of pain generally occur in combination with underlying bony pathology. For patients with symptoms directly attributable to an acute trauma, the damage may be related to an acute dislocation or subluxation event. Focal cartilage damage can also occur after a direct lateral impact to the greater trochanter during a fall [23]. Because there is often little soft tissue to absorb the force of the fall, the force is transmitted to the central joint surface. Characteristically, the resulting cartilage lesions are focal defects in either the medial femoral head or in weightbearing portion of the acetabulum just above the fossa [23].

The quality of symptoms is less specific for cartilage pathology. Nonetheless, mechanical symptoms including sharp groin or buttock pain, stiffness, clicking, popping, or catching may suggest a loose cartilage flap or fragment [23, 24]. Labral tears can also present with similar mechanical symptoms, and labral tears and cartilage lesions often occur concurrently.

No single examination maneuver is specific for chondral pathology. Pain with weightbearing or specific examination maneuvers may depend on the location of the lesion. Pain that is provoked by logrolling the hip is generally indicative of associated synovitis or a synovial effusion.

Radiographic Findings

We routinely order AP pelvis and cross-table lateral x-rays for all young patients with hip pain. These should be closely scrutinized for dysplasia, FAI, joint incongruity, and arthritic changes.

Patients also undergo magnetic resonance imaging with intraarticular contrast (MR arthrogram). On high quality MR arthrography, the cartilage defect can be seen directly and any associated labral tears can be evaluated. In general, MR arthrography for a suspected hip labral tear or cartilage lesion should be performed with either a 1.5 Tesla (T) or a 3 T magnet, and a small field of view coil. Sequences should include coronal, sagittal, axial, and radial images. Although MR arthrography is useful for evaluating the labrum, it is somewhat less effective for evaluation of the articular cartilage [24, 25]. The size of a cartilage lesion should be measured, and the quality of the underlying bone evaluated, including the presence of bone marrow edema or cystic changes. Edema in bone adjacent to a cartilage lesion may be indicative of a recent trauma [23] or of local overload [24]. Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) is one means of assessing the biochemical integrity of cartilage. DGEMRIC is most often used for cartilage biology research, but is not routinely used clinically [26].

Diagnostic Injection

The response to an intraarticular injection often helps with surgical decision-making, particularly when the imaging or examination findings are equivocal. Diagnostic injection is sensitive and specific for intraarticular pathology, with 90 % accuracy for determining whether the pathology is intra or extraarticular [27].

Treatment Options and Results

The indications for treatment of focal cartilage defects in the hip include: acute trauma with an unstable cartilage fragment, loose bodies visible on pre-operative imaging, or continued pain despite conservative management with a defect visible on preoperative imaging and a positive response to diagnostic injection. The timing of surgery is dependent on the type of lesion, the age of the patient, and the type and duration of previous interventions. Often the choice of arthroscopic or open management is dependent on the location of the lesion and associated bone and labral pathology. We perform arthroscopy with the patient supine. For open treatment of cartilage lesions in the hip, we perform a surgical hip dislocation as it allows for wide intraarticular access, treatment of FAI and other bony pathology, and preserves the blood supply to the femoral head. This has been described extensively in multiple publications [1, 19, 28].

Non-operative Management

For patients with the insidious onset of pain and a stable cartilage lesion on MR arthrography, an initial course of nonoperative management is appropriate. This generally entails some combination of activity modification, physical therapy, medical management, and injections, all of which are well-covered in other chapters of this book.

Operative Management

Direct or Primary Cartilage Repair

Direct or primary cartilage repair is indicated for an acute unstable osteochondral fragment or an unstable osteochondritis dissecans lesion. This requires a surgical dislocation to access the joint. The femoral head is gently dislocated to minimize further damage to the unstable fragment. The unstable fragment is then elevated and any fibrous or cystic tissue at the base is then debrided. Sclerotic bone at the base of the lesion should be microfractured or drilled. Areas of cystic change or bone loss should be bone grafted with cancellous autograft from the stable portion of the trochanter. The fragment is then fixed back to the donor site rigidly and under compression with a headless compression screw [5].

Arthroscopic Debridement and Chondroplasty

Arthroscopic debridement of a cartilage defect is considered to be a palliative therapy. Nonetheless, debridement of loose bodies or flaps of cartilage can be quite effective for relieving symptoms and allowing patients to return to activity [23]. It is not unusual for patients undergoing hip arthroscopy for treatment of FAI or labral pathology to have a concomitant and undetected cartilage lesion. Furthermore, if preoperative imaging was inconclusive but suspicious for labral or cartilage lesions, arthroscopy is considered definitive for the diagnosis. Arthroscopic debridement may also be indicated for patients with dysplasia undergoing acetabular reorientation and who have mechanical symptoms [29].

Microfracture

Microfracture is one type of bone marrow stimulation technique. All bone marrow stimulation techniques involve perforation of the subchondral plate with either a microfracture awl or drill to promote bleeding from the bone marrow into the lesion [30–33]. This results in the migration of mesenchymal stem cells and formation of a "superclot" in the lesion. The ultimate goal is complete filling of the defect with reparative fibrocartilage because the best functional results correlate with the degree of defect filling [34, 35]. The stability of the superclot contributes to the success of the procedure [36, 37]. Thus, the walls surrounding the lesion should be vertical and consist of normal, stable cartilage. This decreases shear and compression forces on the clot and protects it during healing [5]. The advantage of microfracture and other bone marrow stimulation techniques is that they are technically straightforward, low cost, and can be performed arthroscopically. The disadvantage is that fibrocartilage contains less type II collagen and has different biomechanical properties than hyaline cartilage. This may make the reparative cartilage less durable over the long-term [36]. In addition, the overall concentration of mesenchymal stem cells in the bone marrow is low and the chondrogenic potential declines with age [38].

Technique. Microfracture is indicated for full thickness lesions in patients undergoing concomitant open or arthroscopic management for FAI or dysplasia [29]. It can be performed arthroscopically for acetabular rim lesions in the contact area as well as for accessible lesions on the femoral head. Microfracture is contraindicated for large or extensive lesions, bipolar or kissing lesions, and for patients who are unwilling to undergo the postoperative rehabilitation.

Once the lesion has been identified, unstable cartilage should be debrided to re-establish stable vertical cartilage walls of the lesion. The calcified cartilage layer at the base of the lesion should be removed with a sharp ring curette so that

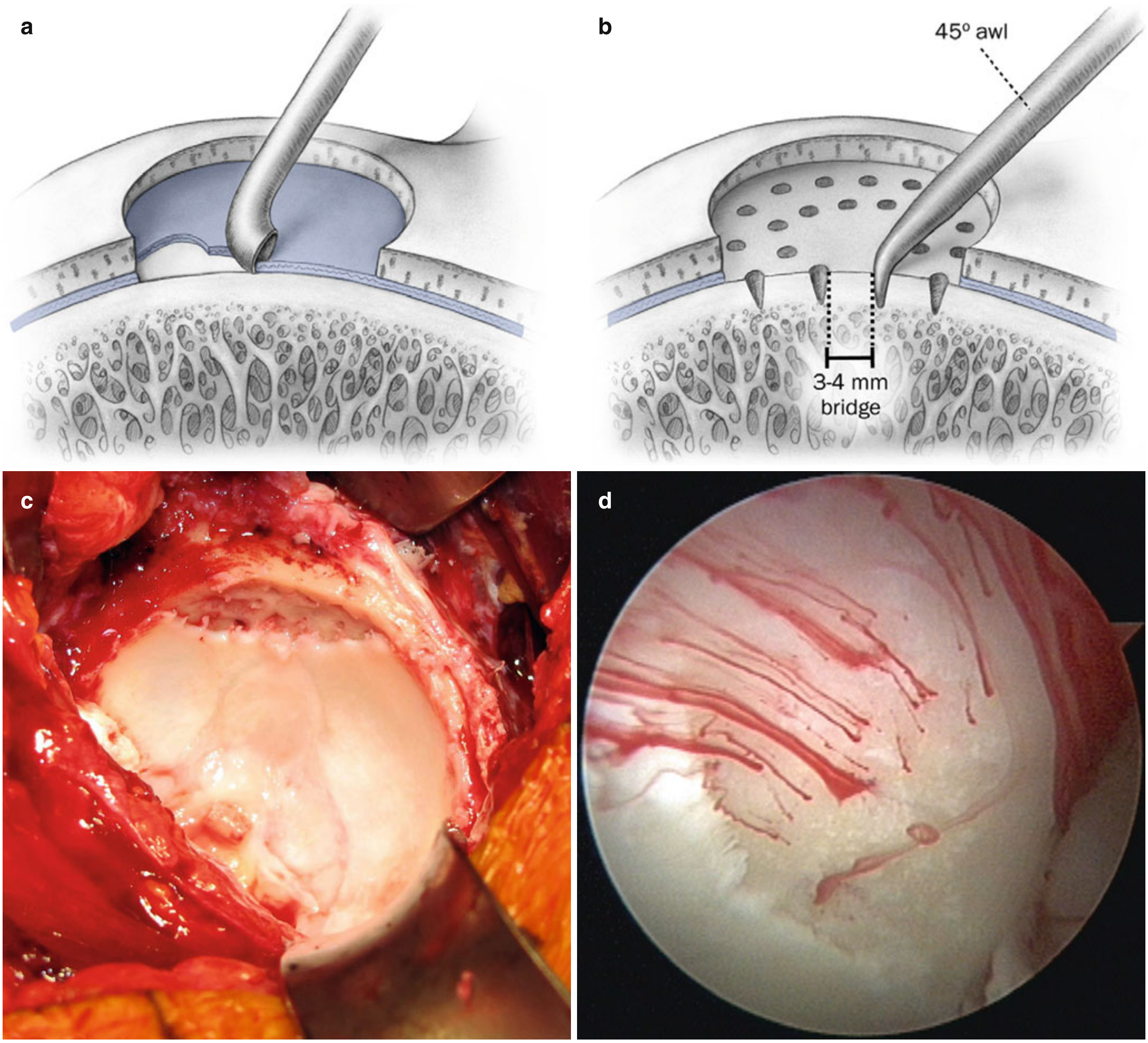


Fig. 18.2 Microfracture technique. (**a**) Preparation of the defect includes creating stable vertical walls and removing the calcified cartilage layer with a ring curette. (**b**) Microfracture awls are then used to perforate the subchondral surface. Holes should be spaced 2–3 mm apart and be perpendicular to the surface. (**c**) Microfracture of the acetabulum performed during a surgical hip dislocation. (**d**) Arthroscopic image of an acetabularmicrofracture. The blood and fat droplets coming from the surface indicate that the holes communicate with the bone marrow and that the microfracture is of adequate depth (**a** and **b** reprinted with permission from Mithoefer et al. [39])

the subchondral bone is visible (Fig. 18.2a). This is important for clot adhesion and the overall success of the procedure. Microfracture awls are then used to penetrate the subchondral surface (Fig. 18.2b, c) [39]. A 1.1 mm wire can also be used to drill the subchondral surface. Holes should be perpendicular to the surface and spaced 2–3 mm apart. Extreme care should be taken to avoid confluence of the holes and destabilization of the subchondral plate. Following arthroscopic microfracture, the pressure in the joint should be decreased so that blood and fatty droplets can be seen coming from the surface (Fig. 18.2d). This is indicative of communication with the bone marrow and appropriate depth of the microfracture [4].

Patients begin CPM on postoperative day 1 for 6–8 h per day [31, 39]. This promotes clot healing, joint nutrition, and decreases adhesion formation. To protect the healing lesion, patients should be non-weight bearing for 6–8 weeks postoperatively [31, 39].

Results for microfracture in the hip have generally been reported as part of combined therapy for FAI [40–42]. In a cohort of FAI patients with concomitant pathology, patients who had microfracture did better than patients who had simple debridement [41]. For larger lesions, the greatest improvement was seen by 8 weeks but was maintained at 12 month follow up [41]. In one series of second-look arthroscopy after microfracture, there was fibrocartilage fill of most or all of the defects [43]. Nonetheless, patients with more extensive lesions still progress to total hip arthroplasty [21, 40, 41, 43], indicating that the technique is limited by the size and extent of the lesion. These are similar to the results reported for microfracture of lesions in the knee, where the best outcomes are seen in younger patients with small traumatic lesions [31, 35]. Age and lower body mass are both independent predictors of improvement [31, 34, 35], with good to excellent results reported in 67 % of patients, fair results for 25 % of patients, and poor results in 8 %. In comparison to other procedures, the results of microfracture may deteriorate over time [34, 35]. Finally, osteophyte formation rather than fibrocartilage fill has been observed in 25–50 % of cases [34], decreasing durability and patient satisfaction with the procedure.

Second-Generation Bone Marrow Stimulation (AMIC)

A second-generation bone marrow stimulation technique has been developed, encompassing concepts from both microfracture and autologous chondrocyte implantation (ACI). This technique has been dubbed autologous matrix-induced chondrogenesis (AMIC). Essentially, AMIC consists of microfracture with the subsequent application of a collagen I/III membrane over the lesion to protect the clot and facilitate chondrocyte differentiation from mesenchymal stem cells [37, 44]. It is frequently compared to ACI and matrix-associated chondrocyte implantation (MACI), but is relatively less expensive and can be performed in a single surgery.

AMIC is indicated for symptomatic full-thickness cartilage lesions and osteochondral lesions in weightbearing regions of both the acetabulum and femoral head. Because the membrane protects the microfracture clot, it should be possible to successfully perform AMIC for lesions that are too large to undergo routine microfracture.

Technique. A surgical hip dislocation is performed and the cartilage lesion is evaluated. If the lesion is appropriate for AMIC, we prepare the lesion as described above for microfracture. Instead of microfracture awls, we use a 1.1 mm Kirschner wire to penetrate the subchondral plate (Fig. 18.3b). If there is subchondral bone loss, an autogenous cancellous bone graft from the stable portion of the trochanteric osteotomy is used to fill the defect, such that the bone is even with the surrounding subchondral bone. An aluminum foil template is used to determine the size and shape of the membrane (Fig. 18.3c). Then, autologous or commercially available fibrin glue is used to fill the defect and entrap the clot. The membrane is sized according to the template and sewn into the lesion with 6–0 vicryl suture. Sutures should be placed about 4 mm apart, taking care to place the knots on the "patch" side of the lesion (Fig. 18.3d). The membrane should be slightly below the joint surface to prevent shearing once the hip is reduced. Fibrin glue is used to seal and smooth the edges of the membrane.

Postoperatively, patients are treated the same as patients who have had a microfracture: CPM, partial weightbearing to 10 kg and limited flexion to 70° for 6–8 weeks.

Results. We have performed AMIC for six patients with follow up ranging from 7 to 24 months. Pain scores subjectively improved for all patients, with no complications and three patients reporting complete resolution of their pain. MRIs performed 6 months postoperatively show resolution of pre-operative bone marrow edema and cystic changes, and no progression of degenerative changes (Fig. 18.4). Similar results have been reported for patients who underwent AMIC in the knee, with improved clinical outcome scores and post-operative MRIs showing healing of the lesion and resolution of pre-operative bone marrow edema [44].

Autologous Chondrocyte Implantation and Matrix-Associated Chondrocyte Implantation

The basic principle behind both autologous chondrocyte implantation (ACI) and matrix-associated chondrocyte implantation or transplantation (MACI, MACT) is implantation of cultured autologous chondrocytes into a cartilage defect [45]. MACI and MACT are subsequent-generation techniques where chondrocytes are delivered on absorbable scaffolds to support the cells during healing. The theoretical advantage of both ACI and MACI is that they have the potential to restore hyaline cartilage in the defect. However, both ACI and MACI are two-stage procedures, requiring an initial arthroscopy for chondrocyte harvest. Similar to AMIC, ACI and MACI also require application of a synthetic collagen membrane to cover the defect. This can be technically challenging. ACI is classically performed with a periosteal patch covering the implanted cells [45], although most physicians now use a synthetic collagen membrane as it minimizes surgical time and decreases complications related to the periosteum [5].

Technique. ACI or MACI is indicated for symptomatic, unipolar, well-contained defects measuring 2–10 cm^2 with no more than 6–8 mm of subchondral bone loss. An initial arthroscopy is performed to evaluate the size and depth of the lesion and to obtain a cartilage biopsy for culture. The second stage is performed 6 weeks later. A surgical dislocation is performed to access the cartilage lesion. Calcified cartilage is debrided from the base of the lesion with a ring curette. The lesion should then be carefully debrided back to stable vertical walls with a 15 blade and ring curettes. Complete hemostasis must be obtained as bleeding can affect chondrocyte viability. This can be facilitated with epinephrine-soaked pledgets. The synthetic collagen membrane can then be sewn or glued into the walls of the lesion, depending on

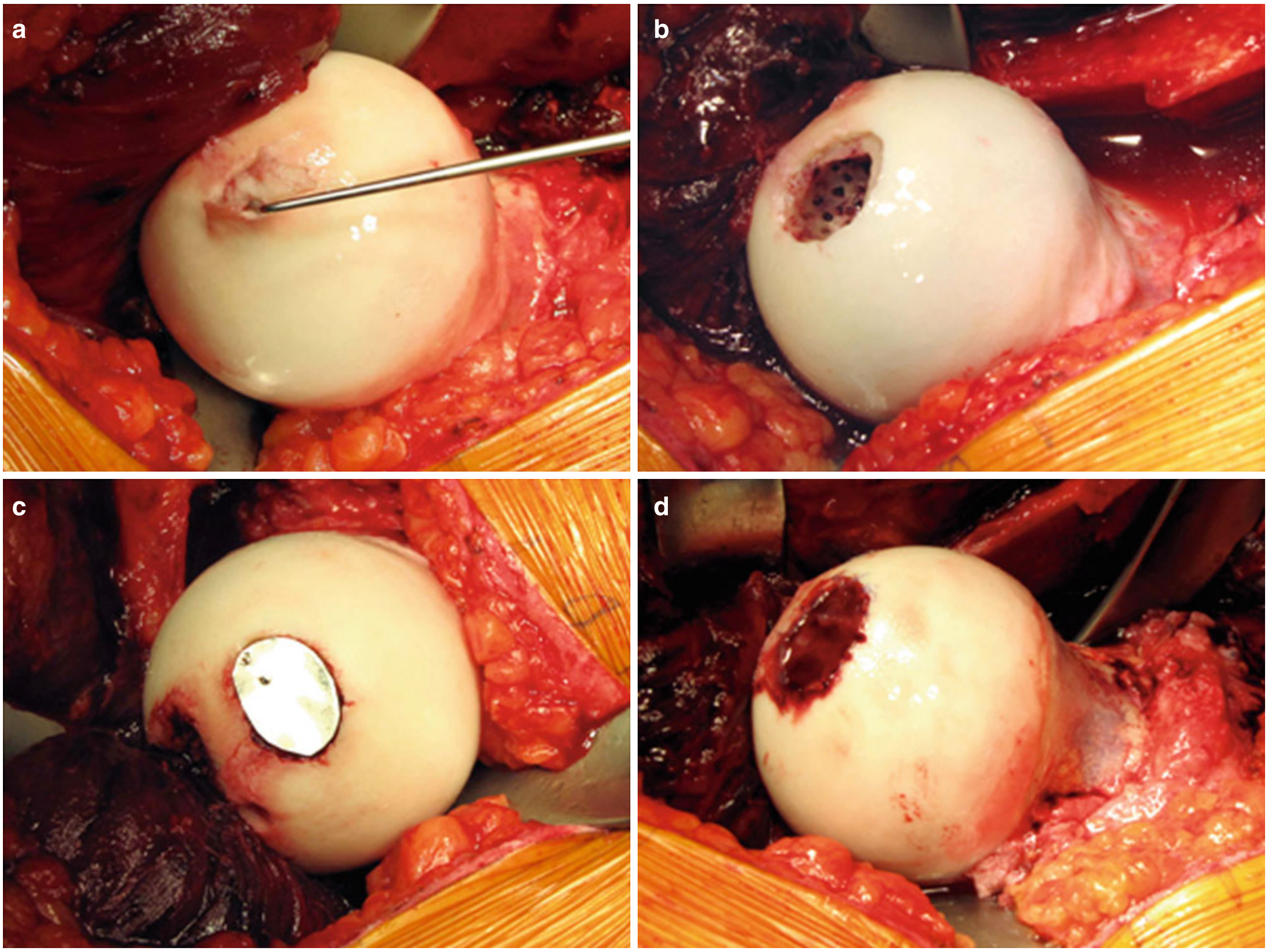
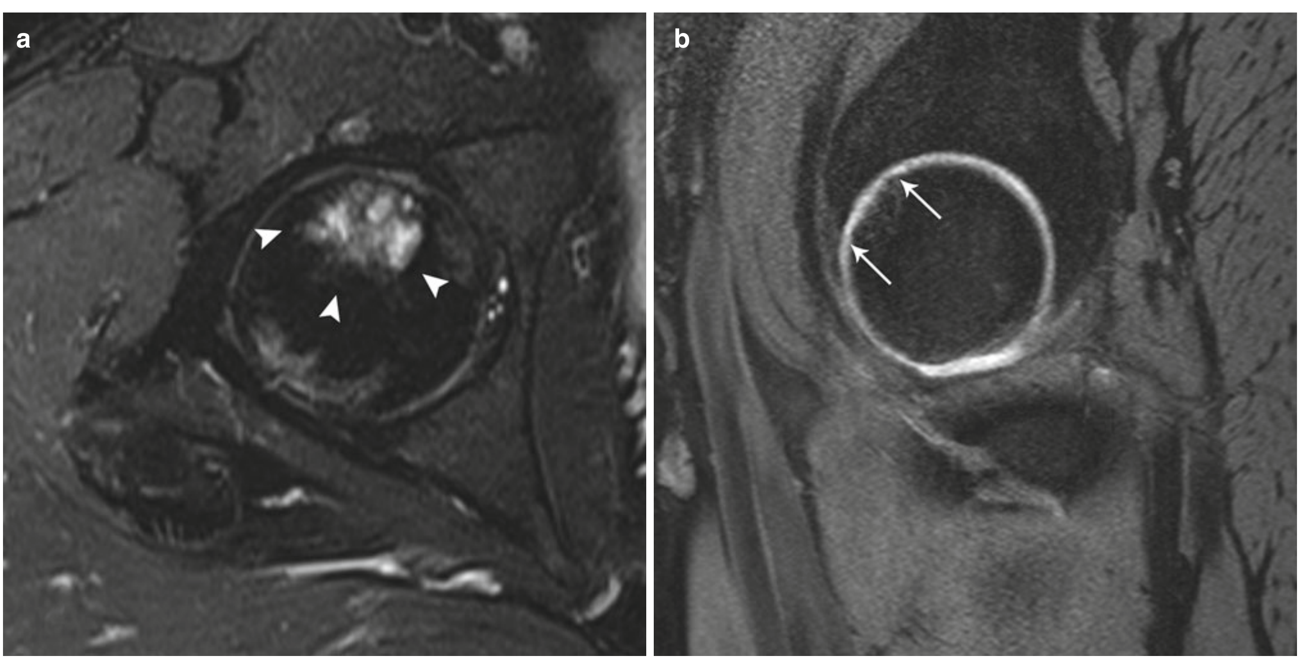


Fig. 18.3 Autologous matrix-induced chondrogenesis. (**a**) Chondral defect in the femoral head. (**b**) Preparation of the defect includes removal of all degenerative and unstable cartilage, unstable or necrotic subchondral bone, and drilling at the base of the defect with a 1.1 mm K-wire. (**c**) The size of the defect is templated with a sterile aluminum foil so that the collagen membrane can be cut to fit. (**d**) Finally, the collagen membrane is sewn into place with 6–0 vicryl suture. Note that the knots are on the "patch side" of the defect



whether ACI or MACI is being performed. When performing ACI, the membrane is sewn in as described above for AMIC with the exception that a gap is left on one side of the lesion for chondrocyte implantation. Fibrin glue is then used to seal the patch and water-tightness is tested with an 18 gauge angiocatheter. The water is removed and the chondrocytes are delivered through the opening in the membrane with the angiocatheter. The gap is then sutured and sealed with fibrin. Postoperatively, patients remain non-weightbearing for 6–8 weeks with CPM and hip flexion limited to 70°.

Results. The results for ACI in the hip are limited to one case report with short term follow up [46]. There are more results for ACI and MACI in the knee. Most of these are case series, reporting 75–85 % good results [4, 5, 47]. Patients who have undergone ACI with a periosteal patch may require additional procedures for problems related to the periosteum, including adhesions and periosteal hypertrophy [48]. Although ACI is often used after failed microfracture or debridement, the results of ACI after microfracture are worse than for patients who previously only had debridement of the lesion [49, 50]. Mid-term results for MACI in the knee have been reported, with high patient satisfaction scores for pain relief (98 %) [51]. Graft hypertrophy and associated mechanical symptoms were observed in 10–20 % of patients, although these symptoms improved following arthroscopic debridement [51].

Osteochondral Autograft Transplantation (OATS)

Osteochondral autograft transplantation (OATS or mosaicplasty) involves transplanting healthy mature cartilage from a nonweightbearing part of the hip or knee to a focal defect. The graft undergoes osseous integration with the subchondral bone and the cartilage integrates with the adjacent host cartilage via fibrocartilage [5, 52]. The advantage of OATS is that it involves the transplant of mature hyaline cartilage in a single-stage procedure. Disadvantages of OATS include morbidity at the donor site, limited graft availability, and potential dead space between grafts [4] (Fig. 18.5).

Technique (Fig. 18.2). OATS is indicated for small to medium-sized focal lesions on the femoral head and acetabulum. The size of the lesion that can be treated is generally limited by the amount of donor cartilage [52]. Although OATS can be performed arthroscopically in the knee, a surgical hip dislocation is required for appropriate access to the femoral head and acetabulum. A commercially available system is used for both graft harvest as well as preparation of the recipient site. A sizing guide is used to determine the number of grafts needed to fill the defect. The graft can be taken from either the non-weightbearing portion of the femoral head or lateral femoral condyle in the knee. When harvesting the

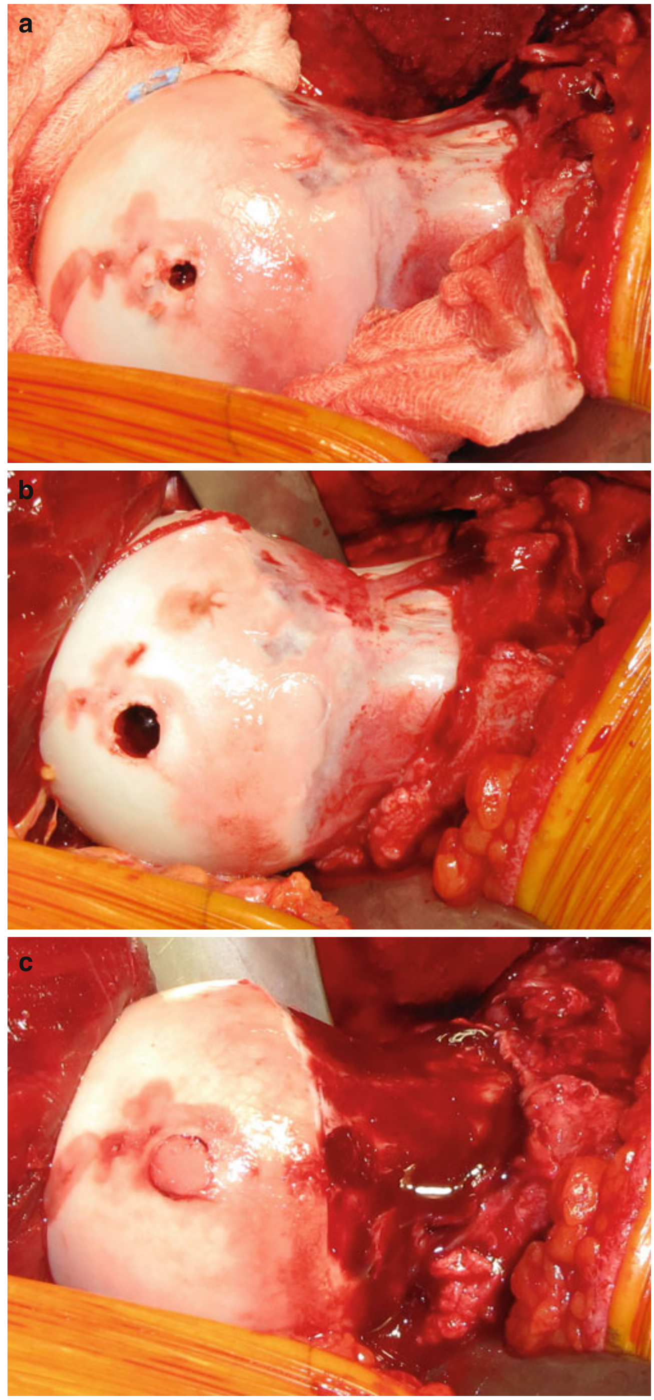


Fig. 18.5 Osteochondral autograft transplantation (OATS or mosaicplasty). (**a**) A chondral defect with a large cyst was present in the femoral head. The lesion has been debrided and the cyst was curetted as part of the lesion preparation. (**b**) The sizing guide was then used to prepare the defect for the autograft, taking care to create vertical walls of the recipient site. (**c**) The femoral head after placement of the graft and osteoplasty for a cam deformity at the head-neck junction. The donor site can be seen just lateral to the femoral head cartilage and was part of the cam deformity

Fig. 18.4 (**a**) Pre-operative axial T2 MRI from the patient in Fig. 18.5. Note the cystic changes within the lesion (*arrowheads*). (**b**) Sagittal T2 MRI obtained 6 months postoperatively. The joint space has been maintained, the cartilage surface appears regular, and the subchondral bone appears normal. *Arrows* indicate the extent of the bone graft and cartilage repair graft and preparing the recipient site, it is important to create well-defined vertical walls perpendicular to the cartilage surface (Fig. 18.2b). This enables congruent plug placement [5]. The goal is to create a press-fit implant flush with the adjacent cartilage surface because elevated grafts increase contact pressure in the graft surface [53]. Chondrocytes can be damaged from the force of impaction, so the graft should be inserted carefully [54]. Postoperatively, the rehabilitation protocol is the same as for other cartilage procedures: patients are non-weightbearing for 6–8 weeks with CPM beginning on postoperative day 1.

Results. There have been a few case series published for patients undergoing OATS in the hip for various indications. Authors generally report good results in short-term (2 years) follow up [55–58]. In a larger series of patients treated for Perthes disease, four patients underwent OATS for osteochondral defects with anecdotally good results [28]. One exception to the otherwise good results was a series of OATS performed for avascular necrosis with 4 out of 5 patients having a poor result and progressing to hip arthroplasty [3]. Reliably good results have been reported for OATS in the knee by several investigators, with long-term results being published by the developer of the technique [4, 59]. The result appears to be durable and, for larger lesions in particular, the results of OATS are significantly better than those for microfracture [4, 5, 59].

Osteochondral Allograft

Osteochondral allograft transplantation involves transplantation of intact viable cartilage and the underlying subchondral bone into a cartilage defect [60]. Because cartilage is relatively immunoprivileged with an avascular extracellular matrix, the host immune reaction to the transplant is limited [60]. As part of the healing process, the allograft bone becomes necrotic and is subsequently absorbed. During the healing process, however, the allograft provides a scaffold for bony ingrowth and supports the articular surface [61]. As compared to OATS, osteochondral allograft can be used for larger defects because it is not limited by donor site morbidity [60]. Disadvantages to osteochondral allograft include graft availability, cost, risk of rejection, and the possibility of incomplete incorporation or disease transmission. In addition, it can be technically demanding to size the allograft to the recipient site [4].

Technique. Osteochondral allografting is indicated for treatment of larger lesions or for lesions with substantial associated bone loss. It is performed through a surgical dislocation. Fresh allograft should be used in all cases as freezing decreases chondrocyte viability [62]. The graft should be slowly warmed from 4° to 37° in room temperature normal saline. Similar to OATS, commercially available kits are helpful for sizing and orienting both the graft and the recipient site. In many cases, press-fit fixation is sufficient for graft stability. When necessary, however, headless compression screws may also be used for fixation. Like other cartilage restoration procedures, patients remain non-weightbearing for 6–8 weeks post-operatively with CPM beginning on post-operative day 1.

Results. A few case reports have been published for osteochondral allografting in the hip. The results are mixed and appear to be technique-dependent. Short-term (2 years) follow up after fresh osteochondral allograft to either the acetabulum or femoral head was promising, with patients having near-normal Harris Hip scores postoperatively [63, 64]. In contrast, a patient who had a fresh-frozen osteochondral allograft for a severe fracture-dislocation had progressive degenerative changes and full-thickness cartilage loss 4 years post-operatively [65]. In a much older series published prior to the description of the surgical hip dislocation, the results of osteochondral allograft transplants for avascular necrosis were mixed [2]. In the knee, 75–85 % of appropriately selected patients subjectively improved after osteochondral allograft transplantation [5]. Increased failure rates have been observed in bipolar lesions, patients with ligamentous instability, and in worker's compensation patients [4]. Overall survival rates of osteochondral allografts are 75–95 % at 5 years, but decrease to 63–73 % at 15 years [4].

Summary and Conclusions

The successful treatment of focal cartilage defects in the hip is relatively new and has been facilitated by advancements in open and arthroscopic surgical techniques. Some, but not all, of the cartilage basic science and treatments developed for the knee are applicable in the hip. A better understanding of the cartilage biomechanics specific to the hip as well as more biomechanical and animal models of hip cartilage lesions would help to advance these treatments. In addition, as all of the current clinical literature consists of case series and small case reports, more prospectively collected data and longer follow up is necessary. To obtain sufficient numbers of patients, some of these may need to be multi-center studies. Nonetheless, the recent experience in treating these lesions is encouraging and appears to be of significant benefit to young and active adults with cartilage defects.

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Treatment of Labral Pathology: Reattachment and Replacement

19

Lisa M. Tibor and Martin Beck

Introduction and Basic Science

Introduction

The acetabular labrum has an important role in the structure and function of the hip. In young, active patients, painful labral tears can limit activities or sports. These may be the result of an acute hip injury but can also be the first indicators of subtle acetabular dysplasia, femoroacetabular impingement, or joint laxity. The biomechanical function of the labrum is complex and continues to be debated. Furthermore, although it is an area of intense interest and current research, it is not yet known if current joint-preserving strategies will ultimately prevent hip arthritis. Nonetheless, addressing labral pathology and contributing bony anomalies can resolve hip pain and allow patients to return to their activities.

Embryology and Development of the Labrum

The cells of the acetabular labrum are first visible at 6 weeks gestation as the limb buds begin to differentiate. By 8 weeks gestation, the major structures in the hip, including the cartilage anlage for the acetabulum and femur as well as the joint capsule and synovium are microscopically identifiable. Correspondingly, the labrum begins to have a more triangular appearance at the acetabular rim [1]. It is important to note that the position of the femur relative to the acetabulum changes during the course of early development and may affect the structure of the developing labrum. During fetal development, the lower extremity internally rotates between weeks 8 and 11. At 11 weeks gestation the hip and knee are flexed and both lower extremities are adducted, with the left leg overlapping the right. The legs continue to flex until approximately 16 weeks gestation, when the full fetal position is attained. In the fetal position the hips are considered to be in a stable position [1, 3] with the inferior portion of the femoral head in contact with the anterior acetabulum [2].

Microscopically, the anterior labrum "caps" the anterior acetabulum during development, with a more tenuous attachment to the acetabular rim than the posterior labrum (Fig. 19.1) [2]. The transition between the acetabular cartilage and labrum anteriorly is somewhat abrupt and the collagen fibers are parallel to the chondrolabral junction (Fig. 19.1) [2, 4]. Posteriorly, the labrum has no intra-articular projections and is continuous with the acetabular cartilage with a gradual and interdigitated transition. Here, the collagen fibers are perpendicular to the chondrolabral junction (Fig. 19.1) [2, 4]. Subsequent changes to the labral structure that occur with more erect posture are not well-described. It is not known if the structure of labrum observed during development leads to the development of an area of weakness that predisposes later tears. In terms of vascularity the developing labrum's blood supply originates from the capsular side of the labrum and traverses to the articular aspect [4, 5].

Anatomy

Gross Appearance

The labrum is nearly circumferential around the acetabular fossa with anterior and posterior horns that are continuous and indistinguishable from the transverse acetabular ligament (Fig. 19.2a) [6, 7]. The labrum is widest anteriorly and thickest superiorly due to its triangular cross-section [7]. The joint capsule inserts on the bony acetabulum proximal to and distinct from the labrum, which creates a recess around the labrum (Fig. 19.2b) [7].

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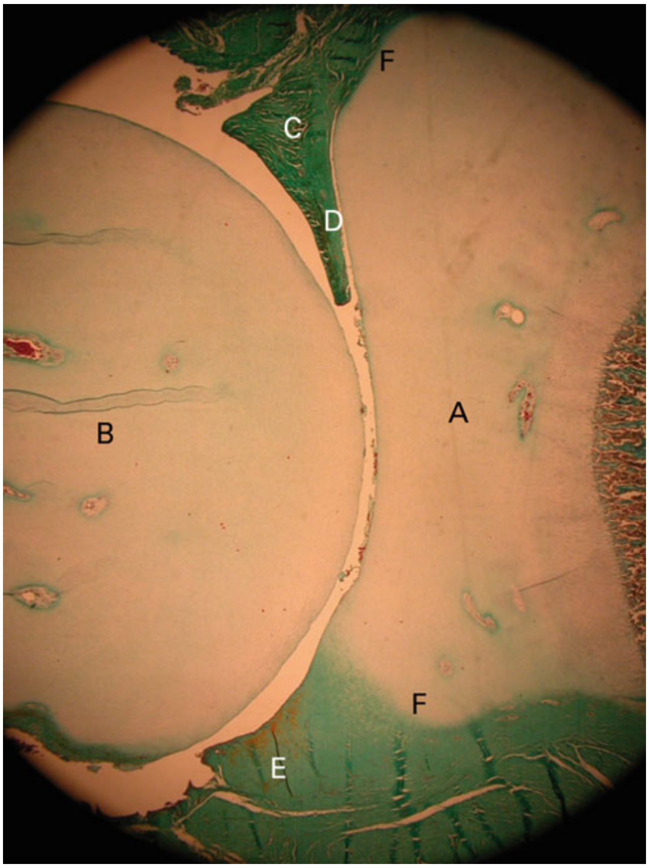
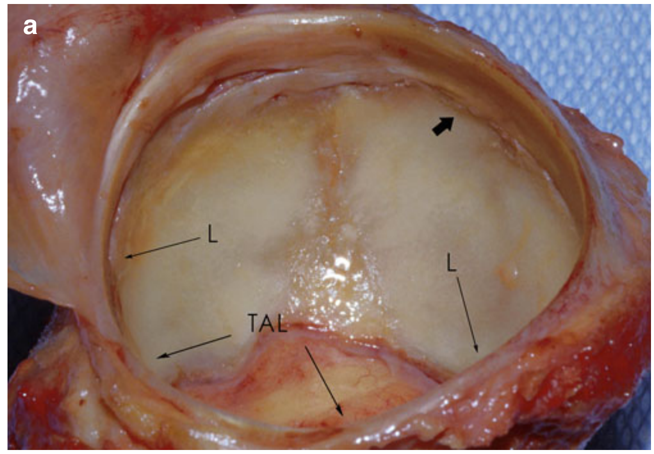


Fig. 19.1 The developing labrum. Photomicrograph of a fetal hip at term showing the attachments of the anterior and posterior labrum to the acetabular cartilage. The transition between the anterior acetabular cartilage and labrum is abrupt, with an intra-articular projection. The posterior labrum is directly attached to the acetabular cartilage with a gradual and interdigitated transition. There is no intra-articular projection of the posterior labrum. *A* acetabulum, *B* femoral head, *C* anterior labrum, *D* intra-articular projection of the anterior labrum, *E* posterior labrum, *F* posterior acetabulum-labrum transition zone (Reprinted with permission, Cashin [2])

Microscopic Anatomy and Histology

In the adult hip, there is a thin extension of bone into the substance of the labrum. In children, this extension remains cartilaginous as part of the acetabular epiphyseal cartilage (Fig. 19.3a, b) [1, 6, 7]. The articular and capsular sides of the labrum are structurally significantly different. The most superficial tissue layer on the capsular side is loose and well-vascularized (Fig. 19.2b). This then transitions to a layer of dense connective tissue, with a continuous transition between this dense connective tissue to a thin layer of fibrocartilage on the articular side of the labrum. This fibro cartilaginous layer consists of chondrocytes embedded between collagen fibrils [8]. The articular side of the labrum is in turn attached to the bony acetabulum via a tidemark zone of calcified cartilage [7]. A physiologic cleft between the labrum and cartilage has been observed under light microscopy at the chondrolabral junction [6, 8] and under scanning electron microscopy, a clear transition



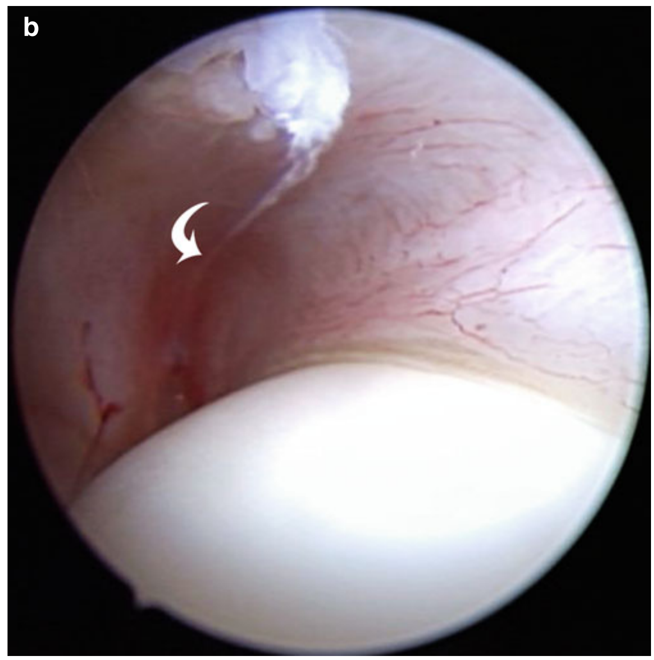


Fig. 19.2 Anatomy of the labrum. (**a**) Cadaveric labrum. The anterior and posterior horns of the labrum (*L*) are continuous and indistinguishable from the transverse acetabular ligament (*TAL*). Age-appropriate degenerative changes can be seen at the chondrolabral junction (*black arrow*). (**b**) Arthroscopic picture of the labrum from the peripheral compartment. The joint capsule attaches on the bony acetabulum above the labrum, creating the capsular recess (*curved arrow*). The most superficial layer of tissue on the capsular side of the labrum is well-vascularized, as can be seen here, and provides the majority of the blood supply to the labrum

between the collagen structure of the cartilage and labrum can be seen. The difference in the collagen ultrastructure is indicative of the distinct functions of the cartilage and the labrum in the hip. The main portion of the labrum is made up of circumferentially oriented collagen fibers that are continuous with the transverse acetabular ligament [8]. These fibers consist of Type I collagen fibers that are divided into bundles by Type III collagen [8]. As collagen bundles are generally oriented in the direction of greatest tension, the circumferential orientation of the collagen

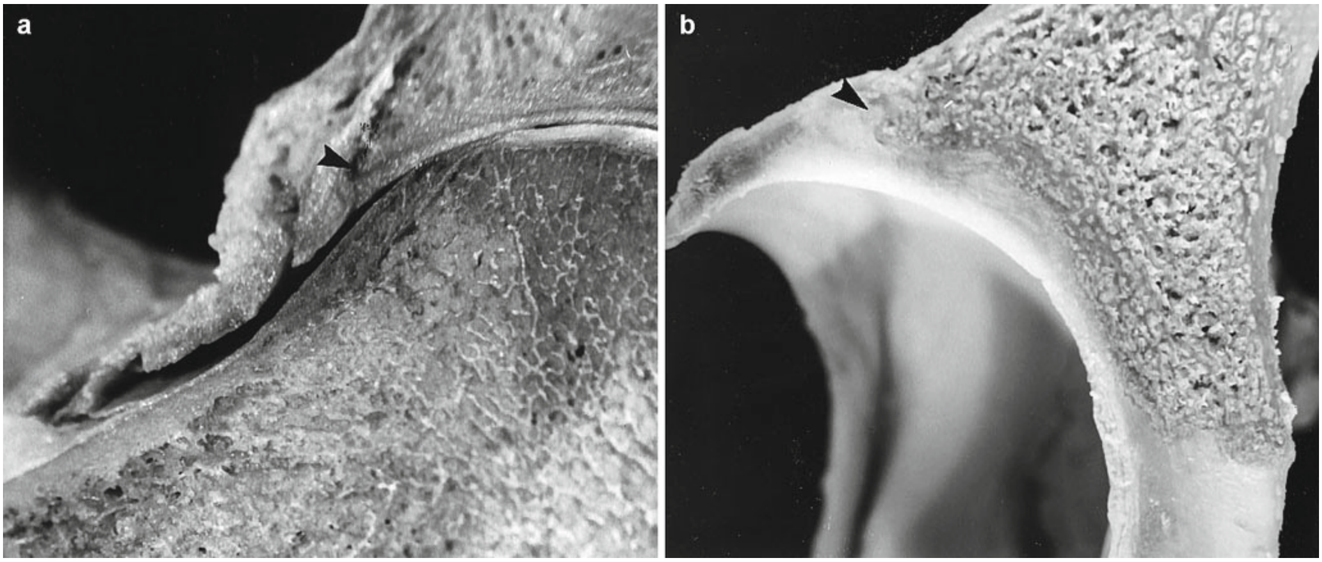


Fig. 19.3 Relationship of the labrum to the bony acetabulum. (**a**) Coronal cross section through an adult acetabulum and labrum. In the adult, the bony acetabulum (*arrowhead*) extends into the substance of the labrum. (**b**) Oblique cross section through the acetabulum and labrum of a child. In children, the acetabular epiphyseal cartilage extends into the labral substance; the ossified portion of the acetabulum (*arrowhead*) does not extend to the labrum (Reprinted with permission, Putz and Schrank [6])

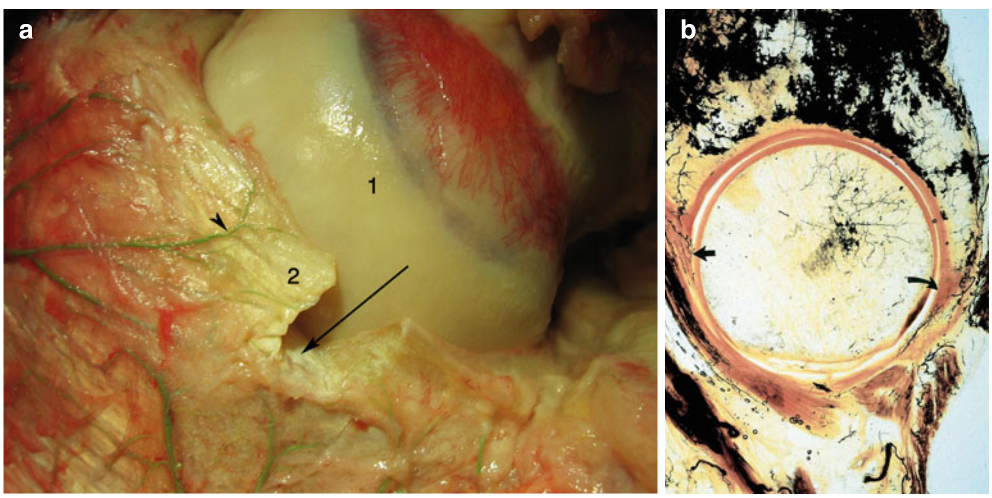


Fig. 19.4 Vascularity of the labrum. (**a**) Macroscopic perfusion of the labrum from radial branches of the periacetabular vascular ring (*arrowhead*). *1* Femoral head, *2* labrum. A section has been resected from the labrum to show the osseolabral junction (*arrow*). There are no grossly visible vessels at the junction (Reprinted with permission, Kalhor et al. [10]). (**b**) Sagittal section of the acetabulum and femoral head demonstrating microscopic vascularity of the labrum. The majority of the labral blood supply is from capsular perfusion, with a small contribution from the subchondral bone. Anterior labrum: *straight arrow*, posterior labrum: *curved arrow* (Reprinted with permission, Kelly et al. [11])

fibers in the labrum may be indicative of its biomechanical function [8].

The innervation of the labrum appears to be mostly on the capsular side. Free nerve endings—thought to primarily sense pain, as well as sensory nerve receptors for pressure, deep sensation, and temperature have been observed [9].

Vascularity

The sources of labral perfusion and the sites of labral vascularity have implications for healing after labral reattachment. Macroscopically, the labrum is perfused by radial branches of the periacetabular vascular ring (Fig. 19.4a). The majority of the blood supply to the ring comes from the superior and inferior gluteal arteries, with lesser contributions from the medial and lateral femoral circumflex arteries [10]. Microscopically, vascularity is greatest on the capsular side of the labrum and is about twice that of the articular aspect [8, 11]. No differences in vascularity have been observed between the anterior, posterior, or superior aspects of the labrum or between intact and degenerative specimens [11]. In addition, there is some perfusion from the bony acetabulum, although this is more variable than the capsular contribution (Fig. 19.4b) [11].

Biomechanics and Function

Biomechanics

The tensile and compressive properties of the labrum vary around its circumference. The Young's modulus (strength in tension) is significantly lower in the anterior-superior region of the labrum compared to the anterior-inferior region [12]. The compressive modulus (strength in compression) is lower in the anterior-superior region compared to the posterior labrum and there are no significant differences in the compressive modulus between other regions of the labrum [12]. Overall, the tensile and compressive properties of the labrum appear to be comparable to that of the meniscus in the knee suggesting a similar role [13]. It is worth noting that these biomechanical studies were undertaken in a cadaver model using older specimens. It is known that the biomechanical properties of connective tissue and cartilage in joints change with age, even if the structures are not obviously degenerative [14]. Labral strain in different positions has also been described [15]. In neutral flexion-extension and rotation, the labrum was found to be in a "pre-stretch" state with some load present already. Flexion and adduction created the highest strain in the anterior labrum; this increased slightly with external rotation as compared with neutral rotation. Hip flexion also caused increased strain in the lateral labrum; this was higher in the neutral position than in combination with abduction or adduction. When examined independently, abduction causes the highest amounts of strain in the lateral labrum, both in flexion to 90° and in full extension. Hip extension and neutral rotation created the highest strain in the anterolateral labrum; this increased with external rotation but decreased with adduction, abduction, and internal rotation. The posterior labrum has the highest overall magnitudes of strain [15].

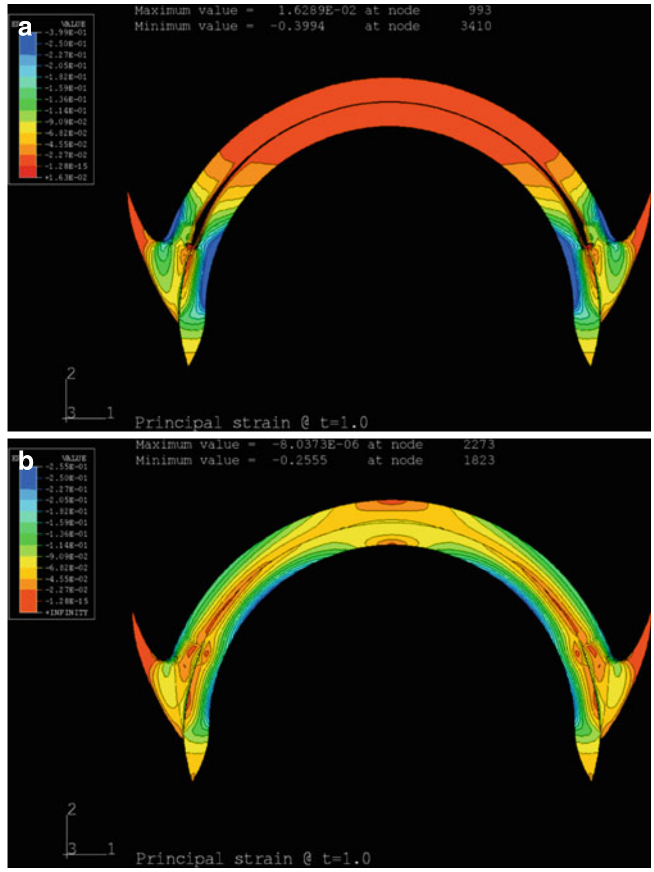


Fig. 19.5 Effect of the labral seal on cartilage stress. Finite element model of hip cartilage stress with (**a**) and without (**b**) the pressurized fluid layer created by the labral seal. With an intact labral seal, articular cartilage stress is evenly distributed and directed towards the periphery of the joint. When the labral seal is disrupted, the pressurized fluid layer is lost. There is direct cartilage contact, which increases friction and load across the cartilage surface (Reprinted with permission, Ferguson [16])

Function

The labrum appears to have multiple roles in the hip. The relative contributions and exact mechanisms of these roles to overall hip function continue to be the subject of debate.

The most accepted of these roles is the labral contribution to hip joint sealing. The labral seal was first described in the nineteenth century [16] and appears to facilitate joint lubrication and cartilage nutrition. An intact labrum is less permeable than articular cartilage or meniscus [13] and is generally resistant to fluid extrusion from the joint [13]. This allows for maintenance of the labral seal, creating a pressurized fluid layer between the cartilage of the acetabulum and the femoral head. Load across the joint is carried by the fluid layer, shielding the articular cartilage from stress and increased friction, with a more even distribution of load (Fig. 19.5a) [16–19]. Loss of the labral seal results in increased load transfer by direct cartilage contact (Fig. 19.5b). This results in increased friction leading to degenerative changes in the cartilage, and ultimately results in arthritis. This has been demonstrated in both finite element [18, 19] and cadaveric studies [17] and an MRI study has shown improvements in distribution of cartilage strain following labral reattachment when compared to labral resection [20]. A recent finite element model suggested that the labrum supports more load in the dysplastic hip than in the normal hip [21]. Interestingly, the model did not observe improvements in cartilage contact stress with preservation of the labrum as compared to labral resection. As a result, the authors argued that the labral seal has a larger contribution to hip stability rather than decreasing cartilage contact stresses [21].

The contribution of the labrum to hip stability is postulated to occur via both the labral seal as well as providing a mechanical block to motion. This is, however, the more debated role of the labrum. Grossly, the labral seal was noted to improve hip stability in the nineteenth century [16]. Multiple articles describing techniques in hip arthroscopy have noted that decreased force is required for traction during hip arthroscopy once the labral seal has been broken by introduction of a cannulated needle into the central compartment

[22]. Preservation of the labrum and capsule was also observed to improve the stability of hip hemiarthroplasty performed for femoral neck fracture [23]. The force required to distract the hip after both venting and incising the labrum was examined in a cadaveric study. The greatest proportional decrease in force occurred after incising the labrum, with 60 % less force required to distract the joint 3 mm [24]. Statistically significant increases in both external rotation and abduction were observed after incising the labrum, although clinically these were small, ranging from 1.5° to 7.5° as compared to the intact labrum [24].

A cadaveric model evaluating the relative contributions of the iliofemoral ligament and the labrum to hip stability found the iliofemoral ligament to be the primary stabilizer of the hip joint for external rotation and anterior translation and the labrum a secondary stabilizer. Based on these results, the authors concluded that when possible during hip surgery, both the labrum and iliofemoral ligament should be repaired [25]. In a joint compression model with the hip in a neutral position, removal of at least 2 cm of the labrum was necessary to destabilize the hip. Radial tears and smaller labrectomies did not destabilize the hip [26]. As a result, it is hypothesized that the labrum acts as a mechanical block contributing to hip stability. It is important to note however, that in this model the hip was only tested in neutral and as such the labrum may contribute more to hip stability at extremes of motion [26].

Labral Pathology

Classification

Beck and colleagues developed the most widely used classification of labral tears (Table 19.1) as part of their work describing femoroacetabular impingement [27]. Although labral tears had been described previously, their system is clear, reproducible, and can be used for labral tears that occur for reasons other than from impingement.

Table 19.1 Beck classification of labral tears

Description	Criteria
Normal	Macroscopically sound labrum
Degeneration	Thinning or localized hypertrophy, fraying, discoloration
Full-thickness tear	Complete avulsion from the acetabular rim
Detachment	Separation between acetabular and labral cartilage, preserved attachment to bone
Ossification	Osseous metaplasia, localized or circumferential

The Beck classification of labral tears is frequently used in studies reporting intra-operative findings and patient outcomes after labral tear or hip preservation surgery. It is a clear and reproducible system that can be used to describe labral tears occurring from any etiology or trauma

Trauma

Labral tears and occasionally small acetabular rim fractures are common in "simple" posterior hip dislocations i.e.—those that do not involve femoral head or acetabular fractures requiring open reduction. The location of the labral tear can be anterior, posterior, or both and is usually associated with a well-recognized subluxation or dislocation event [28–30]. Labral tears associated with acute trauma are often associated with significant chondral lesions and tears of the ligamentum teres. Bucket-handle and other substantial labral tears can also occur in the setting of acetabular fractures [31] and should be addressed at the time of surgical management of the fracture.

Dysplasia

Labral pathology was first recognized in dysplastic hips. In one series of patients undergoing hip arthroscopy for labral tears, nearly half of the patients had radiographic evidence of dysplasia [32]. The acetabular deficiency that occurs with dysplasia creates a static instability of the femoral head. As a result of chronic shear stress occurring at the acetabular rim, the labrum undergoes hypertrophy and helps to contain the femoral head [33, 34]. If the shear stress persists, the labrum becomes degenerative and ultimately fails. Myxoid degeneration and ganglia can be seen in the labrum on MRI (Fig. 19.6). These changes are generally rare in FAI patients [33]. The chondrolabral junction can also be avulsed from the acetabulum due to the shear stress of the femoral head. When this occurs, an avulsed piece of cartilage often remains attached to the torn labrum. This has been termed an "inside-out" lesion (Fig. 19.6) [34]. Radial labral tears occur more often in patients with dysplasia [31], which corresponds to the lateral force of the femoral head pushing on the labrum. Anterior and superolateral tears are most common [32, 34, 35]. There is also a high amount of associated acetabular rim degeneration in dysplasia [32, 34, 35]. A labral tear may hasten the progression of this degeneration as the load increases at the lateral edge of the joint [36]. It is important to distinguish between labral pathology due to dysplasia and that due to FAI, because it will influence surgical decision-making [37] patients with symptomatic hip dysplasia require a periacetabular osteotomy to reorient the acetabular socket and address the underlying bony insufficiency [34, 35, 37, 38].

Femoroacetabular Impingement

The concept of a "degenerative" labral tear is evolving. Many of the labral tears in patients who do not have dysplasia are due to subtle underlying bony anomalies that result in femoroacetabular impingement (FAI). In FAI, labral and cartilage injury results from hip motion in patients with abnormal femoral head and/or acetabular anatomy [39]. This

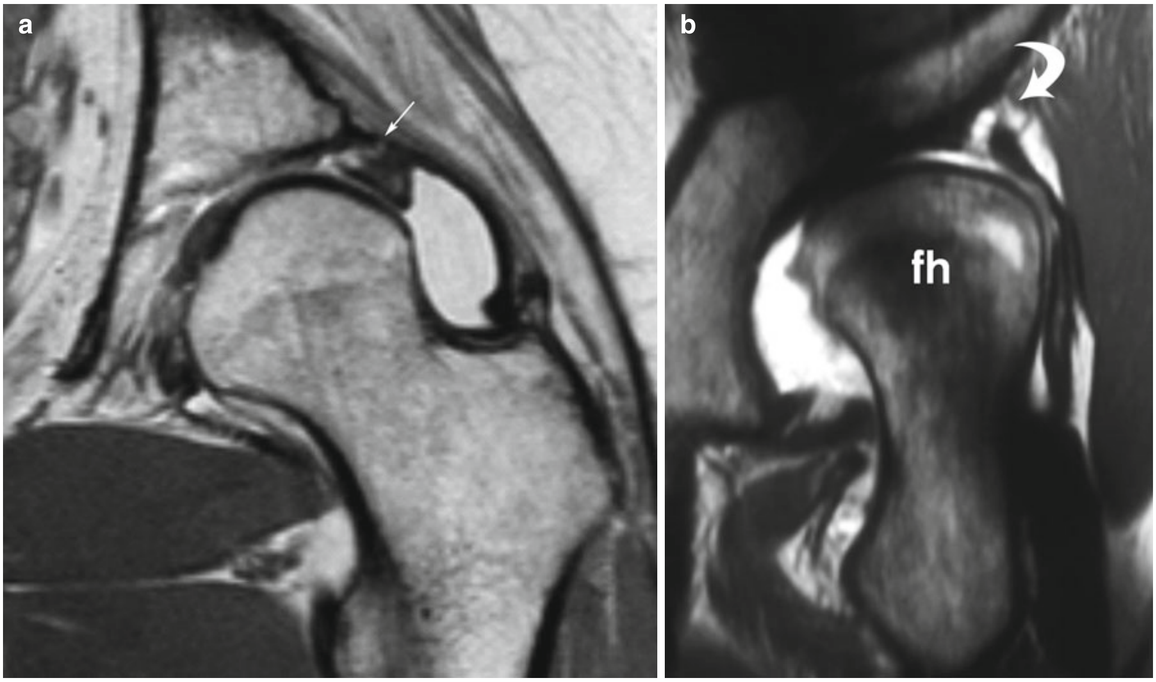


Fig. 19.6 The dysplastic labrum. (**a**) Coronal T1 MRI of a dysplastic labrum. Static overload results in myxoid degeneration and ganglia within the substance of the labrum. The shear stress of the femoral head causes an "inside-out" labral lesion (*thin arrow*): avulsion of the chondrolabral junction from the acetabulum. (**b**) MR arthrogram of a ruptured labrum (*curved arrow*). The femoral head (*fh*) has begun to migrate out of the acetabulum

is in contrast to dysplasia where static overload of the joint causes the associated labral and cartilage damage. Although FAI can result from various underlying bony anomalies, mechanically it can be grouped into cam impingement, pincer impingement, and mixed—both cam and pincer—impingement [27, 39]. The mechanical type of impingement correlates with the pattern of labral and cartilage damage that occurs (Fig. 19.7) [27].

In cam impingement, an aspherical portion of the femoral head (the "bony bump") jams into the acetabulum during flexion. The resultant shear force on the acetabulum leads to abrasion of the acetabular cartilage and labrum, creating an "outside-in" lesion (Fig. 19.7a, b) [27, 39]. About 2/3 of cam impingement patients have a focal labral tear. This usually occurs at the anterior or anterosuperior rim of the acetabulum. It is much less likely to involve the posterior acetabulum—18 % in one cohort [40–44].

In pincer impingement, global or focal overhang of the socket causes linear contact of the labrum and the femoral head-neck junction during flexion. This results in a crush injury to the labrum (Fig. 19.7c, d) [27, 39]. Patients with more predominant pincer pathology are less likely to have localized anterosuperior acetabular cartilage damage [40, 42], but may have a more circumferential labral lesion [27, 41]. Pincer impingement can also result in a secondary posterior impingement—a contrecoup injury to the posterior head and acetabulum when the femoral neck levers against the anterior rim as patients attempt to achieve a greater hip range of motion [27, 39]. This seems to be particularly common in patients with protrusio acetabuli [44].

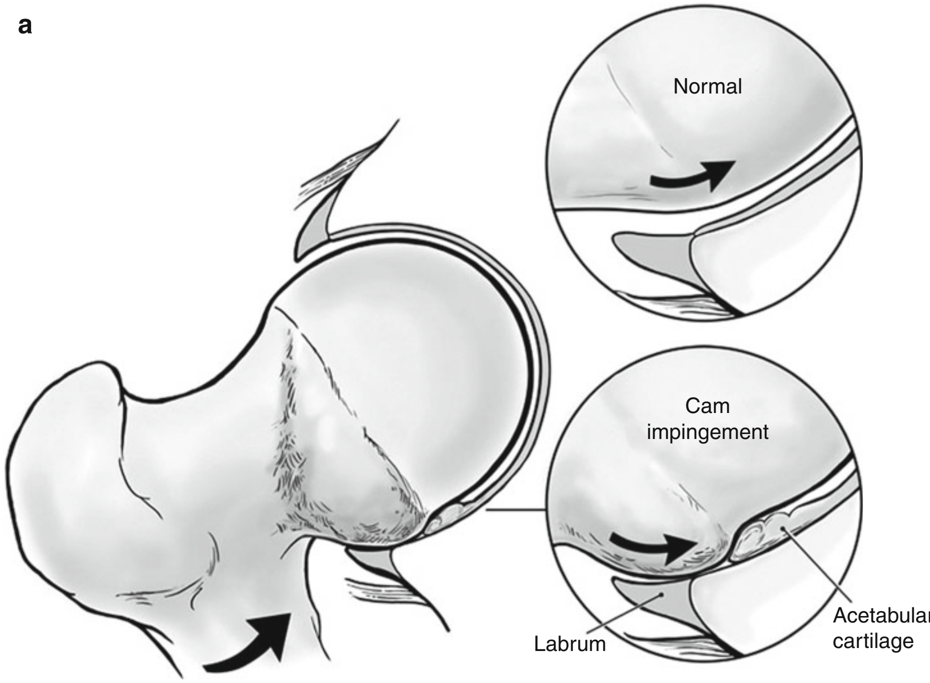
Labral ossification may be visible on a plain radiograph or MRI as well. The labral crush injury from pincer impingement often results in labral ossification (Fig. 19.7d, e) [27, 39, 44, 45] which worsens the mechanics of pincer impingement. Histologically, the labral crush injury is associated with microfractures at the acetabular rim, which causes subsequent calcification and callus formation [43]. It appears that the bony callus formation and reparative tissue at the acetabular rim pushes the labrum away from the bone [43, 46].

Asymptomatic Labral Tears

Some labral tears may be asymptomatic. An MRI study of asymptomatic male Swiss army recruits observed abnormal labral morphology and labral lesions in 2/3 of the cohort. Labral pathology was observed more frequently in patients who also had bony cam lesions, occurring in 85 % of patients with a cam lesion. The adjusted odds ratios for this varied from 2.08 to 2.45, depending on the nature of the labral lesion [47]. In a series of elite and asymptomatic hockey players playing at the professional or collegiate level, 56 % had evidence of labral tears on 3 T MRI. All were actively playing without any limitations from their hips [48]. In addition, not all patients with radiographic evidence of labral tears obtain relief from intra-articular local anesthetic. This suggests that extra-articular sources may be the cause of pain, even in the presence of a labral tear [49, 50].

Laxity

The idea that capsular laxity may also be responsible for labral pathology is somewhat controversial. The proposed mechanism is one of secondary instability or micro instability. As a result of the instability, extra-physiologic motion results in increased pressure on the acetabular labrum and other structures [51–53]. A cadaveric study verified that there is increased anterior displacement of the femoral head with the hip in extension and external rotation. Although no labral tears were generated with the model in the study, this was associated with increased strain at the bone-labrum interface [52]. A motion capture study of professional ballet dancers with normal bony morphology observed superior and posterosuperior impingement in some dance positions at the extremes of motion. MRIs performed in these dancers confirmed the normal bony morphology but found degenerative changes superiorly and posterosuperiorly, corresponding to the observed areas of impingement [54]. Clinically, there are particular sports that involve repetitive hip rotation and axial loading. These include golf, figure skating, tennis, baseball, ballet, martial arts, and gymnastics. The repetitive



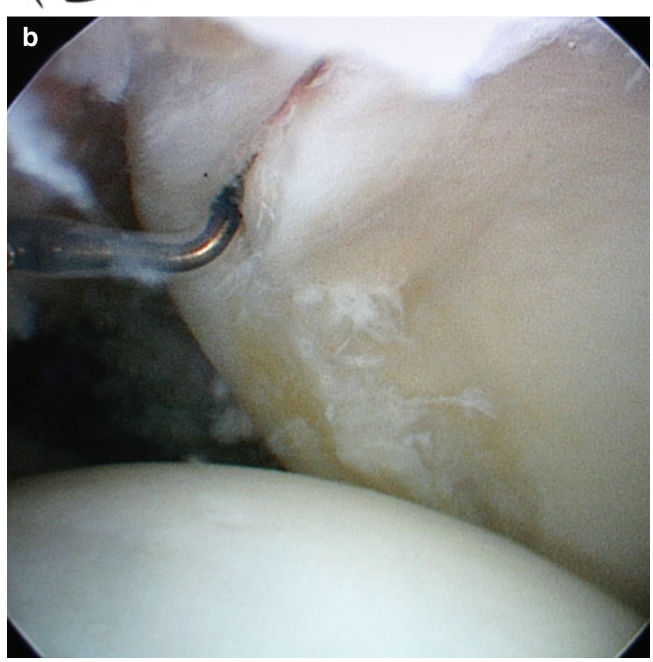


Fig. 19.7 The labrum in FAI. (**a**) Line drawing of outside-in cartilage delamination and labral tear caused by cam impingement. (**b**) Arthroscopic picture of a labral tear and cartilage delamination caused by a large cam deformity. (**c**) Line drawing of a labral crush injury caused by pincer impingement. (**d**) Picture of a completely ossified labrum due to pincer impingement seen during surgical hip dislocation. This patient also had a cartilage delamination injury (*probe*) from a cam deformity (Images **a** and **c** reprinted with permission, Byrd and Jones [45]). (**e**) Labral ossification (*arrow*) as seen on the radial T1 images of an MR arthrogram

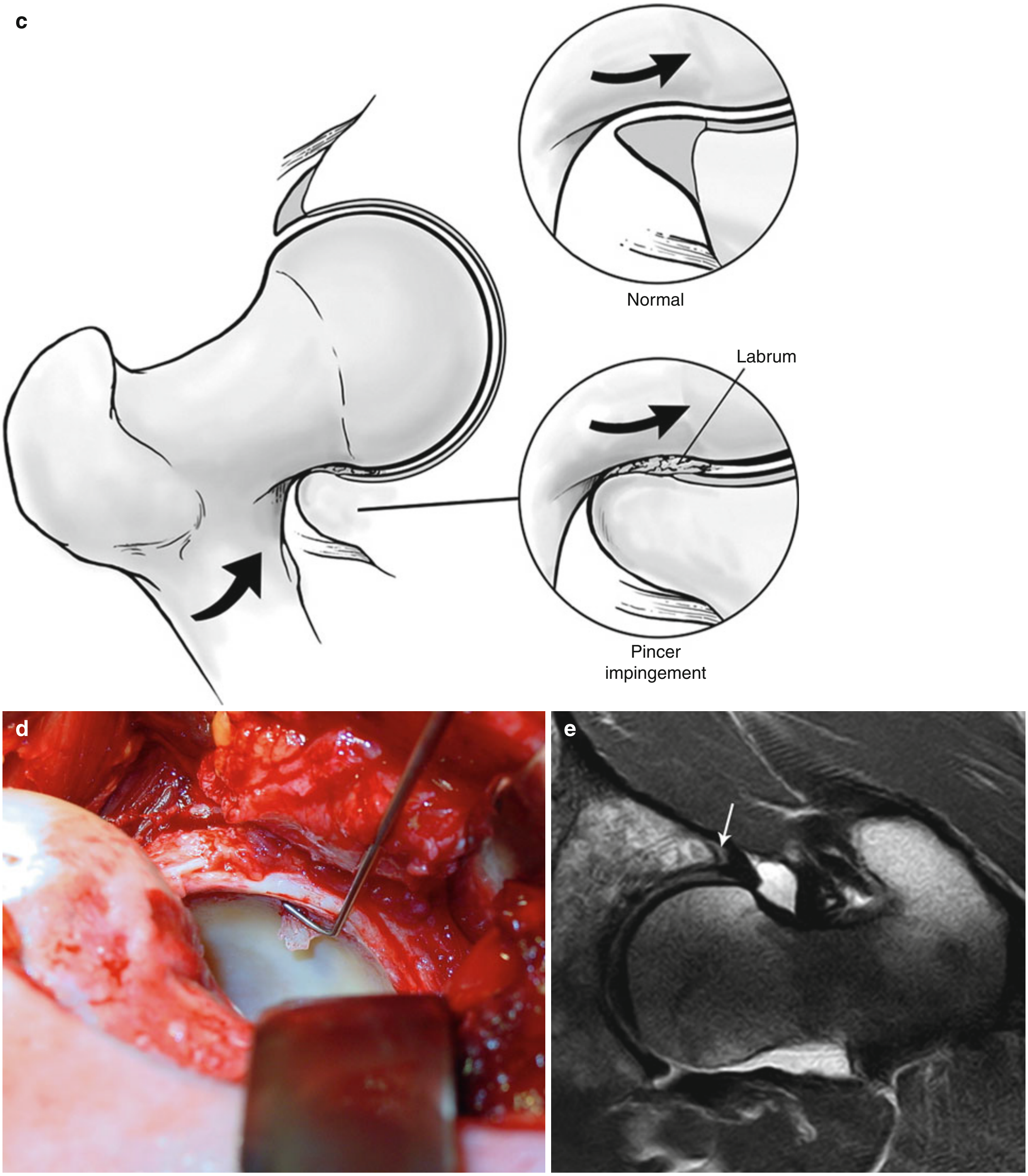


Fig. 19.7 (continued)

motion and subsequent laxity may be a predisposing factor for labral pathology in these athletes [53, 55]. Conversely, other authors have noted that patients with symptomatic labral tears generally have recognizable bony abnormalities. In some series, up to 90 % of patients with labral tears have associated bony pathology consistent with either FAI or dysplasia [56, 57].

Treatment and Surgical Techniques

Clinical and Radiographic Findings

The symptoms associated with labral pathology are variable and patients often have a combination of symptoms [58]. Patients with labral tears describe either an acute or an insidious onset of symptoms. Most often, the acute onset of symptoms is associated with a minor trauma or pivoting injury; the onset of symptoms is less often associated with a significant trauma. Generally there is some combination of groin pain with buttock, lateral leg, or thigh pain. The pain may be dull or intermittently sharp and is often worse with activity, walking, or prolonged sitting. Half of patients describe mechanical symptoms, which may consist of catching or clicking [58]. On gait exam, patients may have an antalgic limp or Trendelenburg lurch. A positive impingement test occurs when the patient has pain with the hip in 90° of flexion, adduction, and internal rotation.

All patients with suspected labral pathology should undergo a standard radiographic exam consisting of an AP pelvis x-ray and a cross-table lateral x-ray of the involved hip. These should be evaluated for signs of dysplasia or femoroacetabular impingement. The degree of existing degenerative change should also be noted. Patients with preexisting degenerative changes have worse results after both arthroscopic and open labral procedures [58–61]. Patients should also undergo MRI with an intra-articular arthrogram, which is both sensitive and specific for labral tears. Meta-analysis of MRI and MR arthrogram indicates that MR arthrogram is a better diagnostic study for detecting labral tears than MRI without arthrogram [62]. A 1.5 T magnet is sufficient, although the series should include a fluid-sensitive sequence with a coil over the hip and a small field of view. The study should include radial slices through the femoral neck to evaluate for cam lesions not seen on standard x-ray views as the presence of a labral tear without an underlying bony deformity is rare [63]. Proper imaging may reveal up to 34.6 % unexpected asphericity of the head-neck junction [63]. The articular cartilage should also be examined for signs of degeneration not seen on the plain films. When it is difficult to determine if the cause of pain is coming from the hip or the back, we recommend a diagnostic intra-articular injection [58].

Surgical Treatment

Conservative management of a symptomatic labral tear may be considered in the presence of pure pincer FAI, because intra-articular cartilage damage usually is minimal and progression of degenerative changes is limited. In contrast, when patients with cam FAI become symptomatic, advanced articular cartilage damage is often already present. Thus, correction of the cam deformity is important for preserving the remaining cartilage. The same applies to labral pathology secondary to dysplasia, where restoration of hip biomechanics with acetabular reorientation is mandatory. Conservative management may include physical therapy for core and hip abductor strengthening, activity modification, non-steroidal anti-inflammatory medication, or cortisone injection. If conservative management does not improve symptoms within 3–4 months, surgical treatment is advocated.

In general, co-existing dysplasia, FAI, and chondral lesions should be addressed at the same time as the labral pathology. Often, the co-existing pathology will determine whether the labral tear will be treated as part of an open or arthroscopic procedure. Contraindications to hip joint preservation surgery, which encompasses most techniques for treating labral pathology, include Tönnis grade 2 or greater osteoarthritis and patients who are unwilling or unable to comply with the postoperative rehabilitation.

Labral Debridement and Refixation

A torn or degenerated labrum cannot be repaired back to its original shape and function. Surgical treatment of the labrum via *reattachment, refixation, or stabilization* results in healing and the formation of a more or less functional scar. If the labrum is not amenable to reattachment, debridement is reasonable. This generally is the case with fraying of the labral edge or extensive intrasubstance tearing. The idea behind debridement is that removal of a mechanical labral flap will improve symptoms. During arthroscopy, this can be accomplished with a shaver; in an open procedure we recommend sharp debridement. Because of the importance of the labrum to hip function, this should be performed in a conservative fashion, with debridement to healthy-appearing, stable tissue.

When technically feasible, labral reattachment is recommended (Fig. 19.8). There is reasonable evidence that the labrum heals following surgical reattachment. In a sheep model of arthroscopic labral reattachment the labrum healed via a fibrovascular scar and direct new bone formation [64]. The sheep were allowed immediate full weight-bearing and labral healing was assessed at 12 weeks. The reattached labrum did appear bunched and misshapen, unlike the smooth triangular appearance of the normal controls.

If indicated as part of the management for concomitant FAI and if one is comfortable with arthroscopic techniques, the labrum can be treated arthroscopically. Arthroscopic treatment is contraindicated in cases of clear acetabular dysplasia; the patient should undergo an acetabular reorientation procedure to address the dysplasia. General techniques for hip arthroscopy are described in detail in Chaps. 16 and 17. The senior author performs arthroscopy in the lateral position with the patient on a traction table and beginning in the peripheral compartment. From the peripheral compartment, the capsular side of the labrum can be assessed. FAI should be evaluated by flexing and extending the hip under direct arthroscopic visualization. The pattern of labral and cartilage damage is also evaluated and used to confirm the preoperative diagnosis of cam, pincer, or combined FAI. From the peripheral compartment, we address any cam deformity

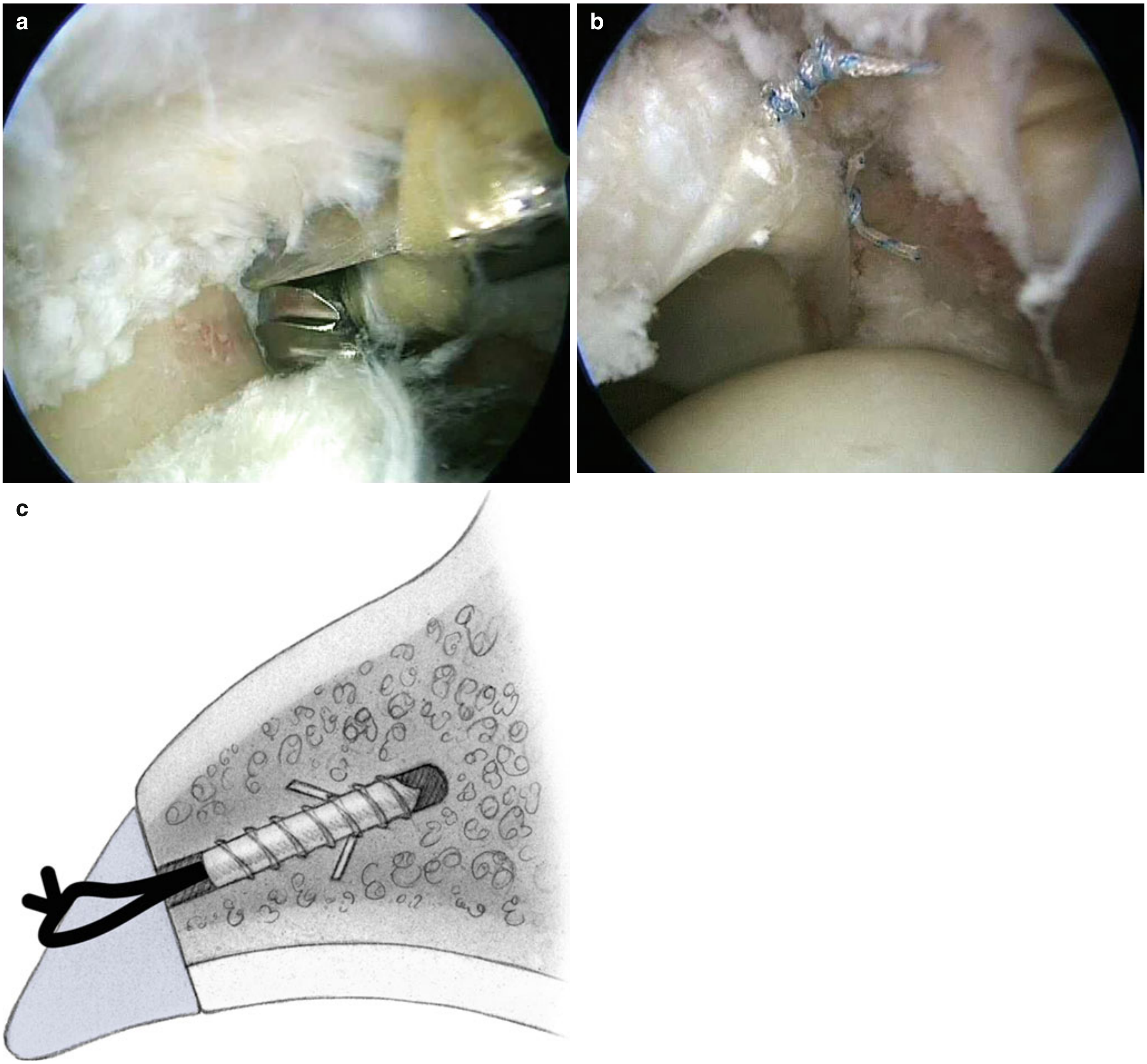


Fig. 19.8 Arthroscopic acetabular rim trimming and labral repair. (**a**) Acetabular rim trimming. (**b**) Appearance of the labrum following repair. (**c**) Anchor placement (**c** reprinted with permission, Espinosa et al. [81])

with a femoral neck osteoplasty. Traction is then placed and the central compartment accessed.

When pincer impingement is present, acetabular rim trimming should be performed. If the chondrolabral junction remains intact but the acetabular rim has clearly overgrown the labrum, the bony overgrowth can be resected with an arthroscopic burr without taking down the chondrolabral junction (Fig. 19.8a). When the labrum is torn at the chondrolabral junction or rim trimming cannot be performed without damaging the labrum, we use an arthroscopic knife or beaver blade to take down the labrum at the acetabular rim. Once the rim has been trimmed, we proceed with arthroscopic labral reattachment. Frayed portions of the labrum that would not be stable after labral reattachment are debrided. The overall length of the tear determines the number of suture anchors used for refixation. We use titanium, single-loaded suture anchors and place anchors through an accessory portal to achieve a better angle on the rim. The safe angle for suture anchor insertion varies with the position on the acetabular rim, the amount of rim trimming, and the depth of drilling [65]. When drilling, we use both intraoperative fluoroscopy and direct visualization of the central compartment cartilage to assess the angle and ensure that the anchor is not penetrating the acetabular cartilage.

To restore the labral anatomy, just the edge of the labrum is included in the refixation on the acetabular rim, leaving the point of the labrum intact (Fig. 19.8b, c). The labrum can be sutured with either simple or vertical mattress sutures. The reattachment is then secured with either sliding locking knots or multiple half hitches on alternating posts, taking care to ensure that the knots remain on the capsular side of the labrum (Fig. 19.8b). Once labral refixation is completed, traction is released. Traction time should be limited to less than 2 h to prevent iatrogenic nerve palsy.

If the patient is undergoing surgical dislocation for treatment of FAI or a periacetabular osteotomy to address acetabular dysplasia, the labrum should be addressed as part of the open procedure (Figs. 19.9 and 19.10). Mini-open approaches via a direct anterior approach to the labrum are also an option for addressing labral pathology when the surgeon is not comfortable performing arthroscopic labral refixation [66]. Regardless of the approach, any necessary rim trimming should be performed. Frayed labral tissue or delaminated cartilage should be sharply debrided. Similar to the arthroscopic technique, titanium, single-loaded suture anchors are used for open labral refixation. The anchor is placed on the rim under direct visualization, taking care not to penetrate the acetabular cartilage. The edge of the labrum is taken in the stitch and the labrum is reattached back to the acetabular rim. Again, the number of anchors used is variable and depends on the extent of the tear or the amount of rim trimming performed. The function of the labrum is assessed by dislocating the femoral head from the acetabulum with the reattached labrum. If a vacuum seal has to be broken with the typical suction sound, the suture or reconstruction is considered sufficient.

Labral Reconstruction

The goal of labral reconstruction is to restore labral function in a hip with a hypoplastic or deficient labrum that cannot be reattached, e.g. a labrum that is completely ossified or had previously been debrided. This is based on current ideas about the biomechanical function of the labrum, the importance of the labrum in preventing further degenerative changes in the hip, and clinical studies demonstrating better mid-term function for patients who underwent labral refixation as compared to patients who underwent labral debridement. The basic science behind this technique is limited to the aforementioned biomechanical models of the labrum. There are no published animal models of labral reconstruction and it is unknown if the reconstructed labrum functions similar to the native labrum. As a result, there are many clinical questions that remain to be answered regarding this technique; these include the time course for healing, whether it differs between graft types, and if the graft needs to undergo a "labralization" process to function like a labrum.

Two different techniques have been published for labral reconstruction [67, 68]. Philippon and colleagues published a technique and early results of arthroscopic labral reconstruction using an autologous IT band graft in 2010 [67]. Sierra and colleagues published a technique of open labral reconstruction with ligamentum teres autograft in 2009 in five patients with brief follow up [68]. A PubMed search for labral reconstruction also found techniques for arthroscopic labral reconstruction with both autograft and allograft hamstring tendon [69–72].

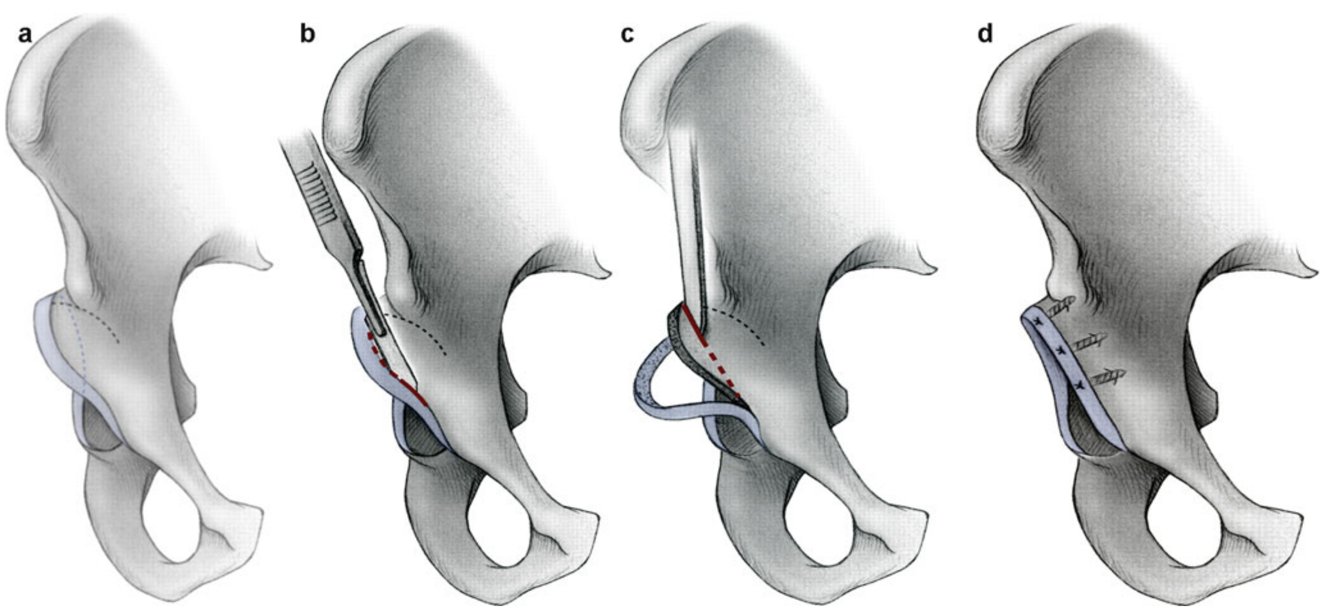


Fig. 19.9 Open acetabular rim trimming and labral repair. (**a**) Retroverted acetabulum. The *dashed line* indicates the bony rim. (**b**) Sharp takedown of the labrum from the acetabular rim. (**c**) Curved osteotome used to perform focal rim trimming. (**d**) Labrum repaired back to the acetabular rim (Reprinted with permission, Espinosa et al. [81])

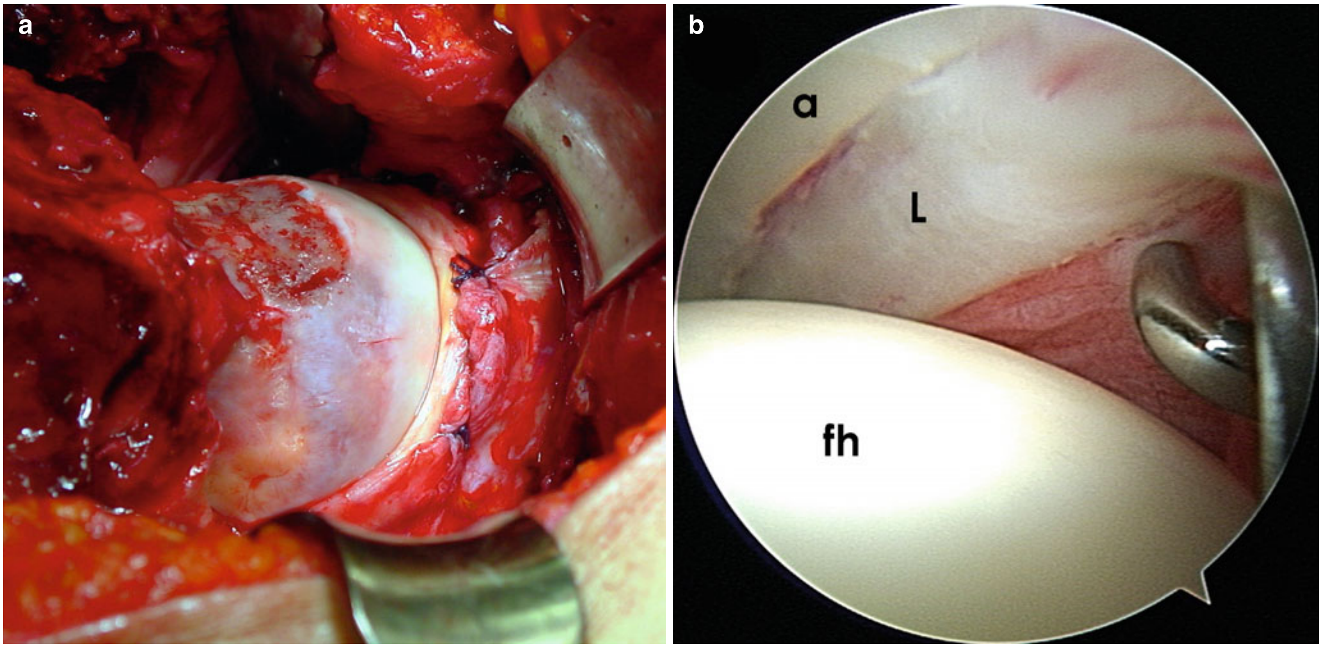


Fig. 19.10 (**a**) Labral repair after open acetabular rim trimming. (**b**) Arthroscopic image of a labrum that was repaired via a surgical dislocation. The labrum is well-healed and the labral seal has been re-created. *a* acetabulum, *L* labrum, *fh* femoral head

The senior author has reconstructed the labrum using the ligamentum teres in 14 patients as part of the treatment for FAI during surgical dislocation (Fig. 19.11). Indications for labral reconstruction using the ligamentum teres are symptomatic patients with a hypoplastic or deficient labrum that cannot be reattached. Contraindications to labral reconstruction are the same as those for FAI surgery and include Tönnis Grade 2 or greater arthritic changes on x-ray. The patient undergoes a surgical hip dislocation in the usual manner. As part of the approach to the hip, the ligamentum teres is divided to allow for full dislocation of the femoral head. The labrum and cartilage are examined and the bony FAI pathology should be addressed with acetabular rim trimming and femoral neck osteoplasty as appropriate. If the continuity and sealing function of the labrum are disrupted, labral reconstruction is performed to restore circumferential tension in the labrum and the labral seal. The remaining ligamentum is sharply debrided from the fovea and femoral head and kept in a saline soaked swab on the back table. The labral defect is assessed and scar tissue removed such that cancellous bone is visible at the acetabular rim (Fig. 19.11a). This restores the bony blood supply to the reconstructed labrum and enables labral healing. Once the size of the labral defect is known, fat and synovial tissue are carefully removed from the ligamentum and the graft is prepared to fit into the defect. Generally the ligamentum is much thicker than the native labral tissue; it should be trimmed as necessary so that the size and thickness are comparable to the remaining labrum. Suture anchors are placed along the acetabular rim and the ligamentum is sewn onto the rim, incorporating the ends of the graft into the original remaining labrum (Fig. 19.11b). Following labral reconstruction, the femoral head is gently reduced and the labral reconstruction is examined to ensure that the labral seal has been restored.

Rehabilitation and Postoperative Care

The postoperative protocols are similar for arthroscopic and open labral reattachments. For patients who have undergone surgical dislocation and open labral reattachment, the trochanteric osteotomy needs to be protected. Thus, patients are allowed 15 kg heel-toe weightbearing with crutches for 4 weeks. They may begin to advance their weightbearing at 4 weeks if the trochanter is not painful with weightbearing. For arthroscopic labral reattachment, patients may begin to advance their weightbearing after 2 weeks. On postoperative day 1; all patients start stationary biking with no resistance and CPM for 4–6 h daily with flexion as tolerated. Patients receive 3 days of non-steroidal anti-inflammatories postoperatively as part of our protocol for multi-modal pain control. This has the additional benefit of providing some heterotopic ossification prophylaxis. Patients receive crutch training in the hospital but formal physical therapy begins after 4–6 weeks, once weightbearing is advanced. Therapy can be advanced as tolerated, focusing on gentle range of motion, gait training, and strength initially, with progression to in-line jogging and sports as strength and proprioception return. Most patients are ready to begin jogging and returning to sports around 4½ months after surgery.

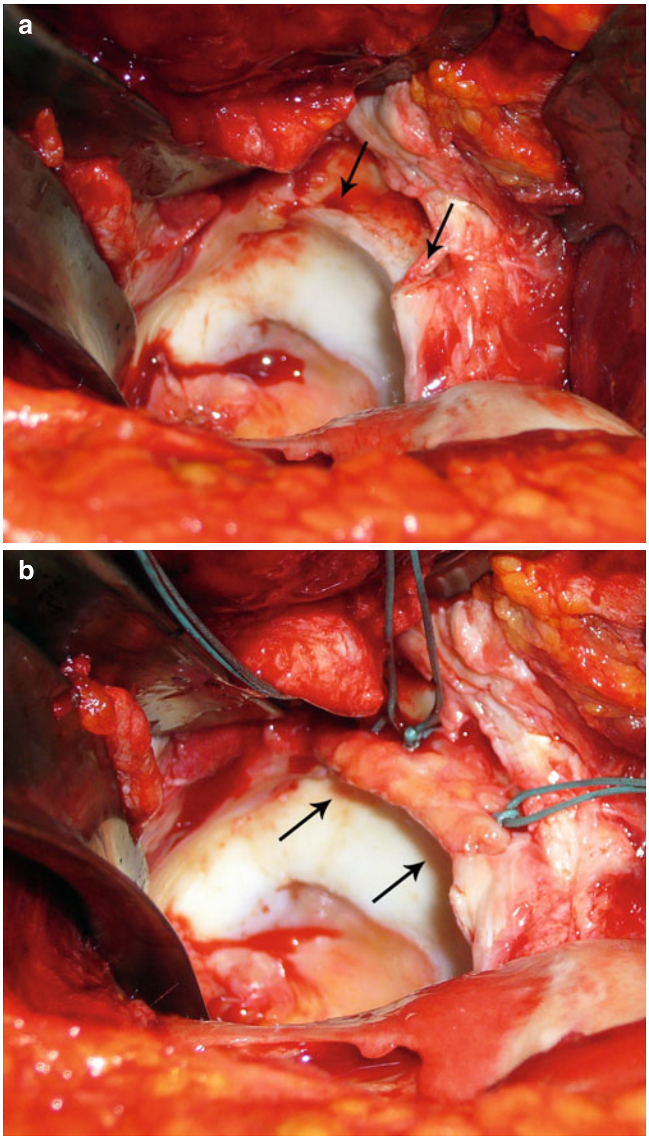


Fig. 19.11 Labral reconstruction. (a) The labral defect is visible between the *black arrows*. Cancellous bone is visible on the acetabular rim. (**b**) The labrum has been reconstructed with the ligamentum teres, held in place with suture anchors (*arrows*)

Results

The data on labral treatments continue to improve but is still limited. Level I or II prospective studies are particularly lacking [73]. Because FAI became more widely accepted only in the second half of the last decade, previously published results for labral debridement likely included patients with underlying FAI. Once the first results for open treatment of FAI were published [39, 74], addressing FAI was incorporated into the treatment of labral pathology [75]. Good results following both arthroscopic labral debridement and labral reattachment have been reported by several authors, with follow-up ranging from 1 to 10 years [59, 73, 75–77]. Arthroscopic and open treatment of FAI and labral pathology have also been compared. One systematic review suggests a lower complication rate for arthroscopy (0–5 %) compared to open management (0–20 %) and a lower conversion rate to total hip arthroplasty (0–9 % compared to 0–20 %) [78]. One caveat to this analysis is that the review included early experience with open FAI management. Since then indications for open management have become narrower and complication rates similar to those published for arthroscopy [79].

Labral debridement and labral reattachment have been compared directly for both arthroscopy and surgical hip dislocation. Clinically, the results are better for patients undergoing reattachment [75, 77, 80, 81]. A clear but mild progression of arthritis, from an average Tönnis grade of 0.6–1.2, was observed radiographically during the first year after dislocation and labral debridement [80]. This was not observed for patients who underwent labral reattachment.

The results of labral reconstruction have only recently been published. In the previously mentioned case series of patients undergoing labral reconstruction with the ligamentum teres, 4 out of 5 were happy with the result after short term follow up (5–20 months). One patient progressed to total hip arthroplasty but had extensive cartilage damage at the time of the labral reconstruction [68]. One-year follow-up was obtained for 41 out of 95 patients who underwent arthroscopic labral reconstruction with IT band autograft over a 3 year period. Of the 41, 4 (9 %) underwent conversion to total hip arthroplasty. These patients were significantly older than the patients who did not subsequently require hip arthroplasty, with average age of 49 as compared to 36 at the time of reconstruction. There was significant improvement in the mean Harris Hip Score, from 62 to 83, and the median patient satisfaction postoperatively was 8/10, ranging from 1 to 10 [67]. In the senior author's experience, 1-year post-operative Oxford Hip scores following labral reconstruction ranged from 30 to 47, out of a possible maximum of 48. Out of the six patients with 1-year follow up, patient satisfaction was generally high (80–100 out of 100), with all patients stating that the operation helped and that they would undergo the surgery again. One patient reported a satisfaction score of 40 and most patients had some residual pain at rest which increased with activity. Thus, although labral reconstruction as a complementary technique to FAI surgery does help to decrease symptomatic hip pain, mild residual symptoms after labral reconstruction surgery may persist.

Although the results are generally reported to be good or excellent after treatment of labral pathology, up to 35 % of patients may not be entirely satisfied. A high number of patients who have a poor result ultimately progress to total hip arthroplasty [73]. In the arthroscopic series, a 7–11 % failure rate has been reported [75, 82]. One study stratified patients by the presence or absence of cartilage lesions. After labral debridement, patients with coexisting cartilage lesions tend to have similar or worse pain. Comparatively, if the cartilage was intact, patients demonstrated improvement after treatment of the labrum [61]. For long-term follow up (10–20 years), survival is defined as progression to total hip arthroplasty. In these series, the biggest predictor of long-term survival was the presence or absence of cartilage damage at the time of the initial arthroscopy [59, 60]. In a pre-FAI cohort who underwent labral debridement, 10 % of patients who had no cartilage damage underwent hip arthroplasty on long-term follow-up (90 % survival). Conversely, for patients with Outerbridge grade III or IV cartilage damage at the time of arthroscopy, 80–90 % had undergone conversion to total hip arthroplasty [59, 60].

Aside from conversion to arthroplasty, the most common reasons for subsequent surgery after both open and arthroscopic surgery include inadequate decompression of FAI [83, 84], lysis of adhesions [82, 84, 85], unrecognized dysplasia [37, 38], failure of labral healing, and loosening of a suture anchor [75, 83]. In addition, after surgical hip dislocation, the greater trochanter screws often need to be removed [79, 86, 87].

The results vary for returning to sports following treatment of the labrum and results have been published for both arthroscopic and open management. In arthroscopic series of athletes undergoing arthroscopic treatment of FAI and labral tears, 73–96 % were able to return to sport at their previous level 1–2 years after surgery [45, 88–90]. Similar results have been reported after surgical hip dislocation for FAI and labral tears [86]. These results should be viewed with some caution as professional athletes in particular have a financial incentive to return to play, regardless of a suboptimal result [73, 86, 88]. Nonetheless, similar to other measures of survival, patients with diffuse cartilage damage at the time of arthroscopy did not return to play [90].

Complications

In general, complications after labral refixation or debridement are related to the specific approach used for surgery. Heterotopic ossification is a recognized complication after both hip arthroscopy [91] and surgical dislocation [79]. Postoperative prophylaxis for 1–2 weeks with non-steroidal anti-inflammatory medication may help to decrease the incidence of this [92]. Other complications occurring after surgical dislocation include mild residual pain over the greater trochanter [87], mild heterotopic ossification [79], non-union of the greater trochanter requiring revision (1.8 %) and post-operative deep vein thrombosis (2/334 patients) [79]. Complications after hip arthroscopy include traction-related transient nerve palsies of the pudendal nerve with associated erectile dysfunction [59, 61, 93–95], lateral femoral cutaneous nerve [59, 61, 93, 94], and sciatic nerve [96]. Other groin injuries including labial hematoma [93], vaginal tearing [96], and scrotal necrosis [95] have also been reported after traction for hip arthroscopy. These are best minimized by attention to the position and padding of the peroneal post preoperatively as well as limiting total traction time to less than 2 hours. Scope-related complications can include instrument breakage [94–96], cartilage damage—which is likely under-recognized and underreported [97, 98], and fluid extravasation into the thigh, abdominal compartment [99], or intrathoracic compartment [100].

Summary and Conclusions

Although the exact biomechanical function and properties of the labrum are still being defined, it is clear that the labrum is important for normal hip function. Labral degeneration and labral tears can be asymptomatic and apparently a part of the "normal" degenerative process. Nonetheless, labral tears are often a source of hip pain. Labral pathology is generally observed in conjunction with an underlying bony abnormality—either FAI or dysplasia—and particularly in gradual onset of hip pain or in association with minor trauma. Positive results have been reported for both open and arthroscopic treatment. This includes both labral debridement and labral refixation. Currently, appropriate treatment of labral pathology includes either open or arthroscopic management of any underlying FAI or dysplasia, and, when feasible, labral refixation. When the labrum is degenerative and unable to be reattached, it should be debrided back to a stable base. Once the labrum is addressed appropriately, good to excellent results can be expected, including the return to professional-level sports. However, patients with associated chondral damage at the time of surgery are more likely to have a poor result and progress to arthroplasty.

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20 Hip Resurfacing for Young Adult Hip Disease

Andrew J. Shimmin, Jon V. Baré, and Gareth Coulter

Introduction

Total hip joint replacement, when performed in young, active patients results in an increased rate of revision when compared to the same procedure being performed in older patients. Modern metal-on-metal hip resurfacing is a bone conserving arthroplasty that offers an alternative to total hip joint replacement in young, active patients with end-stage hip osteoarthritis. The selection of an appropriate prosthesis that provides good functionality and durability is especially critical for this patient demographic as they are most likely to outlive any contemporary implant. In addition, hip resurfacing has conceptual benefits in that it allows for easier component placement in those who have deformities of the proximal femur from prior surgeries or injuries relating to their underlying hip pathology [1, 2].

History

As osteoarthritis of the hip is predominantly a joint problem, the originators of hip arthroplasty first attempted a surgical solution with a resurfacing concept. At the time, in the 1970s, materials were such that metal on polyethylene was the chosen bearing. Of course at that time the vulnerability of thin polyethylene was poorly understood. The failure of those initial resurfacings was initially thought to be due to the failure of the concept but in retrospect, the thin polyethylene may well have been the most significant contributing factor. Modern hip resurfacings evolved in the mid-to-late 1990s with the ability to reproducibly manufacture hard-bearing resurfacing devices.

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Clinical Benefits

There have been many suggested benefits of the concept of hip resurfacing namely bone preservation, restoration of biomechanics, greater stability and ease of revision.

Indications

There are several common pathological conditions in the young hip that may lead to end stage osteoarthritis. Femoro-acetabular impingement and the dysplasia/instability spectrums, slipped capital femoral epiphysis and Legg-Calvé-Perthes disease are the most common causes of a degenerative hip in young adults [3–5]. These pathologies often create anatomical changes in both the proximal femur and the acetabulum that must be considered when undertaking hip resurfacing arthroplasty (HRA).

Femoro-Acetabular Impingement

End stage degenerative changes secondary to either undiagnosed or untreated femoro-acetabular impingement (FAI) are an increasingly recognized cause for young patients to present for hip arthroplasty. A retroverted native acetabulum that results in a prominent anterolateral acetabular edge that can impinge on the femoral neck in flexion and internal rotation must be addressed by correct acetabular component orientation [6]. Likewise, the decreased head neck offset seen in the cam type impingement will exacerbate this impingement if not addressed [4, 7].

Dysplasia

Hip degeneration secondary to mild dysplasia is also an indication for HRA. However, some of the pathologic changes associated with hip degeneration make HRA more complex in these patients. Initial stable fixation of the mono-block cup can be difficult and changes on the femoral side such as coxavalga and excessive femoral neck anteversion, make placement of femoral component more complex [4, 8].

Legg-Calvé-Perthes Disease

Patients who have Legg-Calvé-Perthes disease may have unique deformities that necessitate variations in the surgical approach. These patients often have overgrowth of bone around the femoral head (coxa magna) or flattening of the femoral head (coxaplana) and thus are at an increased risk for limb length shortening and femoral neck impingement after HRA [9–11]. Care must be taken to avoid notching of the femoral neck when preparing hips with deformed femoral heads. Trochanteric advancement has been described as a useful adjunct to resurfacing surgery in situations when a high riding is present as part of the pathological process [12].

Slipped Capital Femoral Epiphysis

Degenerative changes after slipped capital femoral epiphysis (SCFE) are due to the femoral head being positioned posteriorly on the femoral neck. This leads to cam impingement [13, 14]. The degree of slip needs to be appreciated before undertaking HRA. As the slip angle increases, the placement of the femoral head component becomes more difficult, with an increased risk of either notching the femoral neck or leaving a residual cam deformity.

Contraindications

Absolute

There are a few absolute contraindications to total hip resurfacing. Although wear rates seen with metal-on-metal bearings are extremely low, there have been reports of increased metal ion concentrations in these patients [15, 16]. Metal ions are excreted by the kidneys and renal dysfunction is an absolute contraindication to hip resurfacing [9].

There is good evidence that both cobalt and chromium cross the placenta and despite the effect of this being uncertain, current recommendations advise against the use of metal-on-metal bearings in women of childbearing age [17].

Although metal ion levels in the maternal blood remain within normal levels, the effect of elevated metal ion levels on the foetus is also unknown. Therefore, women of childbearing age should be informed of the theoretical risk and attempt to delay arthroplasty surgery as long as possible, preferably until they no longer want to have children. Women who have had a hip resurfacing should delay pregnancy for at least 2 years after the procedure [18].

Relative

Relative contraindications to hip resurfacing include inflammatory arthritis; severe acetabular dysplasia; poor proximal femoral bone geometry such as a short femoral neck with a high riding greater trochanter; poor femoral bone stock subsequent to large femoral head cysts; erosive arthritis; known metal sensitivities; and limb-length discrepancy greater than 2 cm [19, 20]. Patients requiring a small implant size should also be counselled about the decreased survivorship in smaller sized implants [21].

Surgical Technique

Surgical Approach

The posterior approach is most commonly used for modern hip resurfacing [18, 19]. Approaches have also been described using lateral, anterolateral, trochanteric flip osteotomy and direct anterior approaches [22–25]. The most important issues to consider when determining a surgical approach to the hip for HRA are sufficient surgical exposure to precisely prepare the acetabulum and the femur for accurate component positioning [26], and preservation of structures around the hip to minimize complications and optimally maintain function. Approaches that detach the abductor tendon are best avoided in the young due to the risk of chronic abductor dysfunction. The anterior approach offers the potential for optimal muscle preservation but also the poorest exposure of the acetabulum, therefore potentially compromising component positioning [27]. The trochanteric flip osteotomy preserves the medial circumflex femoral artery but requires screw fixation of the osteotomy [27]. The posterior approach to the hip involves division of the medial circumflex femoral artery, which has been shown to reduce femoral head blood flow intra-operatively [28], but there have been no clinical reports of poorer results from the posterior approach compared to approaches which preserve the medial circumflex femoral artery. As the posterior approach provides excellent exposure of the acetabulum and posterior femur and has been associated with excellent long-term clinical results [29, 30] it is the author's preferred approach.

Templating

Implant positioning in HRA has a greater impact on implant survivorship and patient function than it does in a conventional hip replacement, and is important in achieving a near normal anatomy of the proximal femur and hip joint. Accurate preoperative templating is an important step in ensuring that the correct component positioning and orientation is achieved. Suboptimal orientation and malpositioning of the components are associated with femoral neck fracture, increased metal ion debris production and FAI [21].

The approach to templating should first involve obtaining good quality radiographs of known magnification and with the femoral neck in neutral version. Templating can then be used to determine the size of components needed, the orientation of the components and the presence of any contraindications to resurfacing.

Contraindications that are seen on plain radiographs include: (1) femoral head cyst >1 cm [31]; (2) femoral head size ≤44 mm [21]; shortening >2 cm; and (3) any significantly abnormal hip joint morphology including excessive coxavara or valga, coxabreva and excessive acetabular anteversion or retroversion [32].

Associated Impingement Surgery

Persistent post-operative FAI is a source of reduced hip range of motion and groin pain. Correct component positioning is aimed at restoring normal hip biomechanics, optimising range of motion and avoiding impingement. This can be achieved by identifying pre-existing FAI and removing impinging anterior femoral neck osteophytes to restore normal femoral head sphericity, and facilitate component sizing, and accurate guide-wire placement [33].

Impinging anterior femoral neck osteophytes or "Ganz lesions", which are often the cause of early onset osteoarthritis, should be identified on preoperative radiographs and resection should be planned as part of the preoperative templating. The femoral neck impingement lesions which are typically present at the anterolateral femoral head-neck junction and the anterior acetabular wall can safely be removed without fear of femoral neck fracture. Resection of up to 30 % of the anterolateral femoral neck does not alter the load bearing capacity of the proximal femur. Conversely, Care should be taken to avoid any notching of the true femoral neck, as this is associated with avascular necrosis and femoral component loosening [34–37].

Retroversion of the acetabulum or femoral neck which can contribute to impingement should also be identified on preoperative radiographs. Some correction can be achieved by positioning both acetabular and femoral components in correct anteversion. The femoral head-neck offset can also be improved by careful anterior displacement of the femoral component, ensuring not to compromise bony fixation [38].

Component Positioning

The femoral component should be orientated with a valgus angle of between 135° and 145° which is approximately 5–10° of relative valgus ensuring that this position does not create notching of the superolateral cortex of the femoral neck. The acetabular component is positioned with an inclination of 35–40° and anteversion of 20°. These component positions aim to restore normal hip joint biomechanics and have evolved to minimize edge loading and the resultant problems of increased wear [39–42].

Poor acetabular exposure increases the risk of acetabular malpositioning. By retaining the femoral head and neck, acetabular exposure is more challenging. A complete capsulotomy is recommended to allow mobilization of the proximal femur. From the posterior approach, the femoral head is usually displaced anterior and superior to the acetabulum during acetabular preparation. However, this may increase the tendency to retrovert and abduct the acetabular component if exposure is inadequate. Exposure may require elevation of the gluteus minimus from the ileum in order to displace the femoral head away from the acetabulum; however, excessive muscle elevation and trauma should be avoided due to the risk of heterotopic ossification.

Femoral component positioning is based upon accurate placement of a guide pin in the femoral neck. Various techniques and instruments aid accurate position of the guide pin which can consistently reproduce the optimal preoperative templating position, and avoid notching and varus positioning. Computer navigation systems may be helpful with correct placement of the guide pin [18, 43].

Fixation Options

Hybrid fixation (press-fit acetabular and cemented femoral components) is most commonly used for HRA. A cementless acetabular cup is typically press fit into the under-reamed acetabulum. The acetabular cup has a surface modification of cobalt-chromium beads or plasma-sprayed titanium with or without hydroxyapatite coating for bone in-growth and fixation [44, 45]. The femoral component is traditionally cemented into place on the femoral neck.

While there is interest in cementless femoral fixation, the majority of femoral resurfacing components are cemented. The philosophy of cement fixation varies with regard to the presence of a mantle of cement and the depth of cement penetration into the femoral head [18]. Based on a series of 600 cases, Amstutz et al. [46], made the following recommendations regarding femoral cementing technique to reduce the incidence of aseptic loosening:

1. Thorough cleaning of the femoral head. This includes the removal of any cystic material with a high-speed burr and cleansing with lavage.
2. Maximization of the area for fixation. This includes the use of multiple small drill holes created with a one-eighth-of-an-inch drill bit, rather than fewer larger holes.
3. Drying of the femoral head before cementation. This includes the use of suction to keep the bone dry until the acrylic has set.

The Outcome of Resurfacing in the Young Adult Patient

Survivorship

The Australian Joint Arthroplasty Registry [47] reports on more than 13,000 resurfacings since its inception in 1999. Overall, the cumulative percentage of resurfacings revised at a follow-up of 9 years is 7.2 % compared to 5.2 % for total hip replacements (THR). However in the young male demographic with a primary diagnosis of osteoarthritis, the cumulative revision rate for resurfacing is 4.8 % compared with of 5.0 % for THR at 9 years. The results for young females are inferior to THR with a 9.3 % revision rate at 7 years for HRA compared to a 6.5 % revision rate at 9 years for a conventional THR . Overall, females have twice the risk of revision compared to males, and this discrepancy between the genders increases with age. This gender difference may be due to the fact that smaller components are used in females. It has been recognized that a head size smaller than 44 mm has a five times higher failure rate compared to sizes 55 mm and larger.

Both the Australian registry [47] and the National Joint Registry of England and Wales [48] have revealed significant differences in outcomes between different implants. These differences have also been noted in the literature [49] and have led to the recall of one implant from the market in 2010 due to higher failure rates than expected. Registry data also allow us to make some conclusions about the primary diagnosis and how it affects implant longevity. If the primary pathology is inflammatory arthritis, developmental dysplasia, or osteonecrosis rather than osteoarthritis, the cumulative revision rate is up to 2.4 times higher at 7 years [50].

Two publications with patients who had an average age of 52 years and a predominant diagnosis of osteoarthritis, and who were operated by independent surgeons as well as those involved in the design of the prosthesis, support these registry data. Treacy et al. [30], published a 10 year survivorship of 95.5 %, with aseptic loosening as an endpoint for the Birmingham Hip Resurfacing prosthesis (BHR; Smith and Nephew, Warwick, UK). In that series males had a 10 year survivorship of 98 %. Coulter et al. [29], also published a series of 230 patients with a mean follow-up of 10 years. In their study of the BHR, the overall survivorship was 94.5 %, with males in the cohort having a 97.5 % survivorship. These studies confirm the conclusion that young males are the ideal patient. Small component size was the main contributor to the poor results in females.

Range of Motion in Comparison with Total Hip Joint Replacement

Range of motion (ROM) is particularly important for younger patients who may return to a highly active lifestyle following joint replacement. In vitro studies consistently show that HRA results in reduced ROM when compared with conventional THR [51] owing to neck-on-cup impingement. Incavo el al. [52], attempted to eliminate all patient-related variables by using a combination cadaver/computer simulation. They found that, with controlled patient variables, THR was able to restore normal ROM more effectively than HRA. HRA showed minor deficits in extension and significant reductions in flexion and internal rotation at 90° compared with the natural hip. The investigators concluded that decreased ROM for the HRA group was attributed to a smaller head-neck ratio or head-neck offset at points of impingement.

These laboratory results have not translated to the clinical environment. In the average patient it may be that pericapsular soft tissue constraints rather than component impingement limit ROM. Vail et al. [53], found that after controlling for age, gender, and preoperative differences, resurfacing resulted in significantly higher ROM scores than did cementless THR after a mean follow-up of 3 years. However, Lavigne et al. [54], failed to find a difference in ROM between HRA and THR after 1-year of follow-up. Le Duff et al. [55], also found no difference in ROM between patients treated bilaterally, with HRA on one side and a conventional THR of the contralateral limb. They reported that the ROM for both implant types was consistent with the ROM seen in normal, un-diseased hips. Malviya et al. [56] recognised decreased cup anteversion correlates with decreased hip flexion in HRA.

Gait Analysis

Currently, gait analysis has failed to show a conclusive difference between THR and HRA. Mont et al. [57], compared walking speed, and abductor and extensor moments after a mean follow-up of 13 months, and found that patients treated with HRA were able to walk significantly faster than patients treated with THR and had gait parameters that were closer to normal. Queen et al. [58], found decreased extension and ground reaction force following THR compared to HRA. Both HRA and THR demonstrated abnormal kinematics compared to the non-operated side. Shrader et al. [59], reported similar findings between THA, HRA, and normal controls in a pilot study evaluating walking speed and stair negotiation. Patients treated with HRA had more normal patterns of movement with greater improvement in hip abduction and extension moments than patients treated with THA. Stair negotiation was also improved in the HRA group. However, Lavigne et al. [54], reported equivalent gait speed at both normal walking speed and fast walking speed and similar postural balance. Patients in both treatment groups reached most control group values after 3 months.

Activity Scores

In the young patient, return to their previous active lifestyle is equally important a goal as pain relief. In the literature, HRA has been superior to THR in achieving higher postoperative activity scores [53, 60, 61]. Vail et al. [53], found significantly higher postoperative UCLA activity scores for patients following HRA compared to THR. Although the outcomes were controlled for age, gender, and preoperative clinical scores, there was variation in the demographic profile and preoperative hip score. However, studies with matched demographic profiles found similar results. Mont et al. [60], found significantly higher postoperative activity levels following HRA that after THR in patients who were matched according to demographics and preoperative Harris hip score, but not according to preoperative activity level. When the study was repeated with matching for preoperative activity levels as well as other demographic and functional scores, they found that the post-operative scores were still significantly greater following HRA when compared to THR. Both groups had similar functional outcome scores [61].

Return to Sport

It has been reported that 97 % of patients who undergo hip or knee arthroplasty played sport at some point, and only 52 % return to sport after their arthroplasty [62]. Naal et al. [63], were one of the first to look at return to sport after HRA. Fifty per cent of their patients returned to sport within 3 months and 90 % within 6 months. Overall, 98 % of their patients returned to some sport. Although they found no significant difference in the numbers of sports participated in before and after surgery, there was a significant decrease in the numbers of high impact sports such as jogging, tennis and soccer after surgery, with a slight but non-significant increase in low impact sports such as exercise walking or weight training. Reasons given for this change in activity were anxiety and protection. These results were supported by Banerjee et al. [64], who also found a significant decrease in high impact sports with a corresponding increase in low impact sports after surgery. Thirty-three per cent of their patients had to give up the high impact sports that they enjoyed prior to surgery. Again, they found that 98 % of their patients had returned to sport within 6 months, with the time to return to sports being shorter for low impact activities. Both studies were subject to bias in that they were retrospective.

The Complications of Resurfacing in the Young Adult Patient

The current generation of metal on metal HRA has now been implanted for over 14 years [65, 66]. The 10-year survival data are currently being reported and these data have helped to identify a number of complications that are associated with HRA [29, 30].

Femoral Neck Fracture

The incidence of femoral neck fracture ranges from 0 % [67, 68] to 9.2 % [69] in reported series of modern HRA. The largest series of 3429 hip resurfacings from the Australian national joint registry [70] reported a femoral neck fracture rate of 1.46 %. The mean time to fracture was 15.4 weeks (range 0–56 weeks). Important patient, surgical and postoperative factors were identified. Women were twice as likely to fracture as men (1.91 % for women and 0.98 % for men) and this was postulated to be due to the decrease in bone density in post-menopausal women. Surgical factors for fracture include superior femoral neck notching and varus placement of the femoral component relative to the anatomical femoral neck shaft angle. All patients in this series were instructed to mobilise fully weight bearing post-operatively.

Reports have shown that by excluding patients with osteopenia, obesity and those with femoral head cysts >1 cm, the fracture rate drops from 7.2 to 0.8 % and the overall complication rate falls from 13.4 to 2.1 % [71, 72].

Adverse Reaction to Wear Products

Currently, the material properties of acetabular shells limits their manufacture to a thickness of between 3 and 5 mm, and therefore hip resurfacing articulating surfaces are limited to metal-on-metal. Earlier generations of resurfacing implants used metal-on-polyethylene bearings that resulted in high wear rates and early failure [73]. Although metal-on-metal bearings have now been used for over 40 years and demonstrate low levels of volumetric wear provided the femoral and acetabular implants are well manufactured and well positioned [74–76], there is currently considerable contention surrounding the use of metal-on-metal bearings in hip arthroplasty in general.

Serum cobalt and chromium levels are elevated in patients with metal-on-metal hip resurfacing arthroplasties (53 and 38 nmol/L respectively, compared to <5 nmol/L of each metal ion in the normal population) [77]; however, the long term effects of these elevated serum metal ions are not known. Although lymphocyte aneuploidy and chromosomal translocation are noted to be more prevalent in patients with metal-on-metal bearings [78, 79], meta-analysis data have not demonstrated an increased cancer risk in these patients [80].

More contentious than the systemic effects of metal ions, is the adverse local tissue reaction (ALTR). These local tissue reactions can be broadly categorized as either metal reactivity (macrophage response to excessive metal particles) or metal sensitivity (lymphocyte-dominated reaction) [81].

Pain is the most common presentation of ALTR, but patients may also present with a large effusion, a cystic/solid mass (pseudo-tumour) [82, 83] or with progressive osteolysis resulting in prosthetic loosening. Recently Amstutz et al. [84] proposed the following classification scheme for ALTR:

1. ALTR I: Osteolysis caused by wear but without soft tissue local fluid or solid mass.
2. ALTR II: Local fluid or solid mass secondary to high wear.
3. ALTR III: Allergy or hypersensitivity without high wear.

Preventing or minimising the risk of ALTR is achieved by minimising wear rates. Factors associated with elevated wear rates and high metal ion concentrations include: (1) femoral component diameter; (2) excessive acetabular cup anteversion and inclination [85]; (3) clearance between femoral and acetabular components; and (4) metallurgy [86–89].

Acetabular cup abduction angles of >55° are associated with edge wear and higher wear rates [42, 90]. The cup arc of cover is not only dependent upon the cup position but also the component size and design [91]. Design and positioning of implants is aimed at optimising fluid film lubrication to minimise wear. Increasing the femoral component size [85] and optimising the clearance between the femoral and acetabular component [76] can encourage harnessing of this lubricating film. Rim contact, edge loading, and femoral head subluxation reduce fluid film lubrication and subsequently dramatically increase wear [86–89]. Some design features exaggerate these predisposing influences. The Articular Surface Replacement prosthesis (ASR; DePuy International, Leeds, UK) has a smaller arc of coverage and smaller clearance relative to other devices [21]. Langton et al. [92], compared the ASR to the BHR and the Conserve Plus (Wright Medical Technology, Memphis, TN, USA) and found that, when matched for size and orientation, component contact always occurs closer to the rim of an ASR cup than in the other designs. For example, within the Conserve Plus size range, the coverage angle varies between 159° and 164° (smallest to largest) compared to a coverage of 144–157° for the ASR, which partly explains the increased wear rate and higher failure rate of the ASR [93].

Another design feature that affects wear is clearance. Small clearance and a low surface roughness allow better fluid film lubrication and results in a more evenly distributed contact pressure [74, 85]. However, if the clearance is too small, there is a risk of equatorial contact that may result in a "brake drum" effect leading to high wear. In vitro studies have shown that a reduced wall thickness and under-reaming of the acetabulum lead to cup deflection, which can predispose to equatorial contact [44]. Other factors such as bone quality and stiffness, as well as surgeon dependent variables may also influence cup deformation, but the tolerances are reduced with reduced clearances, and clearances may be further reduced with smaller component sizes. Although the ideal clearance is not known, the higher failure rate of the ASR is likely to have been in part due to its smaller clearance.

Component Loosening

The incidence of femoral component loosening is low with long-term loosening rates less than 2 % [65, 94–96]. Higher femoral loosening rates have been reported with resurfacing in the setting of avascular necrosis, but long-term femoral component failure from aseptic loosing is still less than 3 % [97, 98]. In the absence of osteolysis, aseptic loosening of the femoral component is most likely related to insufficient or improper initial fixation or to fatigue failure of the underlying cement-bone interface. Correct cementing technique plays an important role in minimising the risk of femoral loosening and has been previously discussed in this chapter. It is also recommended to avoid resurfacing if more than 30 % of the femoral head is involved with avascular necrosis and if femoral head cysts are >1 cm [71]. In these settings, the structural support of the femoral head may be compromised or large volumes of cement may generate thermal osteonecrosis adversely affecting the bone-cement interface.

Reports of acetabular component aseptic loosening are low, with large, long follow-up series consistently reporting rates of less than 1 % [29, 94, 99]. As with the femoral component, failures have been attributed to both prosthetic design and surgical technique. The key to achieving long-term fixation is to achieve stable initial fixation. Achieving initial fixation varies with different designs that have a variable amount of hemispherical coverage (165–180°), roughness of coatings (porous beads of various sizes, plasma spray titanium) and supplementary fixation (peripheral fins, peripheral expansion, peripheral screws (e.g. Birmingham dysplasia cup)). It also varies with the quality of the underlying bone, as reported with a higher acetabular failure rate in developmental dysplasia of the hip [100].

Dislocation and Impingement

FAI is a leading cause of early onset osteoarthritis especially in the male osteoarthritic population. As HRA is most frequently indicated for this group, any underlying FAI needs to be recognized and treated pre and intra-operatively to avoid on-going impingement post-operatively. Beaulé et al. [33] reported that 57 % of hips, in a group of 63 hips treated with HRA, had an abnormal head-neck offset preoperatively. Although, HRA offers a theoretical advantage over THR of improved stability and increased ROM due to the larger head size, it becomes disadvantageous from these view-points if impingement remains post-operatively. It is more important to optimize the head-neck ratio than to increase the diameter of the head. Post THR impingement has long been recognized as a cause of restricted ROM and instability [101, 102]. This problem is potentially greater in HRA due to the retention of the original femoral neck.

Persistent post HRA impingement can be treated with arthroscopic surgery to remove the offending bone.

Other Complications

Other complications may occur with HRA as they do with THR. Heterotopic ossification, femoral and sciatic neuropathies and mechanical noises are worthy of mention.

Heterotopic ossification has been reported at rates of over 50 % [103], the vast majority being Brooker grades I and II [104]. The incidence of Brooker grades III and IV have been reported to be significantly higher in resurfacing compared to THR [105], which may be explained by the extra muscle trauma and bone debris generated during a resurfacing procedure. An appropriate sized skin incision and careful acetabular exposure can help to minimize muscle trauma. Elevation of the gluteus minimus from the ilium need only be performed if there is difficulty displacing the femoral head away from the acetabulum. Postoperatively, consideration can be given to up to 6 weeks of oral Indomethacin [9].

Femoral and sciatic nerve palsies have been reported following HRA. It is not possible to give an accurate comparison of the incidence of these nerve injuries compared to THR surgery. Postulation of a higher incidence is plausible due to the additional manipulation and traction required to expose the acetabulum with a retained femoral head and neck and also to expose the femoral head during preparation. Nerve injury risk can be minimized by performing an adequate soft tissue exposure. The sciatic nerve should be monitored during surgery to ensure that it is not placed under tension. Consideration can be given to releasing the femoral insertion of gluteus maximus to the linea aspera, as this may be a point of sciatic nerve tethering.

Mechanical noises following HRA are not uncommon. These usually occur within the first six postoperative weeks. They are due to the hard-on-hard bearing surface and settle when normal muscle tension has been restored. In a cohort of 230 patients at 10 years, Coulter et al. [29], reported occasional painless audible clicking in two hips and a clicking sensation without audible noise in 13 hips. None of the hips had on-going squeaking. These types of reported painless clicking can generally be regarded as benign. Persistent or reproducible squeaking, clunking or pain associated with the mechanical noises should be regarded as more sinister. These may represent subluxation and edge loading. Careful monitoring for the sequelae of metal wear debris should then be undertaken.

Monitoring

As hip resurfacing arthroplasty is done in younger and hence potentially more active individuals, it is increasingly important to monitor them more closely than older, less active individuals. The optimum method of monitoring is in evolution. It is the author's observation that patients who have qualified for consideration of hip resurfacing will be more active once their painful arthritis has been resolved. It is therefore vital that they are reviewed more regularly. It is the authors' practice to review hip resurfacing patients with clinical scoring systems and plain radiology every year. Due to the reported occurrence of soft tissue lesions surrounding some of these implants, if there is anything abnormal on plain films or if the patient has any symptoms whatsoever, an ultrasound is advisable. The measurement of serum metal ions is also something that can be considered, but at this stage is not considered to be a method of review in isolation.

Conclusion

Hip resurfacing provides a useful addition to the available treatment possibilities for degenerative hip conditions in younger, more active patients due to its preservation of bone stock, and reported clinical success. Concerns regarding metal-on-metal wear debris and greater complication rates in certain patient subgroups can be mitigated by careful implant positioning and attention to the suitability of patient selection. Furthermore biomechanical studies demonstrating a reduced range of motion compared with THR appear not to be evident postoperatively.

Acetabular components currently in use can only be made from metal. Whether or not the indications for resurfacing can be expanded in the future will depend on the application of ceramic or other composite materials into the design concept. Some of the known design deficiencies in the current resurfacing devices would also need to be addressed.

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21 Osteotomy of the Femur for Young Adult Hip Disease

Christopher Rees Gooding and Aresh Hashemi-Nejad

Introduction

A proximal femoral osteotomy can be an extremely useful technique for the surgeon with an interest in hip preserving surgery. The aim of such a procedure is to reduce pain and either prevent if not delay, the degeneration of the hip joint.

The intertrochanteric femoral osteotomy was first described as a treatment of non-union of a fracture of the femoral neck. However, the indications have been somewhat expanded to include femoral neck malunion, femoral head osteonecrosis, Legg-Calvé Perthes disease, leg length discrepancy as well as a slipped capital femoral epiphysis. In the treatment of developmental dysplasia of the hip, isolated femoral osteotomies have largely been replaced with a peri-acetabular osteotomy with or without a femoral osteotomy. Furthermore, for an isolated femoral osteotomy to be considered, the major deformity should be on the femoral side of the hip joint. If there is a deformity on both sides of the joint, an isolated femoral osteotomy is likely to fail and should only be considered in exceptional circumstances [1]. Santore et al. [2] clarified the indications and contraindications for a valgus or varus proximal femoral intertrochanteric osteotomy (ITO). They considered that an ideal candidate should have a clearly correctable biomechanical abnormality with mild arthritis and a good range of motion. Patients should demonstrate at least equivalent if not improved congruency of the hip joint on radiographic or fluoroscopic examination in adduction (for valgus osteotomy) or abduction (for varus osteotomy) combined with flexion (if an extension component needed) or rotation if needed.

Trousdale et al. [1] concluded from their study that the risks of stiffness, pain or other modes of clinical failure increase particularly with the severity of pre-operative degenerative changes. Other pre-operative factors that may result in early failure include a high body mass index (BMI). Patients with a BMI of more than 30 should be encouraged to lose weight pre-operatively [2]. Hip flexion of less than 60° pre-operatively, an incongruent joint, neuropathic arthropathy, severe osteopaenia, inflammatory arthritis and active infection are all factors which are likely to lead to early failure of an ITO and should be considered as absolute contra-indications and alternative options should be sought. Relative contra-indications include patients who undergo heavy labour and those over the age of 60 years [2].

Pre-operative Planning

When it comes to pre-operative planning, an anteroposterior (AP) pelvis radiograph should be taken with the hips in internal rotation so that the normal neck shaft angle can be visualised. If there are other mechanical problems in the alignment of the limb then a full-length radiograph from the hips to the ankles with the patient standing should be obtained. Additional radiographs can be obtained with the limb in various positions to assess the position of the best joint congruity. This can also be done with an arthrogram under fluoroscopy. Femoral neck anteversion is often best assessed clinically with the patient prone on the examination couch and assessing the rotation of the hip in extension. If there is any doubt as to the amount of anteversion present a computed-tomography (CT) scan of the hip along with one slice through the femoral epicondyles can be helpful.

Muller described the technique of planning the osteotomy using tracing paper [3] to calculate the degree of correction and where the wedge should be taken. As this technique has been well described elsewhere, it will not be repeated here.

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Varus Intertrochanteric Osteotomy

An isolated varus ITO may be considered in patients with either a discrete area of osteonecrosis of the femoral head, an ipsilaterally long limb associated with mild dysplasia and coxa valga [4] and some cases of early osteoarthritis [2, 5]. Patients must have a minimum of 15° of passive abduction pre-operatively, if not and a varus osteotomy is performed regardless, the patient will be left with a fixed adduction deformity and will require early revision to correct it. The neck shaft angle should not fall below 115° otherwise the patient as at risk of developing an Trendelenberg gait.

Surgical Technique

It is our practice to use a radiolucent operating table rather than a fracture table with the patient positioned supine so that an AP radiograph of the hip can be obtained with the image intensifier. A lateral view can be obtained with the hip in the ‘frog-lateral’ position.

The surface markings of the greater trochanter and shaft of the femur should be identified and a lateral incision made from the tip of the greater trochanter and extended distally to allow placement of the fixation device. We tend to use a blade plate (Synthes Holding AG, Solothurn, Switzerland) as our fixation device but there are other methods of fixation including locking plates which are gaining in popularity.

Once the incision has been deepened through the subcutaneous fat and fascia lata the femoral shaft is exposed via a sub-vastus approach. Once the shaft is exposed a Kirschner wire is placed over the top of the femoral neck until it abuts the femoral head. This identifies the amount of femoral anteversion which will allow for the correct placement of the blade plate. The angle that the blade plate is inserted into the femoral head relative to the shaft is dictated by the amount of angular correction that is to be achieved. If a 20° varus correction is desired then the blade should enter the femoral neck at a 70° angle to the femoral shaft. A second Kirschner wire can then be drilled into the most cephalad part of the femoral head at 70° to the femoral shaft. The amount of anteversion of this wire is guided by the first wire that was placed over the top of the femoral neck. This wire then acts as a guide for the direction of the blade plate cutting chisel. The image intensifier should be used throughout the procedure confirming the correct position of the cutting chisel.

Before proceeding with the osteotomy it can be helpful to score the femoral shaft longitudinally with an oscillating saw to serve as a marker to indicate whether any rotation has occurred. The osteotomy is then performed by making the first cut perpendicular to the femoral shaft cephalad or at the level of the lesser trochanter. Once this cut has been completed to the far cortex a second osteotomy is made halfway across the bone at the distal end of the proximal fragment, to achieve a 20° wedge medially. The distance between the osteotomy and the cutting chisel should be more than 2 cm, otherwise there is a risk of fracture. Once this has been achieved the seating chisel can be removed and the blade plate inserted. This should be done under fluoroscopic control so as to avoid starting a false passage. Once the plate is properly seated and having taken into account the degree of medialisation that is to be achieved, the remaining cortical screws are used to secure the plate to the femoral shaft.

Some have argued that a medial displacement of the femoral shaft is an essential part of this osteotomy to ensure clinical success and avoid early failure [6–8]. They have suggested that a varus osteotomy results in genu varum which can be addressed by displacing the femoral shaft medially restoring normal alignment to the leg. However, Santore et al. [2] concluded from their experience that good results were not necessarily dependent on medial displacement and that problems with union of the osteotomy and difficulties with placement of a femoral stem during a future hip replacement were related to the degree of displacement. In our experience, as long as the piriformis fossa is directly in line within the femoral canal then there should be no difficulties in performing a future hip replacement. Clearly excessive medial displacement resulting in the longitudinal access of the femoral canal being medial to the piriformis fossa will result in considerable difficulties when it comes to performing a hip replacement.

If a varus osteotomy of more than 25° is performed in a normal hip, it may be necessary to perform a trochanteric transfer to maintain normal abductor muscle function. The need for a trochanteric transfer becomes even more important if the hip already has a reduced offset as seen in patients with Perthes disease where there has been a proximal physeal growth arrest. Other potential pitfalls with this technique include the risk of delayed or non-union with an opening wedge as opposed to a closing wedge osteotomy. However, the advantage of an opening wedge is that it can preserve leg length as opposed to a closing wedge which results in substantial shortening of the limb particularly if a full wedge is resected. Patients may also be prone to early clinical failure from a persistent trochanteric bursitis due to the prominence of the greater trochanter and may require additional surgery should non-operative measures fail.

Post-operative Instructions

Patients are allowed to partially weight-bear on crutches and full weight-bearing is permitted once there is radiographic evidence of bony union. The majority of patients do get some irritation to the fascia lata from the blade plate and so it is our practice to remove the blade plate at 1 year, as long as there is radiographic evidence that the osteotomy has united.

Results of Proximal Femoral Varus Osteotomy

The results following a proximal femoral varus osteotomy in the treatment of avascular necrosis of the femoral head have been encouraging in certain patients. Saito et al. [9] reported excellent results in 4 patients who had Ficat stage III disease. The mean age of these patients was 33 years and each patient had a minimum follow up of 2 years with a mean follow up of 4 years. In all cases there was no radiographic evidence of post-operative collapse of the femoral head and there were no degenerative changes at final follow up. In addition there were no significant complications. Other authors have advocated the technique for hip dysplasia in appropriately selected patients [4].

Koulouvaris et al. [10] reviewed 52 patients with hip dysplasia who underwent an isolated proximal femoral varus intertrochanteric osteotomy. The mean follow up was 10.98 years and the mean varus correction was 15.87° (10–25°). There was 98 % survival at 8 years and 93 % at 9 years using the Kaplan Meier Survivorship curve. No variables were proven to be a significant predictor of failure. The authors did acknowledge that the very favourable results that they reported for this technique was undoubtedly due to the very strict selection criteria. These criteria included patients with mild hip dysplasia (Grade I), spherical femoral head, good joint congruency in the abducted position, major deformity on the femoral side and patients less than 60 years of age. In addition the majority of the patients (51 out of the 52 patients) had minimal degenerative changes with only mild joint space narrowing and minimal osteophyte formation. There were no mal/non-unions. The authors did note that 36 patients (67 %) did complain of a delayed limp on walking and some weakness on prolonged walking in the first year post surgery. Interestingly, no patients complained of leg length discrepancy and the authors put this down to the fact that they did not perform a wedge resection when performing the varus osteotomy.

Schneider et al. [11] reviewed 48 hips with avascular necrosis which had been treated with a flexion/varus proximal femoral osteotomy, 5 hips treated with a combined flexion/valgus osteotomy and 10 hips with a flexion osteotomy. The mean follow up was 8.1 years for all 63 patients. At 5 years 17 hips out of the original 63 hips had been revised to a THA and at 10 years that figure increased to 27. The complication rate was 17.5 % for this group. The complications included six hips in which the fixation had been lost, one pseudoarthrosis, one subtrochanteric fracture, one deep infection and two deep vein thrombosis. The authors also identified that patients in this group with a necrotic sector of less than 180° achieved the best survival probability.

Valgus Intertrochanteric Osteotomy

The commonest indication for a valgus intertrochanteric osteotomy is a non-union of a femoral neck fracture. This technique is able to convert the shear stresses into compressive forces, increasing the likelihood of union and has the advantage of preserving the native hip. Other indications include correction of a proximal femoral deformity, early osteoarthritis, sequelae of Legg-Calvé Perthes and slipped upper femoral epiphysis in adults and an ipsilateral short limb. Similar to a varus osteotomy, patients should have a flexion arc of ≥60° and also should have ≥15° of passive adduction to avoid a fixed abduction deformity post-operatively with resultant early clinical failure.

Surgical Technique

As highlighted by Santore et al. [2] it is important to appreciate the implications of placing the femoral head and neck in extreme valgus of more than 150° as this will shorten the trochanteric lever arm. This will result in the abductors having to work harder particularly during the single stance phase of walking and could result in a delayed Trendelenberg test due to abductor fatigue. In addition if an excessive valgus correction is made there is a risk of premature joint failure and degeneration due to the increased pressures on the femoral head. One of the advantages of the valgus osteotomy is that it lengthens the limb. This is particularly helpful in non-unions where there is often a varus deformity of the femoral head and neck associated with some bony resorption resulting in considerable shortening of the limb.

A closing wedge, valgus osteotomy is one of the easier techniques to perform. This involves the removal of a wedge of bone, the angle of which is equal to the planned correction. It is our practice to use a blade plate with a blade of a minimum length of 65 mm. With this technique the most commonly used is the 130° angled plate. The distal cut of the osteotomy is angled and the proximal cut is horizontal. This will result in some inter-fragmentary compression.

Pauwels was one of the first to establish the valgus osteotomy as a treatment for femoral neck fracture non-union [12, 13]. His technique was subsequently modified by Muller [14–16] which forms the basis of the technique employed in today's hip preserving practice.

Pauwels Y-shaped osteotomy is useful particularly if the patient is significantly short as well as in varus as some additional length can be achieved by performing a lateralisation of the shaft. This can be achieved by siting the seating chisel of the blade plate at 80° to the femoral shaft and then making the proximal cut of the osteotomy parallel to the chisel. The distal cut is made at 30° to the femur but does not reach the far cortex but instead exits approximately halfway across the shaft to create a wedge of bone. Then a 130° blade plate is inserted but is not seated all the way into the femoral head, we tend to leave it approximately a centimetre proud. The shaft is then reduced onto the plate and held with at least four cortical, fully threaded screws. This should result in the lateral edge of the proximal fragment being apposed to the medullary surface of the distal fragment and lateralising the femoral shaft.

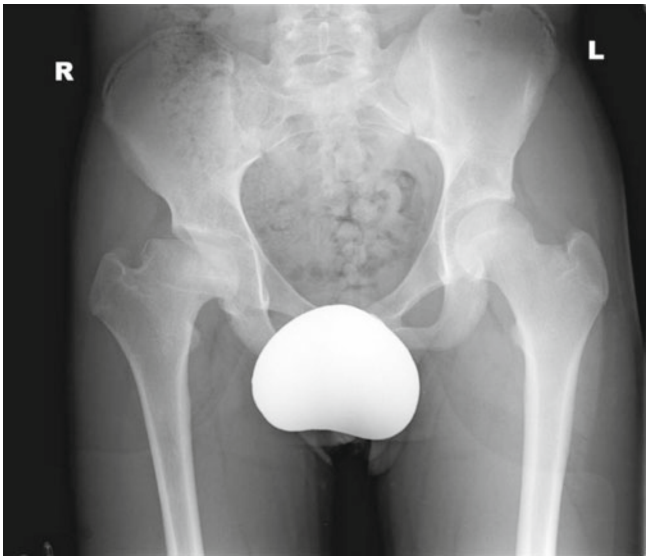

Fig. 21.1 AP pelvic radiograph showing Perthes of the Right hip

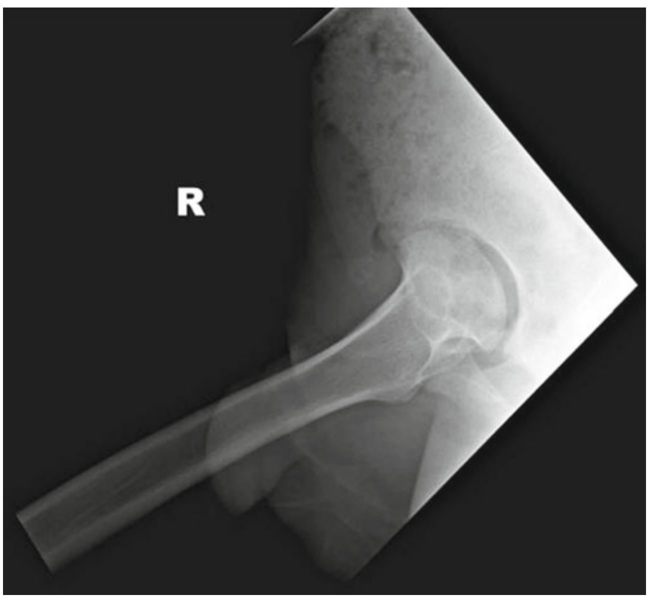

Fig. 21.2 Lateral radiograph showing Perthes of the Right hip

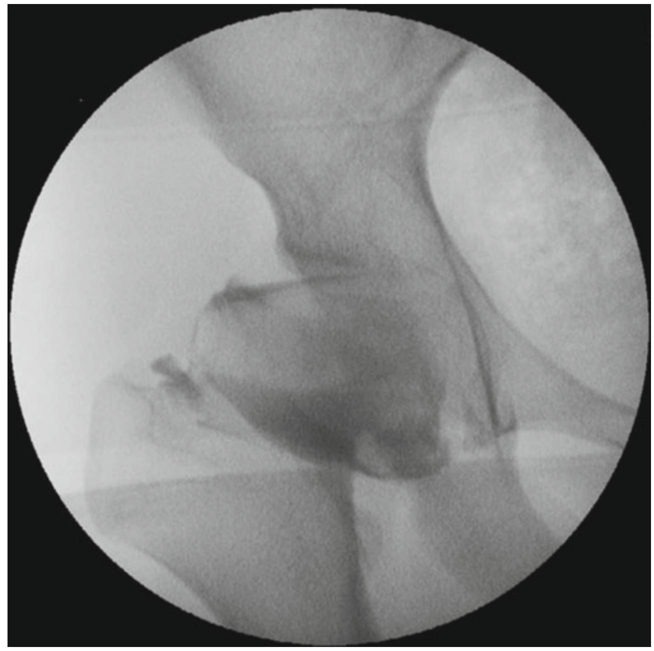

Fig. 21.3 AP fluoroscopic image of the Right hip following injection of contrast with the hip in 20° of adduction

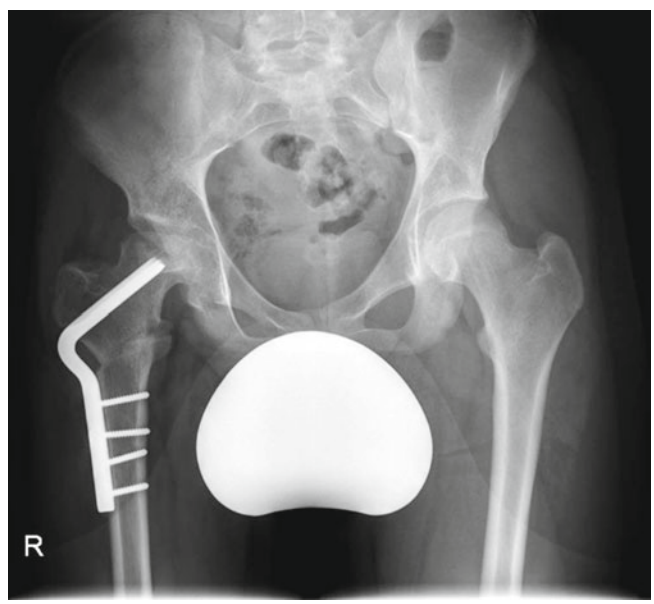

Fig. 21.4 AP pelvic radiograph post proximal femoral valgus osteotomy and femoral head neck debridement

Figures 21.1, 21.2, 21.3, 21.4 and 21.5 illustrate a patient with Legg-Calve Perthes disease of the right hip treated with a proximal femoral valgus osteotomy and a femoral head neck debridement. A pre-operative radiograph of a Perthes hip is illustrated in Figs. 21.1 and 21.2. As part of the pre-operative planning an arthrogram (Fig. 21.3) has been performed which confirms that in 20° of adduction the femoral head and acetabulum are congruent and the labrum which has been outlined by the contrast is downward sloping. These are essential criteria for a valgus osteotomy to be performed. In Figs. 21.4 and 21.5 the post-operative radiographs have been shown. This confirms that the limb has been lengthened and the hip is congruent. Also the mechanics of the hip have improved by increasing the trochanteric lever arm so that the hip abductors are able to work more efficiently and are less likely to fatigue and result in a delayed Trendelenberg gait. However it is essential not to perform an excessive valgus osteotomy (>150°) as pointed out earlier as this will reduce the lever arm and result in an unsatisfactory result for the patient.

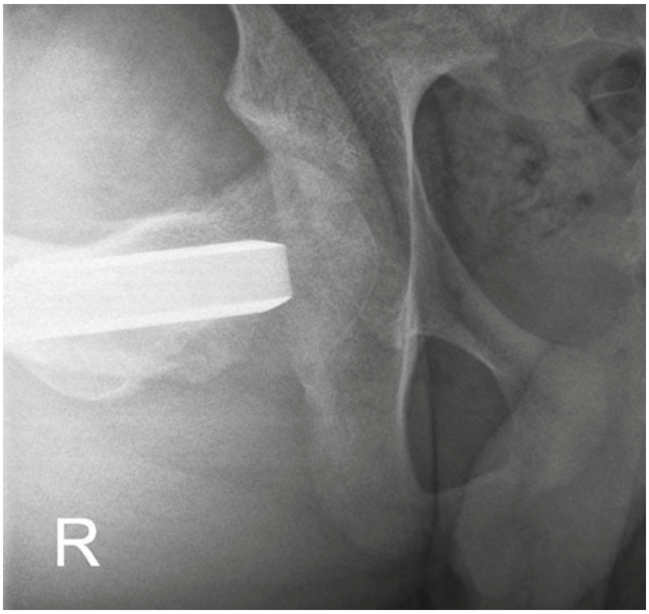

Fig. 21.5 Lateral radiograph post proximal femoral valgus osteotomy and femoral head neck debridement

Results of Proximal Femoral Valgus Osteotomy

Maistrelli et al. [17] reviewed 277 intertrochanteric valgus-extension osteotomies for osteoarthritis in patients with a mean age of 51 years and a mean follow up of 11.9 years. They concluded that patients had a significantly better result if aged 40 years or less compared to those of more than 55 years of age, who the authors recommended had a total hip replacement and not an osteotomy. Also patients with a pre-operative flexion of more than 60° had a better outcome and were less likely to be dissatisfied as a decrease in hip mobility was one of the major factors responsible for clinical failure. Poor results and early failure were observed in patients with subluxed or dislocated hips with a shallow acetabulum. Poor results and early failure was also associated with severe degenerative changes and bilateral involvement. Patients with medial degenerative changes also did poorly and were more likely to fail early which was attributed to the poor pre-operative flexion range which was reduced further following the osteotomy. The authors concluded that a biplane correction of at least 20° was essential in order for the technique to be effective and avoid early failures. They added that a valgus-extension osteotomy alone is unlikely to be adequate in the management of severe acetabular dysplasia and should be combined with a pelvic osteotomy.

There have also been encouraging reports in the treatment of slipped upper femoral epiphysis with a proximal femoral osteotomy. Imhauser et al. [18, 19] reported on 68 hips in 55 patients with a follow up of 11–22 years. Only 27 % showed evidence of degenerative changes and 1 patient had evidence of severe arthritis and had pain. Five patients had reduced hip motion with one patient who was not satisfied as a result. Aronson et al. [20] reported on 24 grade 2 slips which were corrected with a triplane intertrochanteric osteotomy. The mean pre-operative slip angle was 58° and patients had a 39 % improvement in the total arc of motion. All patients were pain free at 2–10 years follow up without any cases of osteonecrosis, chondrolysis, infection or non-union.

The aim of performing an osteotomy in the treatment of osteonecrosis is to try and direct the area that is affected away from the weight-bearing area of the joint. If correctly performed the patients symptoms can improve dramatically. Jacobs et al. [21] reported on a 22 patients who underwent this procedure for osteonecrosis with a mean follow up of 63 months. Five out of six patients had a good or excellent result for Ficat [22] stage II osteonecrosis and in 11 out of 16 patients with stage III disease. The authors commented that success following the procedure was inversely related to the size of the lesion. A larger series reported by Maistrelli et al. [23] of 106 intertrochanteric osteotomies revealed that 71 % had good results at 2 years and 58 % good or excellent at a mean follow up of 8.2 years. The mean age of the patients was 47.5 years. A total of 24 patients required a total hip replacement or arthrodesis because of pain. Those patient who were under the age of 55 years did better than those 55 years or older and hips with an idiopathic or post-traumatic pathology did better than those cases that were alcohol or steroid induced. In Ficat [22] stage III disease satisfactory results can also be achieved. Scher et al. [24] prospectively reviewed 45 hipsin 43 patients with a mean age of 32 years with osteonecrosis affecting the anterosuperior aspect of the femoral head. There were notable exclusions in the study including all those over the age of 40 years, had an underlying systemic disease, had been treated with steroids, had extensive femoral head involvement or were poorly motivated. Treatment included curettage of the avascular part and autogenous bone grafting as well as a proximal femoral valgus-flexion osteotomy. A survivorship analysis suggested an 87 % survival rate at 5–10 years follow up (mean follow up was 65 months). Failure was defined as a Harris Hip score (HHS) of less than 70 points or patients undergoing a total hip replacement.

Simank et al. [25] compared proximal femoral osteotomy with core decompression in the treatment of the more severe cases of osteonecrosis. A total of 177 procedures were performed and the patients' mean age was 41 years. There were a total of 94 core decompressions and 83 osteotomies. The rate of survival for the advanced stages of osteonecrosis when failure was defined as the need for further surgery was lower in the core decompression group (56 %) than after an osteotomy (76 %). The risk factors for failure that were identified included age >40 years, history of corticosteroid use, advanced stage of osteonecrosis (Steinberg [26] stage ≥III) and core decompression. Equivalent results were noted in the early, pre-collapse stages however. The authors concluded that core decompression was advocated in the treatment of the early stages of osteonecrosis but a femoral osteotomy was a better option in the more advanced cases.

Considerable success has also been achieved in treating patients with the late sequelae of Legg-Calve Perthes disease. In our experience, we also combine it with a femoral head neck debridement performed through an anterior approach to the hip to restore near normal head –neck offset to enable internal rotation in flexion (as illustrated earlier in Figs. 21.1, 21.2, 21.3, 21.4 and 21.5). Raney et al. [27] reported on 31 patients who were evaluated at a mean follow up of 5 years. The indications for surgery included hinge abduction and pain. The average Iowa hip score post-operatively was 93 points in 21 patients, the remaining 10 patients were unable to attend for assessment but did report that they had good pain relief and were satisfied with their post-operative outcome. A total of 62 % of patients reported good and excellent results following a combined clinical and radiographic review.

Myers et al. [28] reported on 15 patients with late presenting hinge abduction following Legg-Calve Perthes disease. All patients underwent a proximal femoral valgus osteotomy. The mean age at the time of surgery was 17 years (range 11–32 years) and the mean follow up was 78 months. The HHS improved from 48 pre-operatively to 89 at a mean of 22 months post-operatively. The authors observed that there was little change in the patients HHS from the time of initial follow up to the final follow-up at 6.5 years.

Proximal Femoral Rotational Osteotomy

This technique can be performed in isolation for particularly severe cases of excessive femoral anteversion. However this is relatively rare and is more commonly performed in children when it is used in conjunction with other procedures to treat developmental dysplasia of the hip.

The surgeon with an interest in hip preservation should also be aware of the patient who presents with femoral head neck impingement but without any evidence of a cam or pincer deformity. This impingement may instead be as a result of retroversion of the femoral neck which then impinges on the acetabulum when the hip is internally rotated in 90° of flexion. When these patients are examined they often have very little internal rotation of the hip and excessive external rotation. Such patients if symptomatic may be a candidate for a proximal femoral rotation osteotomy.

In cases where there is an isolated rotational deformity it is important to avoid any overcorrection as this may result in an opposite deformity. Just using two parallel longitudinal marks scored onto the femoral shaft to assess the degree of rotation can be very difficult. As a result the angular deviation of two pins can be a more accurate technique of reproducing the desired correction. The intertrochanteric region of the femur is exposed as previously described ensuring that the periosteum is sufficiently stripped to allow free movement of the proximal and distal fragment to avoid any tethering once the osteotomy has been made. Then two smooth Steinmann pins are drilled into the anterior surface of the femoral shaft, one pin proximal to the proposed osteotomy site and one distal ensuring that both pins engage the distal cortex. The pins should be placed sufficiently medial so that they do not get in the way. Once the pins are sited, the seating chisel is located in the femoral head using the 90° guide. A transverse osteotomy is then made between the two pins at the level of the lesser trochanter. With the proximal fragment stabilised the distal fragment is rotated externally to correct the excessive femoral anteversion using the angled guides. It can be useful at this stage to check the rotation clinically having first temporarily stabilised the construct with a unicortical screw. Once the surgeon is happy with the correction the plate should be secured with four cortical screws.

Alternatively a technique which involves a rotation osteotomy of the femoral neck described by Sugioka et al. [29] has also been reported in the literature (illustrated in Fig. 21.6). This involves osteotomising the greater trochanter and reflecting it proximally with the attached gluteus medius muscle. The short external rotators are then transected along with the quadratus femoris muscle, taking care to avoid injuring the posterior branch of the medial circumflex artery which is found just above the lesser trochanter. Then a circumferential incision is made 1 cm distal to the intertrochanteric crest towards the lesser trochanter and in a plane perpendicular to the neck. To determine the plane of the osteotomy 2 K-wires are placed through the greater trochanter both anteriorly and posteriorly. These wires should be placed perpendicular to the femoral neck. A second osteotomy is then made from the upper margin of the lesser trochanter to the line of the first osteotomy. When a rotation of more than 70° is required the iliopsoas tendon should be divided near the lesser trochanter before rotation. Then two large pins should be inserted in parallel into the proximal and distal fragments and the femoral head is rotated anteriorly by turning the proximal pin. Once happy with the rotation a large screw is inserted in a valgus position. The correction as well as the screw placement should be confirmed using an image intensifier. The pin is then removed and a second large pin is inserted to help stabilise the construct (see Fig. 21.6).

Results of Proximal Femoral Rotational Osteotomy

Saito et al. [9] reported on a series of 15 patients who had a proximal femoral rotational osteotomy as part of their study evaluating some of the joint preserving treatment options for idiopathic avascular necrosis of the femoral head. In this study

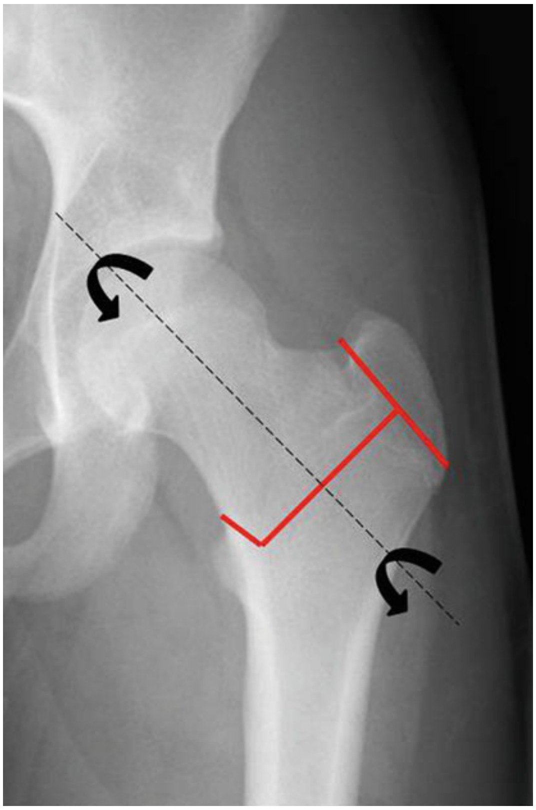

Fig. 21.6 Transtrochanteric rotation osteotomy (Sugioka [29]) illustrated on a plain AP radiograph of the left hip. The necrotic focus is rotated to the antero-inferior part of the femoral head, away from the weight as indicated by (*arrows*), bearing area

the mean age of the patients was 33 years and each patient had a minimum follow up of 2 years with a mean follow up of 4 years. In this group there was radiographic evidence of post-operative collapse of the femoral head of more than 2 mm in 40 % of patients and 20 % showed evidence of degenerative changes. The authors identified specific risk factors for failure in the rotational osteotomy group which included the size and location of the femoral head necrosis. If the area of necrosis was centrally located and deeply involved the centre of the femoral head as seen on the lateral radiograph, the results were disappointing. There were seven hips in this study with such lesions and six (86 %) of them resulted in failure following a rotational osteotomy, the remaining eight hips without deeply located lesions which were treated with this technique did have successful results. However it was noted in this study that there were significant complications associated with this technique. Five out of the 15 cases had a femoral neck fracture, two cases developed further avascular necrosis and a further two cases went on to develop a late varus deformity although did not require any further surgery.

Schneider et al. [11] reviewed 29 hips with avascular necrosis where they had performed a proximal femoral rotational osteotomy as described by Sugioka et al. [29]. At 5 years, 21 of the 29 patients had been revised to a total hip replacement and at 10 years 24 patients had been revised to a THA. Predictors for failure identified in this study did include size as well as the Ficat [22] and Steinberg [26] stages. There was a significant complication rate of 55.2 % in this group. This included two screw loosenings which subsequently required revision to a THA, 11 delayed unions (two of which went on to develop a pseudoarthrosis) and one infection. The authors concluded that the high complication rate could be attributed in part due to technical difficulty of the Sugioka technique for rotational osteotomies.

Yashamoto et al. [30] reported their results of four young patients who had a subchondral insufficiency fracture who underwent an anterior rotational transtrochanteric osteotomy as described by Sugioka et al. [29]. The mean age of the patients was 22 years (16–29 years) at the time of surgery. The mean follow up was 4.1 years (2–9.1 years). The average anterior rotation performed was 85°. The postoperative Harris Hip score improved from 71.6 to 97.2 at the latest follow up. Radiographically the fracture healed and there was no collapse of the femoral heads in all patients. As the authors pointed out, this technique should only be considered in patients who fail non-operative management. They explained that most subchondral insufficiency fractures in this age group occur in the anterosuperior aspect of the femoral head. Therefore by rotating this area away from the weight-bearing zone and instead transposing the posterior segment of the femoral head to the weight bearing area should resolve the patients' symptoms. For this technique to work the posterior segment must be unaffected. Clearly in older patients with greater femoral head involvement a total hip replacement maybe a better option.

Summary

In summary, the judicious use of a proximal femoral osteotomy in the young adult patient can be an extremely useful technique. However very careful patient selection must be employed to avoid any unnecessary surgery and careful preoperative planning must be observed to obtain the best outcome for the patient.

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22 Pelvic Osteotomy for Young Adult Hip Disease

Jacob T. Munro, Andrew J. Graydon, and Donald S. Garbuz

Introduction

Since the 1960's the widespread use of total hip arthroplasty (THA) has proved highly successful in the treatment of degenerative disease of the hip. Despite broad indications for THA, there is logic in treating hip disease presenting in the young patient. Such disorders cause pain, impair function and lead to early degeneration requiring hip replacement at a younger than desirable age. Developmental dysplasia of the hip (DDH) is a common cause of symptomatic disease in young adults, with a natural history of premature osteoarthritis (OA) [1–3]. Acetabular development may be affected by any condition in which the femoral head is not concentrically reduced. The most common of these is developmental dysplasia but also includes: neurologic conditions, e.g. cerebral palsy and motor and sensory neuropathy; conditions resulting in ligamentous laxity, e.g. Down's and Ehlers-Danlos syndromes; infection, e.g. poliomyelitis and septic arthritis; birth defects, e.g. proximal femoral focal deficiency; skeletal dysplasia and trauma. The common pathology, regardless of cause, is a shallow upward sloping acetabulum with a hypertrophied labrum. Wiberg [4] described the centre-edge angle as a measure of acetabular dysplasia in 1939 and correlated degree of abnormality to later development of OA [5].

A variety of approaches have been described using different means to achieve coverage and containment of the femoral head. This may involve surgery to redirect or remodel the femoral head or pelvic osteotomy to improve coverage and containment. Pelvic osteotomies suitable for adults may be considered under two broad groups: salvage and reconstructive. Salvage osteotomies aim to prevent further subluxation of the femoral head by creating a shelf of bone superiorly [6] and may allow medialisation of the centre of rotation [7]. These options rely on metaplastic fibrocartilage formation between bone and the femoral head and are limited in correcting more severe deformity. True reconstruction involves a redirectional osteotomy that corrects the orientation of the acetabulum and repositions the hip centre of rotation. This improves coverage while containing the femoral head. Redirection can be achieved by mobilizing the hemipelvis entirely [8, 9] or by osteotomy close to the acetabulum leaving the posterior column intact [10, 11].

The periacetabularor Bernese osteotomy (PAO) was first described by Ganz et al. in 1988 [12]. It has come to be recognised as a powerful reconstruction option to alter the pathological mechanical environment caused by a maldirected acetabulum, thereby preventing secondary osteoarthritis (OA) [5, 13, 14]. The proposed advantages are: (1) the large multidirectional correction that can be achieved; (2) the maintenance of an intact posterior column allowing early weight bearing; (3) preservation of the blood supply to the acetabulum; and (4) the maintenance of the shape of the true pelvis which allows normal childbirth [12]. While acknowledged as a technically challenging operation with a difficult learning curve, several centres around the world have adopted the PAO. This has lead to refinement of the indications [15–19], development of different surgical approaches [20–23] and publication of mid to long-term results with excellent outcomes in well selected cases [16, 24–33].

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Indications

Patient selection for PAO is a key component in achieving good surgical outcome. The classic indication for PAO is the treatment of symptomatic, adolescent or adult DDH that requires correction of congruency and containment. Although expanding indications have been described as experience grows with this procedure, certain key variables have been demonstrated to strongly influence outcome. PAO is contraindicated when there is high subluxation or dislocation; when there is end-stage arthritis; and when here is insufficient acetabular volume to contain the femoral head. Careful consideration should be given to alternate options in older patients, the obese and patients with limited functional demands.

Presence of OA pre-operatively has been clearly identified as a predictor of poor outcome. As an extension of the original series reported by Ganz, Trousdale et al. [34] published the results of 42 patients who had a PAO with radiologic evidence of OA pre-operatively. While the Harris hip score (HHS) significantly improved, those patients with Tönnis grade-3 changes on X-ray were significantly more likely to require total hip arthroplasty within 5 years. The post-operative HHS was also lower in this group. Multiple authors have reported the association of preoperative OA with poor outcome after PAO [10, 19, 26, 27, 30, 35–37].

The lower age limit for PAO is determined by closure of the tri-radiate cartilage. The upper age limit remains controversial. Most authors favor a younger age group who are less likely to have cartilage loss and exclude older patients who can expect an excellent outcome with total hip arthroplasty (THA). In long-term follow-up, older age has been associated with poorer outcomes [26, 27, 30]. Garbuz et al. [26] compared a cohort of 28 patients older than 40 undergoing PAO against a matched group undergoing THA. In the PAO group 64 % of functional outcomes and 73 % of pain outcomes were good or very good. This was however lower than the THA outcome scores with a much higher complication rate. Ten of twenty-eight patients sustained a complication in the PAO group against 1 of 34 in the THA group. Millis et al. [19] reported similar functional outcomes in an unmatched cohort of 70 patients (87 hips) over the age of 40 undergoing PAO. Compared to younger hips this group had a higher risk of progressing to THA (24 % at average follow-up of 5.2 years) especially in the setting of moderate OA at the time of surgery (Tönnis grade-2). Yasunaga et al. [38] compared outcomes of rotational osteotomy in 24 patients older than 46 years, to a group of 60 patients younger than 46. While the outcomes measured by the Merle d' Aubignéscore were equivalent, predicted 10-year survival in the older group was 70 % compared to 93.7 % in the younger.

Femoro-acetabular impingement (FAI) is a less common but recognised indication for PAO. FAI occurs when there is reduced clearance of the femoral head within the acetabulum. This may arise from anatomical abnormality on the femoral or acetabular side. Retroversion of the acetabulum occurs when there is posterior orientation relative to the sagittal plane [39, 40]. The anterior prominence of the acetabular rim may then impinge on the femoral neck during flexion, adduction and internal rotation. PAO may be used to redirect the acetabulum into appropriate anteversion. Siebenrock et al. [41] reported the outcome of 29 PAO's performed for symptomatic, radiologic retroversion. Significant improvements in range of motion (ROM) and the Merle d'Aubigné score were reported.

Consideration for Additional Procedures

Intra-articular pathology can be identified on pre-operative MRI scan and confirmed during PAO by performing an arthrotomy. Visible areas of articular cartilage may be assessed for evidence of osteoarthrosis. Full thickness areas of cartilage loss may be debrided to a stable base with consideration given to drilling of the subchondral bone. Dynamic impingement can be demonstrated with hip flexion, adduction and internal rotation and osteochondroplasty performed.

Labral pathology includes intra-substance degeneration and detachment with or without an osseous fragment. In Ganz's original series [12] labral tears were identified in 17 of 75 cases. Typical detachments occur in the anterosuperior quadrant and may involve 50 % of the circumference [42]. If detached, the labrum should be fixed to the acetabular margin using anchors [43, 44]. If this is not possible or there is advanced intra-substance degeneration, then the labrum should be debrided to a stable base. Although not specifically studied for PAO, Espinosa et al. [45] found superior clinical and radiologic results in patients who had labral refixation as opposed to resection during treatment of femoro-acetabular impingement.

In severe deformity, it has been suggested that some patients may benefit from proximal femoral osteotomy (PFO) combined with PAO [18, 46, 47]. This has been theorized to improve the degree of coverage, containment and congruency of the joint and to improve ROM in certain deformity. Clohisy et al. [48] reviewed 108 dysplastic hips and identified coxavalga in 44 %, coxavara in 4 % and insufficient head-neck offset in 75 % of hips. The decision making process is very difficult without extensive experience and careful consideration. Ganz et al. [47] categorized abnormalities requiring a PFO in addition to a PAO as intra or extra-articular. Intra-articular causes include: (1) inadequate improvement of coverage (centre-edge (CE) angle <25, acetabular index >10, extrusion index >30 %); (2) inadequate containment (distance between ilioischial line and femoral head >5–7 mm); and (3) inadequate congruency (non-congruent joint space with width >3 mm). Extra-articular causes include: (1) a high riding trochanter with a short neck and (2) a prior varus femoral osteotomy. Trousdale et al. [34] made comment on 10 patients who had a combined PAO with femoral osteotomy but did not perform sub group analysis. Clohisy et al. [49] reported outcomes for 28 hips undergoing combined PAO/PFO and compared this to outcomes for a matched cohort undergoing isolated PAO for lesser deformity. The PAO/PFO group had slightly lower average Harris hip score but function was comparable between groups. Using PFO in conjunction with PAO may broaden indications and improve outcomes for those with severe deformity.

Clinical Evaluation

Symptoms may vary depending on etiology but young active patients with hip dysplasia typically complain of sharp, activity-related pain localized to the groin. This is more prominent with positions of high flexion combined with rotation. Associated mechanical symptoms such as clicking or clunking anteriorly may be reported. Often patients will feel the hip is unstable and they may experience unexplained falls. Initially functional impairment occurs during high demand physical activities such as running and sports. This usually progresses to involve everyday activities especially those requiring hip flexion.

The gait may be normal but can become antalgic as symptoms deteriorate. Abductor strength is assessed, weakness indicating pain or shortening of the limb with subluxation. The true leg lengths are assessed carefully as patients may present with mild femoral overgrowth of the affected side. ROM is assessed and is often normal. Particular attention is paid to stiffness, which may indicate OA. Mechanical symptoms may be demonstrable with movement. Groin pain can usually be reproduced with flexion, adduction and internal rotation. Likewise, apprehension may be produced with external rotation with the hip extended over the bedside. A screen for generalized ligamentous laxity may be appropriate.

Radiologic Workup

Plain radiography is the mainstay of diagnostic imaging and planning in the management of DDH. Initial assessment should include a standing anteroposterior (AP) pelvis, a false profile view and an abduction view [50].

The AP X-ray gives the most information. It should be performed standing as this provides a view of the hip during weight bearing (see Fig. 22.1). The entire pelvis must be assessed to ensure that there is neutral rotation and inclination. Inspection of the position of the coccyx relative to the pubic symphysis is assessed. The two structures should be in the same sagital plane. The average vertical distance between the symphysis and the sacro-coccygeal joint is 32 mm in men and 47 mm in women [51]. Shenton's line is assessed, disruption indicating subluxation. Acetabular rim fractures and para-labral cysts may indicate overload of the rim and labrum respectively. Tracing the path of the anterior and posterior walls indicates the presence of acetabular retroversion if the two cross (cross over sign). Care should be taken during interpretation as increasing pelvic inclination has been shown to increase the apparent acetabular retroversion [51]. Retroversion is also indicated by a prominent ischial spine and by the posterior wall sign, arising when the lateral extent of the posterior wall does not reach or cross lateral to, the center of the femoral head [52]. Finally, a careful inspection for signs of osteoarthritis is essential.

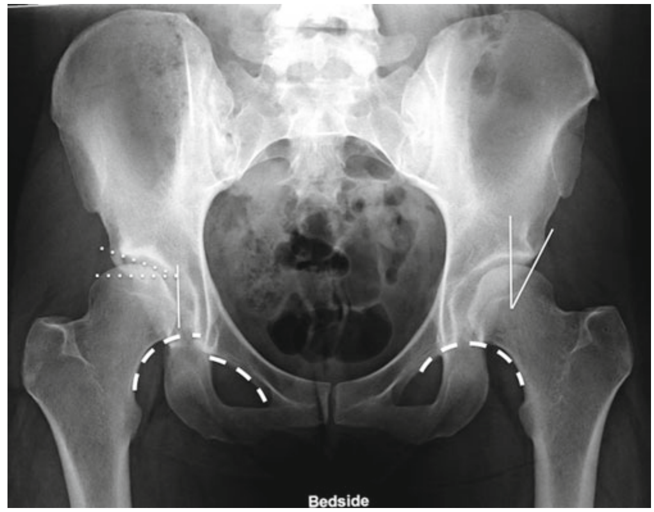

Fig. 22.1 AP pelvis X-ray of a 25 year-old woman with symptomatic right hip dysplasia. Shenton's arch is disrupted on the right (*heavy dashed line*). The Tonnis angle is increased on the right (*dotted line*). The CE *angle* is marked on the normal *left side*

Several radiologic measurements have been described. The center-edge (CE) angle (or lateral CE angle) (see Fig. 22.1) is that subtended by a line from the center of the femoral head to the lateral acetabular margin and a vertical line passing through the center of the femoral head [4]. The CE angle is normally greater than 25°and considered borderline if between 20° and 25°. The Tönnis angle (see Fig. 22.1) is created by talking a line from the lateral acetabular margin to a point on the acetabular surface marked by a vertical line that passes through the most medial point of the femoral head. It should be less than 10°. The extrusion index [53] is the ratio of the femoral epiphysis contained by the acetabulum to the total width of the femoral epiphysis, expressed as a percentage.

The false profile view (see Fig. 22.2) is a true lateral of the acetabulum taken with the unaffected hip rotated 65° from the plane of the radiographic plate. This view allows

Fig. 22.2 False profile view of the right hip. Note that this view is used in the operating room to direct osteotomes

Fig. 22.3 The abduction view confirms that the joint is congruous and essentially reproduces what the osteotomy will achieve

assessment of anterior femoral head coverage. It should normally be greater than 25°.

The abduction radiograph (see Fig. 22.3) is an AP view performed with the hip in maximal abduction. Effectively this reflects the position of femoral head and acetabular alignment following the PAO. This view ensures that the hip reduces, that the femoral head is covered, that the joint space is maintained and that the hip is congruent.

Several adjuncts to the basic radiographs may be performed. A true cross table lateral view of the hip may show posterior joint space narrowing secondary to osteoarthritis. An elongated femoral neck lateral (Dunn view) in 90° flexion 20° abduction shows the anterior neck and can define cam lesions.

Computed tomography (CT) may be useful. The CE angle can be precisely measured without structural overlay and femoral head coverage can be assessed in multiple planes. The acetabular version is easily assessed on axial slices. The post-operative correction is more clearly measured when compared to plain films and can be used to decide on the amount of coverage required when compared to data from normal subjects [54, 55].

Conventional magnetic resonance imaging (MRI), with or without gadolinium, may be used to confirm labral pathology [42]. Recent advances in the use of delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) have shown improvements in detecting arthritis prior to surgery [56].

Technique

Objective

The objective of PAO is to reorient the acetabulum to correct deformity. This is achieved by creating a "free fragment" of the peri-acetabular region, with a polygon shaped juxta-articular osteotomy [44]. There are several proposed advantages to this approach. (1) The adequately mobilized fragment allows correction of deficient lateral coverage, medialisation of the centre of rotation and preservation of appropriate anteversion; (2) Bernese PAO has been shown to preserve the blood supply to the acetabular fragment [57] improving healing time and reducing the risk of avascular necrosis; (3) The intact posterior column provides support to the pelvis during rehabilitation and protects the sciatic nerve. Since the original development and description many authors have added variations and modifications, but the basic objectives remain the same.

Anaesthesia and Perioperative Considerations

A crossmatch with 2 units of red cells should be available. Autologous pre-donation may be considered. A cell-saver system should be available. The operation may be performed under regional or general anaesthesia depending on the experience of the surgical team. Use of epidural anaesthesia provides optimal post-operative analgesia in the first 48–72 h. An Indwelling catheter is inserted.

Equipment Required

- Radiolucent table
- Image intensifier and portable X-ray machine
- Cell saver
- Retractors [58]

  - Pointed and blunt Hohmann retractors
  - Bone spreaders
  - Langenbeck retractors
- Thigh support – steadies the hip in ranges of flexion, reducing assistant fatigue.
- Osteotomes [58]
  - Lambotte flat chisels, 10 to 20 mm widths
  - Ganz PAO-chisels 30° angled neck with wide and narrow curved blades.
- Awl and pointed/ball head bone spikes.
- Oscillating saw.
- Schanz pin and handle.
- Fixation: AO screws long 3.5 and 4.5 (consider titanium) threaded K wires.

Radiology Setup

Fluoroscopy has greatly contributed to the ease of PAO [23]. Indeed the more recent minimally invasive and endoscopic techniques described rely heavily upon intra-operative imaging [22]. Fragment placement with the use of the II approach also depends on fluoroscopy for accuracy. Placement of the fluoroscopy greatly depends upon the approach utilised and surgical preference, but an AP image obtained with 30° of medial to lateral angulation will visualise the posterior column for the ischial osteotomy well, and an intraoperative AP pelvis radiograph enables measurements and the accuracy of the correction to be assessed.

Approaches

A number of different approaches have been described for the PAO, each with its own advantages and disadvantages. The Smith-Peterson (SP) anterior approach was originally described by Ganz [12]. Due to concerns over blood loss, post-operative gait problems, acetabular fragment vascularity and the time-consuming nature of the abductor release the original approach was modified by Ganz to limit abductor release from the iliac crest [20].

The Ilioinguinal approach as initially described by Letournel [59] has long been proposed as an alternative method for accessing the required osteotomies. It was initially popularised by several authors [60, 61] but may increase the risk of damage to the femoral neurovascular bundle.

Developed by Millis, Murphy and others in the early 1990s, the direct approach seeks to combine the SP and ilioinguinal approaches [62]. It affords good visibility of the inner pelvis, whilst maintaining the abductor musculature and retaining the ability to approach the joint. This approach can be made through a bikini line incision reducing anterior scarring which occurs with a Smith-Peterson anterior approach.

Using a dual approach [20] it is possible to perform all the osteotomies under direct visualization. While the osteotomies are performed through a modified SP approach, a second lateral incision is utilized to expose the posterior column. This has been recommended as an approach for surgeons who are learning the procedure.

Minimally invasive approaches have been described with improvements in blood loss and recovery time and similar corrections to extensile approaches [22]. These approaches should be limited to experts.

Modified Smith-Petersen Approach

This is the most commonly used approach for performing PAO. The patient is positioned supine on a radiolucent table. A plain AP radiograph confirms position of the pelvis and can be correlated to the pre-operative films. The image intensifier should be freely maneuverable to provide PA and false profile views during surgery. Marking the position of the machine on the floor and the oblique angle on the C-arm improves efficiency. The entire hindquarter is free-draped with exposure to the umbilicus in the midline and the nipple line cranially.

An incision is made over the anterior third of the iliac crest curving distally and continuing over the anterior superior iliac spine (ASIS). It then passes downwards over the Tensor Fascia Lata (TFL) finishing over this muscle 12–15 cm below the ASIS. The fascia over the TFL is incised laterally to protect the Lateral Femoral Cutaneous Nerve (LFCN). The interval between TFL and sartorius is defined and then an osteotomy of the ASIS is performed resulting in a bone block of approximately 1 cm × 1 cm × 2 cm (see Figs. 22.4 and 22.5). The abdominal musculature is reflected from the crest by sharp sub-periosteal dissection maintaining a continuous soft tissue connection with the bony osteotomy. The belly of the Iliacus is released sub-periosteally from the inner table. Performing this early in the dissection facilitates medial retraction for the distal and medial dissection. The quadrilateral surface is exposed in the same way. Sub-periosteal dissection of a narrow channel down the exterior surface of the ilium is performed, elevating enough of the gluteus minimus origin to place a blunt retractor down into the sciatic notch. A cuff of 10 mm of soft tissue above the acetabulum must be kept, as this contains the inferior branch of the superior gluteal artery, necessary for acetabular blood supply of the free fragment. Abductor release should be limited only to that required to protect the later osteotomy.

The leg is then placed into slight flexion and adduction, and the anteroinferior parts of the capsule and pubis are exposed. Sartorius attached to the osteotomised ASIS, along with the mobilized iliacus can be retracted medially. Rectus femoris is divided at its reflected insertion and detached from

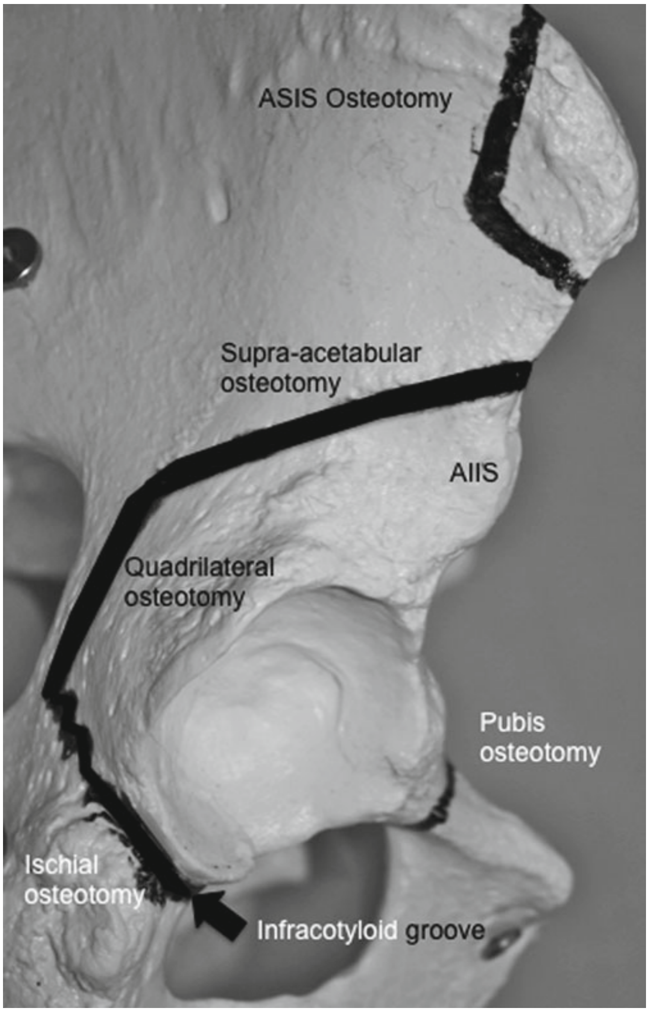

Fig. 22.4 The right hemipelvis from the lateral perspective. The infracotyloid groove (*arrowed*) is the start point for the ischial osteotomy. Note the proximity of the ischium, landmark for the sciatic nerve

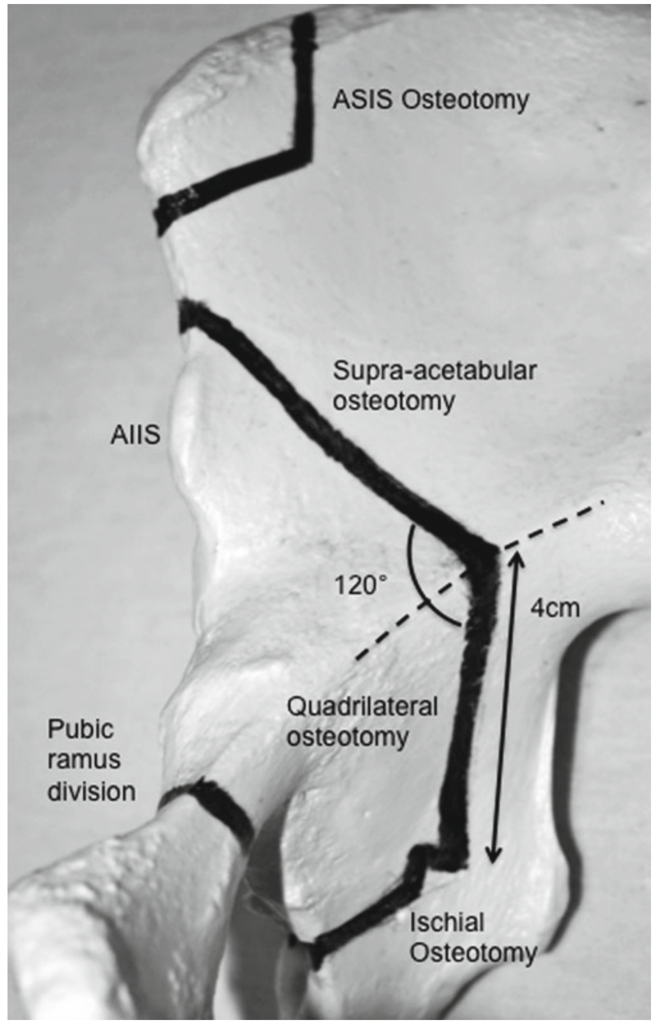

Fig. 22.5 The right hemipelvis from the medial perspective. This correlates to the image obtained in the operating room II images (see Figs. 22.6 and 22.7). The pelvic brim is indicated by the *dashed line*

its direct origin at the anterior inferior iliac spine (AIIS). A suture should be used to tag the rectus origin for later reattachment. By peeling off the capsular insertion fibres of the iliacus, the hip capsule is exposed, as well as the tendon of the psoas and pubic body beyond the iliopectineal line. The interval between the inferior capsule and psoas tendon should be opened up using careful blunt dissection directed inferiorly beneath the femoral neck. This is where the angled osteotome will be passed to score the ischium. The infracotyloid groove is identified first by scissors and then palpation. It is not seen.

The quadrilateral surface can be exposed with subperiosteal stripping down into the true pelvis. This can be a source of persistent bleeding during the operation, but is necessary to visualise the posterior extent of the supraacetabular cut and the quadrilateral surface osteotomy. A blunt retractor placed on the ischial spine allows retraction of the iliacus while a sharp Homan positioned in the superior pubic ramus retracts the Sartorius and the ASIS fragment.

A significant advantage of this approach is the ability to perform an arthrotomy and address intra-articular pathology such as labral tears. The free acetabular fragment is also directly visualised for reorientation and fixation. The drawback of this approach is that the ischial cut is performed in a "blind fashion", which adds to the technical complexity.

Osteotomy

The three dimensional nature of the acetabulum requires careful planning. Ganz originally described a sequence of four osteotomies in the creation of the free acetabular fragment [12] (see Figs. 22.4, 22.5, 22.6 and 22.7).

1. Scoring of the Ischium. This is achieved with a 30° angled osteotome with a curved blade. It is introduced into the interval between the psoas tendon and the inferior capsule anteriorly, at the level of the infracotyloid groove (see

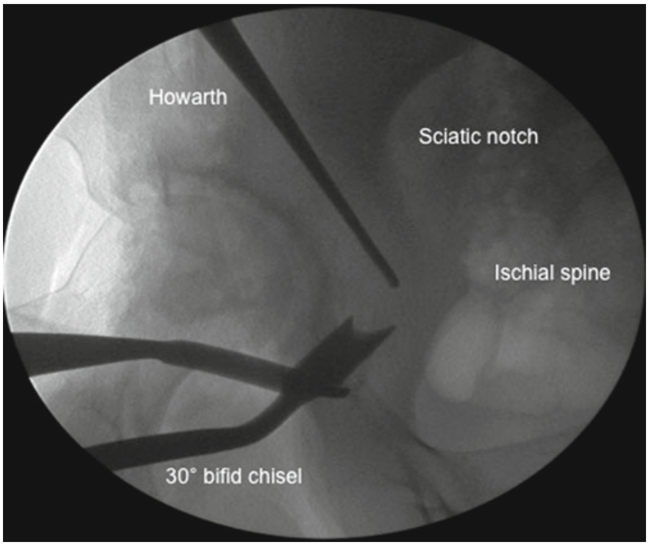

Fig. 22.6 Intra-operative view of the right hemipelvis. The 30° bifid chisel has started at the infracotyloid groove and passed 10–15 mm into the ischium. A sharp retractor (superimposed) is inserted in the pubis medial to the osteotomy. The Howarth is being used to check the direction of the quadrilateral osteotomy. A finger is used to confirm that the width of the posterior column is acceptable as obliquity of the image can give a false impression of bone posterior to the cut

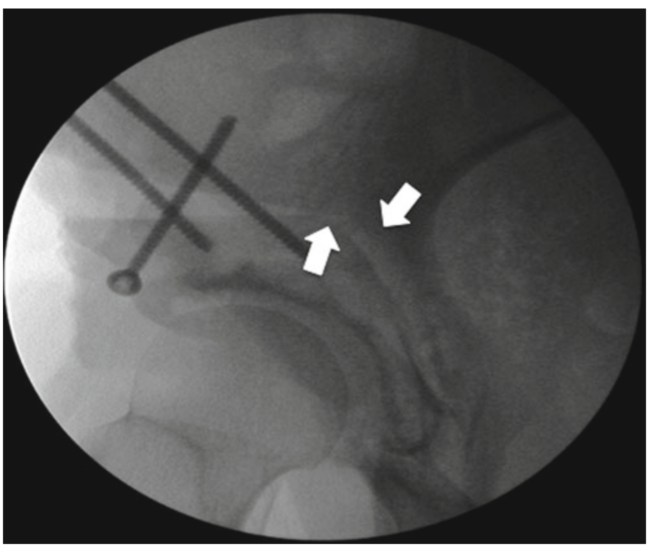

Fig. 22.7 Intra-operative view following correction. The postero-superior corner has moved laterally (note the shift the shift in the *arrows* which would be opposing prior to correction). In this view the final fixation is in place with two near parallel screws through the ilium and a single screw through the AIIS back into the posterior column

Fig. 22.4). The hip should be positioned in 45° of flexion and slight adduction. An image intensifier assists in positioning and directing the osteotome as it is advanced, avoiding intra-articular osteotomy. The usual start point is 10 mm below the inferior lip of the acetabulum with the chisel aiming for the ischial spine. It is advanced directly posteriorly 10–15 mm. Care is taken to avoid completing the osteotomy. This ensures that the controlled fracture that occurs following the fourth osteotomy will exit the posterior column anteriorly and be extra-articular, thus maintaining the integrity of the posterior column and the joint. The blade position can be confirmed by careful palpation down the quadrilateral plate

2. Pubic Ramus division. The pubic ramus must be completely separated from the acetabulum in order to place the centre of rotation of the fragment superiorly or at the midpoint of the femoral head. This avoids lateralisation of the hip centre of movement. Sub-periosteal dissection aids protection of the femoral nerve and artery medially and the obturator nerve and artery inferiorly and enables sufficient mobilization. Anoblique osteotomy, which assists displacement, is performed immediately adjacent to the acetabulum (see Fig. 22.4). It is essential to free the obturator membrane from the pubis. Failure to do so can result in tethering which causes the fragment to hinge around the pubis leading to acetabular retroversion. A gigli saw or fine oscillating saw may be used to make the cut.
3. Supra-acetabular osteotomy. The sub-periosteal space beneath the anterior portion of the abductors is exploited to access the ilium. The limb is slightly abducted and extended. There are two parts to this osteotomy. The first is the anterior cut, made proximal to the level of the anterior inferior iliac spine (AIIS) in a directly posterior direction aiming at the sciatic notch (see Fig. 22.5). It is continued back to the capsular margin posteriorly and to a level 10 mm from the pelvic brim in the inner table. An oscillating saw is used. This cut may be difficult in the more vertical iliac blade encountered in male patients. The second cut involves both the inner and outer tables which are scored with a straight osteotome at an angle of 110°–120° from the anterior thigh. This aims towards the ischial spine. It does NOT need to be completed beyond the first 15 mm.
4. Quadrilateral osteotomy. The acetabular fragment is now only attached to the ischium. In order to provide control of the free fragment about to be created, a Schanz screw is inserted into the supraacetabular bone. The hip is flexed and adducted to reduce tension on the medial structures. The angled osteotome can then be introduced into the quadrilateral surface 40 mm below the pelvic brim, and orientated 50° to the quadrilateral surface. It is advanced some 10–15 mm in this direction. It is best to start at the posterior edge of the supraacetabular cut. The osteotome should also be oriented 10°–15° away from the sciatic notch. This orientation protects against intra-articular extension of the osteotomy [63]. Often 2–3 chisel widths are required progressing down the posterior column. With gentle tension exerted through the Schanz screw the controlled fracture occurs through onto the lateral side and

into the infracotyloid notch, thereby creating the free acetabular fragment. The angled chisel in place for the ischial osteotomy can be used to cut the lateral cortex of the ischium but this must be done with the leg in extension to protect the sciatic nerve.

Acetabular Fragment Positioning

The dysplastic acetabulum is characterised by deficient anterior and lateral femoral head coverage, superolateral inclination of the acetabulum and a relative lateral position of the hip joint centre [44]. The objective of the PAO is the reorientation of this acetabulum. Achieving 'normal' orientation can be difficult. Hussell et al. [20] stated that in essence there existed only one optimal correction for each individual. Although pre-operative radiologic assessment to define this correction has been described [50, 54, 55] the majority of authors utilize intra-operative assessment clinically and fluoroscopically [12, 21, 25]. The position of the free acetabular fragment is noted, particularly at the posterosuperior corner, which should move laterally and anteriorly relative to the ischium (see Fig. 22.7). At the pubis the acetabular fragment should displace superiorly and medially. Care must be used interpreting intra operative fluoroscopy, especially if PA screening is performed. This can mask retroversion as the anterior wall is further from the beam. A formal AP pelvis X-ray centred on the pubis should be performed prior to and after insertion of metal-ware to conform adequate correction (see Fig. 22.8). Computer assisted techniques have also been described [64] as well as the use of intraoperative measuring devices [65].

In all corrections, the femoral head should be positioned to the central point of hip rotation. The acetabulum is then rotated around this point to provide optimal coverage. Failure to do so results in either excessive lateralisation or medialisation of the hip centre. In unilateral deformity the centre of rotation may be matched to the unaffected side. Hussell et al. [66] recommended maintaining the femoral head approximately 5 mm lateral to the ilioischial line.

Fixation

Fixation of the fragment has evolved with different techniques and approaches. Ganz et al. [12] initially described a single 4.5 mm cortical screw passed through the AIIS just distal to the osteotomy into the posterior column. This was augmented with two 4.5 mm cortical screws placed from the iliac wing down in to the fragment anteriorly and posteriorly (see Fig. 22.7). The iliac fixation has been modified to three 3.5 mm screws due to metalware prominence issues [66]. One 3.5 mm cortical screw is used to re-fix the ASIS osteotomy. A 5 % incidence of secondary migration has been described

Fig. 22.8 An AP pelvis X-ray is performed in the operating room prior to insertion of the definitive metalware. Note that the anterior wall (*solid line*) and the posterior wall (*dashed line*) are clearly visible on the right hip confirming appropriate version. The teardrop (*arrowed*) is checked to confirm medialisation. The CE angle and Tönnis angle are now corrected

using this technique, but it is not felt to be significant. Major loss of fixation (<1 %) is often associated with non-union, a complication seen in association with large corrections [66].

The addition of fixation placed medially can reduce this secondary migration rate. Biomechanical studies suggest a significantly increased load to failure in both tensile and compressive cyclical loading with the addition of a transverse screw. However, such a screw significantly complicates routine hardware removal, and does not increase construct stability enough to allow immediate full weight-bearing [67, 68]. Techniques using plate fixation have been described [67].

While standard stainless steel is most frequently used, titanium screws may be utilized. These allow a degree of flexibility that can assist metalware placement in the relatively small space afforded by the acetabular fragment. Cannulated systems can also be used to aid stability while definitive fixation is placed. The disadvantage with both options is the weaker nature of the screws although there is no evidence that this compromises fixation. Attempts to remove titanium and cannulated screws often results in breakage of the screw heads but as this is the source of irritation this is not a critical issue.

Post Operative Care

A comprehensive multimodal analgesia plan should be in place. Epidural anaesthesia can be continued for 48–72 h and tapered as required. This can be complemented by local anaesthetic injected at the completion of surgery or with pain pump systems delivering local anaesthetic into the subcutaneous tissue for 24–48 h. Patient controlled analgesia supplemented with oral agents is instituted immediately. Prophylaxis against heterotopic ossification may be considered. DVT prophylaxis is initiated according to institutional protocols.

Passive hip motion may be initiated while the patient is in bed. Continuous passive motion (CPM) may be used. Mobility begins with partial weight bearing using two crutches. Active hip flexion is restricted in the first 6–8 weeks. At this stage clinical and radiographic assessment is performed with progression to full weight bearing. Strengthening exercises and gait rehabilitation begin.

Complications

PAO is a complex procedure with a significant learning curve. Major complications are common and occurrence rates of 6–37 % have been reported [69]. The most common major complications include nerve injury, intra-articular osteotomy, fracture of the posterior column, intra- and post-operative bleeding, malposition of the acetabular fragment, failure of fixation and symptomatic heterotopic ossification. Less commonly infection and DVT/PE are reported. Moderate complications include metalware irritation and incisional hernia [70].

Neurovascular Injury

Sciatic nerve injury can occur during exposure of the sciatic notch or by errant placement of retractors and osteotomes. During the first and the fourth osteotomy, lateral penetration of the osteotome directly threatens the nerve. The nerve may be damaged by bone fragments or entrapped if the posterior column fractures. Haematoma may compress the nerve. Nerve conduction monitoring has been advocated [71] and regular post-operative clinical assessment is essential. Permanent sciatic nerve dysfunction is often quoted at less than 1 % and most large series from expert centres concur with this [16]. Matheney et al. [27] reported a 6.7 % incidence of peroneal nerve palsy but all were transient. Hussell et al. [66] reported 5 sciatic nerve palsies in 508 PAOS, all recovered some function over time.

The lateral femoral cutaneous nerve exits below the inguinal ligament and pierces the fascia lata distal to the ASIS [72]. It is directly at risk during the approach. Osteotomy of the ASIS carries the Sartorius and the inguinal ligament medially providing a degree of protection to the LFCN but care should be taken not to exert excessive traction. A rate of 30 % was quoted by Hussell et al. [66]. Although often considered a minor complication, LFCN palsy has been associated with worse subjective outcome scores [36].

The femoral nerve may be injured by errant retractor placement. Direct anterior approaches have been associated with femoral nerve palsy especially in the setting of prior surgery with scarring [20, 66].

Vascular structures may also be injured. The femoral artery is at risk in similar situations to the femoral nerve. Troelson et al. reported a 3 % rate of arterial thrombosis following ilioinguinal approach [22]. Trumble et al. [32] reported 2 femoral artery and 1 iliac artery thrombosis using the same approach. The obturator artery may be damaged during osteotomy of the pubis. The superior and inferior gluteal vessels can be damaged at the sciatic notch or during careless handling of the abductors. Care should be taken to identify and control perforators supplying the iliac blade during exposure of the quadrilateral plate.

Intra-articular Osteotomy

Intra-articular osteotomy can occur at several points during PAO. During the first ischial osteotomy, incorrect positioning of the osteotome above the lip of the infracotyloid groove (see Fig. 22.6) causes the cut to progress into the joint and separates the inferior portion of the acetabulum from the superior. The weight bearing aspect of the joint may be congruent in this situation but there may be increased risk of avascularity of the fragment. Similarly during the fourth osteotomy to complete the PAO, the iliac osteotomy can fracture into the posterosuperior aspect of the joint. When the fragment is mobilized, the anterior portion of the acetabulum is pulled away from the posterior column leaving an incongruent weight bearing area. If unrecognized this is likely to lead to joint degeneration. Hussell et al. [66] detailed 11 hips where an inferior intra-articular extension occurred. Nine had no clinical sequelae, 1developed osteoarthritis and one osteonecrosis. Siebenrock et al. [29] reported two cases, both had poor results.

Acetabular Fragment Malposition

Acetabular deficiency is highly variable and there can be a very narrow margin for error. There are several potential positional problems. Under-correction of the deformity defeats the purpose of undertaking PAO. This can lead to recurrence of pre-operative symptoms and subsequent joint degeneration.

Care must be taken not to “over-correct” the acetabulum. The shallow nature of the dysplastic acetabulum varies in severity [44] and when extremely deficient, anterior coverage may be achieved at the expense of posterior uncovering. This can lead to two situations. The first is posterior instability, which is uncommon although well described. The other is secondary femoro-acetabular impingement. This can be due to overcorrection, causing the femoral neck to contact the anterosuperior acetabular margin during flexion, or by 'unmasking' femoral neck deformity which contacts in the same region but in an appropriately positioned fragment [48, 73, 74]. By visualising the joint during and following correction, impingement may be addressed by controlling the degree of correction or by performing a femoral neck osteochondroplasty to restore head-neck offset and increase clearance [73].

Retroversion is linked to excessive correction as the orientation of the acetabulum comes to face posteriorly. This can also cause anterior impingement with secondary labral damage and later degeneration. FAI may be more common in males following PAO. Ziebarth et al. found positive impingement signs in 47.8 % of males after surgery [74]. A useful method to prevent FAI occurring is to perform examination of the hip range of motion (ROM) prior to commencing the procedure, and record the measurements on the back table. Following placement of the acetabular fragment, ROM can again be checked. If there is decreased flexion, internal rotation or cross body adduction, then it may be prudent to visually inspect the hip to evaluate for either overcorrection, or associated femoral deformity.

Posterior Column Fracture

Posterior column fracture occurs during the completion of the final osteotomy. Care should be taken to orient the osteotome accurately and leave a bridge of at least 5 to 10 mm of posterior column [66]. If fracture occurs during surgery, PAO can be completed but the posterior column should be stabilized with internal fixation by conventional means. If detected on post-operative imaging, weight bearing should be restricted until radiographic healing is observed. Late detection of fracture does not usually result in an inferior outcome but fragment migration may occur without protection.

Nonunion, Heterotopic Ossification and Osteonecrosis

Nonunion may occur at any site but has been most commonly observed at the pubis and ischium. Rates of 1 to 2 % have been reported [27, 66]. Risk of nonunion may relate to the size of the inter-fragmentary gap after reorientation. Hussell et al. only observed nonunion in gaps greater than 10 mm [66]. If symptomatic, internal fixation with bone grafting may be considered.

Heterotopic ossification has been reported in around 1 % of cases [66, 75] and can be severe enough to limit range of motion. Careful soft tissue handling with lavage of bone debris assists in prevention. Prophylaxis with anti-inflammatory agents may be employed although this may increase risk of nonunion.

Osteonecrosis is considered rare in primary PAO [29, 66]. The nature of the bone cuts and soft tissue exposure has been shown to preserve blood supply to the acetabular fragment [57, 76]. Spherical and triple osteotomies are thought to have increased risk of osteonecrosis because of disruption to the arterial supply. Risk is likely to be increased in those who have had prior surgery.

Deep Vein Thrombosis

Pelvic surgery alone is generally considered a high risk for DVT [77] although this encompasses patients having surgery following trauma. Zaltz et al. [78] conducted a large multicentre study investigating the incidence of DVT following PAO. They reported an incidence of clinically symptomatic thromboembolism of 9.4 per 1,000 procedures. Of note, DVT prophylaxis in this group was highly variable ranging from none to mechanical prophylaxis to chemoprophylaxis with several agents utilized. All other risk factors such as use of oral contraceptives, prior personal or family history and obesity should be noted and controlled where possible.

Outcomes

The levels of evidence for PAO are low with the majority of publications being level IV retrospective case series from expert centres.

Radiologic Correction

PAO has been consistently demonstrated to correct radiological abnormalities associated with dysplasia. In a 2009 literature review, Clohisy et al. [69] reviewed 13 papers reporting outcomes of PAO. The mean change in acetabular inclination ranged from 4.5° to 29°, mean anterior CE angle from 16° to 51° and mean lateral CE angle from 20° to 44.6°. Reported medial translation of the hip center ranges from 5 to 10 mm. Potential corrections of the CE angle greater than 50° have been reported in severe cases [18]. To date, no correlation between degree of correction and functional outcome has been reported.

Functional Outcome Measurements

Pain and Functional Scores

Several authors have reported excellent improvement in pain and functional scores following PAO, with preservation of these results over the long term.

Table 22.1 Reported medium and long-term results for PAO in cohorts larger than 50 patients. Note that only the longest follow-up for each group has been reported. While authors have reported on factors predicting failure not all are quantified

Lead author and institution	Patients/hips	Follow-up years (range)	Failure criteria	Survival by failure criteria (mean time)	Conversion to THA (mean time)	Factors predicting failure
Matheney et al., Boston, MA, USA [27]	109/135	9 +/− 2.2	1. WOMAC pain score >10 2. THA	76 % (9 years)	13 % (6.1 years)	1. Age>35 2. Incongruent joint pre-op
Steppacher et al., Berne, Switzerland [30]	58/68	20.4 (19–23)	1. THA 2 Fusion	60 % (20 years)	38 % (11.7 years)	1. Age 2. Poor preop func score 3. +ve impingement test 4. OA grade 5. Post op extrusion
Troelson et al., Aarhus, Denmark [35]	96/116	6.8 (5.2–9.2)	1. THA	81.6 % (9.2 years)	18.4 % (9 years)	1. Severe dysplasia 2. Osacetabuli 3. Extrusion and subluxation post op

PAO has been shown to improve gait, hip strength and functional outcomes. Sucato et al. [31] reported significant improvements in abductor strength, flexor strength and gait kinetics in a cohort of 21 patients 1 year after surgery. The group had a young average age (16.2 ± 3.5 years) that may have assisted optimal recovery.

In long term analysis functional scores have been shown to decline. Steppacher et al. [30] showed significant decreases in the Merle d'Aubigné and Postel scores. In41 hips surviving at 20 years the mean score was 15.4, similar to preoperative score. Flexion, rotation and abduction range of motion was significantly reduced compared to preoperative measurements.

Activity Specific – Childbirth Sports

Valenzuela et al. [79] questioned 88 female patients following PAO on the specific subject of sexual activity and childbirth. 84 were satisfied with the procedure. 16 women had 24 pregnancies with 15 vaginal deliveries and 8 caesarian sections. 16 cases were identified with acetabular retroversion, 15 of these had hip pain post operatively. In the 18 cases completely free of pain, none had radiographic evidence of retroversion.

Return to sporting activity was assessed by van Bergayk and Garbuz [33]. Using a sport specific questionnaire, postoperative satisfaction was high (mean 89.7/100) with an increase in subjective Tegner and Lysholm scores (1.9 preoperatively, 4.4 post-operatively). A variety of sports activities were reported including martial arts, distance running, cycling and tennis.

Longevity of the Native Joint

Several authors have reported medium and long-term survival of PAO (See Table 22.1).

Experienced surgeons should expect a failure rate of 1–2 % per year considering THA as the failure point. This rate is higher when functional results are used as criteria for failure.

Outcome by Specific Diagnosis

Correcting Retroversion

Acetabular retroversion occurs when the mouth of the acetabulum faces in a posterolateral, rather than an anterolateral direction. PAO may be used to rotate the acetabulum into at least a neutral, if not anteverted, position [39, 41]. This is technically difficult to achieve as the acetabular fragment is difficult to position under the osteotomies and can be restrained by soft tissue. Siebenrock et al. [41] reported the outcome of 29 PAO's performed for symptomatic, radiologic retroversion. Significant improvements in range of motion (ROM) and the Merle d'Aubigné score were reported.

Pathology Other Than DDH

Katz et al. [17] reported acceptable corrections for 8 dysplastic hips in 6 patients with Down's syndrome. Although no hips had undergone THA, no functional scores were reported. MacDonald et al. [15] reported outcomes for 13 dysplastic hips in 11 patients with underlying neurologic causes including flaccid and spastic paralysis. While no soft tissue procedures were necessary, 4 patients required varus PFO at the time of PAO. All patients had elimination or improvement in pain.

Predictors of Poor Outcome

Preoperative degeneration is strongly associated with poorer outcome following PAO. In a level II prognostic study, Cunningham et al. [56] performed a prospective cohort study of 47 patients undergoing PAO. All patients were assessed preoperatively with dGEMRIC scans to establish evidence of underlying cartilage degeneration. Failure was defined as a postoperative WOMAC score of >10 points or a decrease in the minimum joint space width to <3 mm. 10 hips failed by these criteria. Evidence of OA was associated with a higher risk of failure indicated by Tönnis grade ($p=0.01$) preoperatively. The dGEMRIC index was significantly lower ($p<0.001$) in failed hips (370 ± 88 ms) compared to those with a satisfactory outcome (498 ± 105 ms).

Steppacher et al. [30] reviewed a cohort of75 hips (63 patients) followed for a mean of 20 years. They identified six factors associated with poor outcome: (1) Age at surgery greater than 30 years or; (2) preoperative Merle d' Aubigné and Postel less than or equal to 14; (3) positive preoperative anterior impingement test; (4) preoperative limp; (5) preoperative Tönnis grade 2 or higher; and (6) increased postoperative extrusion index of 20 % or more. Matheney et al. [27] found age >35 years ($p<0.01$), preoperative joint incongruency ($p=0.02$) and Tönnis grade >1 ($p<0.01$), predictive of failure.

Careful clinical and radiologic assessment should be performed to detect preexisting degenerative change. Limiting PAO to patients aged less than 35, probably less than 30, is appropriate given the improving success of THA.

THA Following Failed PAO

Favourable results have been reported for THA following failed PAO. While many cases are straight forward, surgeons should be aware of potential issues with several aspects of management that can make cases highly complex.

The approach may be more difficult following prior surgery. While a variety of approaches have been used, the surgical exposure should protect the abductors and allow an extensile exposure of the acetabulum and femur.

The acetabulum may be still be shallow and can be malpositioned, usually into retroversion. The presence of metalware may obstruct acetabular reaming. Occasionally it is necessary to remove screws but to avoid further morbidity, these can be burred back from within the acetabulum. Normal anatomical landmarks may be absent or obscured, requiring alternate techniques to accurately position implants. Many cases will be suitably treated with a hemispherical cementless cup, but in complex situations, augmentation with trabecular metal or structural bone graft may be required.

Femoral deformity should be assessed and specialized modular implants should be available. Excessive femoral anteversion is often associated with DDH and further complexity may be involved when femoral osteotomy has been performed. The ability to manipulate version is useful in balancing hip stability following insertion of the acetabular component. Further difficulty may be encountered in cases with prior femoral osteotomy. Prior metalware may need to be removed and shortening or trochanteric osteotomy may be needed in some cases.

Parvizi et al. [80] evaluated records for 41 patients (45 hips) who underwent THA after PAO. Average time to THA was 6.3 year (range 4 months to 14 years). A variety of implants both cemented and cementless, were used according to femoral and acetabular deformity encountered. The most common deformity complicating the procedure was acetabular retroversion. A single patient with non-union of the PAO required grafting and plate fixation. At average follow-up of 6.9 years, Merle d' Aubigné and Postel score significantly improved from a preoperative mean of 11.2 points (range 8–14) to 17.1 points postoperatively ($p<0.001$). The acetabular component position was reported as acceptable (45° abduction and 15° anteversion) in 91 % of procedures. Three reoperations and two revisions were reported.

Baque et al. [81] reported outcomes for a group of eight patients who developed symptomatic degenerative OA at an average of 7.5 years following PAO for DDH (range 1.2 – 13.9 years). At the time of surgery, the acetabulum was found to be "dish like". The surgical reconstruction of the acetabulum involved reaming a standard sized cup into the "dish" with radiologic guidance. The mean abduction angle of the socket was $44° \pm 4°$and mean anteversion angle $26° \pm 7°$. Average Merle d' Aubigné functional hip score was significantly improved postoperatively at 17 ± 0.5 compared to 13.7 ± 4 preoperatively ($p<0.001$). No dislocations or implant failures were reported.

Future surgical intervention should be considered during any hip preservation surgery. However, excellent outcomes can be achieved when THA is used in the salvage of failed PAO.

Summary

The PAO is a powerful tool for correction of acetabular deformity. Its ability to correct pathology associated with acetabular dysplasia, makes it an excellent option for hip preservation in patients at an increased risk of premature hip degeneration. Further procedures including PFO, labral repair and osteochondroplasty may also further broaden the indications and improve outcomes.

Careful patient selection is crucial for success. Factors such as older age, pre-existing OA, obesity and joint incongruency have been repeatedly shown to be associated with poorer outcomes following PAO. If strict criteria are applied, then durable and significant improvement in hip function can be expected for 10–15 years in greater than 75 % of cases.

PAO is extremely demanding, and significant complications are reported. This surgery should only be performed in a tertiary care hospital by suitably trained surgeons. While excellent results have been reported for THA after failure of PAO, these can also be complex cases requiring careful consideration.

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23 Innovations in Total Hip Replacement for Young Adult Hip Disease

Edward M. Vasarhelyi and Steven J. MacDonald

Background

There have been significant advancements in recent years in the management of hip disease in young adults through the development of joint preserving surgery, however there still remains a key role for arthroplasty in the symptomatic management of these patients. There are challenges in the use of hip arthroplasty for young active adults with respect to balancing the demands that a young individual places on the arthroplasty given an often active lifestyle with the survival of the implant. With our current techniques and technologies, there is yet an implant that will definitively last the lifetime in a patient. There have been many innovations in implant design, bearing surfaces and techniques such as resurfacing that are currently employed in an effort to maximize patient function while theoretically extending the survivorship of the implant.

This chapter will focus on the implant options and their respective results in young adult patients. The definition of a young adult varies in the literatures as it pertains to total hip arthroplasty. The most inclusive definition is those adults undergoing surgery under the age of 60 years. This is a somewhat arbitrary watershed area in which an arthroplasty in patients younger than this age will more likely require future revision arthroplasty for aseptic causes of failure in comparison to those older than 60 years [1]. The reasons for this are felt to be the added demand that more active younger individuals place on their implants which leads to greater rates of wear and loosening [2–4] in addition to their predicted longer life expectancy.

Osteoarthritis is the most common cause of hip pathology in patients over 60 undergoing total hip arthroplasty, however the pathology in younger adults is caused by differing etiologies [5]. Hip dysplasia has been reported to account for approximately one-quarter to one-third of THA in adults younger than 40 years in the Norwegian registry, making it the most common etiology in young adults [6]. The next most common diagnosis was rheumatoid arthritis, followed by sequelae of Perthes disease and slipped capital femoral epiphysis, idiopathic osteoarthritis, post traumatic and then ankylosing spondylitis [1, 6].

Not only are the absolute numbers of total hip arthroplasties increasing each year in a trend that is expected to continue, but the proportion of total hip arthroplasty in young patients relative to the total number is projected to increase significantly over the coming decades. By some estimations, more than 50 % of primary total hip arthroplasties will be performed in patients younger than 65 years old by 2030 [7]. The fastest growing segment within this group is projected to be those in the category of 45–54 years of age, growing by a factor of nearly 6 [7].

Conventional THA

Over the past decade there have been numerous areas of innovation towards improving the function and survivorship of hip arthroplasty implants. These can broadly be divided into alternative bearing surfaces, arthroplasty coatings, stem designs and fixation technique. Prior to examining the results of more recent technologies for total hip arthroplasty, the results of conventional total hip arthroplasty in young adults should be examined [1]. There are numerous studies that report on cemented, uncemented and hybrid arthroplasty in very young adults. One of the challenges when examining the results of total hip arthroplasty in young adults is that many of the longer-term follow up studies in the literature used previous generation uncemented implants that had poor survivorship.

Dorr et al. [8] reviewed cemented total hip arthroplasty in very young adults divided into those under 30 and those over 30 years old at the time of their first arthroplasty. At 16 years,

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those younger than 30 years had a revision rate of 82 % for aseptic causes, while those over 30 had a revision rate of 56 %. Most failures were on the acetabular side. These results are similar to those reported by other authors who report on high rates of revision for aseptic loosening in very young adults. In a comprehensive review of the literature De Kam et al. [9] reported on the outcomes of total hip arthroplasty in young adults. Examining the 2007 annual report of the Swedish National Hip Arthroplasty Register they found that there was less than 90 % survivorship in patients under 50 years old at 10 years for both cemented and uncemented total hip arthroplasties. At 16 years there is 74.7 and 72.5 % survivorship of cemented total hip arthroplasties in males and females respectively. In contrast, there is 57.4 and 54.3 % survivorship in the same groups with uncemented total hip arthroplasties. These results must be interpreted with the caveat that specific implants are not reported; first generation uncemented implants are no longer in use and most second and third generation implants have much shorter reported follow up, and that there is a strong bias towards cemented implants in the registry.

Uncemented arthroplasty in young patients, which is performed in more than 90 % of cases in North America have comparable results [9]. None of the current literature satisfy the NICE criteria of 90 % survivorship at 10 years [10]. One of the most comprehensive looks at uncemented reconstructions was that of McAuley et al. [11]. In their series of 561 hip replacements over 15 years with all-cause revision as an endpoint found a survivorship of 60 % in patients under 50 years old. In the very young patients (those under 40 years old at time of primary arthroplasty), the 15-year survivorship was 54 %.

When considering the components of the reconstruction in isolation, there is a large volume of research in the literature examining cemented versus uncemented fixation for acetabular components. There is support in these works for both forms of fixation. In comparison to previous generation cementless implants, there is superior survivorship with cemented implants [12]. More recent designs however are suggestive of superior results with uncemented components [13]. Uncemented components in particular trend towards improved osteolysis and acetabular migration. That said, in a comprehensive review of the literature, Pakvis et al. [12] found that when only examining randomized controlled trials comparing cemented and uncemented fixation there were no statistically significant differences between groups with respect to osteolysis, migration and cup survival. All of these results however were based on short- to medium-term follow up. It is in non-RCT trials that the literature supports improved results for the uncemented components [14–17].

When specifically examining acetabular components in young patients there are some studies suggestive of superior results with uncemented acetabular components. Based on the results from the Finnish arthroplasty register, Eskelinen et al. [18] found that in patients younger than 55 years old, there were some clear differences between cemented and uncemented acetabular components. When considering revision for aseptic loosening, there was a three-fold increase in revision for cemented cups. If endpoint is defined as all-cause revision the two groups were nearly equal with a 10-year survivorship of 94–93 % for cemented and uncemented respectively. The most common of the uncemented revisions were for liner exchange. Current press-fit acetabular components appear to be resistant to loosening, however continue to have failures as a result of polyethylene wear and failure of the locking mechanisms between the liner and shell [19]. These results show that although the revision rate is not insignificant, for most people a liner exchange would be far preferable to an acetabular revision for aseptic loosening.

The femoral components in young adults are a more reliable component of the reconstruction. There is are very good reported results in the literature for both modes of fixation in young adults. Kim et al. [20] in their study of 219 patients randomized to either uncemented or cemented femoral components showed 96 and 97 % 20-year survivorship respectively, in patients younger than 50 years old. Numerous studies in the literature point to similar success rates with femoral aseptic revision at long-term follow-up for both methods of fixation [19, 21–24].

Overall, when considering conventional total hip arthroplasty in young patients, the short- and medium-term data show very good survivorship and clinical outcomes. There are, generally speaking, excellent outcomes with conventional femoral components. Unfortunately applicable long-term data in patients with uncemented acetabular components is somewhat more sparse, but point to high rates of revision once in the second decade of implant use. This is especially true of the very young patients. Some caution however must be taken when interpreting these numbers, given that they represent outcomes with older generation implants. There is a marked difference in outcomes between older and young patients, which has driven many of the attempts at innovating the reconstruction and dictates resource allocation when using alternative bearing surfaces and implants that often have significant cost increases over conventional implants [25]. The remainder of the chapter will focus on recent innovations in total hip arthroplasty, unfortunately however, very little in the literature at this point can actually answer the question as to whether the implant changes improve long term survivorship and function of the hip reconstruction.

Stem Design

Even though the primary mode of failure is on the acetabular side, femoral survivorship is not 100 %. Particularly for young patients, there continues to be efforts directed at bone preservation through techniques such as hip resurfacing and short femoral stems. The short stems are also often advocated to be used with alternative approaches to the hip such as the anterior approach, which typically presents challenges in accessing the femur [26]. There is no evidence to suggest that these stems reduce intraoperative complication of fracture [27]. Theoretically the shorter stems may reduce stress-shielding through loading the proximal femur and avoid the potential challenges of a metaphyseal-diaphyseal mismatch [28], although again there is no definitive evidence for this or clinical correlation to outcome improvements.

Implant Coatings

The use of coatings on implants have been purported to improve bony ingrowth, and by extension, improve survivorship of implants. The evidence in the literature is somewhat sparse in this regard, in part owing to the relatively short timeline since the introduction of coatings such as hydroxyapatite. Hydroxyapatite has been extensively used in modern uncemented implants, however a volume of recent literature does not show superiority to hydroxyapatite coated stems in comparison to uncoated stems at 10 year follow up. Lazarinis et al. [29] compared Bi-Metric (Biomet) hydroxyapatite and uncoated stems from the Swedish registry. They found no differences in 10-year survival with either implant. Both had a 98 % survivorship. These trends have been also reported in two meta-analyses that did not find any differences in revision rates in coated or uncoated uncemented femoral stems [30, 31].

There are several authors that have found inferior results of hydroxapatite coating compared to uncoated porous implants, especially for acetabular components in young patients [32]. Lazarinis et al. [33] found that patients, particularly those under 50 years old with hydroxyapatite coated acetabular cups had a higher risk of failure caused by aseptic loosening. Implant survival is predicated on minimizing osteolysis, cup loosening and polyethylene liner wear [33]. It has been postulated that the wear particles from the hydroxyapatite coating facilitates the wear rates [34, 35].

Tantalum implants are another of the more contemporary hip implants currently in use. There is no long-term data on the survivorship beyond the first decade [36]. There are numerous properties of this metal theoretically making it an ideal component to use. Tantalum has high porosity, low modulus of elasticity and high frictional coefficient making it conducive to achieve bony ingrowth and have a favourable load-share profile [37]. It also has a monoblock acetabular design with the polyethylene liner. It is more commonly used in revision arthroplasty, but there is a growing body of evidence in support of its use in the setting of primary total hip arthroplasty as well. To date, the series do not focus on young patients specifically, but have survivorship reported as high as 100 % at 10 years [38]. Mid-term results as well show no cases of revision for aseptic loosening in primary total hips [36, 37, 39, 40]. Tantalum has many tribological properties that make the implant appealing to use. There is however no convincing evidence in the literature to adopt its widespread use in young patients at this time, particularly in the context of the significant cost increases over conventional implants.

Bearing Surfaces

A great deal of research has gone into developing bearing surfaces for total hip arthroplasty. The initial bearing couple introduced by Sir John Charnley was a Teflon coated acetabulum that had poor results caused by early loosening. Over the next several years he developed an articulation couple of ultra high molecular weight polyethylene acetabular articulation with a 22 mm stainless steel femoral head [41]. This formed the basis of today's conventional total hip replacement. Today this combination is satisfactory for older adults, but given the rates of osteolysis and wear debris that is seen with longer-term follow up in younger patients work has been done on improving the wear characteristics and longevity of polyethylene [42].

Polyethylene in recent history has been modified through changes in sterilization technique, storage and degree of cross-linking [25, 43, 44]. Over the past 20 years, various permutations of handling polyethylene were trialed and lessons were learnt that have resulted in current techniques. Sterilization was initially carried out with gamma irradiation in air, however this resulted in entrapped free radicals that during exposure to air during both storage and in vivo resulted in oxidation of the polyethylene. The effect of this was decreased fatigue strength, toughness and wear resistance [44]. Sterilization is currently performed in either a vacuum or nitrogen gas to minimize free radical production. Modern irradiation techniques are used to cause cross-linking of polyethylene. This creates cross-linking, which improves wear characteristics but must be balanced against free radical production. The amount of radiation varies among manufacturers, generally most irradiate between 5 and 10 Mrads as it has been shown that there is no significant improvements in wear rate with doses greater than 10 Mrads [45]. Alternatively, polyethylene can be sterilized without radiation using gas plasma or ethylene oxide which serves to minimize free radicals, but does not confer the wear resistance achieved with highly cross-linked polyethylene [46]. In addition to reducing the amount of irradiation, the production of free radicals are reduced through annealing or melting following radiation. Annealing preserves the mechanical properties of irradiated polyethylene, but does not control free radical production as well as melting which eliminates free radicals but causes a conversion of polyethylene to its amorphous form from it crystalline form [47].

To address these material issues, techniques such as repeated irradiation, consisting of a series of three low-dose radiation with intervening annealing to achieve more extensive cross-linking and eliminate free radial production. This has been demonstrated in laboratory studies to improve wear resistance over both conventional as well as first-generation highly cross-linked poly [48]. Unfortunately, these implants, although used extensively in young adults, do not have any medium or long-term clinical studies showing their effectiveness. These results are inferred from laboratory wear data. The last of the common areas to improve polyethylene is the use of Vitamin E to reduce free radical production. In addition to the free radical reduction, simulator testing has found this to confer additional fatigue resistance for the polyethylene [49]. There are no clinical studies reporting on this technique however.

The current literature on highly cross-linked polyethylene suggests that there are short-term advantages with respect to wear in comparison to traditional polyethylene, however no long-term studies have been conducted yet to confirm whether these translate into long-term benefits [36]. As has been shown with other technologies, in vitro modeling and wear, do not necessarily translate into clinically significant in vivo benefits. That being said, highly cross-linked polyethylene has now been in widespread clinical use globally for over a decade and very clearly there is a significant reduction of wear. At 10 years, on plain radiographs, polyethylene wear and osteolysis can not be seen, which is a significant change from previous generations of polyethylene at the same clinical followup interval.

Ceramic-on-polyethylene has been proposed as a bearing couple to reduce polyethylene wear over metal-on-polyethylene owing to the decreased surface roughness in comparison to metal. Original ceramic heads were made of zirconia but have since been recalled as a result of very high early failure rates attributable to its thermal instability that made it susceptible to phase transformation and subsequent cracking which resulted in third body wear [50]. Second and third generation ceramics that are a composite of zirconia and alumina have a lower propensity to fracture and in laboratory studies as well as mid-term clinical studies show favourable results. The potential advantages over a metal-on-polyethylene articulation are its hardness, scratch resistance, lower coefficient of friction, improved lubrication and superior wear resistance [51, 52]. Alumina ceramic heads on cross-linked polyethylene have been shown to have a 50 % lower wear rate in in-vitro studies [53] and small mid-term studies have reported survivorship of 95 % at 10 years [54]. In a prospective randomized comparison of ceramic-on-polyethylene with ceramic-on-ceramic mid-term results showed increased wear in the ceramic-on-polyethylene group, but no clinical differences between the groups [55].

The hard bearing surfaces consist of metal-on-metal, ceramic-on-ceramic and more recently, ceramic-on-metal. Each has their respective relative advantages and disadvantages, both realized and theoretical. Metal-on-metal bearing surfaces have the longest history of alternative bearing surfaces. There were several design attempts early in the development of total hip arthroplasty that were abandoned secondary to manufacturing shortcomings. It wasn't until the late 1980s that the second generation metal-on-metal bearings attained widespread use.

Metal-on-metal implants are an appealing bearing couple in young adults from several standpoints. The ability to use a large head diameter is a potentially significant advantage of this bearing couple. Large femoral heads increases stability, range of motion, and decreases impingement and rates of dislocation [56, 57]. There is evidence indicating that larger head diameters reduce already low volumetric wear in total hips through fluid film lubrication and the ability to self-polish which minimizes particle debris [58, 59].

Metal-on-metal bearings however have recently begun to fall out of favour with many surgeons for several reasons – recalled implants, local soft tissue reactions, hypersensitivities and concerns regarding effects of metal ions. While the volumetric wear is very low, the number of particles owing to their small size is greater than those seen in metal-on-polyethylene total hips. It is speculated that wear is increased in hips with less than optimal acetabular orientation, namely in cups that are aligned with too much inclination, and to a lesser extent, anteversion [60]. It has been demonstrated that hips with acetabular cup inclination greater than 50° are associated with increased blood ion levels [61, 62]. There have been reports of pseudotumour and aseptic lymphocytic vasculitis associated lesions (ALVAL) associated with metal-on-metal bearings. The etiology of this is unclear at this time. There have been theories such as a Type IV delayed hypersensitivity reaction, however these have not been reliably demonstrated [63, 64]. The true incidence of pseudotumour has not been accurately documented, however, it is estimated to be as high as 1 % incidence within 5 years [64].

Ceramic bearing surfaces, as previously outlined, have many properties that make them desirable implants to use. They should have prolonged longevity as a bearing owing to their inertness, low roughness, lubrication, low friction, high wetability and high wear resistance [65, 66]. These make it a preferred bearing surface in young patients, including women of child-bearing years, in whom concerns regarding metal ion level preclude its use.

There are however some concerns with ceramic bearings. The risk of fracture, although improved, is still estimated to be around 1 in 5,000 [67]. This is true of both the acetabular liner, which can sustain rim chipping on insertion, and the ball. There is conflicting information in the literature regarding revision of fractured ceramic components. Fractures result in intra-articular ceramic fragments as well as damage to the trunion placing the revision head at increased risk of re-fracture [67, 68]. For these reasons, revision following ceramic fracture is a challenge. Some authors recommend a thorough irrigation and debridement followed by conversion to a metal-on-polyethylene articulation, while authors advocate the use of another ceramic-on-ceramic bearing to minimize the chance of accelerated polyethylene wear from microscopic ceramic debris.

The properties of a ceramic-on-ceramic articulation limit options that are available with other bearing coupling. There are no offset options for the liner and given the brittleness of ceramic, thicker liners are required, resulting in a smaller head size. Stripe wear is another consideration which can result from either impingement or edge-loading [69]. The incidence of a squeaking ceramic-on-ceramic hip has been reported to range from 0.5 to 7 % [45]. There are numerous theories regarding the source of squeaking, but no clearly accepted explanation. Some series have shown it to be more common in younger, heavier and taller patients [45]. Although some authors have linked squeaking with component malpositioning, others have shown there to be no relationship between positioning and the incidence of squeaking [70, 71]. A squeaking hip should be monitored, but when otherwise asymptomatic, does not warrant revision surgery.

Hip Resurfacing

Hip resurfacing arthroplasty is a technique that has been used historically, abandoned and reintroduced in the past decade. It is advocated to be a procedure for younger patients requiring a hip arthroplasty in whom it is desirable to preserve bone stock in anticipation of possible revision surgery in the future. It is indicated in young, generally male, patients with hip osteoarthritis. Careful patient selection is important in achieving satisfactory results; the lowest risk of failure is in those patients who are male less than 55 years old with no proximal femoral deformity and of normal weight [72, 73]. The Australian Registry indicates higher mid-term revision rates in cups less than 50 mm and patients older than 65 years old [74]. Failures in this category are likely related to poor bone quality, reduced coverage arc and possible increased metal hypersensitivity [75]. Given the femoral fixation, resurfacing arthroplasty is generally contraindicated in pathology that causes proximal femoral deformity or affecting bone stock. Such examples include avascular necrosis, prior fracture, proximal femoral hardware, large bone cysts, prior slipped capital femoral epiphysis and Legg-Calve-Perthes disease [76–78]. Hip resurfacing arthroplasty is more technically demanding than total hip arthroplasty and may benefit from computer assisted or individualized templating techniques [79, 80].

Clinical outcomes in prospective, randomized trials showed no differences between resurfacing arthroplasty and large head total hip arthroplasty in young adults [81, 82]. The Australian registry data indicates a higher mid-term revision rate in resurfacing arthroplasty of 7.2 % in comparison to 5.4 % for total hip arthroplasty at 9 years [74]. Early failures are most commonly femoral neck fracture [83]. A meta-analysis has also shown higher early rates of failure of 2.6 % at 3.9 years in comparison to 1.3 % of cementless total hip arthroplasty [84]. Similar to total hip arthroplasty, acetabular alignment, and inclination in particular, has been shown to be an important predictor of implant function. As inclination, or abduction angle, is increased to greater than 50–55° there is a significant correlation to increased circulating cobalt and chromium serum levels. It is speculated that this is owing to the greater risk of edge loading [85].

At the present time there are no long-term studies comparing hip resurfacing arthroplasty to total hip arthroplasty in young patients. Registry data indicates a higher reoperation rate in those patients with a resurfacing arthroplasty at mid-term results. There are no clear differences with respect to post-operative function and patient satisfaction in appropriately matched groups. That said, in some young, male patients, resurfacing arthroplasty can be a viable option provided the patient and surgeon have a clear understanding of the differences of the implants and that measures are taken to ensure accurate component placement as resurfacing arthroplasty appears to be more sensitive to malalignment than total hip arthroplasty.

Summary

Total hip arthroplasty is being performed with increasing frequency in all age groups, especially young adults in particular. These are challenging patients as there is generally higher expectation about the level of functioning of the arthroplasty. There is also a differing distribution of etiology necessitating the arthroplasty. These factors in combination place significant demands on the implant. Although total hip arthroplasty is one of the most successful surgeries that is performed across all disciplines, the results in young adults demonstrate some shortcomings with the procedure still. There are many innovations that are brought to market on relatively short lifecycles that make long-term conclusions regarding survivorship challenging. Those studies that do provide long-term data have the caveat that the reported implants are often no longer available for use as primary implants. This creates challenges for the surgeon, and in some instances the patient, to decide on the most appropriate implant for a given patient. Based on the current evidence in the literature, there is no definitive answer regarding the best implant to use. Ultimately, the surgeon must decide based on familiarity and comfort with a given implant and technique in combination with a detailed discussion of the pros and cons with the patient regarding implant types, in particular bearing surfaces. Caution must be exercised when interpreting industry marketing and laboratory data. Although it can be suggestive of improved wear and implant survivorship, with the current state of technology, the differences in implants are often subtle, and would require large, long-term survivorship studies to establish advantages of an implant over another, which is not currently available in today's literature.

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Mini THR for Young Adult Hip Disease

24

N. Santori, D. Potestio, and F.S. Santori

Introduction

Despite the increasing use of hip joint preservation techniques, many young patients present with end-stage arthritis of their joint requiring total hip replacement (THR). Common goals of joint replacement surgery are pain relief, maintenance of activity levels, restoration of hip function, and enhancing quality of life. Active, high-demand younger patients are the fastest growing segment of the hip replacement population. There is increased emphasis on the return to an active-normal lifestyle after THR with tolerance of high activity levels and maintenance of their previous athletic life.

Important goals when considering joint replacement in young patients include the preservation of proximal femoral bone stock, physiologic stress transfer to the proximal femur, normal hip kinematics, low dislocation rate and easy femoral revision procedure when necessary.

The increasing interest in bone-conserving designs has led, in the last decade, to the introduction of a number of smaller femoral components. These implants are commonly identified with the term mini THR. When we look in detail at these devices, each has a distinctive reading of hip biomechanics but all share a number of theoretical benefits which appear valuable above all for young patients. Small implants sacrifice less bone and aim at simulating natural stress distributions, allowing for effective peri-prosthetic bone remodelling, and lower rates of post-operative thigh pain. Mini THR should facilitate minimally invasive surgical procedures and allow a more active/normal lifestyle.

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In this chapter we summarize the current status of mini hip replacement, outline the reasons which drive the recent interest for smaller femoral implants, evaluate possible advantages over traditional total hip replacement and attempt to classify the different possible options.

Why a Mini THR

In conventional THR, there exists a mismatch in the modulus of elasticity between the implant and femur (determined by the higher stiffness of the implant). Periprosthetic bone loss related to stress shielding in the proximal third of the femur, as a direct result of this mismatch was a concern reported from the early standard length implant design.

Young's modulus is a measure of the stiffness of an elastic material. It is used also as a parameter of femoral bone elasticity; it changes with age and is influenced by bone demineralization. A greater amount of bone-metal micro-movement is seen in porous bone for a given magnitude of stress. This is why, in many series, patients with preoperative poor bone quality experienced an elevated incidence of thigh pain after THR [1, 2]. In young patients, the bone has a higher Young's modulus, a decreased displacement in the transversal plane, and hence higher stiffness for a given magnitude of stress [3]. However, younger patients have a more active lifestyle and higher loads are applied on the bone-implant system thus intensifying the sharp change of Young's modulus at the level of the stem tip.

In a living biological material, such as in bone, the disparity in stiffness between the implant and bone carries some concern for the potential failure of the prosthesis in several aspects. The stiff stem bears the majority of the load, and prevents natural loading of the femur. Areas of the femur subjected to lower interface stresses become susceptible to bone resorption over time [3, 4]. This phenomenon, the so-called stress-shielding, is more pronounced under axial loading, when distal fixation of the implant relieves the proximal femur. The occurrence of stress shielding is largely

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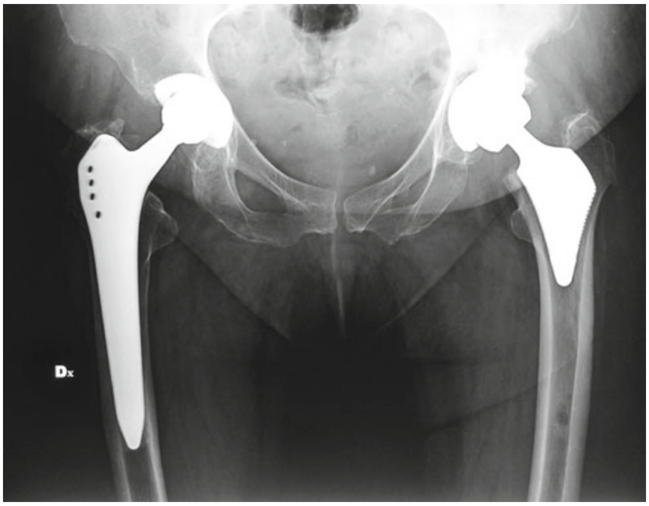


Fig. 24.1 Bilateral THR. On the *right*, a traditional Zweymuller stem at 12 years follow up. The bone-metal stiffness mismatch causes proximal bone resorption. On the *left*, 5 years follow up of a short Proxima stem. Mini hips, respecting the natural femoral flexibility, promote a positive bone remodelling of the proximal femur over time

unpredictable but a correlation with implant material and size has been proved [1, 2, 4]. With large size implants, the increased stiffness leads to higher offload [4] of the proximal bone envelope and thereby larger bone resorption (Fig. 24.1).

A second major problem of some traditional implants is thigh pain. The abrupt change of Young's modulus at the level of the stem tip is regarded as being, directly or indirectly, the main cause of thigh pain [5]. Stress-shielding creates a high stress situation due to the mismatch in stiffness between the bone-implant system proximally and the bare femoral diaphysis below the tip of the stem. Almost all traditional long implants, with any stem geometry, are, to some extent, associated to thigh pain and stress-shielding [5, 6].

The role of different implant materials, with different modulus of elasticity, was held, at least partially, responsible for thigh pain post-operatively [7, 8]. Comparison of implants that had the same design but were made of different alloys showed no significant difference in the outcomes or rates of thigh pain [7, 9]. An indirect confirmation of this aetiology of thigh pain is the high rate of success of cortical onlay strut allografting of the femur [10, 11]. The theoretical rationale for this surgical treatment involves the increased structural rigidity of the femur after application and subsequent incorporation of the allograft.

A different and somehow extreme attempt to avoid thigh pain and prevent bone resorption due to stress-shielding is the model of isoelastic stems. These implants of composite design, aimed at reproducing the natural flexibility of the human femur [12]. Unfortunately, most flexible-isoelectric stems create high proximal stem-bone interface stress, causing interface debonding, relative motion, and late femoral component loosening [13].

Mini THR and short stems are the best theoretical solution for these problems, since clearly. There is no more natural situation than the complete absence of the diaphyseal portion of the stem. Respect of the natural femoral flexibility and of the diaphyseal environment, by enforcing complete proximal load transfer, removes original sources of both stress shielding and thigh pain (Fig. 24.1).

Classification of Mini THR Femoral Implants

Mini THR of various types have been introduced with differing femoral designs. A systematic and univocal classification of mini THR is not easy. A common feature of all mini THRs is the multi-tapered profile. The tapered shape, in this application, is intended to convert axial forces into radial compressive forces hence delivering load more proximally and limiting the effects of stress-shielding [14]. Categorisation according to the implant rationale is not possible because many of these devices claim a combination of biomechanical philosophies to achieve stress transfer and initial stability.

A number of criteria for classification of mini THR devices are possible, including biomechanical rationale, size and region of anatomic invasiveness. Because of the objective difficulties of cataloguing rationale and size, we have gone for an anatomic classification based on three categories: (1) femoral head designs; (2) femoral neck designs; and (3) femoral metaphysis implants (Table 24.1).

Capping Designs

Hip resurfacing arthroplasty (HRA) is not the topic of this section and HRA technique is widely described in other chapters. HRA maintains a loading state similar to that of the native femur and it is by far the best theoretical solution for end stage hip disease in young patients [15]. This type of operation has presently met a number of early and mid term complications [16, 17].

In our experience, hip joint destruction, in the typical young active male patient is mostly the result of femoroacetabular impingement (FAI), largely as result of a cam deformity. The absence of a correct head/neck ratio in cam hips introduce a severe challenge to anatomic reconstruction during the resurfacing procedure putting the femoral neck at high risk for notching in the anterior, superior quadrant of the femoral neck and postoperative fracture (Fig. 24.2) [16].

Femoral Neck Designs

Within this group three different types of femoral neck designs can be identified (Table 24.2).

A sheer femoral neck design consists of a barrel positioned within the neck of the femur and does not invade the

Table 24.1 Classification of mini THR according to the region of proximal femoral interest

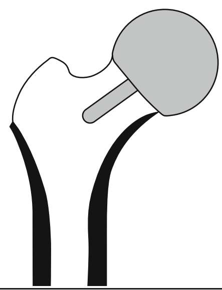
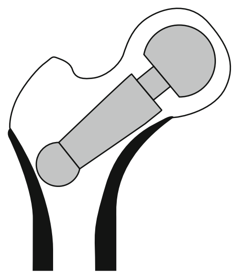
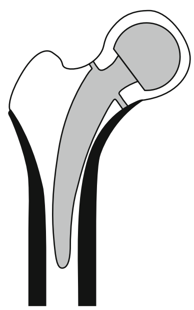
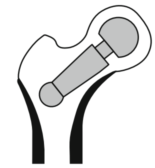
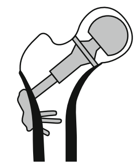
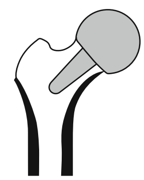
Femoral Capping	
Femoral neck implant	
Short metaphyseal implant	

Table 24.2 Three different types of femoral neck implants. For each type some of the most common devices are listed

a. Sheer femoral neck implants • Silent – Depuy Leeds, United Kingdom	
b. Femoral neck implants with side plate • TPP (Thrust Plate Prosthesis) - Sulzer Medica, Baar Switzerland	
c. Mid Head Resection arthroplasty (MHR) • BMHR, Smith and Nephew Orthopaedics Ltd Warwick, United Kingdom • Emicefalica – Lima LTO Sam Daniele Friuli Italy	

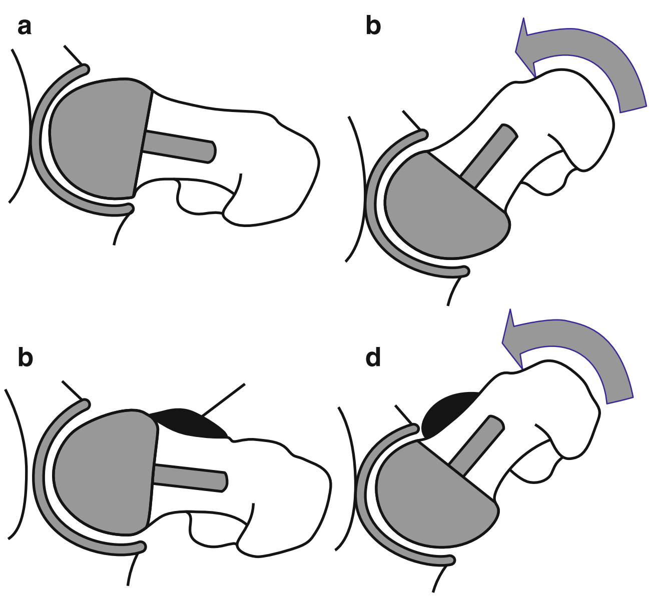


Fig. 24.2 Capping in normal and Cam hips. With a normal head/neck ratio, HRA allows a normal impingement free range of motion (**a** and **b**). In a femur with Cam deformity, HRA does not resolve impingement and promote implant malfunction, rim loading and lift off (**c** and **d**)

femoral canal. The head is applied on the Morse cone located at the proximal end of the implant. The shape and position of these devices are intended to load either the cortex or the stiff cancellous bone of the medial neck [18]. The idea is to follow and somehow reproduce the direction the trabeculae follow, from the femoral head, streaming down to the calcar, thus transmitting load on the medial femoral column. The angle the trabecular pattern form in relation to the mechanical axis of the femur reproduce the force vectors measured during motion [19]. Therefore, if the femoral neck device follows the femoral neck axis, and not the direction of the trabeculae, this model will generate a shear force component that can be decreased only by orienting the device in extreme valgus (Fig. 24.3) [18]. Unfortunately, this is technically very difficult and raises other potential biomechanical concerns and technical problems associated with the consequential reduced femoral offset [20, 21].

To counteract the shear force component, some femoral neck designs have adopted different modes of lateral support in the trochanteric region. The Wiles design [22] and the Thrust-Plate [23] design receive additional support from the use of a side plate, the Munting design [24] relies on screws alone, and the model proposed by Walker has a small spigot which passes through the lateral cortex [18].

The mid head resection arthroplasty (MHRA), even if is likely to retain the problems of metal-on-metal bearings, has recently been introduced as an alternative for young patients looking at conservative arthroplasty solutions, likely to require revision surgery in the future. A large barrel fixed rigidly into the femoral neck achieves primary stability. The MHRA technique employs an osteotomy through the

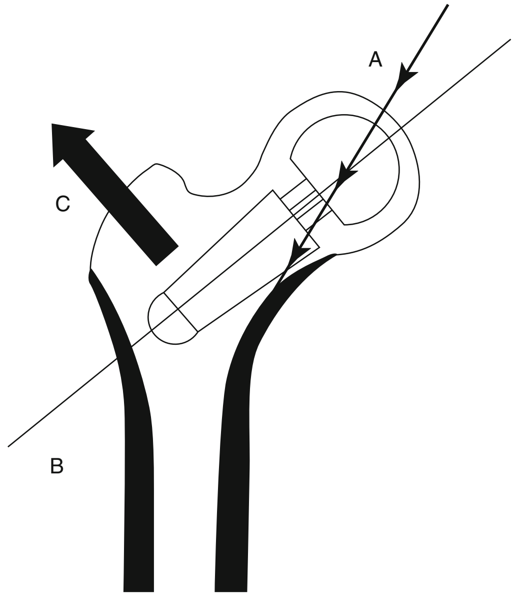


Fig. 24.3 Proximal femur with femoral neck device. Vector (**a**) reproduces the resultant of forces measured during motion applied on the medial column of the proximal femur. The angle between vector (**a**) and a femoral neck device positioned along the neck axis (**b**) produces a shear force (*black arrow* **c**)

head-neck junction and thus should provide some theoretical advantages over resurfacing [25]. As the head is excised and replaced, the level of osteotomy can be carried out few millimetres above or below the head neck junction. MHRA should allow for a precise reconstruction of the hip biomechanics and reduce the risk of impingement and edge loading including with FAI arthritic hips [16, 26].

Metaphyseal Femoral Implants

Short stem hip arthroplasty (SHA) is an attractive option for younger patients in whom the use of a true bone conserving implant without the worries of the potential devastating complications reported after metal on metal HRA [16, 17, 27, 28]. In this variety of mini THR, a wide range of short devices are currently available, with differences in design, surgical technique, and published outcomes (Table 24.3). Almost all short stems are designed for cementless fixation and are originally intended for use in young patients with good bone stock. Because of the limited dimension and lower bone-metal interface, short implants are, by definition, less forgiving than standard implants and require a meticulous surgical technique. Primary stability, as in conventional THR, is the key element for a good clinical and radiological result [6]. A number of factors influence the initial stability of both conventional and short femoral stems: geometry, surface texture, surgical technique, and bone quality. In the ideal situation, these factors provide primary fixation for the first 4–12 weeks, minimizing micro-motion and thus promoting bone ingrowth or ongrowth [29].

Implant profile has a prominent role in load distribution, in implant surface cortical/cancellous contact and primary stability. Long-traditional implants have an extended bone metal contact. Most straight or anatomical stems, achieve stability thanks to a tight mechanical fit in the lower metaphyseal region or in the proximal third of the femoral canal. As is known, even if undesired, the presence of metal in the diaphysis enhances implant stability by providing additional fixation at different levels of the femoral bone (Fig. 24.1).

Primary stability in SHA is a more delicate and sophisticated issue. The limited bone metal contact requires a very effective design to achieve the same stability that is normally reached with a longer implant.

Primary stability requires control of both rotational and axial forces. The first cementless implants, and most of the currently available standard femoral stems, engage the femur in the metaphysis and distally in the femoral diaphysis. Rotational stability is mostly attained by the bone-metal contact at the level of the diaphysis [6]. The standard neck cut, for traditional THR, is 1 cm above the lesser trochanter, therefore removing almost all the neck. Such kind of neck cut does not fit properly with sha since most small implants rely on the neck cut above all for rotational stability. Whiteside et al., in 1995, demonstrated that preserving the femoral neck could effectively reduce micro-motion and increase torsional and axial stability [30].

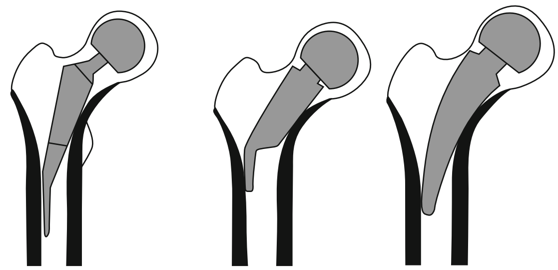
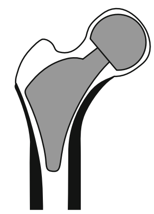
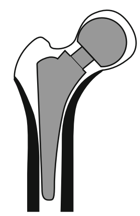
Nowadays, a common feature of SHA is a bone resection level right under the femoral head, in order to preserve as much as possible of the femoral neck. The only device categorised as "short", which is implanted with a standard low-neck cutis the MAYO stem. This is also the first short implant popularized by Morrey in 1989 [31]. All other SHA achieve rotational stability thanks to a high neck cut.

Control of axial forces is a crucial issue for SHA and we can identify, within the presently available short stems, two different models of axial stress transfer. The first is a replica of the classic Koch's theory [32] of load distribution applied to short devices. The second relies on a revisited model of hip biomechanics [33].

Axial Stresses Transfer in Koch's Model SHA

According to this theory, natural femoral loading produces tensile stresses on the superior neck and the proximal lateral three quarters of the femoral shaft. Conversely, the distal, lateral and the entire medial aspect of the femur will be subject to compressive forces. This was the state-of-the-art representation of hip biomechanics for many years and succeeded as the source for development of all traditional cementless

Table 24.3 Classification of short metaphyseal implants in three different sub groups (a, b, c) according to their biomechanical rationale

A. Claassic koch model of load transfer •Metha – BBraun Aesculap, Tuttlingen, Germany •Nanos – Smith and Nephew Orthopaedics Ltd, Warwick, United Kingdom •Mayo – Zimmer, Warsaw, Indiana •CFP (Collum Femoris Preserving) - Waldemar Link, Hamburg, Germany •Mini Hip – Corin, Cirencester, United Kingdom •Collo-MIS - Lima LTO, San Daniele Friuli, Italy •Cut – ESKA, Lubeck, Germany	
B. Latral flare model of load transfer Proxima – DePuy, Leeds, United Kingdom	
C. Short version of pre-existing implants •Taperlock Microplasty - Biomet, Warsaw, Indiana •Balance Microplasty - Biomet, Warsaw, Indiana •Brevius – Zimmer, Warsaw, Indiana	

The ESKA Cut is included in sub-group A and not in the femoral neck group because the tip is studied to lie adjacent to the lateral femur of Gruen zone 2 therefore sharing the same biomechanical principles of other SHA

THA systems. In this model, all axial loads are delivered on the calcar, and the long stem fixed in the femoral intramedullary canal halted varus migration of the implants. All SHA implants, excluding the PROXIMA hip, have been designed applying a shortened version of the classical Koch's model [31, 34–40]. By delivering the load only in the calcar region, a shear force is created, and therefore, to counteract the varus moment on the implant, the distal tip of the stem, no matter how short it is, must rest on the lateral cortex of the femur (Fig. 24.4). This means that the load distribution mechanism closely resembles the traditional long stem design, the only difference being the area of bone-metal contact used to neutralise the varus moments is smaller.

The possibility of varus tilt raised concern with the short stem, whether the stability of the fixation can be obtained without diaphyseal fixation. However, supporters of short tapered implant, simply dismiss this point stating that historically, varus malalignment of tapers has not impaired clinical results [41, 42]. These arguments were refuted, as in both these studies the tapered stem were bulky and large such as the ALLOCLASSIC hip implants (Sulzer, Zurich, Switzerland).

Morrey, in 2000, observed the appearance of a neo-cortex and increased cortical density in 55 of the 162 implants at an average of 6.2 years follow up, most commonly in zone 2

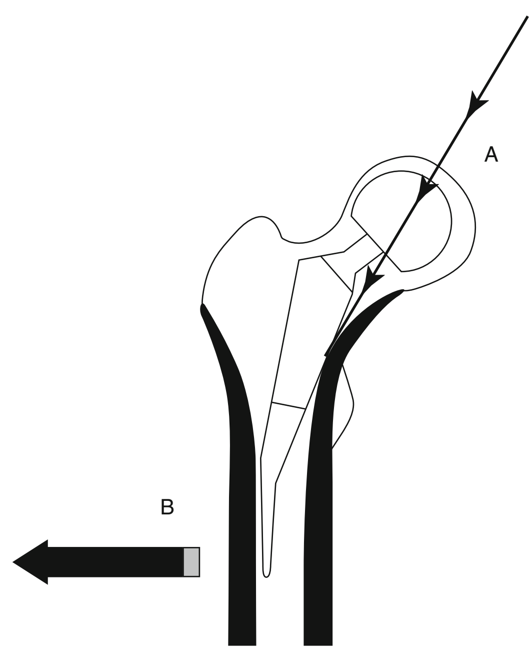


Fig. 24.4 Proximal femur with SHA of sub-group A. According to biomechanical rationale of this sub-group, the load (vector **a**) is delivered on the calcar and the tip of the stem lays on the proximo-lateral cortex to counteract varus migration (*black arrow* **b**)

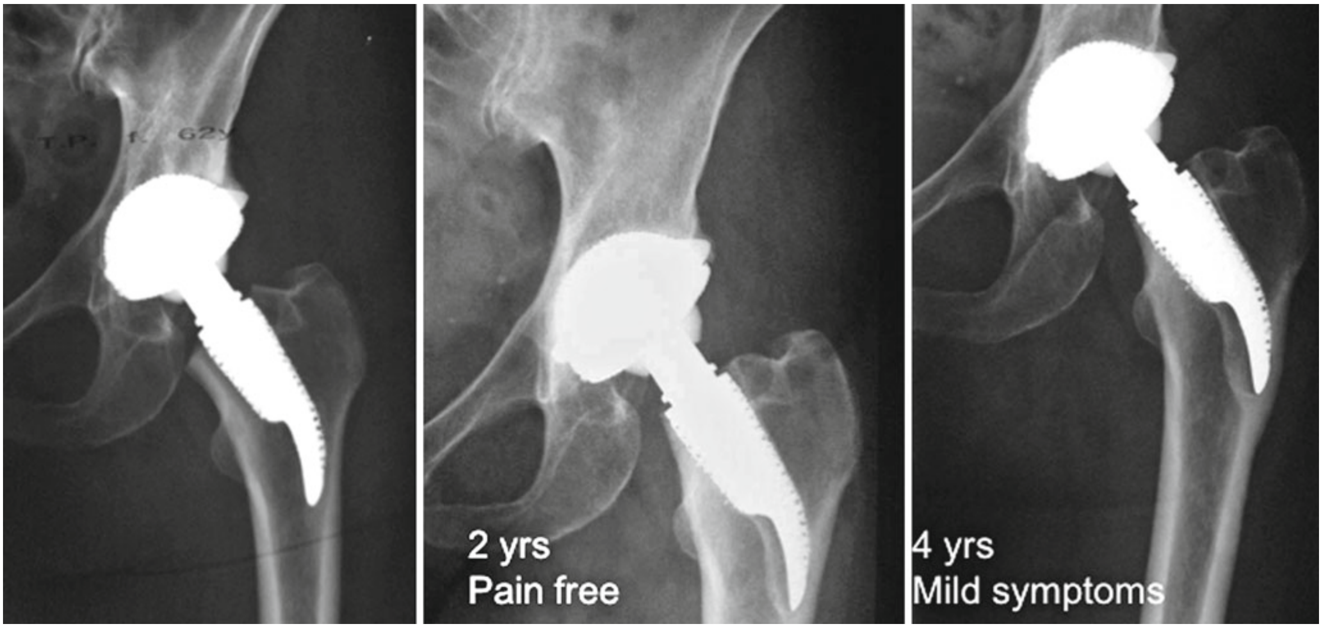


Fig. 24.5 Progressive varus migration of ESKA Cut implant. This patient was pain free for the first 3 years notwithstanding progressive cortical hypertrophy in Gruen zone 2 and varus tilt. The evolution of the negative bone remodelling confirm the poor biomechanical model

[34]. His opinion was that this finding had to be considered beneficial and evidently indicated femoral remodelling rather than stress shielding. Lateral cortex hypertrophy was reported also by Falez with the MAYO [43] and a comparative DEXA analysis between different femoral designs confirmed a prevalence of distal stress transfer along the MAYO stem to the lateral femoral cortex and stem tip [44]. Progressive varus migration associated with cortical hypertrophy is the most common mechanism of failure of the ESKA Cut femoral neck stem (Fig. 24.5) [36, 45]. This is the shortest implant affiliated to this group of mini THR. Ishaque et al. reported an unacceptable 30 % (28 of the 82 hips) revision rate after an average 8 years follow-up [45].

In conclusion, with this mode of load transfer, the proximal-lateral cortex (Gruen zone 2) is loaded, confirming that this biomechanical model generates shear stress. If bone quality is suboptimal, or bone-metal contact in this area too limited, this leads to varus tilt and early loosening [36, 45]. If, on the other hand, bone quality is good and the bone-metal contact is large [34], then implant survival is possible, with favourable down-regulation of bone remodelling [34, 43, 44]. Other implants in this category [35, 38, 39], with the same mode of load transfer, have intermediate dimensions and very short follow up. Therefore it is not sure yet whether they will behave, over time, in the same manner.

A final group of stems have recently been added in this category. These implants are created by utilising only the upper one-third of pre-existing corresponding traditional long implants and don't adopt any design of the modifications states above. This seems a market strategy promoted by some medical companies aware of the increasing interest in SHA rather than the development of an authentic innovative implant (Table 24.3c).

Axial Stresses Transfer in Lateral Flare SHA

A finite element investigation, comparing a straight with a lateral flare femoral implant, showed that, in the latter, all interface stresses were proximal, leaving the lower half of the stem unloaded [46]. This happens, most likely, because load distribution in the proximal femur does not occur as calculated with the static Koch model [32]. Indeed, a re-examination of hip biomechanics, through the inclusion of muscles and ligaments in a dynamic, more physiologic situation, demonstrated that compressive loading is generated both laterally and medially throughout the femur distal to the greater trochanter [33]. The iliotibial band and the gluteus medius – vastus lateralis complex operate as a dynamic tension band along the lateral side of the thigh during the unilateral support phase of gait [33]. Therefore, when the body weight is applied and the muscles taut, the lateral proximal femur does not work in tension but in compression (Fig. 24.6) [18, 46–50].

In this model of load transfer, the addition of a lateral flare, engages the endosteal surface of the lateral femur, and delivers compressive loading to the very upper portion of the lateral femoral column (Fig. 24.7). The homogeneous distribution of forces on both the medial and lateral femur abolishes the moment, which may produce a varus tilt [33, 46, 48, 49].

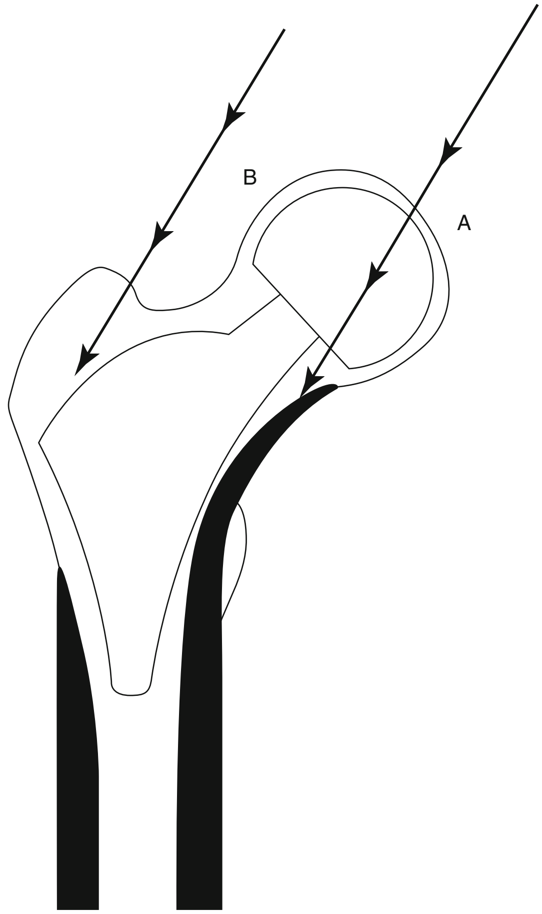


Fig. 24.6 Proximal femur with SHA of sub-group B. According to biomechanical rationale of lateral flare implants, compressive forces are delivered both on the medial (**a**) and on the lateral (**b**) columns. In this model no shear forces are produced

In lateral flare implants, the 'metaphyseal' breadth of the stem is markedly wider than the diameter of the upper femur. A broader base of support in the metaphysis grants a more physiologic load distribution in the proximal femur [46]. The stem rests upon the proximal lateral and medial cortices or on the stiff cancellous bone of this region, building an inherently stable construct [49]. Removal of the diaphyseal portion of the implant in this model of load transfer has a strong biomechanical rationale [18, 33, 46, 48–51].

Extensive spot-welding bordering the lateral flare of ultra short implants confirms the effectiveness of this load transfer mechanism [50–57]. In our practice, we have acquired a preference for under-sizing the lateral flare of short implants in young patients (Fig. 24.8). Primary stability, with good bone quality, is effectively achieved in spongious bone which promotes positive bone remodelling of the trabeculae, and thereby encouraging load transfer to the lateral column of the femur [52, 53, 58].

Results from up to 14 years of follow-up of lateral flare implants with high femoral neck resection, and no diaphyseal stem, has shown no failure of the femoral component, no thigh pain and progressive bone remodelling with deposition of new bone around the implant [52]. Other studies have recently reported gratifying clinical results, absence of thigh pain and confirmed the effectiveness of this load transfer model in young patients [51, 55–58].

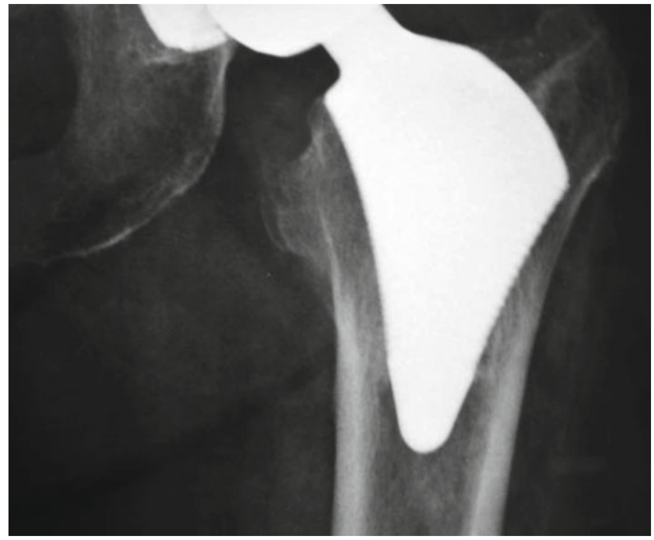


Fig. 24.7 Proxima hip at 5 years follow up. Extensive medial and lateral spot welds denoting proximal load transfer and positive bone remodelling

Fig. 24.8 Proxima hip at 4 years follow up in a 42 years old patient. With good bone stock, lateral flare implants may be effectively seated in metaphyseal spongious bone with no varus migration. Spot welds streaming to le upper lateral femur are visible. The small implant is medialized thus allowing perfect hp anatomy reconstruction

In addition, Kim et al. [54] have adopted the use of a lateral flare short stem devices inserted in elderly patients, and have also demonstrated it is possible to achieve optimal fixation without diaphyseal anchorage.

Bone Remodelling After Mini THR

Proximal bone resorption is commonly seen after insertion of an uncemented stem. The average decrease in BMD has been reported to be between 4 and 45 % [59–61]. The mutual opinion is bone mineral density (BMD) decreases the first and second post-operative years after THR, followed by a progressive recovery [62]. Unfortunately, this is not always the case and some anatomical designs have shown progressive proximal bone resorption 7–10 years after hip replacement, in over of 50 % of the patients [63]. With some implants, the percentage of patients with proximal bone resorption, loss of trabecular bone density, proximal cortical thinning, and distal cortical hypertrophy continue increasing over time [64].

Capello et al. [65] examined plain radiographs of cementless proximally HA-coated stems followed for a minimum of 15 years post-THA to evaluate the incidence, nature and progression of late remodelling. The average age of these patients at the time of surgery was 51 years. In this study, the Authors observed that adaptive remodelling did not stop after the first few years and, in a number of hips, the area of cortical hypertrophy transferred distally over time. Therefore, in these hips, stress transmission moved from proximal to distal over time and 47 of the 145 patients developed generalised cortical porosis 15 years post-THA. In this same group of patients, cortical porosis was present only in 1 hip at 5 years and 7 hips at 10 years follow up. Similarly, Berry et al. [66] examined long-term serial radiographs of well-fixed stems with a minimum of 15–20 year follow-up. A time dependent cortical thickness decrease around all stems was recorded. They noted a 57 % decrease in cortical thickness around extensively porous coated cobalt chrome stems and 17 % overall bone loss around proximally porous coated anatomic metaphyseal filling stems.

Such negative remodelling, in a young cohort of patients, may definitively threaten implant survival and generate future difficulties when revision surgery is planned (Fig. 24.1).

One of the supposed advantages of SHA it is a better bone remodelling over time. Very few investigators have studied bone behaviour after SHA. Different short implants, with different philosophies, inspire apparently different bone response. Brien [67], reported a pattern of remodelling with appearance of cortical thickening in the distal part of the CFP stem thus confirming negative proximal bone remodelling with this device. This data has already been observed by other Authors [44]. Schmidt [68], has recently found progressive proximal cortical bone density loss between 1 and 3 years after surgery and concluded that metaphyseal fixation could not be achieved with the CFP design.

Calcar atrophy, distal stress transfer and thickening of the lateral femoral cortex are common features of the MAYO stem [31, 34, 43, 44]. The METHA and NANOS stems mimic, to some extent, the shape and the biomechanical principles of the MAYO stem [43]. Presently, there are no reports on the pattern of bone remodelling around the METHA stem, whereas, the NANOS stem, triggers an increase of BMD in the lateral inferior region of the femur, resembling MAYO results in as early as 1 year after implantation [39]. Overall, the Authors concluded that NANOS stem guarantees good short-term clinical results, but not the desired load transfer in the metaphyseal region of the proximal femur [39]. Progressive periprosthetic radiolucency's, increasing cortical hypertrophy in zone 2 as well as atrophy of the calcar have been described after implantation of the CUT stem [45]. Cumulative survival of this device, with revision as a primary end point, was 49.6 % at 8 years.

Lateral flare SHA has extensively been studied with conventional radiology and dual energy X-ray absorptiometry (DEXA) scan [44, 52, 53, 58, 69]. Progressive positive bone remodelling with spot welds bridging metal and the endosteum along the metaphyseal trabecular pattern suggestive of a physiological model of strain transfer, were observed at average 8 years follow-up [52]. Deposition of new bone, close to the lateral flare of the implant, implies that lateral

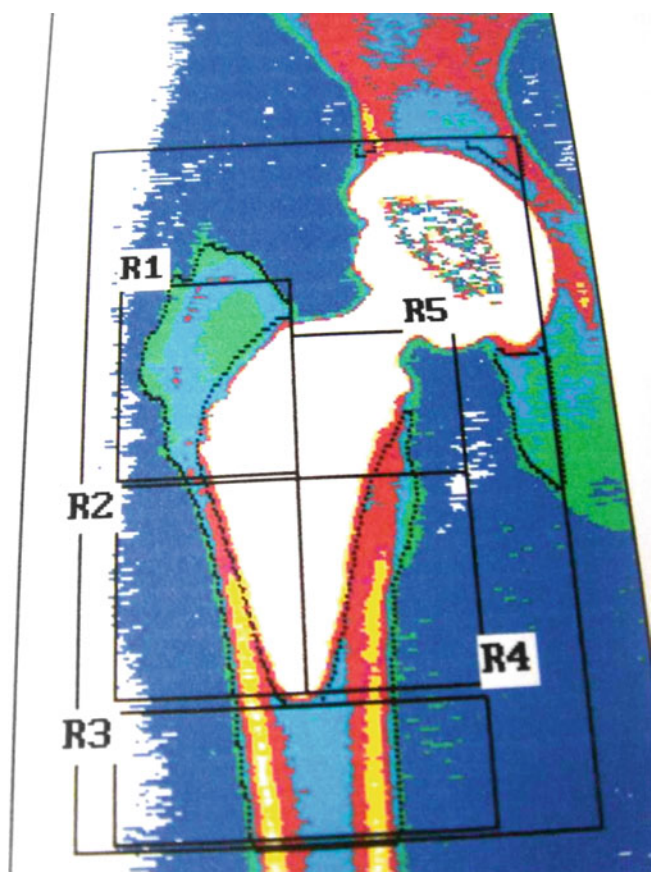


Fig. 24.9 Dexa scan of al lateral flare implant 5 years after surgery

column of the femur is physiologically loaded preserving its natural function [51, 54, 55, 70]. A DEXA evaluation of a stemless lateral flare implant showed a 9.5 and 9.4 % increase of bone mineral density (BMD) in lateral flare and calcar region respectively [58]. The more physiological pattern of strain in the proximal femur provided by lateral flare SHA promotes a better evolution of periprosthetic bone remodelling (Fig. 24.9).

Conclusions

Mini THR appears a valuable solution for young patients facing joint replacement. However, to date, it is not possible to state that mini THR, including, hip resurfacing, may allow a more active lifestyle and a superior return to sporting activity. Duration and magnitude of repetitive load produce wear-related problems caused by bearing surfaces performance rather than from implant dimensions [71–73].

The effect of physical activity on THR outcomes in young active patients is still largely unknown and, when asking whether sports can be permitted after THR, patients usually receive a variety of answers. The only possible sincere response, nowadays, it is that the possibility to return to high impact sports depends on the resistance of hard on hard surface coupling at long-term follow-up. This data it is still largely unknown. Therefore, it is not justified to present mini THR, claiming a greater prospect of a normal athletic life. The question whether a patient can or should do a specific activity remains unresolved, and related more to the surgeon's experience and belief rather than the existence of long-term follow up studies.

As longevity of cementless femoral components enters its third decade, concerns arise with long-term effects of fixation mode on femoral bone remodelling [65]. Young patients face a higher risk of implant failure which, when coupled with longer lifetime expectancy increases the likelihood of one requiring revision surgery [74]. Negative bone remodelling observed after traditional THR [59, 61, 63–66] may increase the surgical challenge of revision surgery and decrease the possibility of achieving a solid anchorage of the subsequent implant.

Mini THR, to an extent, offer a more physiological strain distribution by abolishing or at least reducing the risk of distal load transfer. HRA and lateral flare SHA promote the best bone remodelling and preservation of bone stock over time. This appears, nowadays to be the main reason to support the use of these devices.

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25 Rehabilitation from Hip and Groin Surgery

James Moore

Introduction

Assessment of groin pain in the young adult population is complex and requires a systematic and integrated approach to create a marriage between the history, the investigations used and the physical examination. Through this process it is possible to ascertain the relationships between the primary and secondary conditions or clinical entities Holmich, and accurately identify the source of pain verses the source of dysfunction.

Historically when describing groin pain in athletes, the term "Athletic Pubalgia" is often used to imply the insidious onset, complex and persistent nature of groin pain in professional athletes. Therefore, it is not unreasonable in academic terms to describe groin pain much like we do with low back pain, where we use the term non-specific low back pain, and thus we use a regional description to encompass a range of musculoskeletal conditions that may cause this pain.

From a literature-based process, we have moved to using terms such as; adductor–related; abdominal-related; pubic joint related; hip joint related. The challenge for the clinician is to be able to apply the knowledge from the literature that describes regional problems, that may be non-specific in nature, to clearly identifying the anatomical structure and pathological process that needs immediate treatment and management.

Groin Pain Overview

Groin pain and tenderness are common in athletes from a variety of codes of football, skiing, hurdling, and hockey. These are all sports that involve high-speed torsion of the trunk, side-to-side cutting, kicking, quick accelerations and decelerations, and sudden directional changes, and encompasses sports that require specific use (or overuse) of the proximal musculature of the thigh and lower abdominal muscles.

In Europe, this problem is most common among soccer players, and the prevalence has been estimated from 5 to 28 % [1].

In the acute setting the most common causes of groin pain in athletes are musculotendinous injuries to the adductor and hip flexor musculature, with less common, but not to be excluded lower abdominal strains to the fascial and tendinous insertions.

Per Renstrom [1] outlined the possible mechanisms for groin injury specific to football to be; an imbalance between the adductors and the abdominals, an imbalance between the anterior and posterior chains, elasticity of the pubic symphysis, a combination of abdominal hyper-extension and thigh abduction with the pivot point being the pubic symphysis, a pull on the strong adductors may weaken the posterior abdominal wall. And estimated the prevalence male > female (~3:1).

Acute injuries are usually fairly straight forward during the diagnostic process, the key comes in identifying any underlying chronic problem that may have predisposed to the acute injury and will influence the treatment and rehabilitation process.

Acute groin injuries may become chronic if not effectively managed, as the damaged tissues will have a reduced load bearing capacity and will be likely to deteriorate further under load.

Persistent injuries are much harder to evaluate and manage as the chronicity of groin injuries increases so does the likelihood of more than one discrete pathological entity occurring. In this scenario a multifactorial approach to examination and treatment if often required. Furthermore the damaged tissues cannot function normally, making it likely that the biomechanics of the region will be subtly changed, causing relative overload and possible injury to other structures.

Puig et al. [2] following a systematic review of the literature concluded that the pathophysiological processes of this lower abdominal pain resulting from over use is unclear, but muscular imbalance might be involved in the pathogenicity.

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This is interesting when you look at Cowan et al. [3] who studied the relationship between motor control of the pelvis and long standing groin pain in 10 symptomatic and 12 asymptomatic AFL players. They showed that the asymptomatic players were able to perform an active straight leg raise (ASLR) task with Transversus abdominus contracting in a feed-forward manner, but in the symptomatic players there was a delay in TvA alone, with all other abdominal muscle working normally.

However, caution is needed in extrapolating too much information from this study and applying it inappropriately. But it serves to highlight that clear differential diagnosis may not always be possible, and sometimes there is a need for an indirect diagnosis, to ascertaining the route cause of the dysfunction first before the clinician can address the anatomical pathology.

Principles of Assessment

The most critical part of any assessment is the history taking, and getting the "story" right. This needs to be compiled of open-ended questioning and specific questions to tease out the components of the presenting problem, do not be afraid to ask direct and specific questions that require a closed answer, if the assessment is left too open then it may result in the clinician chasing the problem, becoming frustrating for both the clinician and the patient. Asking the appropriate questions should be based upon a thorough understanding of the literature, the underpinning science and the patterns that have been demonstrated.

Greater light on the history can be placed when one combines the information from two authors published, that of Bradshaw [4], Holmich et al. [5] and Holmich [6]. We can gain a lot from these authors who have advanced the knowledge of groin pain over a number of years.

Holmich, was the first to propose the notion of looking at the groin in terms of clinical entities, rather than trying to come up with one clear anatomical diagnosis, he presented the notion of accepting that there are multiple clinical entities that can co-exist, and as a result try and highlight which is the primary driver in the pain process.

Holmich et al. [5] has done an intra and inter reliability study of athletes with groin pain. He was able to show a good physical examination could accurately differentiate between clinical entities. The protocol was designed to detect one or more pathoanatomical structures associated with symptoms. A good place to start; abdominal groin pain OR adductor groin pain OR hip pain.

His results were able to show that there was clinical overlap in 40% of the cases. However, he did not use investigations as part of his diagnostic pathway, nor did he consider the hip joint as part of the examination. Of the 207 athletes he examined, he was able to show that the primary complaint in 57.5 % (119) was adductor related, with Ilio-psoas-related being primary in 35.3 % (73). However, possibly slightly more interesting is the fact that of the 33.3 % (69) of athletes who had a secondary complaint, Ilio-psoas related pain was present in 19.3 % (40). The majority of which were females who ran in a straight line.

This point is relevant when you compare it to Bradshaw's study [4] where he examined 208 patients, and found that hip pathology was present in 44 %, adductor related in 23 %, and psoas in only 7 %.

The comparison of these two studies, taking into consideration their limitations, may lead you to believe, that Iliopsoas related pain, is potentially a presentation that occurs in relation to hip joint pathology, or at the very least the Iliopsoas muscle in the presence of other pathology takes on a guarding role to "protect" the groin region, and thus is rarely the primary problem.

Of note, neither study, identified a high incidence of abdominal related groin pathology or sportsman's groin (2–6 %).

History

Location of pain – Greg Lovell, in a review of 189 cases, looked at the final consult what was the end diagnosis/pathology that was treated and compared it to the location of pain that the patient had complained of at the initial consult. He was able to show a strong correlation between the area of pain and the pathology involved Malycha and Lovell [7].

Anterior thigh – Iliopsoas, Hip pathology, NOF stress #
Inguinal Canal – Incipient hernia
Pubic Region – Osteitis pubis, Pubic Instability
Inner thigh – Adductor lesions, Obturator neuropathy

This was further enforced by Falvey et al. [8] who was able to show a correlation with the location of pain in reference to the groin triangle and its association to the underlying pathology.

Despite this correlation it is important to remember that with groin pain multiple diagnoses are common:

Nonmusculoskeletal Causes – Psoas muscle abscess, Spine problems, Hernia, Endometriosis, Ovarian cyst, Peripheral vascular disease.
Unknown Etiology – Transient osteoporosis of the hip, Bone marrow edema syndrome,
Synovial Proliferative Disorders – Pigmented villonodular synovitis, Synovial Chondromatosis, Chondrocalcinosis
Metabolic Causes – Paget disease, Primary hyperparathyroidism,
Extra-Articular Pathology – Coxa saltans (internal or external), Psoas impingement, Abductor tears (rotator cuff tears of the hip), Athletic pubalgia, Trochanteric bursitis, Ischial bursitis, Osteitis pubis, Piriformis syndrome, Sacroiliac pathology, Tendinitis (hip flexors, abductors, adductors).
Traumatic Causes – Subluxation or dislocation, Fracture or stress fracture, Hematoma Contusion, Labral Pathology,

Femoroacetabular impingement (FAI), Hypermobility, Trauma, Dysplasia

Infectious/Tumorous/Metabolic Conditions – Septic arthritis, Osteomyelitis, Benign Neoplasms of bone or soft tissue, Malignant neoplasms of bone or soft tissue, Metastatic disease of bone

Inflammatory Conditions – Rheumatoid arthritis, Reiter syndrome, Psoriatic arthritis,

Chondral Pathology – Lateral impaction, Osteonecrosis, Loose bodies, Chondral shear injury, Osteoarthritis,

Capsule Pathology – Laxity, Adhesive capsulitis, Synovitis or inflammation

To further complicate the matter, Mitchell [9] reviewed 81 patient's pre hip arthroscopy (53 female) and found an average of 6.4 sites of pain, with the pain being experienced any where from the lumbar spine to the calf and shin. To note all 81 of the patients had deep inside anterior groin pain as their primary complain. There was an average symptom duration of 4.3 years, which may account for the many different pain locations as various different compensations would have occurred. The other interesting finding from this study is that 60 % of these patients were not diagnosed with hip pathology on their first consult.

Groin localisation is important but may be difficult, as it may be felt in a number of different areas simultaneously [10].

Presenting complaint – listen closely to the choice of words, as this can often give an indication of the structures involved (joint, muscle, nerve), in general a pain that is vague, deep and non-specific (it covers an area) is likely to be joint in nature (hip or pubic joint), A sharp pin point pain brought on by a specific movement may be indicative of a muscular problem. Simplistically, ask "can you put one finger on the problem", if they can this is more indicative of a specific muscular problem, e.g. sportsman's groin, however, if they use the flat of their hand, or cannot localise, then it may indicate a deeper seated problem from the joint, or overlapping clinical entities. The Orthopaedic surgeons, make reference to a "C" sign in relation to hip joint pain, where the patient cups the hip joint between their index finger and thumb and says "it is in here".

The age of the patient can be a big indicator of the type of pathology. Different conditions occur at different age groups e.g. irritable hip syndrome (10–15 years) vs. OA hip degeneration (>45 year typically). ROM decreases with age; Congenital hip dysplasia is seen in infancy, primarily in girls; Legg Calve-Perthes disease more common in boys aged 3–12; Elderly women are more prone to osteoporotic NOF fracture. Do not miss slipped upper femoral epiphysis (SUFE) which typically occurs in 12–15 year old overweight boys (4:1), with an incidence of 3 per 100,000, they commonly present with a limp, and medial thigh pain.

Always ask if there was an incident or specific mechanism of injury, often the injury has occurred during a sporting movement and thus the exact mechanism cannot always be recalled, or there has been a gradual onset of worsening symptoms, that have not hampered sports but just resulted in reduced performance, and as a result the patient is presenting some months (or even years) down the line. In these scenarios it is important to try and differentiate as much as you can.

Bradshaw el al. [4] was able to show that the type of activity was also correlated to the pathology, in that if you were involved in a kicking sport there was a greater incidence of developing pubic pathology, however, if you were involved in a twisting sport (without kicking) or you ran in straight line, the incidence of hip pathology was greater.

When trying to ascertain the irritability, do not just ask about aggravating and easing factors, be specific with your functional questions (examples below), but try and find out about, movements they avoid, or they feel weak or a loss of power when performing, or even just a lack of confidence. The patient may well have avoided certain movements for some time in order to function and they have forgotten by the time they present for the consultation.

Examples of specific questions are:

(a) Putting on socks & shoes/trousers – generally done the same time every day, so gives a level of functional outcome, and will impingement the hip and groin.
(b) Climbing up and down stairs – gives a functional outcome of single leg stance and load on the hip and hemi-pelvis.
(c) Getting in and out of the car/bed – possible inflammatory component if first thing in the am, or just the mechanism of impinging the hip and tensile loading the groin.
(d) Driving for long periods – sustained compressive load on the hip, or over-activity of the hip flexors with relation to subtle pelvic dysfunction.
(e) Sleeping/rolling over in bed – classically related to the hip joint, but can be pubic joint in nature.
(f) Abdominal work (sit up)/coughing – classically related to a sportsman's groin, but also can be associated with a pubic joint injury.
(g) Accelerated/unguarded movements – associated with groin disruption
(h) Catching/giving way/'grasp sign' – classically associated with a hip joint pathology.
(i) Overuse injuries account for up to 80 % of athletes presenting with hip & groin pain [11].

In essence you are trying to establish a mechanism of injury for the groin injury, which can be summed up into two words "exceeded capacity". Those two words incorporate the following.

- The area was not strong enough
- There was a muscle imbalance and poor synergy
- The load was so high that anyone would have been injured
- Were they fatigued?
- Do they have altered movement patterns or altered motor control

- Was there a change in their compliance of their tissues (timing of contraction from eccentric to concentric), the body of evidence is now really clear that flexibility does not have a strong correlation to injury or to reducing the risk of injury.

There is always an extensive differential diagnosis, with up to 30% of all athletes having multiple pathologies (Lovell 1992) meaning that you may have up to three or more working hypotheses at any one time.

It is easy to find an adductor strain or tendonopathy, but miss the underlying hip pathology that predisposed the condition. This should be reflected in your questioning, the clinician needs to tease out every detail, otherwise there is an incomplete history, which may lead to an inaccurate diagnosis.

Physical Examination

It is also easy to attribute a complaint to a musculo-skeletal dysfunction without having a working hypothesis as to the ongoing pathology, e.g. a movement dysfunction at the hip into extension, due to poor gluteal activation and tightness of Iliopsoas TFL, and the adductors, but there is an underlying hip synovitis.

That said sometimes all you can do is address the underlying abnormalities, until you have a solid working diagnosis. One must always keep an idea as to the possibilities of the underlying pathology while going through this process.

For every test carried out you should ask yourself two questions:

- Does it add to the picture already formed?
- Am I reliable?

Having a systematic approach will help to make sure that all bases are covered.

When conducting the physical examination, always inspect the area, looking for any bruising, swelling or colour changes. If it is not appropriate because of the age or gender of the patient, then ask them whether they have noticed any of the above while in the shower?

It is important to observe how they move, as everyone moves differently, this movement observation needs to be related to the demands of their sport, or physical activity.

From the literature there are only a few tests that have been researched to try and find a correlation with clinical testing and groin pain.

Verrall [12] performed three clinical tests on 89 AFL players with and without groin symptoms. The three tests used were single adductor test, squeeze test, bilateral adductor test. The three pain provocation tests demonstrated only moderate sensitivity (range 30–65 %). Positive predictive values were moderate to high (67–93 %) depending upon the individual test. The Bilateral Adductor test was the most sensitive test with the highest positive predictive values.

Verrall later demonstrated a reduction in hip range of motion in athletes with chronic groin injury diagnosed as pubic bone stress injury [13].

Holmich (2004) investigated clinical examination techniques for groin pain in athletes and evaluated the reliability of these tests in 18 athletes (9 symptomatic, 9 controls). The examination techniques used were; long lever squeeze tests for pain and strength, pain on palpation of Adductor longus insertion, pain on passive abduction, pain on palpation of the pubic symphysis, pain on palpation of the Rectus abdominus muscle insertion to the pubic bone, pain and strength on a resisted sit up, pain on palpation of psoas, pain and strength of the Iliopsoas muscle, pain and tightness on passive stretching of Iliopsoas. The only test without acceptable interobserver reliability was the strength test for Iliopsoas.

Diagnostic examinations may or may not prove helpful in formulating a final diagnosis. There are various different combinations of investigations that can be conducted to ascertain the true nature of the pathology in the groin. Invariably, this cannot be done with one investigation, the challenge for the clinician is to pick the combination of investigations that provides the most clinically relevant information that adds to the presentation.

In summary, when taking your history and conducting your examination of the patient, it is important to:

- Listen to the patient
- Build the picture, by applying the science in the literature to the presentation in front of you
- Look for the patterns described in the literature
- Be aware of your beliefs and biases.

Always ask yourself when planning the objective

- Is my test valid
- Am I reliable
- Does it add to the picture? Or is it just an unrelated dysfunction?
- When assessing try and prioritize the areas into clinical entities

At the end of every consultation, try and conclude by having three working hypotheses:

- Anatomical – Adductor longus vs. conjoint tendon vs. intra-articular hip joint
- Pathological – reactive enthesopathy, inflammatory, tear, degenerative
- Functional – what movement discrepancies or weaknesses may have led to the problem

Adductor Related Groin Pain

Adductor Muscle Strain

In sport the most common injury to the groin is likely to be an adductor strain. Ekstrand et al. [14] reported that 13 % of all injuries in one season of the Premier League (n = 326) were adductor muscle injuries. O'Connor [15] reported that 23 % of all injuries over two seasons (n = 100) in rugby union occurred in the adductor muscles. While Molsa et al. [16] commented that in ice hockey adductor muscle injuries accounted for 43 % of all muscle strains over three seasons (n = 134).

As previously mentioned the pelvis is a force producer and the highest net force often occurs here. When developing power (force x velocity) there are huge muscular actions at the pelvis trying to generate speed of movement when accelerating, cutting, twisting, and kicking. Torry [17] describes the role of the adductors as working as a brace around the hip joint, in that, they work with the hip abductors to maintain pelvic stability during stance phase in gait and running, while simultaneously, dampening the contraction of the abductors after the propulsive phase.

In the acute phase there are three types of adductor injuries [18]

- Bony avulsion
- Avulsion of the fibrocartilage (enthesis)
- Tear at the musculo-tendinous junction

The latter most commonly occurs at Adductor longus (70 %), with Magnus second (15 %), it is less common to damage the other adductor muscle (15 %) [19]. These injuries should be straight forward to manage, however, Orchard et al. [20, 21] reports that there is a recurrence rate of 22 % in the AFL of adductor strains. This observation goes far to highlight the complex nature of the mechanics around the groin.

As far as the enthesis (the fibro-cartilaginous join from tendon to bone spanning approximately 1–2 mm, and largely avascular) goes Adductor longus has a unique one in that in a sagittal section, coronal view, appears like a triangular fibrocartilage, perfectly designed to absorb the tensile and shear forces of the oblique nature of the adductor longus tendon.

The diagnostic challenge for the clinician is to be able to distinguish between an acute strain to a "healthy" muscle and a strain to a muscle that has adaptive changes, i.e. neural overactivity due to radiculopathy, or early signs of tendonopathy.

Presentation is likely to occur after a sudden change in direction, or an eccentric adductor muscle contraction with concurrent hip external rotation and abduction (mechanism in most football codes). It will be well-localised and tender to palpation, with pain on passive abduction, pain on resisted adduction or combined flexion and adduction. By varying the degree of rotation, the lever arm and the range that the leg is tested in, it may be possible to determine which adductor is injured.

Management

Adductor Muscle Injuries

Inflammation is our friend in the first 48 hours, so we avoid the use of NSAID's, ice and compression is critical, it is thought that compression is more important as it can influence the swelling and the pacinian corpuscles in the skin and thus influence both pain and reflex inhibition. Early movement is useful, however, you want to avoid any stretching for the first 48–96 hours, as often because of the common innervation and functional similarity, if one of the adductors has been strained the other muscles in the group respond by increasing their tone and thus guarding the area, any attempt at increasing range in the short term may provide an increase in strain rate to the guarding muscle group and the joint, and if there is an underlying joint dysfunction this may delay healing and perpetuate the pain cycle.

The same principle applies for direct soft tissue work. Finally there is a propensity in elite sport to travel to get the latest treatment for the injury, the merits and risks have to be weighed up between the strain placed on the groin with flights lifting heavy bags and travelling versus the virtues of rest. The same principle applies to a weekend warrior who has hurt his groin playing in a Sunday league, and wants to come in for treatment on a Monday morning, the benefit gained from 30 to 60 min treatment versus the value of resting for 24–48 hours before travelling needs to be weighed.

The merits of early injection therapy is discussed in the chapter on medical management.

After 48 hours continue modalities, gradually increase stretching and strengthening exercises, focusing on active abduction/adduction, adduction/flexion against resistance, stabilising exercises, CKC & OKC, progress to deep massage, functional strengthening, Cross training (bike, pool, straight line running).

Progress to; shuttle runs, crossover drills, sports specific conditioning.

After the immediate medical management of the soft tissue injury, and you have allowed for an appropriate time frames for healing, one can commence a rehab phase. The key thing with the rehab is restoring the balance around the hip while aiming to maximise function for return to sport. The goals of this phase can be taken from two key papers. Tyler et al. [22] monitored 47 NHL players over 2 seasons and measured their isometric hip strength pre-season, 8 players had 11 adductor muscle strains over the 2 seasons. When the data was reviewed they found that the players who did not get an injury had an adduction strength that was 95 % of their abduction strength, however, the players who received a groin strain, their adduction strength was only 78 % that of their abduction strength. When analysed further they concluded that if the adduction strength was 80 % or less than that of the abductor strength then you were 17 times more likely to get a groin strain. This philosophy of hip muscle ratio balance being important versus peak strength has been echoed by O'Connor [15] who commented on an over focus on gluteals at the expense of the adductors, allows the ratio to become poor. He goes on to mention that the Hip flexors should be incorporated into this and that the focus should be on total hip strength. Furthermore, he found that flexibility in the hip and groin was not related to injury.

Recurrent Adductor Muscle Strain

They are a lot more common than would be desired. They can be due to inefficient rehabilitation in the first instance, resuming sport to quickly, not resolving associated problems, such as lumbar spine/altered biomechanics.

Orchard el al. [10] suggest that there should be a restoration of strength to approximately 90 % of the non affected side on isokinetic testing, and a restoration of range/flexibility comparable to the other side, and that there should be full functional field testing before the athlete is allowed to return to their sport.

Despite this many athletes can pass the "test" before they have reached full recovery, and in terms of hamstring injuries abnormalities on MRI have been shown to persist for up to 6 weeks post return to full play in the AFL [10].

In running sports there is a need to asses running style Adductors play a major role in dampening the contraction of Gluteals in the propulsion phase of running (Tidow and Wiemann), and work synergistically with the hip abductors to maintain the stability of the pelvis during the stance phase. Pelvic stability is required to prevent excessive eccentric load on the adductors.

Pubic Joint Injury

Persistent adductor related groin pain may involve a whole host of pathologies/clinical entities [5], and can incorporate Adductor tendonopathy; adductor enthesopathy; pubic bone stress reaction, pubic disc degeneration; pubic symphysitis, pubic instability; "osteitis pubis"; Pubalgia. While Holmich has called for this to all be termed "adductor-related groin pain", Mens [23] has gone further to describe it a "adduction-related". This simple distinguishing statement, goes a long way to highlight the difference between an anatomical description versus a function description. This subtle differentiation is echoed by Orchard et al. [10] who state that "whilst all muscles have anatomical individuality, they do not have functional individuality".

The extensive nature of the differential diagnosis, with the potential for multiple co-existing pathologies can mean that a persistent injury to this region is frustrating for the athlete and clinician.

The literature has attempted to define persistent groin pain by looking at regional descriptions for the symptoms, and thus we have a number of different terms to describe groin pain. It may be that so far we have been unable to clearly differentiate and include them in the diagnostic tree, a pubic joint injury, and what we have attempted to describe in the past have just been subsets of a pubic joint injury/overload.

A pubic joint injury occurs with an overuse injury of the pubic Symphysis, leading to a bone stress reaction, which in turn leads to joint and disc degeneration. Initially there may or may not have been an acute injury to the adductor muscle group, with or without an inflammatory response. The athlete usually presents with a gradual insidious onset of pubic groin pain and weakness, pain can be felt in the adductors, anterior thigh, lower abdomen, perineal and testicular regions. Symptoms can be vague, can move from proximal to distal or left to right, and can be bilateral. Pain is usually worse with exercise such as twisting/turning/kicking, they can also get pain with abdominal contractions, coughing, at night rolling over in bed and on standing up, all of which have overlap with abdominal and hip joint related symptoms. It does not have to manifest as pain, but rather a feeling of weakness or vulnerability, and an inability to generate force, they may report a loss of kicking length or top-end running speed with a decrease in performance, rather than missed games. NSAIDs, decrease symptoms, but do not give permanent relief. Short periods of rest reduce the severity of the symptoms but on resumption of normal sporting activity the pain often returns to its original intensity and severity. Natural history of the condition is of one of progressive deterioration with continued activity until such time as the symptoms prevent participation.

Most at risk are young men, aged 16–30 years of age, it is rare in women and children or older men. It is rationalised that this may be due to the anatomy of the recto-gracilis ligament which is much more patent, wider and thicker in the female pelvis [18]. The highest incidence occurs in sports that involve agility and kicking [4] and in the AFL is reported as the second worst injury in terms of missed games. There is an association with a sudden increase in load beyond the regular training volume of the individual.

Other risk factors include: lumbar spine and SIJ dysfunction; increase in rectus abdominis tone; shortened iliopsoas muscle; increased adductor tone; reduced lumbo-pelvic stability; and probably the highest correlation is with limited hip internal rotation (general ROM) [24].

This condition has been previously called "Osteitis Pubis", first described by Beer in 1924 [25], but is now regarded as a poor descriptive term as it suggests "inflammation of the pubic bone". This confusion over the nomenclature was largely settled with a study conducted by Verrall et al. [26] who conducted a biopsy of ten footballers with chronic groin pain undergoing surgery. They found there were no inflammatory markers present, and concluded that the term "Osteitis pubis" is inaccurate. Instead they found the formation of new woven bone, and the increased signal seen on MRI suggests a bone stress response.

Despite this, the radiological consequence of bone marrow oedema in sport is not pathognomonic, it is argued that it represents load and nothing more and is just part of the mechanotransduction adaption of the Osteocytes in the bone in response to increased activity.

In an attempt to answer this question Lovell (2006) studied MRI for bone marrow oedema (BMO) and its relationship to training and symptoms in 19 elite junior soccer players. They demonstrated that 11 of the 18 (61 %) asymptomatic players showed moderate to severe BMO on MRI. There was a poor correlation between BMO and the development of pain. They concluded that progressing the load slowly in athletes with a low training load is a useful strategy for preventing pain and symptoms in junior soccer players. However, it does raise a further question, "is the increased signal/presence of BMO a pre-cursor to the development of groin pain?" They are completing the follow up on these players now to see whether those with high signals developed persistent groin pain later in their career.

So why is there a greater incidence of pubic joint injury reported now than there was 20–30 years ago? Firstly the advent of MRI imaging means that our investigations are clinically more sensitive and able to pick up and define pathology where previously it was left to a clinical impression. But we also need to look at more generic factors, there is an increase in volume of sport at a younger age, the sports are faster and yet paradoxically, it has been reported that there is an increase in weight but reduced fitness of junior football players (AFL). A sports epidemiologist noted that the difference in activity between 1970 and 2000 in kids aged 10–14 is dramatic. There has been a big decline in overall activity levels due mainly to TV/computers and less physical education and 'play'. Also single parent kids do not play as much sport and smaller families mean less play (these days if you don't have a brother you don't play much sport). He suggested that today's kids would need to do a 10km walk a day to catch up to the general activity levels of the late 1960s!

On examination there is exquisite tenderness over the pubic bone, especially over the inferior pubic rami, but also the superior pubic rami and along the pubic joint line. Adductor muscle guarding may be present as demonstrated with a reduced "fall out test". There is likely to be pain and or a loss of power on squeeze testing, these tests should be conducted with the feet close together/touching, and one of the examiners fists between the knees, or ideally using a pressure cuff (measuring up to 300 mmHg). This can be tested in three different positions, 0, 60 and 90° of hip flexion. Finally, looking for a positive Pubic Symphysis Stress Test (PSST), this involves placing the patient in a modified Thomas's test position over the end of the plinth. And sequentially placing them in the following four positions:

1. Passive hip extension to EOR, looking for passive load transfer in the sagittal plane, this is testing the tensile integrity of the pubic joint and the peri-articular structures thus testing the form closure about the pubic joint.
2. Passive abduction while maintaining full extension, looking for passive load transfer in the coronal plane, which means that the superior aspect of the joint is being compressed while the inferior aspect is being gapped, again testing the form closure and pressure sensitivity of the joint.
3. Returning to the first position and resisting hip flexion, with a static isometric contraction, this has the added value of increasing the torsional stress about the joint in the sagittal plane, and testing the form closure about the joint.
4. Finally returning to position 2, and performing a resisted static contraction of into adduction, this will increase the compressive element on the superior joint while increasing the torsional strain on the inferior joint. Again testing the force closure about the pubic joint at higher loads.

A positive test is reproduction of pain or any change in tone/tightness on the flexed limb (the opposite limb being tested), if the latter is present that is know as a cross-over sign and is a clinical indicator to stop running.

Further tests to be conducted include:

Adductor squeeze in bilateral SLR:

This is a high load test that incorporate, an isometric contraction of the abdominals, hip flexors and adductors in 30° hip flexion. This will provide maximal compression to the pubic joint, and is primarily a provocation rest, however, in later stage rehab can be used as a clinical outcome measure for return to running and return to sport.

Short and long lever adductor loading.

Two consecutive tests, where the hip is taken into FABERs position and then end of range abduction. In both positions, the examiner monitors, any change in tone in the adductors (primarily longus) as a sign of guarding, and thus any subsequent loss of range. Finally when the end of the available range has been reached the subject is asked to contract maximally, and it is ascertained whether the contraction can be over-powered, if so it would imply that there is a dysfunction within the musculo-tendinous complex or an inhibitory mechanism from the joint itself.

Treatment and Management of Pubic Joint Injury and Their Subsets

The focus should be a gradual progression of training load based on the athletes ability and training history [12, 16]. Any previous groin pain should be respected as it may have altered the normal pelvic mechanics, and the therapist should attempt to maximise the range of motion in the hips, especially internal and external rotation [13].

Management should continue along previously advocated sound principles like; a balance between the local and global muscular systems, correct timing and muscle stiffness appropriate for the task, functional re-education of movement patterns, special emphasis should be placed upon adductor length and the use of a slide board to restore the anterior/posterior chain balance.

Remember that load has to be progressed without pain as pubic pain can increase adductor tone.

Pubic Joint Injury Rehabilitation

The principles of this approach has been modified from Anthony Hogan.

Unload [26] – it is essential to “buy time” from the athlete to allow the pathology to heal on a cellular level. Bone stress in any other area of the body (e.g. Navicular) would be treated with the upmost respect and caution and allow 8–12 weeks to settle, a similar approach needs to be adopted for a pubic joint injury where there is a component of a bone stress injury. Once you are happy that the clinical signs have settled (self assessment of squeeze test and BKFO) then loading can commence. We are guided when to load by the clinical markers and not by time frames. That said when you start to load you must establish warning signs and educate the athlete to report any change early rather than persisting with the program. Initially, loading without pain is desirable, certainly in response to any acute joint injury. However, with more persistent adductor related groin pain, you may allow a level of discomfort to be experienced during the loading phases. This will need to be monitored closely clinically, if there is any persistent pain post loading, and increase in muscular stiffness or soreness the next morning and any inhibition of activities of daily living these are warning signs that the loading phase is too advanced for the state of the healing of the tissues.

The use of compression shorts (largely proprioceptive and heat) can be invaluable, there is also certainly evidence to suggest that the use of a Sacro-iliac belt may help to return pelvic biomechanics to their homeostatic state. As Mens [23] demonstrated that the use of the belt could not only change groin pain but also improve muscle functional synergy and power output on a PSST, and squeeze test.

Mens et al. [23] took athletes with pain in the groin(s), provoked by playing sports, with duration of complaints for at least 1 month and pain provocation on isometric adduction of the hips. They found that groin pain was bilateral in 41 %; pain was also located at the posterior aspect of the pelvis in 32 %. They concluded that adduction-related groin pain with a positive belt test may be treated by stabilisation of the pelvis, and is not necessarily related to adductor tendon pathology.

Manual therapy – the role of manual therapy can take many different forms, from manipulation, mobilisations, soft-tissue release, myofascial release and trigger point therapy, to neural mobility and dry needling/intra-muscular stimulation. They all work on various mechanisms from mechanical stimulus, neurophysiological mechanisms, peripheral mechanisms, spinal mechanisms and supra-spinal mechanisms [27]. In essence the goal of the clinician is to restore normal pelvic mechanics both in terms of arthrokinematics and myokinematics, so that there is an optimum homeostatic state as possible to commence and optimise the rehabilitation. As without restoration of muscle function and effective energy transfer/force production across the pelvis the chance that the athlete may break down again remains high.

Local strength – Holmich conducted the only RCT on persistent adductor related groin pain [28] where he took 68 subjects and split them evenly between two groups, an active training group and a Physiotherapy group. They both underwent a treatment period of 12 weeks, and at the end of this period he was able to show that the active training program was more effective than a conventional physiotherapy program. However the conventional physiotherapy program consisted of Laser, TENS, frictions and stretches, while the active group did ball squeezes, trunk exercises and slide board, work. At this time it would be common place that exercises focusing on local strength would be a significant part of any Physiotherapy program. The take home message from this paper is that it is important for any Physiotherapist that the specific local strength should be the primary part of any program administered to any patient and other aspects such as manual therapy should be there to compliment the exercise goals.

Thorborg et al. [29] Tested isometric hip adduction and abduction strength in elite soccer players and matched controls: a cross sectional study. Conclusion: Eccentric hip adduction strength was greater in the dominant leg than in the non-dominant leg in soccer players, but not in matched controls. Eccentric hip abduction strength was greater in soccer players than matched controls, but soccer does not seem to induce a similar eccentric strength adaptation in the hip adductors.

Therefore eccentric hip adduction and abduction strength plays an important role in treatment and prevention of groin injuries in soccer players. Lower extremity strength deficits of less than 10 % on the injured side, compared to the uninjured side, are often considered the clinical milestone before returning an athlete to sports following injury and rehabilitation.

Furthermore a side-to-side eccentric hip adduction strength symmetry cannot be assumed in soccer players, since eccentric hip adduction is greater on the dominant side. Knowledge of a side-to-side eccentric hip adduction strength difference is relevant, when using the non-injured side as control in the strength assessment of injured soccer players.

Functional Strength

The guidelines given by Holmich are further enhanced when combined with the paper by Wollin [30] where he looked at return to play guidelines in 4 case studies of academy footballers. While the evidence is not as strong as that of Holmich, empirically, there is increased value clinically when you combine the guidelines of the two papers.

Wollin [30] was able to show that when the targets for a large ROM eccentric to concentric adductor loading exercise (3 sets of 12 reps with 6 KG) and a slide board skating drill (3–5 sets at 3 m for 1 min) was completed, these clinical and non-functional tests equated to a return to short sprinting performance that was comparable to the rest of the team who had not sustained an pubic joint injury (Osteitis pubis).

There is also some limited anatomical evidence that Adductor Magnus has some fibres that attach to the posterior and inferior aspects of the pubic Symphysis and thus may have a role in improving force closure around the joint. Restoration of Adductor Magnus function, cross-section area and density through single leg activity in greater than 45° hip flexion (Magnus is the strongest hip extensor in hip flexion) will help to improve the force capacity across the joint and thus load transfer.

Bone modelling, this may be a little beyond the scope of this chapter, however, it deserves a mention. When implementing a rehabilitation program for a pubic joint injury the therapist has to take into consideration the fact that a subset of the pubic joint injury maybe a pubic bone stress injury. Therefore adapting the loading parameters to account for bony remodelling and cellular communication is poignant.

Bone remodels through mechanotransduction, this is a normal cellular process, where a load is applied externally to the bone producing a mechanical stimulus, there is fluid flow in the canaliculi which is picked up by the osteocytes through mechanorecpetors, which in turn will promote the turn over in cells between the osteoclasts and osteoblasts [31].

In a series of studies carried out to identify bone response to loading Rubin et al. [32] showed that Strain rate is more important than strain amplitude which implies bone formation is enhanced by dynamic loading thus magnitude and frequency of loading are important parameters for bone formation.

Rubin et al. [32] showed that low magnitude and high frequency, which are common in activities of daily living.

Fritton et al. [33] showed that high impact physical activity including jumps in unusual directions have a great osteogenic potential.

Bone formation is stimulated by dynamic vs. static loading, therefore low magnitude high frequency may be as stimulating as high amplitude low frequency [34].

Burr et al. [35] demonstrated that shorter and frequent bouts of exercise enhance bone mass – Bone accommodates quickly to mechanical loading. Great improvements in bone mass have been demonstrated by splitting exercise bouts into shorter and more frequent sessions. Dividing 360 cycles into shorter bouts with recovery period (3 hours) significantly increases the rate of bone formation.

Bone strain distribution – Bone is sensitive to the applied strain distribution. Applying the same load at different location stimulates new bone formation. Running has been described as osteogenic "sub-optimal" due to it's even strain distribution. Unusual bone strain patterns are good for improving bone quality via alterations in trabecular microstructure [36].

Skill Integration

Establishing a strength balance, applying the principles outlined from a total hip strength [15] and abductor to adductor ratio [22]. Looking at specific local strength in both a functional a non-functional manner, and applying the principles of loading appropriate for the tissues involved (bone, enthesis, tendon, muscle) will allow for effective adaption of the pathology and injured tissue to provide a good stable background where the athlete can move forward and incorporate specific skill acquisition.

The application of these specific skills need to be implemented from the therapist and designed appropriately for the sport and the individual's movement patterns.

Holmich et al. [28] 18 % of male soccer players reporting adductor-related pain every year, therefore Holmich and colleagues conducted a randomised clinical trial. The program consisted of static and dynamic exercises that were aimed at improving the muscles stabilizing the pelvis and the hip joints, in particular the adductor muscles.

In the active training group, 24 patients (79%) successfully returned to sports activity. The time to return to previous levels of activity ranged from 13 to 26 weeks (median: 18.5 weeks). Only four of the patients in the physical therapy group successfully returned to active sports participation. This difference, as well as improvement in adduction strength, showed the significant benefit derived from active training, compared with physical therapy. With regard to other outcome measures, trends in favour of active training did not reach statistical significance. In the subjective assessment, significantly more patients in the active training group than in the physical therapy group rated their condition as much better.

The authors conclude that the active training program was highly effective in returning athletes with longstanding adductor pain to full sports participation. A program aimed at improving muscle strength and coordination is more effective than the traditional physical therapy program and receives higher subjective ratings from patients.

Mens et al. [23] took athletes with pain in the groin(s), provoked by playing sports, with duration of complaints for at least 1 month and pain provocation on isometric adduction of the hips. They found that groin pain was bilateral in 41 %; pain was also located at the posterior aspect of the pelvis in 32 %. They concluded that adduction-related groin pain with a positive belt test may be treated by stabilisation of the pelvis, and is not necessarily related to adductor tendon pathology.

Monitoring Progress

When progressing the rehab, the therapist should be able to constantly monitor changes in pelvic function, the guidelines recommended would be:

- To establish one, or a series of baseline tests and a normative score, or target score for that individual
- Measure first thing in the am.
- Measure as soon as at the training park or just before training
- Measure post training
- Measure post treatment

The key guidelines to monitoring the progress of the rehab are to establish some parameters for self monitoring and baseline scores for the individual either pre injury or post injury.

Guidelines that have been used are:

- No pain or increase in stiffness the morning after.
- No change in squeeze scores when self monitoring with one fist between the knees, or when using a sphygmomanometer,
- Baseline measures should be established with a squeeze score, (0, 60, 90°) with a pubic Symphysis stress test and with a bent knee fall out.
- Guidelines during loading should be, in the acute phase or with a reactive component, no loading into pain. In the more persistent phase, some loading into discomfort may be acceptable, then we would allow loading into discomfort that measures a 3–4/10 (0=no pain and 10 is pain taking you to the emergency room) and no higher. Provided that discomfort does not persist post loading, or has any influence on the ability to perform the individuals activities of daily living.
- Ideally the baseline scores should be measured, first thing in the am/as the athlete arrives at the training ground.
- If the initial score is poor, treatment should be administered to restore normal pelvic mechanics. Following treatment if there is an improvement in the score then a loading phase should be administered.
- Following the loading the baseline scores should be reassessed. If there is a significant deterioration then it may be an indication that the loading phase was greater than the capacity of the groin. This serves as a tool for potentially adjusting the next training session.
- First treatment to the pelvic region should be administered, as the primary hypothesis would be that the loss of function would be due to a change in the pelvic mechanics. If there is a quick return to normal baseline off minimal therapeutic intervention then training should continue along the prescribed guidelines, however, if there is not a full restoration after treatment then the next training session should be potentially adapted, depending on the response the next morning.

There are many potential roadblocks to progress with persistent groin pain, frustration at the speed of the progress can be a key parameter that needs management. To aid with this make sure that there is effective use/management of the following:

- Cross training – essential for maintenance of cardiovascular fitness, but do not allow for adaptation of essential muscles as they train
- Weights room – only upper body in the short term, but need a "gym monkey" as picking up and moving weights as if done by the patient can be detrimental for the groin.
- Early running – use of ladders and different drills that control stride length can be very useful.
- Use many small exercise progressions to keep the mind engaged, as the real value in the rehab is the consistency of loading, however, without variety the program becomes very monotonous, and this can lead to a lack of compliance, so being inventive with the progression and interactions of the exercises can make a big difference.
- Try to utilise clinical milestones where possible as this can serve to be a motivating tools, e.g. you cannot run until you can do X
- External pressure from management, family and agents amongst some needs to be monitored and managed accordingly.

The goal of any rehab program should also be to restore normal movement patterns, aim for thoughtless fearless movement.

Abdominal Related Groin Pain

Differential Diagnosis

The prevalence of such a lesion found on exploration in athletes with chronic groin pain is reported to be high. Smedberg et al. [37] showed an 84 % incidence of hernia in symptomatic groins and a 49 % incidence on the asymptomatic side in the athletic population.

Researchers suggest that these injuries occur because the adductor action during sporting activity creates shearing forces across the pubic symphysis that can stress the posterior inguinal wall.

Consequently repetitive stretching or a more sudden intense force can lead to their separation from the inguinal ligament.

Such an injury could develop as a result of repeated micro-trauma or overload, or after a single traumatic incident leading to failure of the musculotendinous unit. This may also account for the common finding of co-existing PJI and adductors tendonopathy or enthesopathy. Which came first, by this stage is often immaterial, but it is important to constantly re-evaluate for changes in the presentation that may reveal an underlying pathology (sports hernia).

The presence of a sportsman's groin can be difficult to detect on physical examination, even by an experienced practitioner. A high index of suspicion is required and the presence of a dilated internal ring, with or without tenderness, must be suspected as a cause of chronic groin pain in athletes.

Ekberg et al. [38] found that pain longer than 3 months had two or more separate pathologies.

Lovell [39] 27 % of all 189 had multiple pathologies, 26 % with sports hernia had a secondary diagnosis.

Orchard et al. [40] report that 80 % of those not treated successfully may have had an ongoing alternative pathology.

Much like adductor related groin pain there are many different pathologies that can be involved in the production of abdominal related groin pain from:

Sportsman's Groin

Sportsman's groin (and all its derivatives) can incorporate a number of different descriptions, which previously have been given individual clinical criteria. It is the authors contention that they are all part of a clinical continuum, and describe various stages of the disease process, but all make up the diagnosis of a Sportsman's groin. The varying terminologies used in the literature are as follows.

- Fascial strain/disruption – this predominantly occurs in the external oblique fascia and aponeurosis but can occur at the internal oblique and transversus as well, with repetitive movement into extension the elastic tissue can become elongated leading to microscopic tears in the fascial plane at the transition area for the inguinal canal. If the athlete returns to training/match play before the soft tissue has had a chance to fully heal then there may be re-tearing of the same weak scar tissue or adjacent tissue. Conversely if the tissue is allowed to over scar or there is a reaction within the fibroblasts within the fascial tissue, it may lead to over scarring and adherence. Because of the nature of the peripheral sensory nerves within the fascia this can lead to neural entrapment [41].
- Compartment pressure – this occurs due to a lack of compliance and sliding of the abdominal fascial tissue, due to scarring, and up regulation of fibroblasts to myofibroblasts which occurs in response to cytokines increasing contractile component and reducing the dynamic sliding of the elastic layers resulting in potential compartment style pressure [42].
- Gilmore's groin/Conjoint tendon injury/Posterior Abdominal wall disruption (PAWD) – A large majority of the awareness of lower abdominal pathology should be attributed to Gerry Gilmore [43], who describes a definitive injury whereby there are a number of structural problems, which often co-exist: A tear in the external oblique aponeurosis (as described earlier); tear in the conjoint tendon (posterior wall of the inguinal canal); Dehiscence (separation) between conjoined tendon and inguinal ligament; Thinning/disruption of the posterior abdominal wall (transversalis fascia); but there is no hernia present.
- Nerve entrapment/irritation – Akita et al. [44] described the production of chronic groin pain through the entrapment of the Boarder nerves (Ilioinguinal, iliohypogastric, Genito-femoral). Anatomically all the nerves can pierce the inguinal ligament and External oblique aponeurosis, through this they can undergo repetitive mechanical tractioning and irritation, potentially causing ischaemia and disrupting the myelin around the nerve, leading to an entrapment neuropathy and potential neuropathic changes in the tissues, such as trophedema, hyper-algesia, and collagen degradation [45].
- Inguinal ligament neuralgia – described by David Lloyd et al. [46], where he notes an Acute/chronic injury of inguinal ligament at pubic tubercle, and describes the appearance of a tatty scarred inguinal ligament at the insertion into pubic tubercle with holes & ruptures
- Incipient hernia – This is a hernia that is beginning to happen/develop but has not developed yet, and is akin to thinning of the abdominal wall tissue.
- Occult hernia – When you suspect a hernia based on the symptoms but you can not clearly see it on examination.

Malycha and Lovell [7] describe an incipient direct inguinal hernia with an associated bulge in the posterior inguinal wall extending anteriorly in 80 % of cases in their series of 50 athletes.

Hackney [47] found a weakening of the transversalis fascia with separation from the conjoint tendon in all of his 16 cases.

Simonet et al. [48] found tears in the internal oblique muscle in the ten elite ice hockey players

Brown [41] a small tear of EO aponeurosis at the site of emergence of the terminal branches of the anterior primary rami of the Iliohypogastric nerve.

Lovell [39] reported when looking at 186 male athletes who had complained of groin pain lasting longer than 8 weeks found that 50 % of them had a sports hernia.

Polglase et al. [49] reported on 64 athletes, showing anatomical defects of the inguinal canal in all. Most of these patients were AFL players. Operative findings included a deranged posterior wall of the inguinal canal in 85 %, splitting of the conjoint tendon in 26 % and previously occult indirect inguinal hernias in 8 %

The true definition of a Sportsman's groin remains unclear. To make things clearer the author would present that a definition for Sportsman's groin that encompasses all of the clinical entities described above should be:

> "Pain or a lesion superior and / or lateral to the superior pubic tubercle as a result of a laxity, thinning or deficit in the lower abdominal region with or without bulging of the posterior abdominal wall, where there is no true hernia present"

In order to fully understand the true nature of a Sportsman's groin, it is pertinent to have a quick refresher of the functional anatomy of the inguinal canal and lower abdominal region.

Anatomically the inguinal canal is a gap through the abdominal wall passing posterior to anterior and lateral to medial passing over and incorporating the inguinal ligament, it is made up of:

Roof – Internal Oblique & transversus abdominus

Floor – inguinal ligament & lacunar ligament

Anterior wall – external oblique aponeurosis & internal oblique aponeurosis

Posterior wall – transversalis fascia & conjoint tendon

The muscles fibres of the transversus and internal oblique arise from the inguinal ligament and insert into the pubic crest and along the pectineal line. These muscles are said to unite into a common tendinous insertion called the conjoint tendon.

It is at this point that the defect occurs possibly due to a tear posteriorly, where it inserts into the pubic crest and more laterally into the pectineal line, resulting in a weak posterior wall and subsequent bulging [39].

As mentioned above the defect in the posterior wall is generally thought to be in the vicinity of the conjoint tendon. So is this area particularly prone towards injury because it is a transition zone for changes in collagen and tissue type. And that it becomes the pivot point for a multitude of forces.

Functionally it is a cavity with four different elastic layers lying on top of each other that all have to interact and slide on one another to effectively produce and transfer force. They have to take the force produced from the hip and transfer it to the pelvis which in turn transfers it to the trunk, and at the same time, control the load and reciprocal movement of the upper limbs. As you can see from the anatomical structure it is primarily made up of non-contractile tissue, and thus will be very well placed to absorb and transfer elastic energy. In that fact lies the potential problem and underlying mechanism for injury, as the area has to take the high forces of mechanical energy produced by the hip and transfer it to elastic energy for force transference around the body, while still maintaining patency of the canal.

Mechanisms

Aetiology? – there are three main mechanisms:

Karlin [50] reports there is often a violent external rotation of the thigh while the leg is abducted and the foot planted

Shearing at the inguinal region – grappling or wresting in a tackle

Repetitive micro-trauma – through repeat kicking and end of range hip extension

Raised intra-abdominal pressure – holding your breath while lifting heavy weights or exerting a force.

All three can occur simultaneously, best described by Dr John Finley, physician in chief to the Detroit Red Wings for 42 years, has proposed a theory (personal communication Brown [41]) he felt that in the modern era of professional and amateur hockey, when the incidence of injury increased, the players played many more games. on land training has become more rigorous. when a player accelerates, changes direction or shoots, he pushes down by closing his glottis and therefore increases IAP pushing outward. To contain the pressure and protect the abdominal viscera from coming out, the EO, IO and TA, contract to protect the integrity of the groin. in addition if a rotation movement is undertaken, it is initiated by these muscles. At the time of repair, they have noted well developed bulky internal oblique muscle in all of their patients.

The limited space of the inguinal region disappears and more and more outward pressure is applied to the EO aponeurosis envelope. At a critical point, the pressure is so much that a tear occurs in the fascia with the fulcrum being the scarred ilioinguinal nerve or its branches – placing the nerve under tension, with each incident the tear increases in size and is associated with further scarring.

It is the authors opinion that the reality of these individual pathologies is that they may all just be part of a continuum of the disease process. Where fascial disruption, can lead to compartment pressure and nerve entrapment, or at least nerve injury and overload, degrading the tissues with neurogenic mediators (Substance P & CGRP) resulting in posterior abdominal wall damage and with continued stress overload of the inguinal ligament and thus the tatty tethered appeared described by Lloyd. This disease process can take a number of years, and so when the patient presents at any one moment in time, it is understandable that they can be attributed with a number of different entities, making it confusing for the clinician and the patient. When in fact there is one injury but it is observed and presents at different stages of the injury process.

The question immediately arises, what is a normal anatomical structure for these athletes, if you were to explore asymptomatic athlete would you find the same level of derangement and "wear and tear"

History

Characteristic history of vague insidious onset of deep groin pain usually the pain is unilateral over the lower abdomen and may extend into the upper thigh, the dull ache may radiate to the scrotum, hip and back.

Complaint – A yard short; The second half/playing twice a week; Getting in & out of the car/rolling over in bed; Pain with cough or sneeze; Weight transfer after activity.

Onset & periodicity – Shortening onset (comes on sooner); lengthy recovery (last longer) with increasing severity.

Aggravated factors can be; coughing, sneezing, but not always related to intra-abdominal pressure. Aggravating movements include sit ups, kicking, sprinting (ipsilateral hip extension and contralateral torso rotation) or even getting up out of a chair

Initially it can be relieved by rest, but will recur with exertion even after prolonged periods of rest, medication or physiotherapy

In hockey players pain is felt during the propulsion phase of skating (first few strides) and during the slap shot motion and is consistently located on the opposite side to the player's forehand shot [51]. In football codes, they may report that they can't drive off to run/ping a ball. this is in contrast to PJI where they can accelerate but cannot hit top end speed, and find they cannot kick the ball as far.

There is usually associated adductor muscle spasm/guarding.

Physical Examination

Pain may be reproduced with resisted adduction, but this may be due to co-existing adductor pathology, and as a sign is not consistent.

A defect (if any) is not necessarily palpable unless the athlete has recently undertaken activities which provoke the symptoms

Localised tenderness above the pubic crest over the conjoint tendon, pubic tubercle, mid-inguinal region is common and may be exacerbated by resisted sit ups.

A small cough impulse may be detected by an experienced practitioner but is not diagnostic.

Contributing factors – weak adductors, weak hip muscles, reduced hip range – flexible, posture, imaging of pelvis – structure

Assessing the external ring – not something to do if you are not experienced, it should require a certain amount of patient mileage to be able to clearly differentiate between a dilated ring that is truly pain producing and not just sensitive as it is being palpated.

It has been reported that palpating a dilatation of the superficial inguinal ring by inverting the scrotal sack and following the spermatic cord "Like placing a finger into a button hole" that reproduces the athlete's pain is a positive indicator [43]. This can also be found on the asymptomatic side (Orchard et al. 1998) the defect may be bilateral in as many as 48 % [52].

Of all these clinical signs there is a massive overlap with other pathologies, the consistency of the findings are irregular, and of those mentioned above, especially the presence of a dilated ring or pain reproduction on palpation, what is sensitivity and specificity of these findings? What would be the occurrence in the normal population?

These questions aligned with the evidence that anatomists have found that greater than 25 % of the adult population who do not complain of pain have a (congenital?) posterior wall bulge [40].

The process with the Physical examination should be to try and establish a direct marriage between tenderness on palpation; weakness; and provocation on testing. E.g. a fascial strain may be tender on palpation and painful on provocation, but not elicit any weakness when loaded. Versus a true internal oblique tear and dehiscence (Gilmore's groin) which will be tender, provocative and weak. The bonus comes with the other indirect and contributing factors, that increase the index of suspicion that there may be abdominal wall injury.

Imaging

Imaging is vital to aid in the effective differential diagnosis. But it should always be guided by the Physical examination, as imaging may not be sensitive enough to pick up all aspects of the pathological process. Certainly X-ray and herniography add little to a good physical examination. The modalities of choice would be MRI and US Doppler.

MRI can reliably see: Inguinal ligament & normal anatomy – Gross scar tissue; gaps; defects & disruptions, can not see subtle changes; scar tissue, or fluid collection [53].

US – (Brown [41]) Should have a specific protocol – Scanning of the adductors, especially the origins off the pubic bone. Scanning of the lower abdominal wall, esp. the RA, Obliques, and Inguinal ligament. Dynamic evaluation for hernias and fascial injuries. Power Doppler examination for areas of active inflammation. Positive findings Anechoic areas within soft tissue representing fluid within tears; Hyper echoic areas within soft tissue fascia representing scar; Areas of fascial dehiscence or tears are demonstrated during dynamic maneuvers (e.g. sit up) Areas of active inflammation are shown by Power Doppler interrogation.

Management/Treatment

In the literature the definitive treatment for a sportsman's hernia is surgery. Within the surgical ranks there are various procedures that can be carried out. Essentially they all involve reinforcement of the posterior wall, either through open repair or via laparoscopic exploration. The majority of the evidence supports the use of surgery following failed conservative treatment.

Sportsman's groin – the primary treatment of choice has been a definitive repair. The godfather of hernia repair was Edwardo Bassini, since then there has been various other adaptations of the 1884 Bassini repair, which have been used for a Sportsman's groin, these are: Marcy Modification, Andrews modification, Maloney Darn modification. The other alternatives are the Shouldice or Lichtenstein repair. It is a modified version of this that Gimore uses to repair his groins.

Gilmore

20 min op, cut along the inguinal fold, occlude veins, locate and tag the inguinal nerve, and flip inferiorly, locate and tag spermatic cord.

Identify the PAW – less white, reinforce with stitches, take conjoint tendon from above and fold down to reinforce, two layers of stitches bottom layer dissolvable, top layer permanent. all takes place posterior to abdominal wall.

Muschaweck

Muschaweck [54] minimal repair – Opening of the posterior inguinal wall only at the area of the defect (intact structures remain intact), Suture line over the pubic bone (tension of the Rectus muscle is reduced), Conservation of sliding mobility of the abdominal wall.

Elastic doubling & fascial separation +/− neurectomy, Relief of rectus abdominus off the pubic bone – special suture repair.

Lloyd

Utilizes a laparoscopic repair via a posterior approach to address the inguinal ligament. The laparoscopic approach also offers unparalleled views of the pubis, internal rings, transversalis fascia, aponeurotic arch, cooper's ligaments, and musculotendinous insertions into the pubis. Laparoscopic division of inguinal ligament and scar tissue, removes sutures from previous surgery. This exposure allows mesh reinforcement of the entire myopectineal orifice, potentially providing structural reinforcement of this region. Lloyd reports treating 250 sportsman's hernias over a 10 year period with only one failure, with 60 % playing sport at 2 weeks and 80 % at 3 weeks [46]

This represents a paradigm shift in thought about the underlying pathophysiology, were by all previous attempts at repair focused on re-enforcing the conjoint tendon and inguinal ligament, whereas this approach focuses on releasing the inguinal ligament, but then reinforcing the posterior abdominal wall with mesh.

While repair of the hernia appears to result in the resolution of symptoms, it is theoretically possible that this reinforcement contributes to the structural integrity of the groin in those athletes who have an associated musculoskeletal problem. Or at the very least changes the force distribution through the pelvis and enforces a prolonged period of inactivity and rehabilitation, were previous adherence to conservative management may have been poor.

Rehabilitation of all types of surgery is particular to the surgeon, and dependent on the extent of the anatomical derangement and re-enforcement required. But generally they recommend:

Avoid sudden sharp movements

Isometric 1st day after surgery

Progress to concentric then eccentric exercises

Walking in the 1st week, jogging at 10 days, straight line sprinting from 21 days, then sports specific conditioning.

Those who have operated on ice-hockey players recommend that they avoid skating for 4 weeks and then a gradual return to activity over 6–8 weeks.

Longer term there needs to be a balance of the slings in terms of flexibility, strength and stability, anterior vs. posterior chains, proximal vs. distal musculature.

When faced with a Sportsman's groin, if a surgical intervention is not desired at that moment in time, then a conservative approach can be adopted by applying the laws of physics to tissue adaptation.

Young's modulus – a measure of elasticity – equal to the ratio of the stress acting on a substance to the strain produced.

Hooke's law – a law stating that the strain in a solid is proportional to the applied stress within the elastic limit of that solid

Wolff's/Davis's law – biological systems quality and orientation of connective tissue adapts to mechanical stress to best resist extrinsic forces – "dynamic flexure"

To be effective a rehabilitation program should be able to account for and address all the potential mechanism as to why the injury occurred in the first place.

Wang [55] has described how tissues adapt to loading, where the (ECM)extra-cellular matrix is stimulated by mechanical forces, which simultaneously stimulates the humoral factors (Cytokines) which in turn stimulate the ECM and become more susceptible to mechanical forces. Khan and Scott [56] describes the process at Mechanotransduction. The physiological process where cells sense and respond to mechanical loads.

Mechanotherapy

The prescription of exercise to promote tissue healing which relates to tendon, muscle, fascia, cartilage and bone.

Regain force coupling anterior and posterior slings; movement correction & MT – pelvic symmetry; regain sliding of facial layers; regain neural mobility; Use injections & pharmacotherapy for pain Mx; set an appropriate time frame then re-evaluate; load the abdominals – multi-direction and daily; maintain pre-existing fitness – regain CV status

Principles of loading; identify the plane of movement weakness; movement specific (not muscle specific); initiate with isometric load in inner range (6 s reps); progress to outer range with eccentric control; add in inertial torque into extension from limbs

Provide a rotation challenge/perturbation; Aim for time under tension and sustained load (>2–4 min); Goal is "strain hardening" and de-sensitization. Increase stress rate – 6 s maximal isometric contraction. planks and manual resisted sit ups; progress by increasing load (wt vs. lever arm) maintain position. Roll outs

The progress time e.g. build to 30 s (sub max). Planks with perturbation/limb movement; Increase the strain rate – time under tension (>2–4 min); Circuits looking at combination of movements in multiple planes, with either high stress (load) or high strain rate (time and tension) e.g. eight exercises each 30 s; Progress to dynamic challenges rotation control; fast perturbations; long lever loads; reactive & rebound activity.

Rehab should include: Establish benchmark; Early loading for tissue regulation and pain; reduction; Progress to dynamic loading – Stress/strain/elastic; Integrate dynamic loading – speed; Balance the hip & pelvis; Progression based on obj functional & clinical markers

Time frame to consider surgery; Total Hip strength; Adductor specific loading – clinical milestones;

Summary

The diagnostic challenge with abdominal groin pain is that more often than not the diagnosis is via exclusion and not inclusion. The clinician needs to establish a marriage between the History, the investigations and the physical examination. A simple algorithm that can help is:

Rule out the Hip joint as a source of pain, diagnose/rule out the adductor related groin pain component to the pathological process. Ask the questions – is there a true hernia? Is there a rectus abdominus tendonopathy? Is there a true iliopsoas related groin pain (if so what is the relevance)? Only if the answer to all of the above is NO, or they cannot explain the abdominal related groin pain, do you suspect a Sportsman's groin and put into action a management plan accordingly.

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26 Outcomes Assessment in Young Hip Disease

Sujith Konan and Fares S. Haddad

Introduction

The term 'outcome' is used in medicine to describe the condition of a patient at the end of therapy or a disease process. The term encompasses a broad spectrum of measures including the degree of wellness and the need for continuing care, medication, support, counseling, or education.

Outcomes Assessment: The Changing Perspective

Historically, the surgeon assessed and reported success or failure of an orthopaedic disease process or operative intervention. While this assessment is extremely valuable, modern day medical practice requires the surgeon to be able to demonstrate outcomes.

Outcome measures or instruments are used to assess the impact of interventions for various purposes such as comparing clinical trials, economic considerations, patient expectations, alternative prostheses, methods' of fixation or surgical techniques. By allowing the comparison between individuals, departments, hospitals and regions with regards to various elements of peri-operative care; outcome assessment enables good practice to be highlighted and propagated, and for remedial action to be instituted where practice is sub-standard.

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Outcome Instruments for the Hip

The study of the properties of outcome instruments is referred to as psychometrics. Outcome instruments use various items such as signs, symptoms, complications, investigations or aspirations as a measure of a dimension. Broadly, all outcome instruments may be classified into two categories. The item measure of a dimension may be the patient's own perception or 'subjective'. If the measure is the result of an observation made by an examiner or device or investigation, it is termed 'objective' data.

Outcome assessment in young hip disease may be performed in several ways such as morbidity from the hip pathology, morbidity following surgical intervention, incidence of specific complications after surgical intervention (e.g.: dislocation rate following hip replacement). Health related quality of life from the disease or surgical intervention, radiological outcomes; in patient hospital stay etc are examples of non-generic outcome tools.

Questionnaires are often used to document various items of measure, which may then be expressed as scores for the purpose of documentation and comparison. Well-designed self-reported questionnaires with or without measurement and physical assessment are currently the most useful outcome tools used for the young hip disease. In addition to this and specifically for the younger patient, motion analysis, kinematic assessment, dynamometers and performance battery tests are useful and sensitive measures of detecting change in outcome. When measuring outcome of rehabilitation following muscle injury or surgical reconstruction of muscles acting on the hip joint, various muscle specific strength testing scores and devices are also available. This chapter discusses the various outcome assessment tools relevant for young hip disease.

Questionnaires

Questionnaires document responses to specific objective or subjective measures that are then expressed collectively as a score. Responses may be constructed as binary (1/2 or yes/no)

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or graded. For graded or scaled responses, visual analogue scales (VAS), Likert scales or some form of adjectival questions are used. In general, questionnaires should be acceptable to patients, simple, easy to use and score, and preferably concise.

The assessments made by questionnaires may be generic, disease-specific, joint-specific or patient specific.

Generic surveys: Assess any medical or surgical intervention and investigate all aspects of quality of life.

Disease specific: Disability relating to a particular condition or single disease entity. Joint specific: Impact of disease in one particular joint.

Patient specific: Currently experimental tool. In this method, the focus is shifted from a group level to an individual level and each patient is classified as a responder or a non-responder (the responder criteria) to a particular intervention; or whether a certain level of low symptom severity is attained (the state-attainment criteria)

Outcome questionnaire tools are often designed for specific populations. The outcome tools tested have to be established as a valid and reliable instrument. An outcome measure must be easy to administer and regular feedback of aggregated results encourages compliance.

Validation of an outcome tool involves testing various criteria [1, 2]. These are briefly discussed below

Redundancy: Refers to whether one or more items of a questionnaire correlate with each other. May be measured using Cronbach's alpha (values between 0.7 and 0.9).

Internal consistency: Refers to the homogeneity of the items in the tool

Agreement: Refers to how close scores are for repeated measurements

Reliability: Refers to how well the measurement can distinguish persons from each other despite measurement errors. Internal consistency determines whether a survey measures a single variable. Reproducibility investigates if a questionnaire produces the same results if repeated under the same conditions. Interobserver reliability (agreement between two or more observers on the same occasion), intra-observer reliability (same observer on separate occasions), and test-retest reliability (stability of the measure over time in the same subject) are all aspects of reproducibility.

Responsiveness: Refers to how well an instrument can detect clinically important changes over time.

Floor and Ceiling effects: Number of respondents with the lowest or highest possible score. 'Floor' effect refers to the situation where a questionnaire is unable to measure a negative value that is lower than the range provided in the choice of answers. 'Ceiling' effect refers to the situation where a questionnaire is unable to measure a positive value that is higher than the range provided in the choice of answers.

Interpretability: The degree to which qualitative meaning can be assigned to quantitative scores.

Validity: Face and content validity assess whether a survey fully investigates the intended topic of interest. Content validity examines the ability of the instrument to measure all aspects of the condition for which it was designed so that it is applicable to all patients with that condition. Criterion validity refers to the extent to which scores on the tool relate to a gold standard. Construct validity refers to the degree to which scores on the tool relate to other measures in a manner consistent with theoretically derived hypotheses concerning the domains being studied.

Various questionnaire based outcome measures are currently used for assessment of young adult hip. They were traditionally developed for the general population and often the older patient but have been used in the younger adult for lack of specific outcome tools aimed at the higher demand patient. Hence, their ability to discriminate the higher demand individual and improved functional outcome in the hip joint is often questioned. These outcome questionnaires may be disease specific, joint specific or generic and continue to provide a tool to document and compare outcomes following surgical intervention to the hip joint. A brief summary of the various commonly used hip scoring systems [3, 4] with their strengths and weaknesses are discussed below.

The Hip Outcome Scores (HOS) [5]

It is a self-reported functional status instrument. Twenty items are tested using two subscales, the activities-of-daily-living (ADL; 19 items) and sports subscales (9 items). Each item has six potential responses, ranging from "unable to do" to "no difficulty," and a response of "nonapplicable". The ADL and Sports subscales are scored separately. The item score total is divided by the highest potential score and multiplied by 100 to get a percentage.

Strengths: Developed as a tool to measure higher demand activities. It has shown strong test-retest reliability and responsiveness.

Weaknesses: No long-term outcome studies have documented the usefulness of this outcome measure.

Non-arthritic Hip Score (NAHS) [6]

It was developed to measure preoperative and postoperative hip pain and function in 20- to 40-year-old patients with hip pain without obvious radiographic diagnosis. It is self-administered and symptom-related only, requiring no physical examination. The scoring system includes 20 multiple choice questions each having five responses. Values are added at the end and multiplied by 1.25 to arrive at a final score. The maximum score is 100 indicating normal hip function. This score is divided into four domains: pain, mechanical symptoms, physical function, and level of activity. All ten questions measuring pain and physical function come directly from the Western Ontario and McMaster Universities Osteoarthritis Index. Four additional questions deal exclusively with mechanical symptoms involving the hip. The fourth set of questions measures activity level. This scoring scheme is aimed at The Strengths: It is self-administered and all of the questions are weighted equally. It is reproducible, internally consistent, valid, responsive to clinical change and has moderate construct validity.

Weaknesses: There are no long term studies documenting its usefulness.

The Hip Disability and Osteoarthritis Outcome Score (HOOS) [7, 8]

A joint-specific survey, which has 40 questions, each of which has five possible answers (scored 0–4). The questions can be grouped into five higher order dimensions: pain, other symptoms, activities of daily living, sport and hip-related quality of life. The scores from each dimension are added together and then transformed onto a scale of 0–100 (100 = best outcome).

Strengths: It valid and responsive. It contains all the WOMAC Likert 3.0 questions.

Weaknesses: It is based on self-report of functional status and performance and this may be a disadvantage when comparing with instruments which have objective instruments.

The University of California at Los Angeles Hip Scale (UCLA) [9]

It is often used to assess post-operative outcome in arthroplasty patients and more recently, to assess hip arthroscopy outcomes. The scale explores four dimensions: pain, walking, function and activity. There are ten points on the scale (ten indicating best outcome).

Strengths: Measures activity level and this gives important qualitative information regarding outcome.

Weaknesses: There is no published psychometric evidence validating the UCLA hip scale.

Merle d'Aubigne and Postel Score [10]

Developed in 1949. Pain, mobility & the ability to walk are scored from 0 to 6, with 0 being the worst and 6 the best. The scores are added together to reach the overall score (out of 18). In 1954, in the mobility section, "can tie shoelaces" was changed to "can reach his foot". Since then, it is referred to as the modified Merle d'Aubigne and Postel score.

Strengths: Simple and easy to apply.

Weakness: Not been validated. Ambiguity between grade 4 (mild walking pain) and grade 5 (mild & inconstant) may result in incorrect scores or make scores not comparable. A clinician examines the mobility section, introducing the possibility of clinician bias. A ceiling effect is noted with this scoring system.

The Charnley Score [11]

A modification of the Merle d'Aubigne and Postel score (developed in 1972). It grades hip pain, mobility and walking on a scale of 0–6. The scores are not combined like in the Merle d'Aubigne and Postel scoring system.

Strengths: Simple to perform, reproducible and easy to apply. Has been validated.

Weaknesses: There is no psychometric testing of the Charnley score supporting its use. As the assessment is entirely performed by the surgeon there is potential to introduce a clinician bias.

Harris Hip Score (HHS) [12]

Developed in 1969 to assess outcomes following total hip arthroplasty. It is a multi-dimensional observational assessment, which contains eight items representing pain, walking function, activities of daily living, and a physical examination- range of motion of the hip joint. The questions are split into three categories: pain (0–44 points), function (0–47 points) and level of activity. Assessment of the functional component is based on the presence of a limp, the use of walking aids, and specified activities. The scores from each section are added together (maximum 100), with a score of 90–100 rated as excellent, 80–90 good, 70–79 fair, 60–69 poor, and less than 60 as failed result.

Strengths: It is able to detect changes in hip function. It is an observational assessment, thus eliminating patient bias. It has been shown to have high validity and reliability.

Weaknesses: It does not account for individual differences in age, health or personal issues that may impact the score. It is an objective interpretation by a subjective individual, and therefore could lead to bias.

Oxford Hip Score (OHS) [13]

A joint specific patient-centred outcome measure that was devised in 1996. The OHS is designed to assess pain and functional ability from the patient's perspective. It consists of 12 questions rated from 1 to 5 (1 representing best outcome and 5 worst). The 12 individual scores are added together to formulate the overall score ranging from 12 to 60

(12 = best outcome). In the revised OHS, each question is scored from 0 to 4, with 4 indicating the best outcome and overall score range from 0 to 48 (48 = best outcome).

Strengths: It is easy to use and can be completed by patients independent of clinicians. It has high responsiveness; is highly sensitive to change in patients undergoing hip arthroplasty; is internally consistent; reproducible; and achieves a high follow-up rate.

Weaknesses: Certain questions lack clarity or are irrelevant and are difficult for respondents to answer. Patient factors such, as co-morbidities are not taken into account. It tries to categorise pain into a single category, which is not always possible

Disease-Specific Quality-of-Life Outcome Measures

The Arthritis Impact Measurement Scale and the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) are two commonly used disease specific quality-of life outcome measures which may be used to assess young hip outcome.

The Western Ontario and McMaster University Osteoarthritis Index (WOMAC) [14]

It is a self-administered disease-specific health status measure for osteoarthritis (hip and knee joint). Three categories: pain (5 questions), stiffness (2 questions) and physical function (17 questions) are tested. Individual question responses are assigned a score of between 0 (extreme) and 4 (none). Individual scores are summed to form a raw score ranging from 0 (worst) to 96 (best). Scores are normalised by multiplying each score by 100/96. This produces a reported WOMAC score of between 0 (worst) and 100 (best).

Strengths: It is valid, reliable and sensitive to change.

Weaknesses: The scores lack specificity and may be influenced by factors such as arthritis in other joints, fatigue, depression, regional back pain and psychological status. Large sample sizes and robust statistical tools are required to demonstrate significance differences in mean scores.

A modified 12-item WOMAC Osteoarthritis Index has also been developed specifically for femoroacetabular impingement (FAI).

Arthritis Impact Measurement Scale (AIMS) [15]

It measures the health status of patients with rheumatic diseases. The 80 questions are split into the subscales: mobility, physical activity, dexterity, household activity, social activity, activities' of daily living, pain, depression and anxiety.

Strengths: It is reliable, valid and sensitive to change.

Weaknesses: Cultural differences have been noted between the Swedish and American patients.

Short-Term Clinical Outcome Measures

They are commonly used to report the clinical impact of operative intervention and the physiological effect of surgery. The Post-Operative Morbidity Survey (POMS) [16] has been used in post-operative morbidity, outcomes and effectiveness research and has been shown to be reliable, valid and acceptable to patients. Other less reliable tools are the event rates, the mortality rate and length of hospital stay.

Generic Quality of Life (QOL) Outcome Measures

They assess overall health-related quality of life and are not specific to age, disease or treatment group. QOL is defined (Testa and Simonson) [17] as 'the physical, psychological, and social domains of health, seen as distinct areas that are influenced by a person's experiences, beliefs, expectations, and perceptions.' The World Health Organisation Quality of Life Group recommended that generic surveys should explore five areas: physical health, psychological health, social relationship perceptions, function and well-being. Commonly used generic outcome measures are: the Medical Outcomes Study 36-Item Short Form Health Survey (SF-36), the Medical Outcomes Study 12-Item Short Form Health Survey (SF-12), the European quality-of-life five dimension questionnaire (EuroQol/EQ-5D).

The Medical Outcomes Study 36-Item Short Form Health Survey (SF-36) [18]

It SF-36 is a multi-purpose questionnaire available in American English as well as United Kingdom English. It refers to health over the previous 4 weeks but a more acute version, referring to health over the previous week, is available. The questionnaire contains 36 questions, each of which has between 2 and 6 answers. Each is scored between 0 (poor health) and 100 (good health). The questions are grouped into one of eight health domains: bodily pain (BP), physical functioning (PF), role limitations due to physical health (RP), general health (GH), mental health (MH), vitality (VT), social functioning (SF) and role limitations due to emotional health (RE). It also has a health transition question does not contribute to any of the eight domains. The domains can be amalgamated into two higher order groups, known as the Physical Component Summary (PCS) and the Mental Component Summary (MCS). The PCS is calculated from the BP, PF, RP and GH scores and is most responsive to treatments that alter physical symptoms. MCS is calculated from the MH, VT, SF and RE scores and is most responsive to drugs and therapies that target psychiatric disorders. Three of the scales (VT, GH and SF) have a significant correlation with both the physical and mental summary measures.

Strengths: It is suitable for self-administration, computerized administration or administration by an interviewer either in person or by telephone. It is valid, reliable, sensitive and acceptable to patients. It has been used in over 4,000 publications assessing over 200 different diseases.

Weaknesses: It has 'floor' and 'ceiling' effects.

The Medical Outcomes Study 12-Item Short Form Health Survey (SF-12) [19]

It is an abridged version of SF-36 with 12 out of the 36 questions which can be amalgamated to produce profiles of the eight SF-36 health concepts but only if the sample size is sufficiently large. The scores are calculated using weighted algorithms for which a computer program is available.

Strengths: It is shorter and quicker for patients to complete and quicker for research personnel to record and analyse data.

Weaknesses: A computer program is necessary for scoring each survey. It has less construct validity and sensitivity than SF-36 producing less precise scores for the 8-scale health profile. This could result in insignificant findings in smaller studies.

The European Quality of Life 5 Dimension Questionnaire (EuroQol/EQ-5D) [20]

It has 15 questions regarding five aspects of general health: mobility, self-care, usual activities, pain and depression. Each question has three possible answers: 'no problem', 'moderate problem' or 'extreme problem'. It also has a visual analogue scale for the patients' assessment of their overall health (0 = worst possible health; 100 = best possible health).

Strengths: It is self-administered, easy to complete and is valid and reliable.

Weaknesses: It suffers from ceiling' effects. There is limited psychometric analysis of the questionnaire.

Motion Analysis [21, 22]

Functional outcome can be assessed using carefully planned questionnaire outcome tools that incorporate subjective and objective tasks. Another reliable method of quantifying function in a joint is by the use of motion analysis. Although it is still widely available as a research tool, motion analysis may be a useful in the outcome assessment of the young adult hip. Subjective outcome questionnaires may not discriminate young adults who maintain high levels of physical function despite pain and muscular weakness. Motion analysis enables kinematic and kinetic data to be obtained. This and can be used to quantify movement patterns and provide reliable outcome tools following open or arthroscopic impingement surgery, osteotomy or replacement arthroplasty. Motion analysis has the advantages of being able to detect force transmission across joints, and subtle improvements or limitations in joint function. Motion analysis has a variety of other applications, such as athletic performance analysis, surveillance, man–machine interfaces, content-based image storage and retrieval, and video conferencing. The process of interpreting human motion involves motion analysis of body parts; tracking movements with multiple camera perspectives; and recognizing human activities from image sequences.

Gait analysis has been used to assess quality of post-operative gait. Using healthy subjects as controls, and by carefully matching variables such as age, height, weight and gender the role of surgical intervention in restoring normal gait and joint reaction forces may be assessed. Also, by repeating analysis at various time points, it is possible to study the long-term effects of surgical intervention in maintaining normal hip biomechanics. Using gait analysis, various authors have demonstrated increased spatio-temporal and kinematic outcomes following arthroplasty. Long-term follow up has shown further improvement, suggesting that optimal functional improvement may occur over longer periods. Data also suggests that hip function and gait may not return to the same level as for a healthy control group following arthroplasty. Motion analysis has also been used to compare results of arthroplasty versus resurfacing with some studies showing similar outcomes for restoring kinematics while others noticing improved kinematics and abductor function with resurfacing arthroplasty. The effect of post-operative rehabilitation regimes may also be compared.

Motion analysis has been used to compare outcomes of different surgical approaches to the hip joint. A faster recovery has been noted only in the immediate stages after an anterior approach, probably because the hip abductors are spared. Once the abductors have healed, no difference is seen between anterior, anterolateral or posterolateral approaches. Outcomes were also not different when minimally invasive approaches were used instead of standard length incisions.

In the outcome assessment of young adult hip, motion analysis enables subtle functional limitations to be detected. This may not be possible using conventional questionnaire based outcome tools. While motion analysis may be less

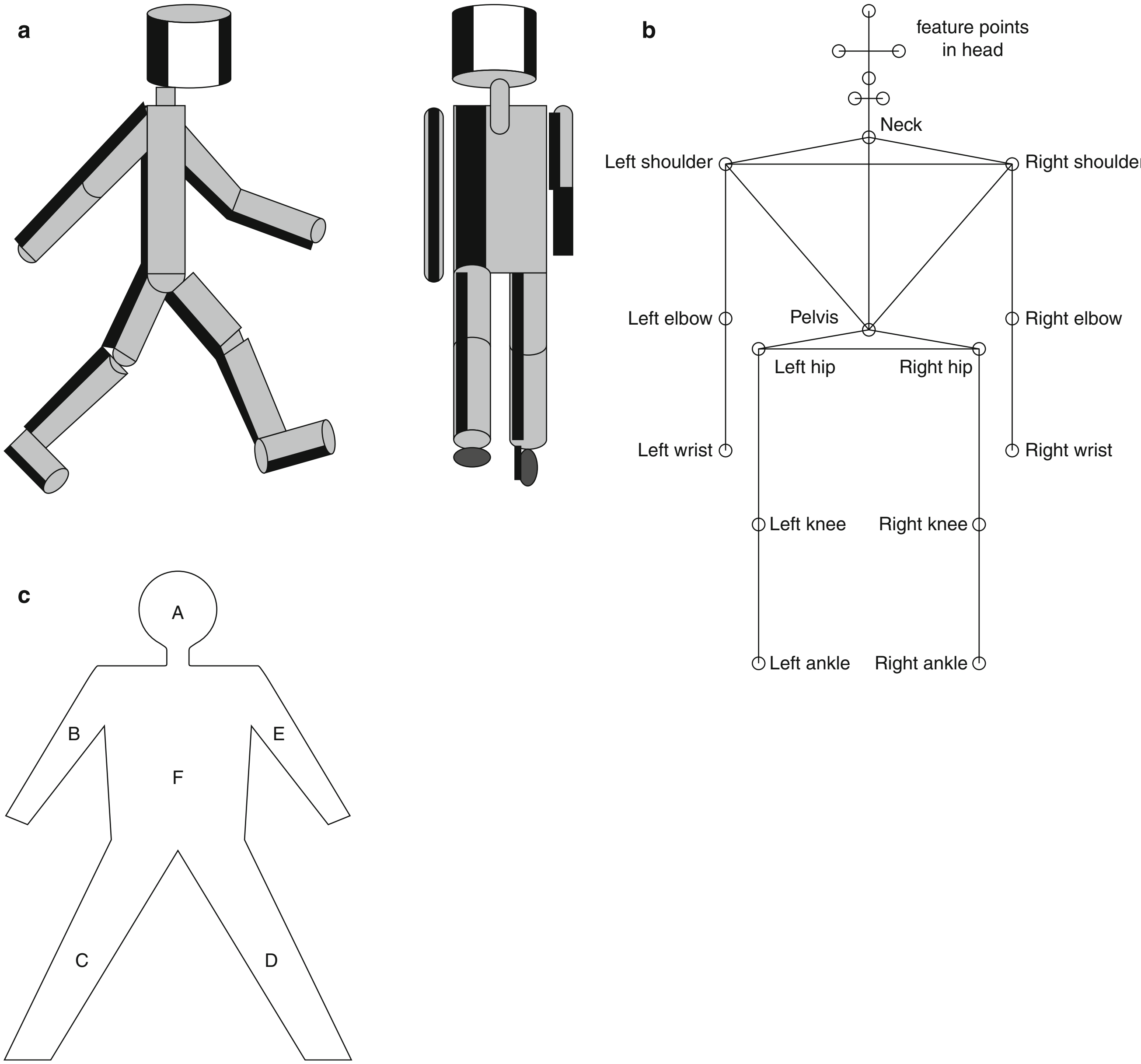

Fig. 26.1 (**a**, **b** and **c**) Figures illustrate one, two and three dimensional motion analysis model. Three-dimensional gait analysis (3DGA) and gait summary measures can be used to quantify the degree of gait deviation from normal, stratify severity, document changes in gait over time and evaluate interventions (Reprinted from Aggarwal and Cai [21] with permission)

necessary in the older adult undergoing routine hip surgery; the younger high demand adult and especially the elite athlete requiring focused rehabilitation would benefit from precise kinematic outcome assessment. Rehabilitation following prosthetic lower limb reconstruction, hip arthroscopy, periacetabular osteotomy, corrective femoral osteotomy and comparison of different types of arthroplasty are some of the other examples where motion analysis based outcome tools may be preferred.

Three-dimensional gait analysis (3DGA) and gait summary measures (obtained by applying data reduction techniques to gait dynamic data) can be used to quantify the degree of gait deviation from normal, stratify severity, document changes in gait over time and evaluate interventions. Figure 26.1a, b, c illustrate one, two and three dimensional motion analysis model. This has mainly been used in cerebral palsy and amputees but its use may be extended for other indications in future. Gait summary measures may be based on instantaneous values like the Gillette Gait Index (GGI) or may utilise the entire waveform as in the Gait Deviation Index (GDI) and the Gait Profile Score (GPS). The Movement Analysis Profile (MAP) elucidates underlying causes of gait deviation by calculating a score for individual kinematic variables.

Performance Based Assessments [23–25]

Self-reports of physical function reflect the ability of patients to do activities, as well as what patients experience during the activities (e.g., pain, exertion). This limits the ability of self-reports of physical function to accurately represent functional outcome.

Detailed assessment and evaluation of physical activity requires the measurement of the mechanical load of activities on the hips, the frequency and duration of recreational activities and the measurement of load cycles. Physical activity monitors, such as pedometers and accelerometers can quantify physical activity. Very few studies have validated a pedometer in hip pathology. Pedometers differ in their validity. Accelerometers may be more suitable because they can also give an indication of the intensity of the activity, which is an important factor in wear production. Accelerometers may also be suitable for etiological and prognostic studies, alone or in combination with questionnaires. They however, have limited ability to measure cycling and swimming.

We have developed and validated a discriminating functional hip [26] score in our institution for use in patients with hip disability that could be used to demonstrate functional improvement in the younger, high demand adult patient. The functional hip score tests five tasks; single leg stance; timed stair climb; lateral step up onto stairs; three forward jumps, standing up between jumps; three sideways jumps. Each task is scored on a mutually exclusive scale of four choices that are ordered in the same hierarchical arrangement for all tests. For each task, the patient also grades the pain associated with performing the test and the difficulty of performing the task, respectively, on a scale of 1–10. A value of 10 represents inability to perform the given task. All scores from the tasks were recorded and used unweighted to avoid any preconceived bias by the person interpreting the results. The final results of the functional hip score are calculated and interpreted as sets of three; function (F), pain (P), and difficulty (D). Our functional hip score has been validated against WOMAC and SF-36 scores and shows good reliability, high internal consistency and lack of floor and ceiling effects.

Radiographs, Computerised Tomograms (CT) and Magnetic Resonance Imaging (MRI)

CT and MRI are commonly used in the diagnosis and preoperative planning of young adult hip pathology. Serial follow up imaging is useful to monitor progression of the pathology and to evaluate post-operative results. They provide valuable tools for outcome assessment of the young hip. Their role as validated outcome tools is yet to be established. Plain Radiographs provide essential information to diagnose and treat musculoskeletal disorders. However, while radiographic classification systems and numerous radiographic parameters have been reported, their reliability remains unclear. Various factors such a patient positioning on table, distance of the patient from the X-ray source and film, body habitus, rotation and deformities of the bone or joint may all influence the standardisation of radiographs. When factored in with other aspects of the patient presentation and physical examination, the diagnostic reliability is improved. The diagnosis and treatment of prearthritic and early arthritic hip disease is an area of intense interest. Despite limitations, radiographic parameters may be used as objective outcome tools by clinicians in pre-arthritic hip conditions and long term follow up. Some of the commonly used plain radiographic parameters are summarised.

Assessments Made on Anteroposterior Radiographs of the Pelvis [27]

Acetabular depth: The relationship of the floor of the acetabular fossa and the femoral head in relation to the ilioischial line. In a “profunda” hip, the floor of the acetabular fossa is tangential or medial to the ilioischial line. In a “protrusio” hip, the medial edge of the femoral head is medial to the ilioischial line. Profunda and protrusion increase risk for pincer impingement.

Acetabular inclination (Tonnis angle): Normal 0 to 10°. The angle formed between the horizontal line running through the most inferior point of the sclerotic acetabular sourcil and a line extending from the most inferior point of the sclerotic acetabular sourcil to the lateral margin of the acetabular sourcil. Hips with an increased Tonnis angle may be at risk for structural instability, and those having a decreased angle for pincer impingement.

Acetabular version: Hips are normally anteverted. In retroverted hips, the anterior wall crosses the posterior wall of the acetabulum before reaching the lateral aspect of the sourcil (“crossover sign”). Errors may occur due to pelvic tilt and/or malrotation. Retroverted hips are at risk for pincer impingement.

Hip center: The hip center is considered lateralized if the medial aspect of the femoral head is greater than 10 mm from the ilioischial line and not lateralized if the medial aspect of the femoral head is less than 10 mm from the ilioischial line. Lateralized femoral heads were considered to be a sign of structural instability or dysplasia.

Congruency: Degree of conformity between the femoral head and acetabulum. Incongruent hips may be a result of dysplasia or impingement.

Pelvic tilt/rotation: The obturator foramina should appear symmetric if the pelvis radiograph is not rotated. In the absence of pelvis tilt on the radiograph, the distance from the tip of the coccyx to the superior aspect of the symphysis pubis should measure 1–3 cm.

Assessments made on anteroposterior, frog-lateral and crosstable lateral radiographs of the pelvis.

Head sphericity: Suggested by the femoral epiphysis extending beyond the margin of the reference circle. Hips with an aspherical head may be at risk for impingement.

Head-neck offset: The anterior and posterior femoral head-neck junction may be at risk of impingement in the presence of convexity or when there is decreased concavity.

Tonnis grade: This classification system grades osteoarthritis from 0 to 3

- Grade 0: no signs of osteoarthritis.
- Grade 1: increased sclerosis of the head and acetabulum, slight joint space narrowing, and slight lipping at the joint margins.
- Grade 2: small cysts in the head or acetabulum, moderate joint space narrowing, and moderate loss of sphericity of the head
- Grade 3: large cysts in the head or acetabulum, joint space obliteration or severe joint space narrowing, severe deformity of the femoral head, or evidence of necrosis.

Muscle Strength Assessment [28–30]

Impairments in muscle strength and range of movements are important correlates of physical function and useful outcome measures in research and clinical settings. Objective measurement of muscle strength provides important clinical information about weakness that may relate to functional limitations. It was traditionally used for serial assessment following neurological injuries. Increasingly, it has become necessary to assess muscle strength during the rehabilitation of muscular or musculo-tendinous tears; following surgical repair or reconstruction of tendon avulsions (e.g.: proximal hamstring tendon) or for testing athletes during pre-participation sports physical examination. Figure 26.2a, b show muscle testing of specific hip muscle groups using purpose made devices.

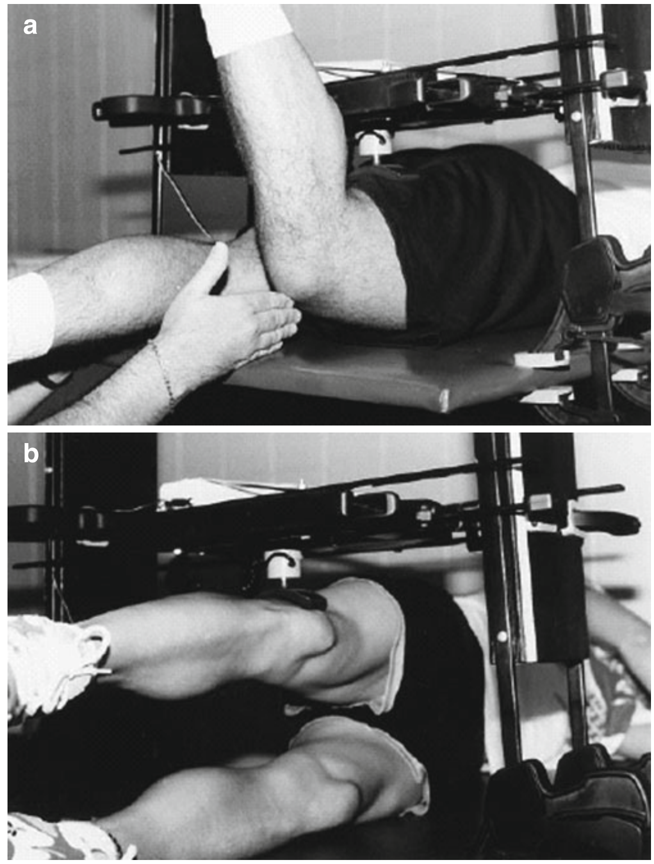

Fig. 26.2 (**a** and **b**) Figures illustrate muscle testing of specific hip muscle groups using purpose made devices. It may be useful to assess muscle strength during the rehabilitation of muscular or musculo-tendinous tears; following surgical repair or reconstruction of tendon avulsions (e.g. proximal hamstring tendon) or for testing athletes during pre-participation sports physical examination (Reprinted from Nadler et al. [29] with permission)

Manual muscle testing (MMT): It is the most common method used for assessing muscle strength. It is easy to perform at the bedside, does not require any special equipment and subjectively grades muscle strength on a 5-point scale. This method of muscle strength testing cannot detect small to moderate strength changes. It is also unsuitable when used to follow up subtle loss of muscle strength (e.g.: scores of four and higher).

Handheld dynamometer (HHD): They provide better objective analysis of muscle strength compared to MMT and can detect small differences in muscle strength than MMT. They are portable, simple, user friendly, and comparatively inexpensive. The downside is that they provide only limited information, such as peak force, time-to-peak force, and total test duration. In order to use the HHDs, the examiner has to stabilise the limb. Hence, differences may be seen in readings between different examiners. Stronger forces requiring capable of producing greater forces are also more difficult to assess using HHDs. They are not capable of generating strength curve profiles or power output estimates. They also do not provide positional information on the limb or joint at which strength was tested.

The Dynamometer Anchoring Station (DAS), is a portable device incorporating an HHD fixed into a platform. This provides the advantage of portability, low cost, ease of measurement and lack of reliability on tester strength especially for the lower limb musculature.

Stationary isokinetic dynamometers (e.g.: the Cybex II). This type of dynamometer provides better stabilization for the patient during testing. Isokinetic machines are considered the criterion standard and provide multiple parameters, such as peak force, endurance, power, and angle of maximal force, occurrence and generate strength curves. They are ideal for hip and thigh musculature. They yield highly reliable strength measurements, but are expensive, not portable and not really designed for routine clinical examinations.

Manual muscle tester system: Some devices have been described that combine force transducer; motion sensor; and a computer. A hand grip or a force pad is used to apply a consistent force directed towards the transducer. The MMT system appears to be a valid and reliable device suitable for clinical manual muscle strength testing. The motion and position device distinguishes the manual muscle tester from other hand-held dynamometers and assure consistent and standardized limb positioning, as well as repeatability. Drawbacks of this system are the issue of the strength and skill of the clinician doing the assessment and the variability noted with the testing protocol, the joint position, the time of day, the type of verbal encouragement and motivation, and the number of examiners doing the strength assessments. Also, some muscle groups are known to give more repeatable results.

Conclusion

Management of young adult hip disorders is an emerging speciality. Advancement in understanding of the precursors of hip osteoarthritis, better techniques of osteotomy, development of hip arthroscopy and emerging techniques of repairing muscle avulsions have all contributed to the surge in surgical management of the young adult hip pathology. Unlike the elderly population, the outcome measures used for assessing the younger adult have to address the higher functional demands and expectations of the patients. Currently, questionnaire based documentation of improvement in pain, function and disability is the most widely available outcome measure. There is a need for development of function based outcome measures that can discriminate high level hip function. Currently radiological tools, gait analysis, dynamometers and motion sensors are widely researched for use in measuring hip function but lack availability, reproducibility and reliability. Future studies may aim at amalgamating various questionnaires, performance tasks and gait and motion sensor tools to develop ideal functional outcome tool. It may also be necessary to develop disease specific or procedure specific outcome measures to demonstrate improvement following surgical intervention.

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