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Anatomy and Physiology of the Pediatric Hip

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Introduction

The hip joint is an articulating "ball-and-socket" joint that is formed by the head of the proximal femur and the acetabulum. The proximal femur consists of the approximately spherical femoral head, the femoral neck, and the greater and lesser trochanters (Fig. 2.1). The femoral head joins the neck at the subcapital sulcus—a deep groove containing the intra-articular subsynovial vascular ring (Fig. 2.1). The acetabulum is a semi-spherical concavity formed by three major components of innominate bone: the ilium, ischium and pubis. During development and maturation, these three separate bones unite at the centre of the acetabulum, known as the tri-radiate cartilage (Fig. 2.2). The femoral head and the acetabulum come into closest contact during maximum weight-bearing and extremes of range of motion, for example flexion and internal rotation [1].

The anatomy of the pediatric hip represents a changing landscape throughout all stages of growth and development, from birth until skeletal maturity. Abnormalities during different developmental stages can cause a number of debilitating hip conditions that can have lasting ramifications into adulthood. Hip joint development begins in the embryonic phase of life, and is a progressive, dynamic process that continues throughout fetal development, infancy and childhood. The relatively rapid hip development that occurs during the prenatal and neonatal phases can have an impact on the different surgical and non-surgical management options used in the treatment of

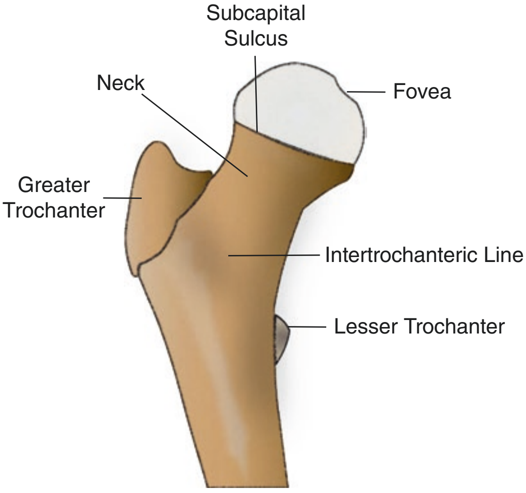

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Fig. 2.1 The proximal femur. The bony proximal femur consists of the femoral head and neck, separated by the subcapital sulcus. The greater and lesser trochanters are non-articular traction apophysis, providing attachment points for muscles, ligaments and tendons of the hip joint. The trochanters are connected by the intertrochanteric line

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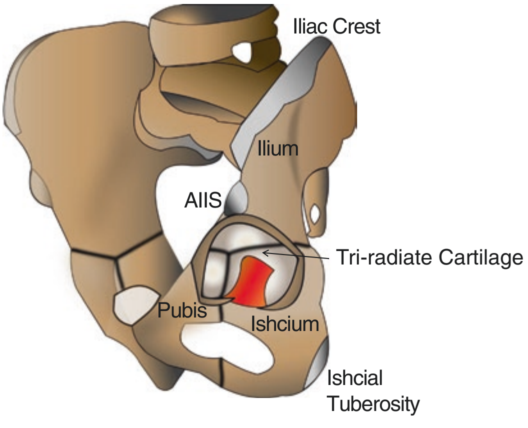

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Fig. 2.2 The bony acetabulum. The acetabulum is a semispherical cavity formed by three components of innominate bone. The ilium (2/5), ischium (2/5) and pubis (1/5) unite during development at the tri-radiate cartilage in the centre of the acetabulum

pediatric hip disorders. In particular, the unique anatomical and physiological features of the developing pediatric hip merit the surgeon's consideration before deciding on the most appropriate treatment for common disorders such as developmental dysplasia of the hip (DDH), slipped capital femoral epiphysis (SCFE), Perthes disease, and hip displacement in cerebral palsy.

Prenatal Development of the Hip Joint

The Embryonic Phase of Hip Joint Development

Primary tissue differentiation occurs in the embryonic phase of pre-natal development, weeks two through eight post-conception. It is in this phase that the entirety of the musculoskeletal system develops, including the immature origins of the hip joint [2]. All the elements comprising the pelvis and the hip joint arise from a single mass of mesoderm, transitioning sequentially to blastemic tissue, precartilage, and cartilage in the early embryonic stages [3]. Appearance of the lower limb buds occurs by 28 days post-conception, and the first recognizable structure of the hip joint—the cartilage model of the femoral diaphysis—appears during the sixth week [2]. At this point, the hip joint is nonarticulating, the precartilage that will eventually form the femoral head being contiguous with the cartilaginous acetabulum. Primitive chondroblasts in this area begin to undergo differentiation and, as their nuclei separate, matrix material is secreted into the cytoplasm and a club-shaped femur begins to form [4]. Undifferentiated mesenchymal cells—blastemal cells—make up the trochanteric projection from the femur that will subsequently form an apophysis with its associated muscle attachments. The precartilage covers the long bone articulations and the cartilage model will form the basis for the development of osseous structures. During the seventh week, a precartilaginous centre develops in the middle of the femoral shaft and the acetabulum begins to distinguish itself from the femoral head, starting as a shallow depression of approximately 65 of the arc of a circle that eventually deepens to 180 over the course of development [2]. There is evidence to suggest that movement is necessary for appropriate joint cavity formation during this period, as studies using neuromuscular blockers in chick embryos resulted in failed hip joint cavitation, failed development of intra-articular ligaments, and replacement of muscle with fat [5].

Concurrent to joint cavity development, the femoral head and articular cartilage are forming, with apoptotic cell death occurring in the interzone to create the joint space [4]. Due to the development of a discernable joint space, this stage is notable as the first time during development that it would be hypothetically possible to "dislocate" the hip. Should that occur, said dislocation would most likely be inferior as a result of poor definition of the transverse acetabular ligament [2]. Differentiation begins in the ilium just above the acetabulum. The deepening of the acetabular cavity throughout the embryonic phase is influenced by pressure from the femoral head, and during this time, differentiation of the ligamentum teres femoris and other protective capsular structures begin [2]. From here, the cartilage of the ilium with attached labrum grows over the femoral head. By the eighth week, at the end of the embryonic phase, both primary and secondary ossification centres in the ilium appear, in addition to early formation of the synovial tissue, liga-

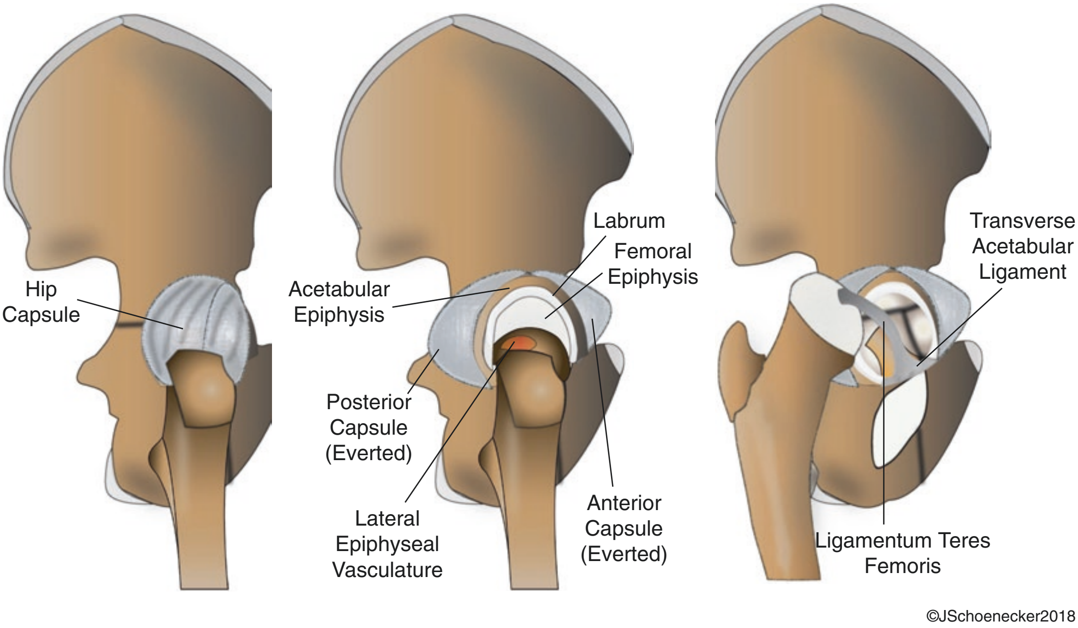

Fig. 2.3 Structures and features of the hip joint. The hip capsule encompasses the articulating components of the acetabulum and femoral head. The cartilaginous labrum encircles the femoral head, and the ligamentum teres femoris attaches at the fovea of the femoral head and blends with transverse acetabular ligament

mentum teres and the acetabular labrum (Fig. 2.3). While the neck of the femur is now elongated, unlike the ilium, the femur has not yet developed a secondary centre of ossification [1, 6].

The Fetal Phase of Hip Joint Development

Ossification, vascularization and maturation of both the proximal femur and acetabulum occur in the fetal phase, which represents week 8 post-conception through to birth. Femoral ossification proceeds from the centre of the diaphysis in both proximal and distal directions while the lower limb bud internally rotates [7]. By the 11th week, the spherical femoral head has reached 2 mm in size and the femur has 5–10° of anteversion [8]. This anteversion will continue to increase throughout fetal development, reaching a maximum of 45° at 36 weeks.

Throughout the fetal phase, the femoral head is also changing shape. During the embryonic phase, an anatomical study of 44 hip joints in fetuses and children reported that the femoral head represents 80% of a complete sphere however, femoral sphericity decreases throughout the fetal phase, resulting in a 50% spherical head at the time of birth [1, 9]. The femoral head gradually regains some sphericity in the postnatal period. As a consequence of this dynamic sphericity, acetabular coverage of the femoral head is at its lowest at birth, before again increasing through infancy and childhood [1, 9].

In the acetabulum, the primary ossification centre appears in the ilium during the early fetal period at 9 weeks. Between the 11th and 16th weeks of fetal development, the muscles form around the hip joint and capsule, the capsule joins with the femoral perichondrium and the acetabular labrum, the ligamentum teres and transverse acetabular ligament form within the capsule, and the articulating surfaces of the femoral head and acetabulum are covered by hyaline cartilage (Fig. 2.3). By the end of the 16th week, the ischial ossification centre of the acetabulum has appeared and the femoral shaft has fully ossified [6]. Following delineation of the three main acetabular epiphyseal centres delineated by the triradiate cartilage, ossification of the ischium begins in the fourth gestational month, and then a few weeks later in the pubis [10]. During iliac ossification, the lateral cortex of the ilium is persistently thicker than the medial cortex, possibly due to asymmetric mechanical stresses imposed by the gluteal muscles. Iliac ossification is also marked by haversian bone remodelling, becoming visible in the 28th week [3]. By 32 weeks post-conception, femoral shaft ossification reaches the greater trochanter and ilial and ischial ossification are complete [6].

Additionally, the vascular supply both to the femoral head and acetabulum matures throughout this time. The nutrient proximal femur artery, extracapsular circumflex arteries and the acetabular artery enter the acetabular fossa in the early fetal period (2 months). Between the second and third month, femoral vascularization also begins to develop distinct metaphyseal and epiphyseal supplies, while retinacular vessels perforate the femoral head and neck [11].

Postnatal Development of the Hip Joint

Acetabulum

The acetabulum remains immature at birth, primarily consisting of a cartilaginous ring around the femoral head, with the tri-radiate cartilage at its deepest, central point. The ischial, ilial and pubic arms of the tri-radiate cartilage eventually fuse to form the non-articulating portion of the acetabulum during the pubescent period [10]. Simultaneously, the cartilage ring grows along with the femoral head to create the load-bearing, articular surface. Three primary ossification centres—ilial, ischial and pubic—help to define the Y-shaped tri-radiate cartilage as ossification occurs (Fig. 2.2). The largest ossification centre is the os acetabuli from the pubis, forming the anterior acetabular wall by maturity. The ilial centre forms the superior acetabular dome, while the ischial centre forms the posterior acetabular wall. These ossification centres typically completely fuse to the body of the acetabulum between 17 and 18 years of age [12, 13].

Femur

At birth, femoral ossification has reached the greater trochanter and femoral neck, while the proximal femur remains cartilaginous. Three separate growth plates contribute to the growth and morphology of the proximal femur throughout postnatal development: the longitudinal growth plate (LGP) of the femoral neck, the growth plate of the greater trochanter (TGP) and femoral neck isthmus (FNI) that connects the two on the lateral neck. The LGP and TGP provide longitudinal growth [1, 14, 15]. LGP activity is influenced by acetabular pressure (Fig. 2.4) [1, 14, 15].

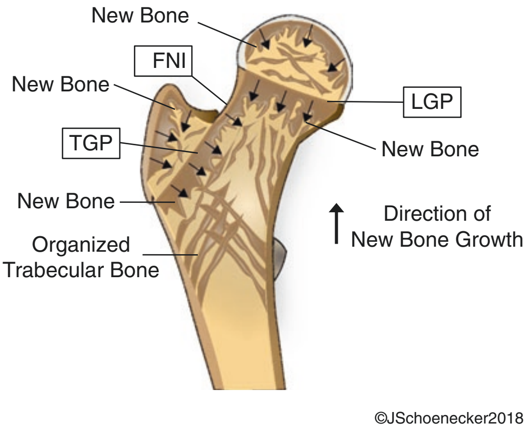

Fig. 2.4 The growth plates of the proximal femur. During postnatal development, three growth plates promote ossification of the femoral head and neck: the longitudinal growth plate of the femoral neck (LGP), the growth plates of the greater trochanter (TGP) and the femoral neck isthmus (FNI). Both the LGP and TGP provide longitudinal growth (black arrows), with the FNI connecting the two growth plates at the lateral neck

The ultimate shapes of both the femoral head and acetabulum at skeletal maturity are intimately connected and depend upon their dynamic interaction throughout development. An anteroposterior view of the pelvis demonstrating the relationship between the acetabulum and proximal femur is depicted in Fig. 2.5. Disruptions in their contact relationship or growth progression can result in angular deformities, shallow acetabuli, or otherwise imperfect hip joint formation. Despite their interconnected nature, few studies have focused on the development of the femur and acetabulum in parallel, instead focusing on one or the other in near isolation. To address this, Birkenmaier and colleagues undertook a geometrical analysis of their parallel development based on plain radiographs [16]. Studying 675 hips ranging in age from

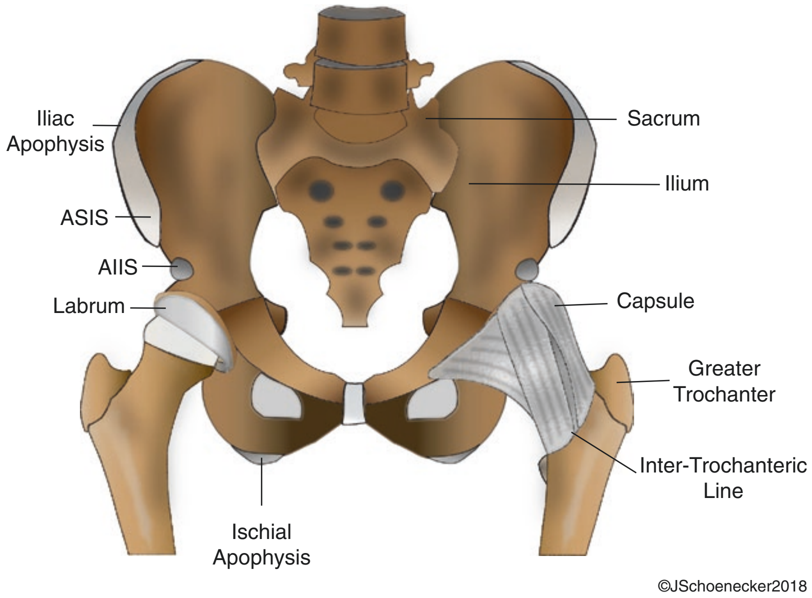

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Fig. 2.5 Anteroposterior view of the pelvis. The diagram denotes key elements of the acetabulum and proximal femur and their intimate contact relationship. The acetabulum and femoral head articulate at the hip joint capsule, held in place by the labrum—a ring of cartilage the follows the outside rim of the joint socket. The iliac apophysis provides attachment sites for the gluteal muscles and tensor fascia latae, the ischial apophysis provides attachment sites for the hamstrings, the ASIS (Anterior Superior Iliac Spine) provides attachment sites for the sartorius muscle and the AIIS (Anterior Inferior Iliac Spine) provides the attachment site for the direct head of the rectus femoris

9 months to 16 years, the authors found that no major changes in angular conformation of the proximal femur took place beyond the age of 10; however, acetabular coverage and centric alignment were dynamic through to skeletal maturity [16]. Load and muscle lever arms also increased through the end of the growth period, but their relative ratio remained constant beyond 10 years of age. These findings provide support for surgical timing considerations for corrective osteotomies of the proximal femur. Little overall impact on hip joint geometry would be expected if performed at or after 10 years of age [16].

Normal Hip Joint Anatomy and Geometry

The surface anatomy of the acetabulum is characterized by its three major components: ilium (superior 2/5), ischium (inferolateral 2/5) and pubis (medial 1/5) (Fig. 2.2). At skeletal maturity, these three bones fuse into one at the central triradiate cartilage (Fig. 2.2). The non-articular acetabular fossa is defined by the crista articularis, or articular ridge, which reaches its highest point on the posterior and inferior surfaces, and the outer articular margin of the acetabulum is continuous with the labrum [1]. The fibrocartilaginous labrum, together with the transverse acetabular ligament, forms a complete ring around the acetabulum which is largely fully-formed and developed at birth [17]. The posteroinferior third of the articular surface—the sustenaculum—supports the femoral head when sitting or in supine [3]. The internal anatomy of the acetabulum is characterized by heterogeneous bone due to the uneven distribution of weight-bearing forces [1, 18].

The proximal femur is comprised of the femoral head, neck, and greater and lesser trochanters. The subcapital sulcus, where the head and neck join, contains the intra-articular subsynovial vascular ring (Fig. 2.1) [1]. On the surface of the medial femoral head, the fovea capitis provides the ligamentum teres attachment site, while the intertrochanteric line provides the attachment site for the iliofemoral ligament (Figs. 2.1 and 2.5) [1, 6]. The trochanteric crest provides attachment sites for the short external rotators, piriformis, obturator internus, gemelli, and quadratus femoris (Fig. 2.5) [1]. Finally, the greater and lesser trochanters provide attachment sites for gluteus medius and minimus, and psoas respectively (Figs. 2.1 and 2.5) [1].

Acetabular Depth

Acetabular depth may be measured on radiographs by drawing a line from the anterior to posterior acetabular rim and constructing a perpendicular line extending to the deepest part of the acetabulum. A few studies have determined acetabular depth, by direct anatomic measurement and arthrographic measurement, in fetuses ranging in age from 11 weeks to term [4, 19]. These studies found that acetabular depth increased an average of 3 mm during weeks 11–24 of fetal development. There is limited availability of information on acetabular depth in children; however, studies in adults suggest a normal acetabular depth of 24–25 mm [17, 20]. Acetabular depth has been reported to correlate with degenerative changes during dysplasia, and a shallow acetabulum has been shown to be associated with hip instability and inferior clinical outcomes following hip arthroscopy for femoroacetabular impingement [21, 22]. Conversely, it has been postulated that a deeper acetabulum may be related to an elevated incidence of SCFE due to increased shear forces on the proximal femoral physis [23]. Whyte et al. found that decreased acetabular depth correlates with poorer clinical outcomes following hip arthroscopy for treatment of femoroacetabular impingement (FAI), and therefore may potentially be used as a prognostic indicator for these patients [21].

Acetabular Diameter

Very few studies have been performed specifically examining acetabular diameter, particularly in association with pediatric hip disorders. The measure of acetabular diameter, however, is important in surgical planning for procedures about the hip joint, particularly those involving the use of prosthetics. One study measured the relative acetabular diameter of 200 fetuses [1, 24]. Their findings indicated that the majority of acetabula were oval (57.5% vertically and 13.5% transversely oval compared to 29% round). Additionally, round acetabula were more common in younger fetuses [24]. In adults, the mean anteroposterior acetabular diameter was found to be 5.1 cm in males and 4.7 cm in females [17]. This difference in acetabular size between males and females is consistent throughout growth to adulthood. During development, the rate of acetabular diameter widening is greater than the rate of growth of the remainder of the pelvis.

Femoral Head Diameter

Femoral head shape is dynamic throughout embryonic and fetal development, and is influenced by its plasticity, joint contact forces, intrauterine fetal positioning, and fetal movement. Femoral head growth rates are accelerated in early development, with the growth rate slowing after birth [1, 24]. Dega noted the femoral head was more round in younger fetuses than older ones, postulating that the femoral heads may become flatter as the fetus grows and hip movement becomes more restricted [12]. Chung measured the femoral head diameters of 51 fetuses (2.8–4.8 months) and 78 children (birth to 15 years) [1]. Their findings indicated that femoral head diameter increased most rapidly in utero, with a growth rate of 23 mm/year. From birth to 6 months, this growth rate decreased to 10 mm/year, and then further decreased to 4 mm/year at 1–2 years of age. Acetabular growth also slows during this period. These observations may help explain decreased success rate associated with closed reduction and hip spica casting for children with hip dysplasia, once over 18 months of age [25, 26].

Chung further postulated another period of increased femoral head growth at approximately 8 years of age, correlating with typical height and weight increases in normal children at this point of development [1]. An anatomic study of 400 adult specimens reported an average head diameter of 49.7 mm in males and 43.8 mm in females [27]. Much like acetabular diameter, femoral head diameter is important to guide surgical planning for procedures involving prosthetics, such as total hip arthroplasty. However, femoral head diameter has been reported to be smaller in infants and toddlers in severe cases of DDH [28]. Whether this is a potential cause or consequence of dysplasia is difficult to definitively determine, and may potentially be some combination of the two.

An important consideration related to, but extending beyond, femoral head size is that of femoral head shape. The overarching concept for the treatment of DDH is that of achieving congruent reduction of the hip. However, as Rosenberg and colleagues argue in a recent study, such congruent reduction is not possible if the shape of the femoral head and the acetabulum do not match [29]. Past studies have explored femoral head shape both in normal hips [30, 31] and in DDH [32, 33], and found the femoral head to be largely spherical in normal hips and aspherical in DDH. However, the two studies examining DDH femoral head shape used two-dimensional plain radiographs and arthrograms to address a three-dimensional question, and lacked normal hips for comparison. Using MRI scans to compare 14 DDH and 12 normal hips in three planes (axial, coronal, sagittal), Rosenberg and colleagues utilized the concept of eccentricity to demonstrate that the femoral head in DDH is less spherical than in normal hips, and this is most pronounced in the coronal plane [29]. They argue, therefore, that since the femoral head is aspherical, a congruent reduction of the femoral head in the acetabulum is not possible to achieve, despite being the current dogma for optimal treatment of DDH [29].

The Neck-Shaft Angle

The neck-shaft angle (NSA) is the angle between the axis of the femoral neck and the axis of the femoral shaft [1]. The NSA is valgus in early development, and gradually decreases from 145° at the 15th week, to 130° at 36 weeks [34]. Postnatally, increases in weight-bearing and muscle forces acting across the hip joint further act to decrease the NSA, which reaches approximately 127° at 18 months of age (Fig. 2.6) [34].

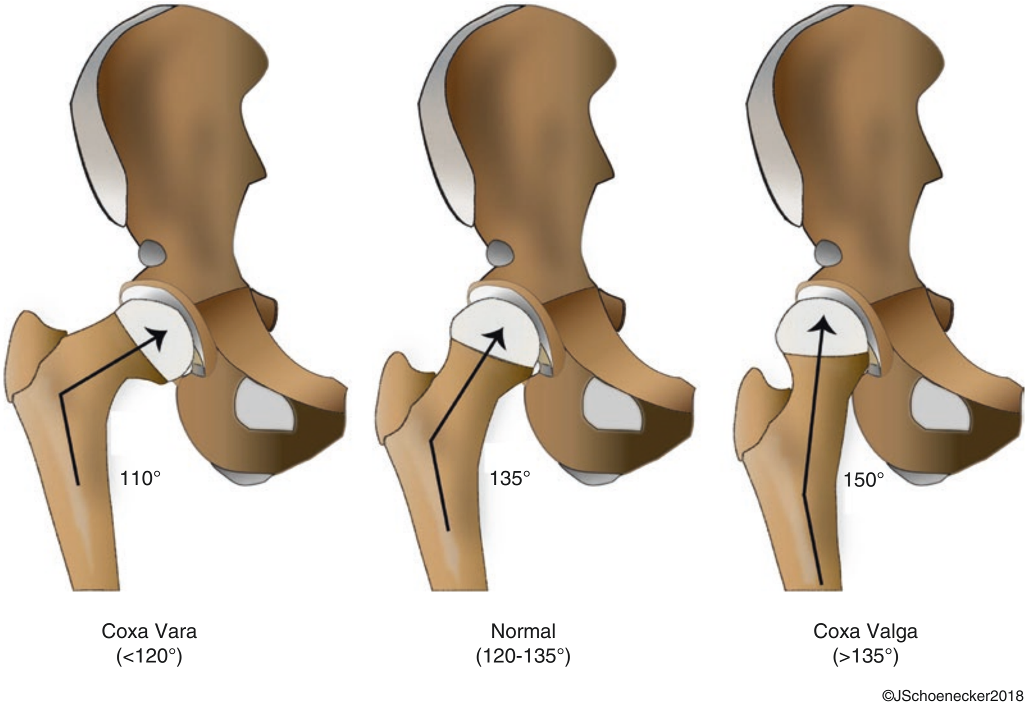

Fig. 2.6 Neck-shaft angle (NSA) of the femur. The NSA represents the angle between the axis of the femoral neck and axis of the femoral shaft (black arrows). Postnatally, a normal NSA measures between 120 and 135° (middle panel), with a decreased NSA resulting in coxa vara (left panel) and an increased NSA resulting in coxa valga (right panel)

Often in patients with cerebral palsy, or other paralytic conditions such as myelomeningocele or polio, the NSA is either increased, or remains constant in the postnatal period from birth [35]. This observation is likely due to the fact that load on the femoral head is less than normal (due to abductor weakness and altered weight-bearing; see Chap. 18) in these patients, and is evidence that normal muscle forces play an important role in normal postnatal hip development [1].

The NSA is important due to its involvement in both a number of pathologic hip conditions, and in the surgical decision-making process [36]. Specifically, Walton and colleagues demonstrated the importance of NSA in guiding device considerations for extracapsular proximal femur fixation [37]. NSA measurement can also impact femoral osteotomy planning for reconstructive and salvage hip procedures in patients with a number of pediatric hip conditions, including cerebral palsy (Chap. 18), coxa vara (Chap. 7), mucopolysaccharidosis (Chap. 27), and osteogenesis imperfecta (Chap. 29), among others [34].

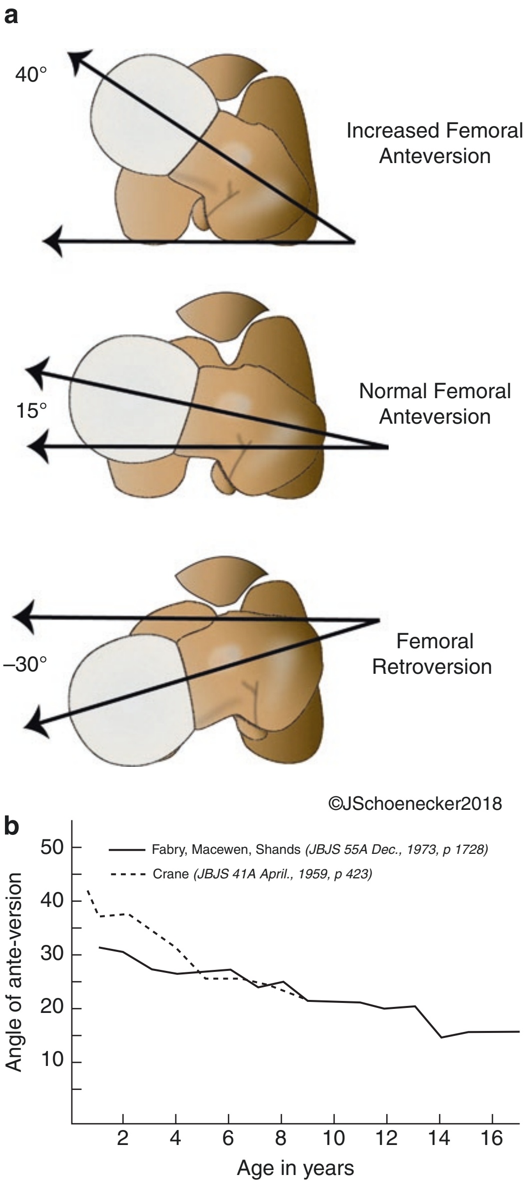

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Fig. 2.7 Femoral Anteversion. (**a**) The femoral torsion angle is formed by the intersection of the coronal plane of the posterior aspect of the femoral condyles (horizontal line) and a line through the femoral neck and head centre (head-neck axis, angled line). Femoral anteversion results when the femoral head and neck point anterior to the posterior coronal femoral condyle plane (top and middle panels). Femoral retroversion results when the head-neck axis point posterior to the femoral condyle plane. (**b**) Line graph depicting the change in femoral anteversion angle throughout development from birth to skeletal maturity. *Figure 5(b) from Chung, 1981, Used with permission* [1]

Femoral Anteversion Angle

Femoral anteversion, or the femoral torsion angle, is formed by the intersection of the coronal plane of the posterior aspect of the femoral condyles and a line through the femoral neck and head centre (head-neck axis) (Fig. 3.3, Chap. 3) [1]. Femoral anteversion is defined as the femoral head and neck pointing anterior to the posterior coronal femoral condyle plane (Fig. 2.7a). In contrast, femoral retroversion is defined as the head-neck axis pointing posterior to this plane. Femoral anteversion can first be measured in the 11th week of prenatal development, when it is typically approximately 5 [1, 38]. This anteversion increases throughout development, plateauing at 45° in the 36th gestational week [38]. Postnatally, muscle forces acting across the hip joint serve to gradually decrease femoral anteversion, with approximate values of 30° at 1 year of age and

15° at skeletal maturity (Fig. 2.7b). Hip instability can result when excessive anteversion occurs in both the femur and acetabulum; whereas, acetabular retroversion can compensate for femoral anteversion. Excessive anteversion improves spontaneously in many children; however, the capacity for spontaneous improvement markedly decreases beyond the age of 8 years [1, 39]. There is currently no strong evidence to suggest excessive femoral anteversion on its own is a potential contributing factor to degenerative changes in the adult hip. However, femoral anteversion is often associated with pathologic conditions such as DDH [40] and metatarsus adductus [1].

Postnatal Ossification of the Femoral Head

The single ossification centre of the femoral head is first radiographically detectable between the ages of 4 and 6 months [1]. Normal (but rare) variations are seen whereby multiple ossification centres occur, each with its own arterial supply [14]. The size of the femoral head ossification centre increases linearly with age through to puberty, accompanied by a corresponding decrease in the total amount of cartilage within the anlage. The proximal femur grows in length throughout this period by cartilage cell proliferation at the capital growth plate, the trochanteric growth plate, the pre-osseous femoral head cartilage, and the greater trochanter pre-osseous cartilage and perichondrium (Fig. 2.4) [1, 41]. Intraosseous blood vessels are most concentrated around areas of endochondral bone formation below the capital growth plate and femoral head articular cartilage [41].

Throughout this femoral growth phase, the shape of the proximal femur is consistently maintained by the coordinated growth and resorption of bone medially at the femoral neck and laterally just below the greater trochanter [1]. Timing of ossification follows a predictable schedule with postnatal ossification occurring first in the femoral head, then the greater trochanter and finally, the lesser trochanter.

Delays in hip joint ossification can be associated with specific pathologies. For example, in DDH, forceful reduction of a dislocated hip may result in delayed ossification. Conversely, prolonged dislocation without reduction can likewise result in delayed ossification, thought to be associated with reduced pressure on the femoral head from lack of contact with the acetabulum. Delays in bone age in comparison to chronological age are also seen associated with pathologies including Perthes disease, hypothyroidism and hypopituitarism, while advanced bone age is seen in Albright syndrome—a genetic disorder impacting bones, skin pigmentation and hormones.

Periarticular Muscles About the Hip Joint

Functional Muscle Groups About the Hip Joint

Muscles about the hip can be grouped based on their functions in relation to hip movement and stability. The major functional muscle groups of the hip joint include those involved in flexion, extension, medial rotation, lateral rotation, adduction and abduction. The primary hip flexors are the psoas major and iliacus that together form the iliopsoas, with assistance from the pectineus, rectus femoris and sartorius [42]. Primary extensors are the gluteus maximus and the hamstrings. The tensor fascia latae and fibres of the gluteus medius and gluteus minimus are the key contributors to medial hip rotation, while the obturator muscles, quadratus femoris and gemelli, with assistance from the gluteus maximus, sartorius and piriformis, are the key contributors to lateral rotation. The adductor longus, brevis and magnus, with assistance from the gracilis and pectineus, control hip adduction, while the gluteus medius and minimus, with assistance from the tensor fascia latae and sartorius, control hip abduction [42, 43]. Figure 2.8 depicts key functional muscles and their locations about the hip joint.

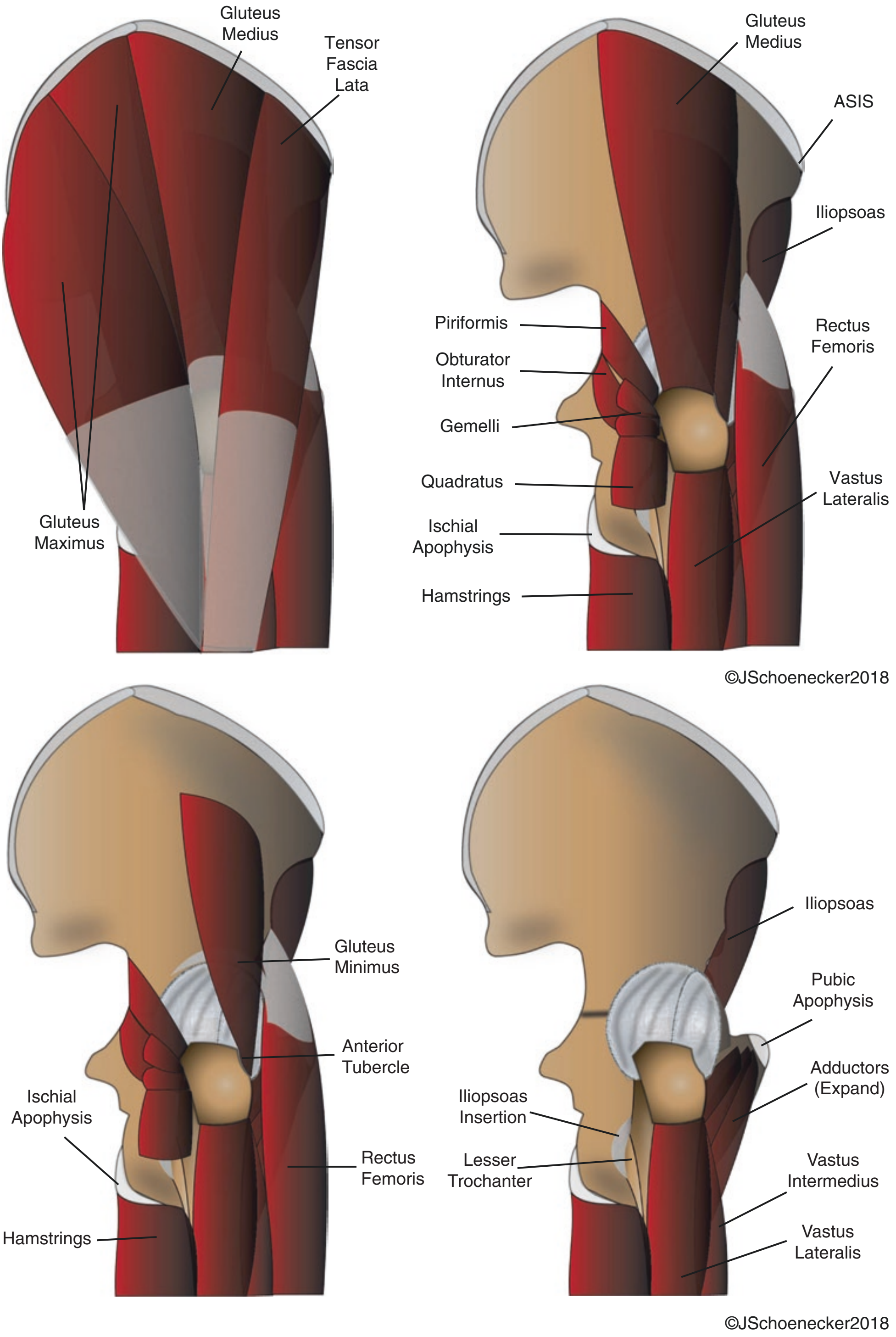

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Fig. 2.8 Functional muscles about the hip joint. Primary hip flexors include the iliopsoas (upper and lower right panel) and rectus femoris (upper right and lower left panels). Primary hip extensors include the gluteus maximus (upper left panel) and hamstrings (upper right and lower left panels). Tensor Fascia Lata and gluteus medius (upper left panel) contribute to medial rotation. The obturator internus, quadratus, gemelli and piriformis contribute to lateral rotation (upper right panel)

Imbalance of these muscle groups can result in changes to the hip joint anatomy over a period of time, and the pediatric hip can be particularly susceptible to any of these muscle loading imbalances due to continual developmental changes during this period [44]. Consequently, increased or decreased muscle loading can influence bone shape and structure differently in newborns, adolescents and adults, and it has been shown that postnatal muscle loading at the hip is critical for the formation of the proximal femur and acetabulum [45–47]. A series of experiments in mice demonstrated that unilateral postnatal unloading of key hip stabilizing muscle groups decreased acetabular coverage and bone accumulation of the femoral head, while also altering the size and shape of the femoral head in unloaded hips versus the contralateral hip [48]. Adaptations to this altered loading during postnatal growth may have a profound influence on proliferation and differentiation of growth plate cells, subsequently resulting in regions of significant loss of acetabular coverage and altered contact mechanics of the proximal femur and acetabulum. Consistent with these findings, it has been reported that 79–90% of cases of osteoarthritis of the hip have hip joint abnormalities that lead to increased impingement or altered loading patterns [49].

Surgical Considerations for Muscles About the Hip Joint

Detailed discussion on the muscles, muscle groups and biomechanics of the hip joint can be found in Chap. 3. However, a brief discussion on their importance for surgical procedures will be outlined here. Consideration of the anatomical orientations of many of the muscles about the hip joint in relation to their function is of paramount importance for good surgical outcomes. The hip joint is covered by a large muscle envelope consisting of 21 muscles that cross the joint (Fig. 2.8) [50]. Specific muscles in this envelope carry major surgical significance depending on the intended procedure approach. Together with the iliotibial band, the tensor fascia latae and gluteus maximus form the main outer layer of this muscular envelope (Fig. 2.8, upper panel); therefore, at least one of these three components must be split to allow access to deeper muscles in the gluteal region [50]. The gluteus medius is also a key muscle to consider in surgical planning (Fig. 2.8, upper panel). It functions as a major hip abductor, and together with the gluteus minimus (Fig. 2.8, lower panel), stabilizes the hip joint during swing phase of the gait cycle. Weakness or inefficiencies of these abductors can cause a Trendelenburg gait, while tightness can cause damage to the femoral head.

Lateral surgical approaches to the hip aim to avoid the need to detach the gluteus medius, or facilitate its reattachment following the procedure [51–53]. Additionally, despite the relatively weak abduction role of the gluteus minimus (Fig. 2.8, lower panel), it also contributes to flexion and internal rotation; therefore, its accurate reattachment during surgery is also of critical importance [50]. Both the piriformis and the iliopsoas are other surgically important muscles (Fig. 2.8, upper panel). The piriformis is a short external rotator of the hip that provides insight into the area's neurovasculature [50]. Specifically, the superior gluteal vessels and superior gluteal nerve enter the gluteal region above the pelvis by passing below the piriformis, necessitating caution during surgical procedures. The iliopsoas is comprised of both the psoas major and iliacus muscles that are usually separate in the abdomen, but merge in the thigh to form the primary hip flexor [54]. The iliopsoas tendon inserts into the lesser trochanter posteromedially (Fig. 2.8, lower panel) and must be released during anterior and medial surgical approaches to the hip joint to facilitate exposure [50].

Finally, the iliocapsularis muscle is often overlooked in its role in surgical planning, but appears to be an important stabilizer specifically in the dysplastic hip [55]. The iliocapsularis—also referred to as the iliacus minor or iliotrochantericus—overlies the anterior hip capsule, originating mainly from an elongated attachment to the anteromedial hip capsule and part of the border of the anterior inferior iliac spine (AIIS), inserting just distal to the lesser trochanter [55]. It serves as an important landmark for exposure of the anteromedial hip capsule and psoas tendon interval during Bernese periacetabular osteotomy (PAO) [56–58]. The Bernese PAO is performed through an anterior iliofemoral incision, and the iliocapsularis muscle must be elevated to allow for the ischial osteotomy interval between the hip capsule and psoas tendon [58]. The iliocapsularis had long been unappreciated or even unmentioned in the surgical literature until this finding during PAO, as it is thought to have a superfluous role in normal hips or hips with excessive acetabular coverage [55]. Babst and colleagues demonstrated that the iliocapsularis is hypertrophied in dysplastic hips, likely due to increased demand on the muscle as a consequence of hip instability [55]. Hip instability causes chronic overloads and shear forces that are most pronounced when in full extension and external rotation. At this point, the iliocapsularis is maximally stretched. Hypertrophy of this muscle may therefore passively assist in constraining the femoral head in a deficient acetabulum. Conversely, when there is acetabular over-coverage, the bony anatomy naturally provides stabilization of the femoral head, thus mitigating the need for the iliocapsularis and leading to muscle atrophy [55].

Surgical Approaches to the Hip Joint

The anterior approach to the hip is also referred to as the anterior iliofemoral or Smith-Petersen approach [55]. The anterior approach facilitates sufficient exposure of the acetabulum while leaving the abductor mechanism intact. The anterior approach is indicated in a variety of situations, including open reduction for a hip dislocation in DDH, synovial biopsy, hemiarthroplasty, pelvic osteotomies, total hip arthroplasty and joint drainage and irrigation. Superficial and deep fasciae are first divided, and then the attachments of the gluteus medius and tensor fasciae latae are freed from the iliac crest (Fig. 2.8 upper panel). A blunt dissection is then performed between the tensor fasciae latae and the sartorius below the anterior superior iliac spine (ASIS). Deep dissection is then performed through the interval between the rectus femoris and the gluteus medius, involving detachment of the rectus femoris from its origins to expose the hip joint capsule (Fig. 2.8 upper panel). The anterior approach enables both the superficial and deep dissections to occur through the internervous planes, minimizing potential neurovascular complications, while providing exposure of the anterior column and medial wall of the acetabulum. The lack of disruption of the abductor mechanism mitigates post-operative limping, and it carries minimal risk of hip dislocation. However, the anterior approach does not provide sufficient access to the posterior column of the acetabulum and femoral medullary canal, limiting its utility for certain surgical procedures [55].

The anterolateral approach uses the intramuscular plane between the tensor fascia latae and gluteus medius and provides better exposure of the acetabulum than the anterior approach [55]. However, this approach necessitates disruption of the abductor mechanism to allow for hip adduction and facilitate acetabular exposure. This approach can be indicated for similar procedures to the anterior approach including total hip replacement, hemiarthroplasty and synovial biopsy of the hip, but also for open reduction and internal fixation of femoral neck fractures and biopsy of the femoral neck. In this approach, the fascia lata is incised at the posterior margin of the greater trochanter, and the interval between the gluteus medius and tensor fasciae latae is identified by blunt dissection. The gluteus medius and gluteus minimus are retracted proximally and laterally in order to expose the superior aspect of the joint capsule covering the femoral neck. In addition to the advantages of the anterior approach, the anterolateral approach also provides good exposure of the femoral neck and carries a low risk of avascular necrosis of the femoral head due to preservation of the superior retinacular vessels supplying the femoral head. However, exposure of the acetabulum remains limited, and it carries a risk of damage to the superior gluteal nerve [55].

Lateral approaches, either direct or transtrochanteric, provide better exposure of the acetabulum than anterior/anterolateral approaches, but require complete or near-complete disruption of the abductor mechanisms [55, 57]. The direct lateral approach, first described by McFarland and Osborne [52], and later modified by Hardinge [53], involves division of the fascia lata and iliotibial band over the greater trochanter, followed by posterior retraction of the gluteus maximus and anterior retraction of the tensor fasciae latae. The gluteus medius is then separated from surrounding muscles by blunt dissection, and the tendon of the gluteus minimus is divided to expose the joint capsule. The trans-trochanteric technique involves an osteotomy of the attachment of the gluteus medius and vastus lateralis (Fig. 2.8, upper and lower panels) at the greater trochanter to enable lifting the muscles and the mobile trochanteric fragment in one piece [59]. This approach facilitates excellent exposure of the acetabulum and proximal femur and permits trochanteric transfer to restore abductor power after total hip replacement. This technique has been further popularized by Dr. Ganz in surgical hip dislocation approaches [60]. However, due to disruption of the abductor mechanism, post-operative abductor weakness can result, and trochanteric nonunion may occur at the osteotomy site. There is also an increased incidence of trochanteric bursitis and heterotopic ossification [61].

Posterior approaches to the hip are most commonly used for total hip replacement but can also be used for posterior hip dislocations [50, 62]. Like the anterior approach, the posterior approach does not disrupt the abductor mechanism and facilitates a rapid post-operative rehabilitation process. However, there is a higher risk of post-operative dislocation and injury to the sciatic nerve [50].

The medial approach was first developed by Ludloff to treat developmental hip dislocations in infants and young children [63]. Here, the dissection plane is between the adductor longus and pectineus; while Ferguson's modification sees the superficial muscle interval between gracilis and adductor longus, and the deep interval between the adductor brevis and adductor magnus (Fig. 2.8, lower panel) [50, 64]. The medial approach requires little dissection, thus keeping operation time and blood loss to a minimum—an important consideration for infants and young children. However, it has limited use only in infants and carries a risk of damage to the medial femoral circumflex artery (MFCA), thus increasing the risk of AVN [50].

While there are distinct merits and drawbacks associated with each of these surgical approaches to the hip joint, the common theme is that the practicing surgeon should possess intimate knowledge and exercise great attention to the anatomical orientations and functional contributions of the hip joint muscles in order to maximize benefit and mitigate risk with any of these surgical approaches.

Vascular Supply to the Hip Joint

Vascular Supply of the Femoral Head

Vascularization of the femur is first seen at the end of the embryonic developmental phase. At the eighth week, capillaries penetrate the cartilage model of the femur at the mid-diaphysis [14]. This is the site of the primary ossification centre of the femur. These capillaries eventually form the nutrient artery in the mature bone. As development continues, a ring of vessels encircle the femoral neck, forming primitive retinacular vessels which invade the cartilage model at the articular cartilage-neck junction during the 14th week of gestation. Once in place, this 'primitive' vascular model remains largely intact through to skeletal maturity. In the postnatal period, the vascular supply to the proximal femur is composed of three main arterial

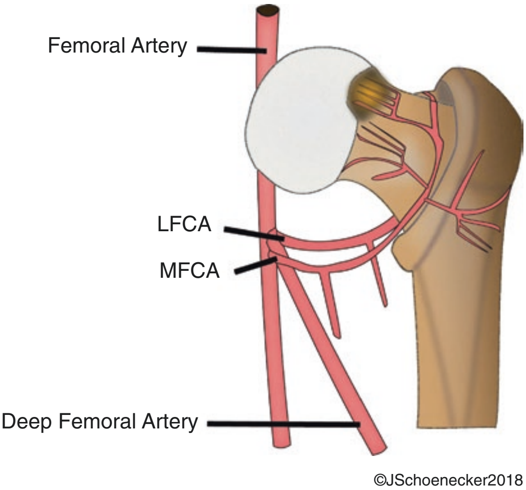

Fig. 2.9 Posterior view of the vascular supply to the femoral head. The medial femoral circumflex artery (MFCA) and lateral femoral circumflex artery (LFCA) branch from the profunda femoris artery or common femoral artery, forming the extracapsular arterial ring. The MFCA branches to form the medial ascending cervical arteries and the LFCA branches to form the anterior ascending cervical arteries that penetrate the hip joint capsule

systems: (1) the retinacular or extracapsular ring of vessels, (2) the foveal or ascending cervical vessels and (3) the intraosseous or intracapsular vessels (Fig. 2.9) [1, 14]. A fourth arterial group, those of the ligamentum teres, are also present but their precise role and contribution to the blood supply of the femoral head is more controversial and less well-defined. The ligamentum teres is routinely excised during surgical dislocation, and for DDH-related procedures, usually with negligible impact [65]. Additionally, in a study involving injections to the femoral head, contributions of the ligamentum teres to vascularization was entirely absent in some cases [66].

The medial and lateral femoral circumflex arteries (MFCA and LFCA, respectively) comprise the extracapsular ring, and arise directly from the profunda femoris artery or directly from the femoral artery (Figs. 2.9 and 2.10) [1, 67]. These arteries are the primary vascular supplies to both the proximal femur and greater trochanter [14]. The second major arterial supply system is formed by ascending cervical branches from the extracapsular ring (Fig. 2.9). These branches penetrate the hip joint capsule and travel around the femoral neck under the synovium, anastomosing laterally at the piriformis fossa. Once intracapsular, the retinacular vessels travel within

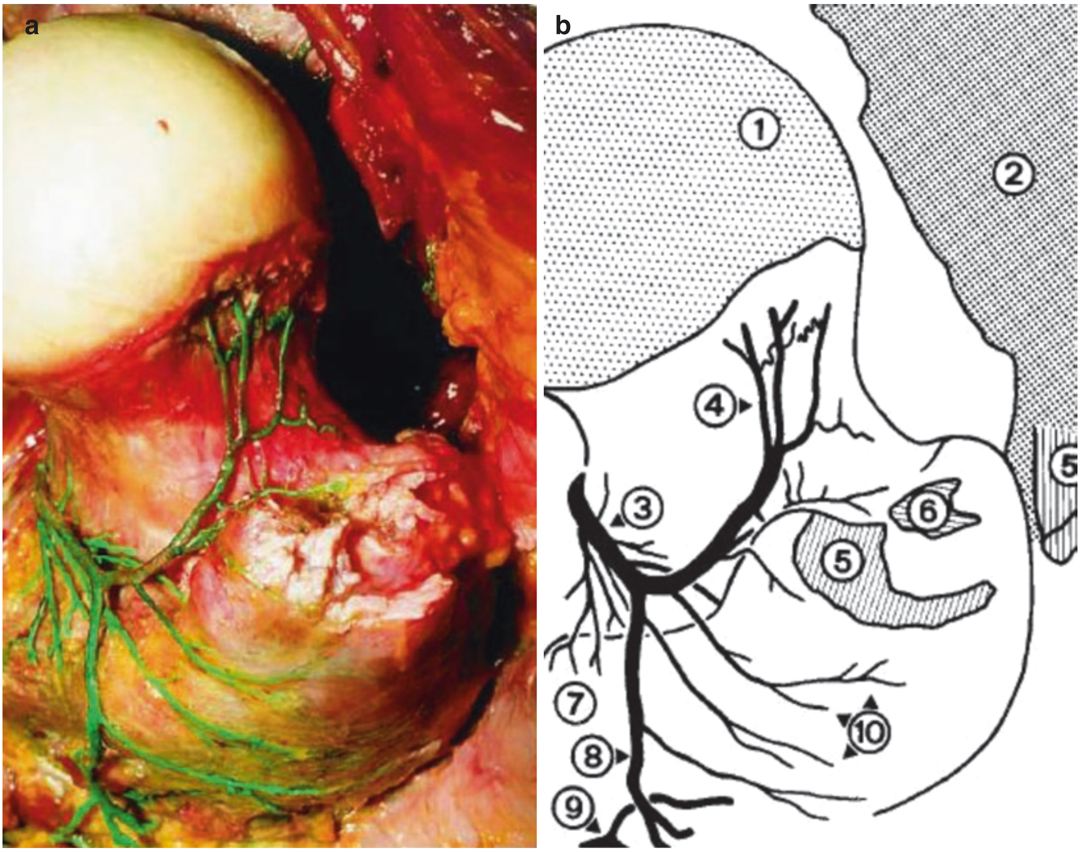

Fig. 2.10 Photograph (**a**) and corresponding line diagram (**b**) of a posterosuperior view of the right hip depicting the penetration of the terminal branches of the medial femoral circumflex artery (MFCA) into the hip joint capsule. The line diagram shows (1) femoral head, (2) gluteus medius, (3) deep branch of the MFCA, (4) terminal subsynovial branches of the MFCA, (5) gluteus medius tendon insertion, (6) piriformis tendon insertion, (7) lesser trochanter and nutrient vessels, (8) trochanteric branch, (9) first perforating artery branch and (10) trochanteric branches. *Figure reproduced with permission of the Licensor through PLSclear from Gautier et al., 2000* [67] *(PLS Reference Number 4914)*

fibrous extensions of the capsule wall. These extensions have been termed the retinacula of Weitbrecht (RW), and they penetrate the femoral head just distal to the articular rim [14, 65, 68]. The femoral neck elongates during growth, and in this stage the anterior retinacular artery (the terminal branch of the LFCA) regresses to supply the anterior metaphyseal area, diminishing its overall contribution to the proximal femoral blood supply [69]. During this phase, the superior and inferior retinacular arteries (SRA and IRA, respectively; the terminal branches of the MFCA) grow along with the femoral neck and increase their overall contribution to the proximal femoral blood supply (Fig. 2.11). The SRA has long been considered to be the primary blood supply to the femoral head, with the IRA being a relatively minor contributor [70]. However, several more recent studies using quantitative MR imaging have demonstrated a potential larger role for the IRA in femoral head perfusion [71].

The third major supply system is the intracapsular synovial ring of vessels that ascend superficial to the perichondrial ring, encircle the femoral head and supply the epiphysis [72]. During growth and development, the proximal femoral capital physis acts as a barrier between the blood supplies of the epiphyseal and metaphyseal ossification centres until the physis closes at skeletal maturity [72]. Throughout this phase, each penetrating vessel supplying the epiphysis is responsible for a distinct zone of vascularity. Consequently, until maturity, patterned necrosis may occur in the femoral head if a particular vessel (i.e. vascular zone) is compromised [72].

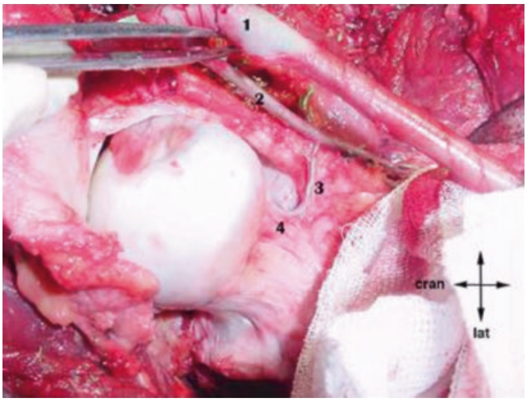

Fig. 2.11 Anterior aspect of the right hip following capsulotomy. Photograph depicting the retinacular artery derived from the medial femoral circumflex artery (MFCA). (1) Femoral artery; (2) MFCA; (3) Retinacular branch; (4) Anterior aspect of the femoral neck. cran = cranial and lat = lateral. *Figure reproduced with permission of the Licensor through Copyright Clearance Center from Kalhor et al. 2009* [68] *(License Number 4275531114422)*

Prenatal Development of the Femoral Blood Supply

In the 8-week-old embryo, the nutrient proximal femur artery, the MFCA, and the LFCA are all present. Vascular sprouts from the medial and lateral ascending cervical arteries then begin to branch, eventually forming a fine vascular network beneath the synovium that extends to the femoral head circumference in the 12–16 week-old fetus [1]. At this point, blood vessel rudiments originating from the MFCA and LFCA can be seen on the medial and lateral greater trochanter. In the following gestational weeks, the number and branches of these rudimentary arteries increases. By 20–24 weeks, four to five ascending cervical arteries are present on the anterior and posterior femoral neck, while the descending metaphyseal artery has branched and passes distally in close proximity to the femoral shaft nutrient artery. At 24–28 weeks, the nutrient artery of the femur anastomoses with the nutrient artery of the acetabulum and the blood vessels on the medial and lateral sides of the greater trochanter anastomose (Fig. 2.12) [1].

Postnatal Development of the Femoral Blood Supply

As described, once established prenatally, the femoral vascular supply remains largely intact throughout postnatal growth and development. The medial, posterior and lateral portions of the extracapsular ring surrounding the base of the femoral neck comprise a continuation of the MFCA, while the anterior portion of the ring is a continuation of the LFCA [1, 14]. The MFCA

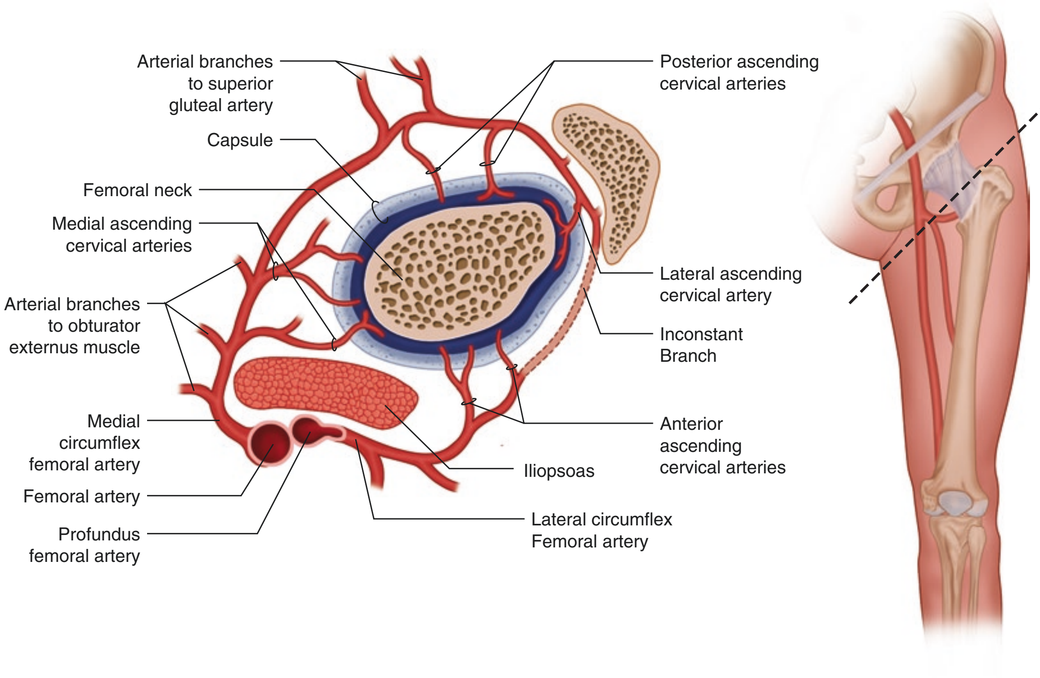

Fig. 2.12 Cross-sectional diagram of the proximal left femur depicting the extracapsular arterial ring and arteries crossing the hip capsule. *Figure from Chung, 1981* [1]*, Used with Permission*

passes posteriorly between the iliopsoas and pectineus muscles and then between the medial capsule and obturator externus muscle before branching to form the medial ascending cervical branches. These branches subsequently breach the capsule and travel up the femoral neck in the synovium, with several branches also supplying the obturator externus muscles. The intertrochanteric crest is located in the posterior extracapsular region. Here, the posterior ascending cervical arteries breach the capsule and travel up the femoral neck, and the MFCA runs adjacent to the posterior capsule before passing through the lateral capsule in the posterior trochanteric fossa. The LFCA passes anterolaterally to the iliopsoas and then divides into several branches, one of which comprises the anterior ascending cervical branch to the femoral head and neck [1, 14].

The ascending cervical arteries pierce the capsule around the base of the femoral neck, with an average of 2 arteries anteriorly, 2 medially, 1.4 posteriorly and 1.1 laterally [1, 14]. The epiphyseal and metaphyseal lateral ascending cervical artery branches all originate from a common arterial stem in the posterior trochanteric fossa that supplies the greater trochanter and femoral head and neck for the entirety of the growth and development period. Epiphyseal branches of the ascending cervical arteries supply the capital secondary ossification centre, mostly crossing the lateral aspect of the mid-femoral neck. All the ascending cervical arteries groups then converge to form a subsynovial ring on the femoral neck surface in the subcapital sulcus. From this ring, some vessels branch to the metaphysis to supply the capital secondary ossification centre, and eventually, the ossified femoral neck [1, 14]. Figure 2.12 shows the locations and connections of the arteries forming the extracapsular arterial ring.

Surgical Implications for the Femoral Vascular Supply

Avascular necrosis (AVN) of the femoral head can be a devastating iatrogenic complication following the treatment of different pediatric hip conditions. AVN is caused by disruption of the blood supply to the femoral head, resulting in osteonecrosis, or bone cell death. Therefore, knowledge of the femoral head vascular supply is critical when performing corrective or hip-preserving surgical procedures. The extracapsular ring comprised of retinacular branches of the MFCA and LFCA provide most of the bloody supply to both the proximal femur and greater trochanter [14]. These vessels anastomose in the piriformis fossa; consequently, due to their substantial vascular contribution, this anastomosis is particularly susceptible to insult during surgical drill entry into the femoral canal, or during femoral neck fracture [73, 74]. Gautier and colleagues later described key central (anterior or medial to the lesser trochanter) and peripheral (posterior or lateral to the lesser trochanter) anastomoses of the MFCA that may explain why certain cases of surgical, traumatic and non-traumatic hip dislocations develop AVN while others do not [67]. The most consistently present peripheral anastomosis was that of the deep branch of the MFCA and the IGA along the inferior border of the piriformis [67]. Grose and colleagues expanded upon the findings of Gautier and Ganz, identifying the anastomotic site between the MFCA and IGA to be extracapsular, immediately adjacent to the tendon of the obturator externus in the trochanteric fossa [75]. Their findings confirmed the postulation of Gautier and Ganz that IGA was capable of perfusing the femoral head in the absence of blood flow in the MFCA [67, 75]. During growth, the relative contribution of the MFCA to the overall femoral blood supply increases while that of the LFCA decreases [74]. Additionally, by 10 years of age, the number of vessels along the medial and anterior aspects of the femoral neck has reduced by 50%, presenting important considerations during femoral neck osteotomy procedures.

Despite the recognized importance of intimate knowledge of the femoral head vascular supply for hip surgical procedures, there had been a lack of precise quantitative information regarding the capsular insertion and intracapsular course of vessels supplying the femoral head. Two recent studies, one using gross specimen dissection [70] and one using gadolinium-enhanced MR imaging [76], have therefore examined the distribution of vascular foramina at the femoral head-neck junction in order to better define potential danger zones and prevent iatrogenic vascular damage during surgical interventions of the hip joint. The findings of these studies have provided a detailed, quantitative map of the arterial topographic anatomy of the femoral head-neck junction. The distribution of vascular foramina is particularly well-visualized when the femoral head is presented as a clock-face with the superior margin at 12 o'clock, anterior margin at 3 o'clock, inferior margin at 6 o'clock and posterior margin at 9 o'clock (Fig. 2.13). Lazaro and colleagues anatomically defined the quantitative locations of the insertions of the deep, ascending and transverse branches of the MFCA into the capsule, as well as the entry points into the articular rim of the femoral head [70]. The borders of the superior, inferior and anterior retinaculum of Weitbrecht (RW) were also defined. To completely preserve the vascular supply of the hip during surgical procedures, the posterior femoral capsular attachment and the superior and inferior RW should be maintained intact and thus should be considered vascular danger zones to avoid. Rego and colleagues also examined the topographic location of the vessels feeding the epiphysis, with particular regard to surgical procedures related to femoroacetabular impingement and cam lesion resection [76]. Using MR imaging techniques, this study found a predominance of arterial foramina from 10 to 12 o'clock, with the retinaculum extending from 1 to 10 o'clock (Fig. 2.13). Their findings suggest that critical areas for perfusion of the femoral head may overlap with the area of anterolateral cam deformity in FAI patients, and therefore presents a guide for the surgeon when selecting cuts for subcapital and intracapital osteotomies [76]. Specific safe zones for the depth of bone resection in these procedures were also elucidated. While both of these studies provide valuable insight to aid in the prevention of iatrogenic vascular comprise to the femoral head during surgical procedures about the hip, caution must be taken in assuming the generalizability of these results as they were based on 14 and 16 anatomical specimens, respectively. Additionally, the information gleaned in these investigations was from normal

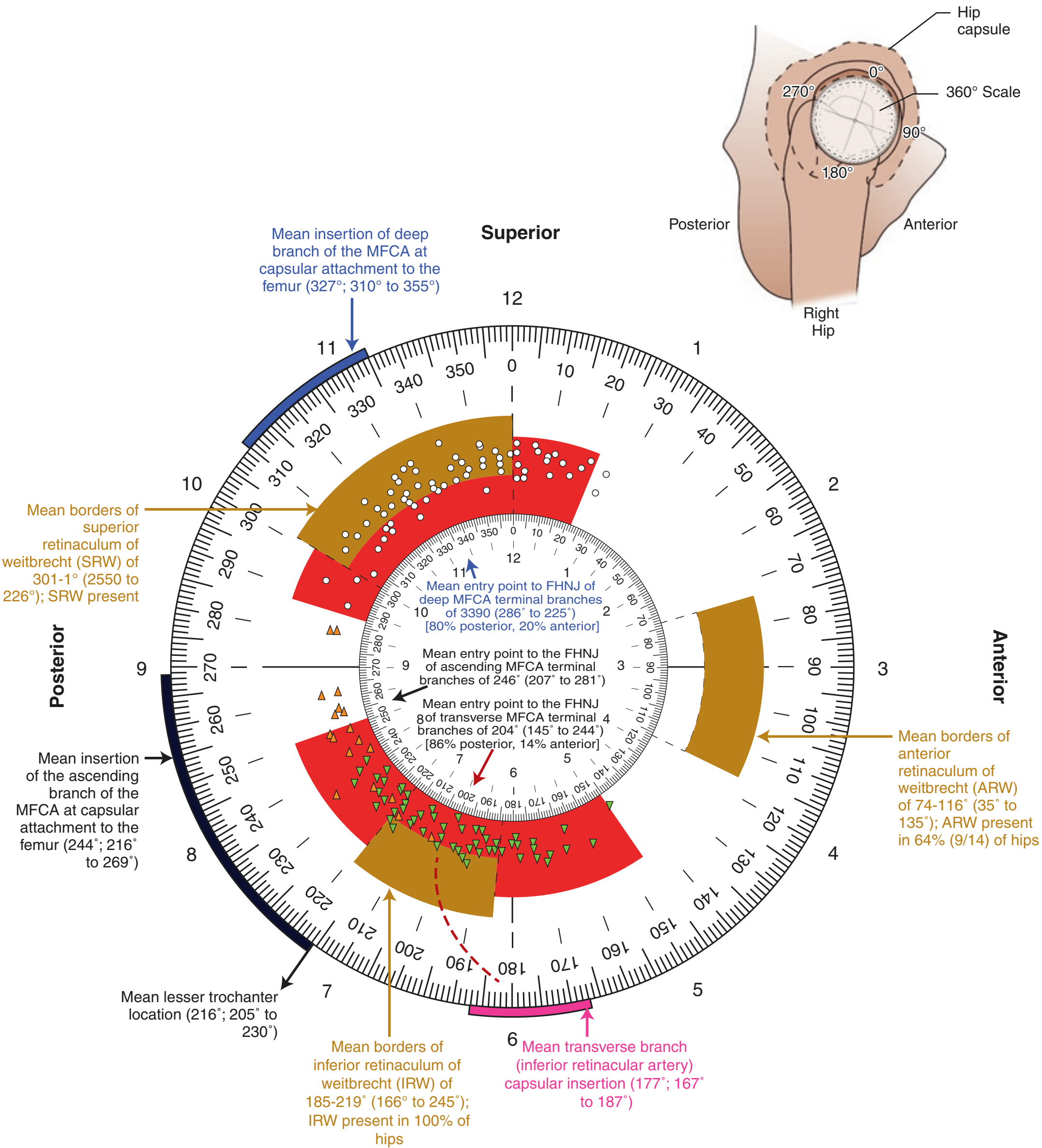

Fig. 2.13 Distribution of the vascular foramina at the femoral head-neck junction. The outer circle shows attachments of the femoral capsule and the inner circle shows the articular rim of the femoral head. MFCA = medial femoral circumflex artery; FHNJ = femoral head-neck junction. *Figure reproduced with permission of the Licensor through PLSclear from Lazaro et al., 2015* [70] *(PLS Reference Number 5670)*

hips, and may not be entirely transferrable to the deformed hip undergoing surgery.

Ganz's work with surgical dissection studies has revolutionized the development of safe surgical dislocation of the femoral head techniques [67, 77–79]. Surgical dislocation of the femoral head has a number of pathologic indications for use, including treatment for SCFE, femoral head reduction in Perthes disease, femoral head-neck osteochondroplasty for cam impingement, and for the fixation of acetabular fractures. Ganz's improvements and modifications have helped surgeons around the world to be more cognizant of the vascular supply when performing hip preservation procedures for a number of these different indications, resulting in a decrease in the incidence of AVN. However, it is vital to recognize that, even with optimized technique, there is a steep learning curve associated with these procedures that influences the rate of complications, including AVN. The importance of surgeon experience and comfort level with the surgical hip dislocation and other procedures involving the pediatric hip cannot be overstated. In support of this, a recent study reviewing proximal femoral varus derotation osteotomy in children with cerebral palsy showed that surgeon volume (number of procedures performed) was a strong predictor of surgical success [80]. Another study investigating the impact of surgeon experience on complications following periacetabular osteotomy did not find such an association, but did find a reduction in operative time with increasing surgeon experience [81].

Despite its importance, the definition, diagnosis, and classification of AVN remain controversial, with reported rates being highly variable across the literature. The identification and classification of AVN is confounded by a number of factors including severity, duration, and overall functional impact. Some cases of AVN are transient, and resolve spontaneously over time with little clinical consequence. However, some hips that have a mild and transient vascular insult early in development can have severe growth disturbances long-term, and factors differentiating these findings have not been delineated. More severe cases can result in permanent consequences, including hip pain due to arthrosis, limb length discrepancy, and gait disturbance; again however, not all cases of more pronounced and prolonged vascular disruption result in permanent functional consequences for the patient. Consequently, despite being a prominent iatrogenic complication associated with treatment of many pediatric hip conditions, a clearer understanding of AVN remains a critical outstanding issue.

There is a large volume of literature now on AVN following hip reconstruction surgery for children with cerebral palsy. Potential relationships between the magnitude of surgery, amount of surgical correction and certain pre-operative radiographic measures (NSA, Reimers Migration Percentage) have been suggested, although none of these have been substantially validated as true predictors or causal factors of AVN [82]. Similarly, for DDH, AVN is a frequently reported complication following both closed and open reduction; however, highly variable rates are reported across the literature, and true prognostic or predictive factors have yet to be firmly elucidated. Persistent low-level evidence has contributed to this issue, with numerous single-centre retrospective studies, small sample sizes in individual studies and a lack of a standardized definition or timeframe for AVN diagnosis limiting cross-study comparison. Surgeons need a detailed understanding of the vascular supply to the femoral head to help reduce incidence of AVN when treating pathologies of the pediatric hip.

Vascular Supply of the Acetabulum

The blood supply to the acetabulum is completely established in the prenatal development phase and is comprised of two independent systems: a central axis originating from the acetabular artery that supplies the tri-radiate cartilage and a peripheral source involving the superior gluteal, inferior gluteal, internal pudendal and obturator arteries, the latter system forming a periacetabular vascular circle, or extra-articular peripheral ring [83]. The blood supply originating from the acetabular artery is formed by three major branches penetrating the cartilaginous nucleus at the centre of the acetabulum. The superior branch originates from the superior pedicle of the ligamentum teres and extends to the primary ossification centre of the ilium [1]. The antero-inferior branch originates from the artery of the ligamentum teres and extends to the superolateral margin of the pubis. The postero-inferior pedicle arises from the posterior branch of the artery of the ligamentum teres and extends to the ischial ossification centre [1].

In the peripheral system, the superior gluteal artery (SGA) arises from the posterior division of the internal iliac artery, and supplies the superior part of the acetabulum and the weight-bearing dome [1, 14]. The SGA is located in the intermuscular plane of the gluteus medius and minimus, tracking along the upper rim of the acetabulum toward the anterior superior iliac spine. The posterior branch of the obturator artery supplies most of the inferior acetabulum while the inferior gluteal artery (IGA) supplies the posterior acetabulum. The inferior gluteal artery has also been described to contribute to the blood supply of the femoral head through an anastomosis with the MFCA adjacent to the tendon of obturator externus in the trochanteric fossa [75]. On the anterior acetabulum, the SGA, the pubic branch of the obturator artery, and the ascending branch of the LFCA anastomose, provide collateralization between the different arterial systems.

Similar to the clock face analogy used described for the femoral head, one can also picture the right acetabulum as a clock face to better visualize the locations of the vessels providing the acetabular blood supply. By convention, the transverse acetabular notch is commonly defined as the 6 o'clock position. With this image in mind, the superior and inferior gluteal arteries exit the pelvis at the greater sciatic notch (10 o'clock). These arteries diverge and supply the anterosuperior acetabulum from 10 to 4 o'clock, and the posterior acetabulum from 8 to 10 o'clock, respectively. At 6 o'clock, the obturator artery exits the pelvis via the obturator foramen and supplies the inferior acetabulum from 4 to 8 o'clock [84].

Surgical Implications for the Vascular Supply of the Acetabulum

The incidence of AVN of the acetabulum is very low, both from idiopathic and iatrogenic causes. Consequently, much of the surgical literature has focused on the vascular supply to the proximal femur. However, AVN of the acetabular fragment has been reported following rotational periacetabular osteotomies in adults and with Bernese periacetabular osteotomy (PAO) when the inferior cut is intra-articular, disrupting the acetabular branch of the obturator artery [84]. In 1992, Damsin and colleagues defined the two independent arterial supply systems involved in acetabular vascularization, and assessed the risks of necrosis following PAO in childhood [85]. In their study, the acetabular fragments remained perfused following sectioning of the ilium just above the acetabulum and the ischial and iliopubic rami at their median portion. The authors did, however, note a susceptible zone at the anterior inferior iliac spine [85]. This particular zone had poor distribution of arterial branches from the anastomotic arch between the artery of the roof, the IGA, internal pudendal and obturator artery. The authors suggest that this poor distribution could contribute to defective development of the outer part of the acetabular roof, a growth disorder that can result following PAO [85]. In 2003, Beck and colleagues produced similar findings when performing the Bernese PAO [84]. Utilizing a modified Smith-Petersen approach, whereby all cuts are performed from within the pelvis, the acetabular fragment remains vascularized by the supra-acetabular and acetabular branches of the SGA, IGA and obturator artery. The degree of correction tolerated by the smaller blood vessels, however, is not clearly defined. Hempfing and colleagues reported a significant reduction in blood flow to the supra-acetabular region during the initial cuts of a Bernese PAO, secondary to disruption to the iliolumbar vasculature [86]. This reduction in blood flow proved to be reversible, however, provided fixation was placed within 30 min of the initial disruption. These findings prompted the authors to suggest leaving a bone bridge of 2–2.5 cm in the supra-acetabular region during periacetabular procedures such as the Bernese PAO in order to enable continued perfusion of the area [86]. Additionally, Seeley and colleagues note caution regarding the Hardinge direct lateral approach to the hip, primarily indicated in total hip arthroplasty and proximal femur fractures [83]. This approach risks injury to the superior gluteal vascular pedicle, which may result in abductor weakness and limping.

Overall, far fewer studies have reported on the impact of the vascular supply of the acetabulum than the femoral head during surgical hip procedures. The majority of the surgeon's focus in preoperative planning and during the procedure itself is on avoiding vascular insult to the femoral head. However, much like in the anatomical development of hip joint geometry, it may be important to consider the impact of the vasculature on both the femoral head and acetabulum in parallel rather than as separate entities due to the intimate relationship between them. Vascular insult to the proximal femur, and the resulting changes in femoral head geometry, have been shown to have an influence on acetabular morphology. In a radiological review of 155 children with Perthes disease, Joseph reported consistent acetabular changes throughout the course of Perthes disease that can influence the final outcome, including increased Sharp's angle, acetabular radius, acetabular depth and ilium height, and persistent irregularity of the acetabular contour (Chap. 6) [86]. It was difficult to ascertain, however, whether these changes could be attributed to vascular disruption in the acetabulum or vascular disruption in the femoral head. More likely, the changes were due to contributions from both sources. It remains unclear if an isolated vascular insult to the acetabulum would have an impact on a well-perfused femoral head. Consequently, a surgeon must approach preoperative planning and the surgical procedure with appropriate consideration and understanding of the anatomy and vasculature of both the acetabulum and the femoral head to minimize potential for complications.

The orthopaedic surgeon must not underestimate the importance of careful consideration of the anatomy and physiology of the femoral head and acetabulum when planning and performing surgical hip procedures in order to optimize functional outcomes and mitigate potential long-term debilitating complications.

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