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Anatomical considerations in adult femoral neck fractures: How anatomy influences the treatment issues?

Mengnai Li [a,b], Peter A. Cole [a,b,*]

[a] Department of Orthopaedic Surgery, Regions Hospital, University of Minnesota, 640 Jackson Street, Mailstop 11503L, St Paul, MN 55101, USA
[b] Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN, USA

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ABSTRACT

Femoral neck fractures in physiologically young adults are relatively uncommon. The reported incidence of avascular necrosis and nonunion rates remain relatively high despite the advancement in understanding and surgical management. Understanding the normal femoral neck anatomy and its relationship to presenting fracture pathology in young adults could help to lessen reported high complication rates to provide better clinical outcomes.

Femoral neck fractures in physiologically young adults are relatively uncommon [1–3]. The reported incidence of avascular necrosis and nonunion rates remain relatively high despite the advancement in understanding and surgical management [4–12]. In a group of 72 patients (73 femoral neck fractures) aged 15–50 years treated with internal fixation, the 10-year survival rate of the native femoral head was only 85% [9]. Understanding the normal femoral neck anatomy and its relationship to presenting fracture pathology in young adults could help to lessen reported high complication rates to provide better clinical outcomes.

Normal anatomy

Bony anatomy

The adult hip joint is a synovial ball-and-socket type joint. The femoral head is not a perfect sphere, and the joint is congruous only in the weight bearing position [13]. A recent study found the absolute measurement difference on an individual's left and right femoral head to be less than 2% and femoral neck less than 4% [14]. The femoral head attaches to the non-articular surface of the acetabulum through ligmentum teres which is located inferior and posterior to the center of femoral head [15]. Ward described in his anatomy book of 1838 the internal trabecular system of the femoral head [16]. The well developed lines of the trabecular arcade come from the calcar region and rise superiorly to the weight-bearing dome of the femoral head and mostly endure compression force. Lessor trabecular patterns arise from the inferior region of the fovea area across the head and superior portion of the femoral neck into the trochanter and lateral cortex. The force on the superior portion of the femoral neck is mostly tension [17]. The term calcar femorale has been used to refer to the dense vertically oriented bone extending from the posteromedial portion of the femoral shaft under the lesser trochanter and radiating lateral to the greater trochanter, reinforcing the femoral neck posteroinferiorly [18,19].

The femur is essentially a tubular structure with distortions that mimic bows and twists. In the coronal plane, the femoral neck is inclined obliquely to the shaft at an angle of $130 \pm 7^\circ$ [20]. The Newcastle Thousand Families study in 2005 found that men had significantly larger femoral neck shaft angle (mean 130°, range 121–138°) compared to women (mean 128°, range 119–137°) ($p < 0.0001$) [21]. Although the neck/shaft angle and neck length are variable, the center of the neck in the coronal plane is at the level of the apex of the greater trochanter. In the axial plane the femoral neck is anteverted relative to the posterior surfaces of the femoral condyles. In the adult, this angle is $10 \pm 7^\circ$ [20]. The degree of anteversion affects many aspects of lower limb biomechanics, including the abductor moment arm, patellar tracking and foot orientation [15].

Capsular anatomy

The adult hip capsule covers the entire femoral head and the majority of the femoral neck, leaving the posterior lateral half of

* Corresponding author at: Department of Orthopaedic Surgery, Regions Hospital, University of Minnesota, 640 Jackson Street, Mailstop 11503L, St Paul, MN 55101, USA. Tel.: +1 651 254 3669; fax: +1 651 254 1519.
E-mail address: Peter.A.Cole@HealthPartners.com (P.A. Cole).

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the femoral neck uncovered by virtue of its more proximal attachment. The capsule is reinforced by circular and longitudinal fibers. The circular fibers (Zona Obicularis) forms a sling in the posterior inferior part of the capsule surrounding the femoral neck. The longitudinal fibers include the iliofemoral, ischiofemoral and pubofemoral ligaments. The anterior capsule is reinforced with an inverted Y shaped iliofemoral ligament (ligament of Bigelow) and pubofemoral ligament. The posterior capsule is reinforced by the relatively weaker ischiofemoral ligament. The anterior iliofemoral ligament originates from the iliac spine and acetabulum superiorly and inserts on the intertrochanteric line inferiorly. It limits hyperextension and external rotation of the hip [22]. The normal hip capsule becomes taut in extension and internal rotation and allows a maximum volume of fluid in a slightly flexed and external rotation position [23].

Vascular anatomy

The normal vascular pattern of the femoral head and neck in both pediatric and adult specimens has been widely investigated [24–28]. Intra-osseous, extra-osseous, and anastomosing systems of an arterial network have been thoroughly studied.

At birth, the proximal femoral epiphysis is supplied by the lateral and medial circumflex arteries, approximately 50% each with a small contribution from the vessel of the ligmentum teres [27]. At about 36 months of age, the lateral circumflex artery supplying the anterior 50% of the femoral epiphysis regresses and the two main branches of medial circumflex femoral artery (posterior superior and posterior inferior branches) now supply the entire femoral epiphysis and proximal femoral physeal plate [27]. This pattern remains unchanged into adulthood [26]. There is variable contribution of the foveal artery coming off the obturator artery supplying the femoral head in adults [24]. Up to 70% of the adult femoral head has variable perfusion from foveolar artery [24,29]. With the development of angiographic techniques, the pattern of the femoral head and neck blood supply has been further elucidated both in normal and pathological conditions including fracture and avascular necrosis [30].

Our understanding of the role of the medial femoral circumflex artery (MFCA) and related anatomical and surgical applications has been profoundly enhanced by the cadaveric and clinical work by Ganz et al. [31]. The MFCA most often branches off the profunda femoris artery. The first major branch of the MFCA perforates the hip capsule inferomedially as it enters the joint. It then continues as an inferior retinacular artery toward the femoral head in the ligament of Weitbrecht [32]. The size and diameter of this artery is variable. Thereafter, the MFCA continues running posterolaterally toward the greater trochanteric fossa. The trochanteric branch coming off the MCFA marks the superior border of the quadratus femoris. The deep branch of MFCA then courses on the posterior surface of the obturator externus before diving underneath the gemellus inferiorly and travels along the rest of the conjoint tendon before perforating the capsule at the superior gemellus. The intra-capsular segment course along the posterior superior surface of the femoral neck and ended with the superior retinacular branches beneath the synovium [33]. A significant constant anastomosis between the inferior gluteal artery and the MFCA was found along the inferior border of the piriformis which may be compensatory after injury of MFCA [33].

Despite the evidence from this hallmark study, the extremely low incidence of avascular necrosis in adult piriformis femoral nailing series suggests that the superior retinacular arteries may not be the sole supply of femoral head perfusion [34,35]. In a recent study from Lorich's group, the sites of anastomosis between the inferior gluteal artery and MFCA was elucidated. In seven out of eight specimens, an anastomosis was found near the obturator externus tendon. The terminal artery coming off this anastomosis then immediately passed directly underneath the capsule ascending the superior aspect of the femoral neck, becoming the lateral retinacular arteries [19]. In this study, the authors found that the deep branch of MFCA was never between the conjoint tendon and the capsule which is clearly different from Ganz's study in 2000 [19,33]. An important observation came from a subsequent Gadolinum (Gd-DTPA) enhanced MR imaging cadaveric study of 14 fresh frozen hips, which elucidated that the inferior retinacular artery (called the inferior vincular artery) played an important role in femoral head perfusion [36]. They found extensive intra-osseous anastomosis between the superior retinacular arteries, the inferior vincular artery (inferior retinacular artery) and the subfoveal plexus [36]. Due to the fact that the inferior vincular artery was not closely applied to the femoral neck as compared to the superior retinacular arteries, it might explain why some femoral heads remained viable after displaced femoral neck fractures. In more recent series, the femoral head blood supply was described as coming primarily from the MFCA via a group of posterior superior nutrient arteries and the posterior inferior nutrient artery. In terms of anastomoses that may also contribute to the blood supply, the anastomosis with the inferior gluteal artery, via the piriformis branch, is the most important [37]. Clinical CT angiography done by the same group demonstrated details of the three main sources of blood supply to the femoral neck in the clinical setting [38]. The digastric hip approach with a capsulotomy and surgical dislocation developed by Ganz and his group has since been utilized widely in complex hip and acetabular surgeries with excellent outcomes and low rates of AVN [31].

Pathoanatomy in young adult femoral neck fractures

It is generally accepted that what ultimately matters the most to influence union and blood flow (nonunion and avascular necrosis) in the setting of femoral neck fractures, comes down to the vascularity of the femoral head. In a selective digital subtraction arteriography study, vascular alterations were observed in 97% of traumatic femoral head avascular necrosis cases while it only occurred in one third of nontraumatic avascular necrosis cases [39]. This suggests that damage to the femoral head vascular supply could be a major etiology in traumatic avascular necrosis. This opinion is supported by a study of 64 patients who underwent open reduction and internal fixation of femoral neck fractures with a minimum of two years follow-up. Intraoperative bleeding following reduction from the drill hole placed into the femoral head was found to be a highly sensitive and specific predictor for the development of avascular necrosis [40]. In this study, 56/56 with intraoperative bleeding did not develop avascular necrosis while 8/8 with no bleeding developed avascular necrosis.

The histological findings supporting the vulnerability of the superior lateral weight-bearing femoral head to ischemic insult was shown by venography [41], phosphorus [32] injection and autoradiography [42], ^{99m}Tc diphosphonate scintigraphy [43] and a barium sulfate injection study by Sevitt [29]. Swiontkowski et al. described a miniature swine model clearly demonstrating the compromised femoral head perfusion after femoral neck fracture and the histological findings of trabecular thinning, subchondral fracture and femoral head collapse during the course of revascularization at 4–6 weeks post injury [44].

The reason why some femoral neck fractures went on to union but still developed avascular necrosis was not clearly understood. Mary Catto did a cadaver study on the histological appearance of late segmental collapse of the femoral head and found this could happen 2.5 years after the fracture event and bony union [45]. In this paper, the subchondral fracture sometimes described as a