The terminal branches of the medial femoral circumflex artery

THE ARTERIAL SUPPLY OF THE FEMORAL HEAD


From Orthopaedic Trauma Service, Hospital for Special Surgery, New York, United States

This study investigates and defines the topographic anatomy of the medial femoral circumflex artery (MFCA) terminal branches supplying the femoral head (FH). Gross dissection of 14 fresh–frozen cadaveric hips was undertaken to determine the extra and intracapsular course of the MFCA’s terminal branches. A constant branch arising from the transverse MFCA (inferior retinacular artery; IRA) penetrates the capsule at the level of the anteroinferior neck, then courses obliquely within the fibrous prolongation of the capsule wall (inferior retinacula of Weitbrecht), elevated from the neck, to the posteroinferior femoral head–neck junction. This vessel has a mean of five (three to nine) terminal branches, of which the majority penetrate posteriorly. Branches from the ascending MFCA entered the femoral capsular attachment posteriorly, running deep to the synovium, through the neck, and terminating in two branches. The deep MFCA penetrates the posterosuperior femoral capsular. Once intracapsular, it divides into a mean of six (four to nine) terminal branches running deep to the synovium, within the superior retinacula of Weitbrecht of which 80% are posterior. Our study defines the exact anatomical location of the vessels, arising from the MFCA and supplying the FH. The IRA is in an elevated position from the femoral neck and may be protected from injury during fracture of the femoral neck. We present vascular ‘danger zones’ that may help avoid iatrogenic vascular injury during surgical interventions about the hip.

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The blood supply to the femoral head (FH) derives from three main arterial systems: retinacular, foveal and intraosseous.1-6 It is well accepted that the retinacular systems provide the primary arterial supply to the FH.1,4,6-10 The anatomical location of these retinacular arteries makes them susceptible to injury either by trauma and/or iatrogenic damage during surgical interventions.2

The retinacular vessels branch from the medial (superior and inferior retinacular arteries) and lateral (anterior retinacular artery) femoral circumflex arteries to penetrate the capsule.2,4 Once intracapsular, these vessels course within fibrous extensions of the capsule wall, known as the retinacula of Weitbrecht (RW).1,3,11-14 and penetrate the FH distal to the articular rim.2,4,9,15 With the elongation of the femoral neck during growth, the anterior retinacular artery regresses to perfuse the anterior metaphyseal area, while the superior and inferior retinacular arteries grow with the neck and provide the dominant blood supply to the FH.4 Conventionally, the superior retinacular artery (SRA) is considered to be the primary blood supply to the FH,1,3,6,7,10,12,15,16,17,20 while the inferior retinacular artery (IRA) has received a more minor consideration over the years.

A study using cadaveric specimens demonstrated through quantitative MR imaging that the IRA provides significant perfusion to the entire FH.16 This information has increased interest in this vessel, specifically during traumatic injuries and surgical interventions about the hip joint. Conventional wisdom dictates that displaced fractures of the femoral neck should undergo arthroplasty, because the FH is likely to have been rendered avascular, and risk of complications is high.21,22 Following a fracture of the femoral neck, the IRA is thought to be protected by the inferior RW, which is elevated from the femoral neck and could potentially avoid direct injury from the fracture mechanism. Conversely, the superior RW and the SRA are in close proximity to the fractured femoral neck and are at high risk of injury.23,24 A recent clinical series of displaced fractures of the femoral neck investigated with dynamic contrast-enhanced MRI demonstrated maintenance of some perfusion to the FH, despite fracture displacement.25 Elsewhere, a series of 110 displaced fractures of the femoral neck have reported intra-operative
findings of preservation of the inferior RW in 98% of the cases.26 Two cadaveric injection studies evaluating perfusion of the FH using gadolinium-enhanced MR imaging demonstrated preservation of femoral head perfusion at a mean of 32%27 to 49%,16 respectively, of specimens when the inferior RW and IRA were preserved. Another cadaveric injection study involving 24 hips reported that the IRA artery was only present in 17% of their specimens,9 although several other studies have reported that this is a constant arterial supply to the FH.1,2,4,6-8,12,13,16,17

The distribution of vascular foramina at the femoral head–neck junction (FHNJ) and the location of the RW has been reported previously with reference to an imaginary clock face.14,15 To our knowledge, no quantitative information exists on the capsular insertion and intracapsular course of the terminal branches of the medial femoral circumflex artery (MFCA) supplying the FH. This study was designed to determine the precise intra and extracapsular course of the MFCA’s terminal branches (SRA and IRA) supplying the FH and evaluate and measure the extra-capsular course of the terminal branches of the medial femoral circumflex artery (MFCA) supplying the FH. This study was designed to determine the precise intra and extracapsular course of the FH, the course and terminal branches of this artery have been under investigation for centuries.2-4,28-33 Unfortunately, inconsistencies in terminology and descriptions of anatomical location persist to this day.33

The terminal branches supplying the FH have received several names. In 1943, Wolcott10 called them “capsular vessels”, while in 1949 Tucker1 named them “retinacular arteries”, based on their intracapsular course within the RW. In 1950, Howe et al2 referred to them as “capital vessels”. Then in 1953, Harrison et al3 and Trueta4 introduced terminology based on the intraossseous course of these terminal branches in relation to the location of the epiphyseal scar, referring to Tucker’s superior and inferior retinacular arteries as “lateral epiphyseal” and “medial metaphyseal”, respectively. Based on their posterior penetration at the FHNJ, several authors refer to them as posterosuperior and posteroinferior.2,4

In more recent studies, the term nutrient arteries has been used when referring to the terminal branches supplying the FH.17 Based on previous descriptions and our observations during gross dissection, we describe the different segments of the MFCA supplying the FH using specific nomenclature (transverse, ascending and deep). We also used Tucker’s terminology (retinacular artery) to refer to the superior and inferior terminal branches of the MFCA.

Materials and Methods
Our Institutional Review Board granted approval for this research investigation. In total 14 fresh–frozen cadaveric hips were used (nine left and five right) with a mean age at time of death of 63.4 years (49 to 86). Causes of death included lung cancer (six), breast cancer (three), renal failure (two), pancreatic cancer (two) and amyotrophic lateral sclerosis (one). Specimens with known vascular disease (including diabetes mellitus), history of hip trauma and/or previous hip surgery, were excluded. We dissected the take-off from the MFCA, then inserted and secured a vessel cannula (DLP model 30000- Medtronic, Minneapolis, Minnesota). A polyurethane compound (PMC-746; Smooth-On, Macungie, Pennsylvania) was injected and the specimens were left untouched for a minimum of 21 hours to allow hardening of the polyurethane, facilitating the arterial dissection.

Using a posterior approach, we carefully dissected the MFCA, documenting the course of the terminal branches that penetrate the FHNJ. The deep branch of the MFCA was identified at the proximal border of the quadratus femoris muscle and measurements were taken to the posterior border of the intertrochanteric crest. The quadratus femoris was incised and elevated laterally, maintaining its relationship with the ascending MFCA, and distances from the lesser trochanter were measured. We followed the deep MFCA to its capsular insertion, assessing its course and relation to the obturator externus tendon and the conjoined tendon of the short external rotators. The conjoined and obturator externus tendons were incised to expose the posterior capsule. We then followed the course of the MFCA proximally, in order to identify the takeoff of the IRA. A circumferential capsulotomy at the acetabular margin provided joint access, exposing the FH, while preserving the intracapsular RW. The dome of the FH was resected, at the level of its largest diameter proximal to the articular rim, and perpendicular to the femoral neck axis, providing a flat surface for our 360° scale. The scale was then secured in place (with 0°, 360° = 12 o’clock at the central point of the femoral neck superiorly and 180° = six o’clock at the central point of the femoral neck inferiorly). Measurements were then performed and recorded. For data processing, we used the right-side equivalents and integrated our 360° data into the commonly used imaginary clock face.34

Results
The MFCA originates from either the profunda femoris artery or, less frequently, from the common femoral artery anteriorly in the femoral triangle. It can be described as consisting of three distinct segments; the transverse, ascending, and deep MFCA (Fig. 1). The transverse segment travels posteriorly between the iliopsoas and pectineus muscles. The vessel then ascends posteriorly, as the ascending MFCA, toward the intertrochanteric crest, running within adipose tissue between the obturator externus and the quadratus femoris muscles. Proximally, the MFCA provides a trochanteric branch laterally, while the main artery crosses the obturator externus tendon posteriorly as the deep MFCA before continuing an intracapsular
course, deep to the conjoined tendon of the short external rotators. Combined results of all 14 specimens, based on our 360° scale/clock-face measurements, are demonstrated in Figure 2.

**Transverse MFCA.** At the inferior-medial aspect, a constant single branch (IRA) arises from the transverse MFCA at a mean distance of 4.1 cm (3.0 to 5.8) from the lesser trochanter. The mean total length of the extra-capsular IRA was 1.1 cm (0.6 to 1.9) (Fig. 3). This vessel was noted to penetrate the capsule at its mid-substance. The mean capsular insertion point was 2.9 cm (2.2 to 3.2) proximal and 2.6 cm (1.7 to 3.5) medial to the lesser trochanter. The IRA capsular insertion was at the level of the anterior–inferior neck at a mean of 177° (167° to 187°) (at 5:54 relative to the clock face) (Fig. 4). Once intracapsular, the IRA courses within the inferior RW in a posterior oblique course (elevated from the femoral neck) from the capsular extension to the posteroinferior aspect of the FH. At the mid-femoral neck, the inferior RW was incised and the IRA dissected and exposed from its capsular insertion to its terminal penetration at the FHNJ. The intracapsular segment of the IRA was a mean of 2.4 cm (1.6 to 3.8) in length. This vessel had a mean of five terminal branches (three to nine) penetrating the inferior FHNJ at a mean of 4 mm (1 to 7) from the articular rim at a mean of 204° (145° to 244°; 10 of 69 (14%) anterior; 59 of 69 (86%) posterior; at 4:50 to 8:10 relative to the clock face; Fig. 2). During a posterior approach, if an imaginary line is extended from the lesser trochanter to the centre of the FH, the IRA was consistently medial to that line (Fig. 3). Any cuts made lateral to that line are within a capsulotomy ‘safe zone’ and unlikely to damage the inferior RW and IRA.

**Ascending MFCA.** The transition point from transverse to ascending MFCA at the anterior surface of the quadratus femoris was at a mean distance of 2.2 cm (2 to 2.3) proximal and 1.2 cm (0.5 to 1.9) medial to the lesser trochanter. The ascending MFCA runs superiorly along the distal border of the obturator externus within adipose tissue that divides the quadratus femoris and obturator externus muscles (Fig. 1b). In total 11 of 14 (79%) specimens, with a mean of 1.5 branches (1 to 3) arising from the ascending MFCA, penetrate the femoral capsular attachment at a mean value of 244° (216° to 269°; at 8:08 relative to the clock face), coursing deep to the synovium through the neck, and usually yielding a mean of two terminal branches.
(1 to 3) that penetrate the inferioposterior FHNJ at a mean value of 246° (207° to 281°; at 6:56 to 9:22 relative to the clock face), at a mean of 5 mm (3 to 9) from the articular rim (Fig. 5).

Deep MFCA. The transition point from ascending to deep MFCA is at the distal border of the obturator externus tendon. During a posterior approach, the deep MFCA is easily identified at the proximal border of the quadratus femoris muscle, at a mean of 1.5 cm (0.7 to 2.3) from the posterior border of the inter-trochanteric crest (Fig. 1a). It provides a trochanteric branch laterally while the main artery crosses the obturator externus tendon posteriorly at a mean distance of 1.3 cm (0.6 to 1.9) from the obturator externus insertion. The deep MFCA penetrates the femoral capsular attachment 3 mm (0 to 5) distal to the distal border of the obturator internus tendon, at a mean distance of 1.2 cm (0.6 to 1.9) from the conjoined tendon insertion. The capsular penetration was measured at a mean of 327° (310° to 335°; at 10:54 relative to the clock face) before it continues its intracapsular course as the SRA. The deep MFCA provides a mean of six terminal branches (4 to 9) that run adjacent to the femoral neck within the superior retinacular system, specifically, the terminal branches arising from the MFCA.1,3,6-10,12,15,18,19 The current study provides the detailed surgical anatomy of the terminal branches of the MFCA, with special attention to the FH vascularity. This has not previously been described in detail.

Discussion
Vascular disruption and subsequent development of osteonecrosis of the FH continues to be of significant concern following both traumatic injury and surgical procedures about the hip joint. The dominant arterial supply to the FH derives from the retinacular system, specifically, the terminal branches arising from the MFCA.1,3,6-10,12,15,18,19
Our study has some limitations. We injected only the MFCA, based on the wide acceptance that the MFCA provides the primary arterial supply to the FH, and therefore did not evaluate contributions from the lateral femoral circumflex, foveal or the intra-osseous nutrient arteries. Furthermore, the polyurethane was injected manually rather than with a pressure-controlled infusion pump, which could precisely control the pressure of each infusion. An infusion pump may have had a theoretical advantage, as each injection could be set to the same parameters, and which may lead to consistent filling of terminal branches with polyurethane. However, we achieved excellent perfusion to terminal branches in all specimens with manual injections. We also performed dissection manually instead of chemically, so it is possible that some vessels were disrupted during dissection. We believe that careful dissection has allowed us to reliably evaluate the arterial supply to the FH to a new level of detail. Finally, we used a relatively small number of specimens but our findings were very consistent and similar to those reported previously.1,2,9,12,14,16,17

Two main branches arising from the MFCA have been traditionally described: the SRA, which is considered the primary blood supply to the FH,1,3,6,10,12,15,16,17,18-20 and the IRA, which has received comparatively little attention or comment. Although a few investigators have described equivalent capability of the superior and inferior retinacular systems,4,35 most studies have reported that the vessels of the superior system were larger and more significant,1,2,6,9,12,13,36 including Tucker1 (diameters of 0.84 mm vs 0.41 mm, respectively, in adults, and 0.73 mm vs 0.47 mm in children). Our findings were consistent with this trend. Although smaller, we found that the IRA was a constant branch (found in all our specimens) arising from the transverse MFCA. In their cadaveric study, Gautier et al9 reported that this vessel was only present in 17% (four of 24) of their specimens, but more recent cadaveric studies12,13,16,17 and several previous anatomical studies1,2,4,6-8 investigating the extra- and intraosseous vascularity of the FH reported that the IRA is a constant terminal branch of the MFCA supplying the FH.

 Howe et al2 described all three retinacular branches (superior, inferior and anterior) penetrating the capsule at the base of the femoral neck, and Kalhor et al12 reported that the IRA penetrates the inferior medial aspect of the capsule but did not describe the level. We found that the IRA penetrates the mid-substance of the anteroinferior capsule (at 177°; at 5:55 relative to the clock face), while the SRA and terminal branches of the ascending MFCA penetrate the femoral capsular attachment at the base of the neck. Both the superior and inferior retinacular arteries follow an intracapsular course within fibrous prolongations of the capsule wall, toward the superoposterior and inferoposterior aspect of the FH, respectively. Weitbrecht37 first described these fibrous extensions in 1752, and in 1929, Anseroff38 described their location (superior, inferior and anterior) and referred to them as the RW. In his study he focused more in the mechanical effect of these retinacula, although Walmsley,11 in 1917, had already described that
all three RW carry the arterial blood supply to the FH. More recent anatomical studies also describe the retinacular arteries coursing within the RW.\textsuperscript{1,3,12-14} Gojda and Barton\'iček,\textsuperscript{14} in their cadaveric study using the imaginary clock face, recently reported the intracapsular location of the RW (superior at 9:00 to 1:00 relative to the clock face, inferior at 5:00 to 8:30 relative to the clock face and anterior at 2:30 to 5:00 relative to the clock face). Our gross dissection revealed relatively similar locations (superior at 10:00 to 12:02 relative to the clock face; 301° to 1°, inferior at 6:10 to 7:18 relative to the clock face; 185° to 219°, and anterior at 2:25 to 3:50 relative to the clock face; 74° to 116°). Our measurements were performed at the mid-neck, possibly accounting for the differences. Gross dissection of the terminal branches of both the superior and inferior retinacular systems revealed that these branches mainly penetrate the posterior aspect of FHNJ (80% superiorly and 86% inferiorly), consistent with previous descriptions.\textsuperscript{1,2,4,15} Lavigne et al\textsuperscript{15} reported that 70% of vascular foramina along the FHNJ were located at the posterosuperior (9 to 12 o’clock) and posteroinferior (6 to 8 o’clock) in 150 dried cadaveric femora. We also found that terminal branches supplying the FH penetrated the FHNJ mainly on the posterosuperior (SRA) and posteroinferior (IRA) aspect, at a mean distance of 6 mm (1 to 11) and 4 mm (1 to 7) to the articular rim, respectively (Fig. 2). Gautier et al\textsuperscript{9} reported that the SRA penetrated the FHNJ 2 mm to 4 mm from the articular rim. This discrepancy may be secondary to measurement technique. Accurate knowledge of the intra-articular course and terminal penetration of the retinacular vessels supplying the FH are vital to avoid iatrogenic damage during intra-articular surgical procedures about the hip. For example, when performing either open or arthroscopic osteoplasty of the FHNJ to treat cam-type femoro-acetabular impingement, having an understanding of the anatomical location of the arterial supply to the FH is essential to avoid complications. Sussmann et al\textsuperscript{39} reported a safe resection arc of 125° at the anterior FHNJ.
Based on our study findings, we agree that this resection arc will not affect the arterial supply to the FH arising from the MFCA, because the terminal vessels’ osseous penetrations are mainly along the posterior aspect. It is also probable that this arc can be extended to 180° (anteriorly) but further studies are needed to confirm this. In another study, Sussmann et al. assessed the risk of injury of the MFCA when using the posterolateral arthroscopy portal. They reported that the MFCA is protected by the overhang of the posterior greater trochanter with a mean distance of 10 mm between the MFCA and the portal tract traversing the piriformis tendon. Our dissections confirmed that the deep MFCA courses below the overhang of the tip of the posterior greater trochanter and can be protected from injury during creation of the posterolateral portal.

The protective benefit of the inferior RW was first mentioned by Smith in 1953 and by Garden in 1961. More recently, Papadakis et al. reported that only two (Garden IV) of 110 displaced femoral neck fractures (71 Garden III and 39 Garden IV) had a torn inferior RW, bolstering the protective concept of this strong and mobile structure. In addition, Dyke et al. recently reported a clinical series of femoral neck fractures demonstrating preservation of some perfusion to the femoral head despite being displaced fractures. Using quantitative contrast-enhanced MRI, Boraiah et al. reported a significant contribution of this artery to the entire FH. Our gross dissection findings confirmed that the inferior RW (and IRA) course was in an elevated position from the femoral neck, illustrating the sub-synovial course of the terminal branch of the ascending MFCA and intra-retinacular course of the inferior reticular artery elevated from the femoral neck.

Photographs of the gross dissection of the posterior aspect of one specimen that depicts the posterior course of the medial femoral circumflex artery (MFCA), its relationship with the obturator externus muscle and conjoined tendon and the intracapsular course of the terminal branches of the MFCA. The inner square depicts the posterior inferior aspect of the femoral neck, illustrating the sub-synovial course of the terminal branch of the ascending MFCA and intra-retinacular course of the inferior reticular artery elevated from the femoral neck.
Gautier et al.\(^9\) reported the deep MFCA to be 1.2 cm and 0.9 cm medial to the trochanteric crest at the level of the insertion of the obturator internus and externus, respectively. They also described the deep MFCA coursing anterior to the conjoined tendon, then inserting into the capsule proximal to the superior gemellus and distal to the piriformis tendon. Gautier et al.\(^9\) recommended incising the conjoined tendon 1.5 cm medial to the trochanteric crest in order to avoid iatrogenic disruption of the deep MFCA. We found that the deep MFCA courses posterior to the obturator externus tendon at a mean distance of 1.3 cm (0.9 to 2.1) from the femoral insertion, then penetrates the capsule 3 mm distal to the lower border of the obturator internus tendon (1.2 cm medial to its femoral insertion). Based on our anatomical findings, we agree that incising the conjoined tendon 1.5 cm medial to the trochanteric crest will preserve the deep MFCA. Further, one could preserve the deep MFCA by reflecting the conjoined tendon at the femoral insertion, because at this level a layer of capsule exists between the obturator internus tendon and the deep MFCA and SRA.\(^{45}\) The vascular danger zone is thus distal to the conjoined tendon and proximal to the quadratus femoris (where the deep MFCA is completely exposed). We agree with the recommendation of Gautier et al.\(^9\) to divide the conjoined tendon distal to proximal, away from the vascular danger zone.

The ascending MFCA is also vulnerable to iatrogenic injury with reflection of the quadratus femoris during an extended posterior approach to the hip. We recently reported consistent disruption of the ascending MFCA during this approach for hip resurfacing, in which the quadratus femoris myotomy is performed 0.5 cm to 0.8 cm from its femoral insertion.\(^{27}\) We found that the MFCA emerged at the proximal border of the quadratus femoris, 1.5 cm medial to the trochanteric crest. Dividing the quadratus femoris more medially may preserve the ascending MFCA. A posterior capsulotomy at the femoral attachment, commonly performed during the standard posterior approach to the hip, completely disrupts the arterial system from the MFCA supplying the FH, as we demonstrated in a recent study using quantitative contrast-enhanced MRI and gross dissection.\(^{27}\)

Previous studies have reported the importance of preserving the posterior capsular attachment to the femur in order to maintain the blood supply to the FH.\(^{26,13}\) Steffen et al.\(^{43}\) evaluated a modified capsulotomy performed at the acetabular margin and reported maintenance of FH oxygenation when using this approach and retaining the posterior capsular attachment to the femur. We found the inferior RW and IRA are constantly medial to an imaginary line between the LT and the centre of the FH. Any lateral extension of the modified capsulotomy should stay lateral to this imaginary line in order to preserve the inferior RW and IRA.
This study demonstrates that the terminal branches of the MFCA penetrate the joint through the mid-substance of the capsule (transverse MFCA) or at the femoral capsular attachment (ascending and deep MFCA). The IRA is a constant branch of the transverse MFCA that supplies the FH. Once intracapsular, it courses within a strong fibrous prolongation of the capsule wall known as the inferior RF. Both the inferior RW and IRA are in an elevated position from the femoral neck and have potential to avoid sustaining injury during fracture. To preserve the vascular supply to the FH during surgical procedures about the hip more completely, the posterior femoral capsular attachment as well as the superior and inferior RW should be maintained. Our results provide precise anatomical location of the terminal branches of the MFCA that supply the FH, and are easily interpreted using an imaginary clock face. We have provided vascular danger zones that should be respected during surgical interventions about the hip joint and may help avoid iatrogenic vascular damage.

Author contributions:
L. E. Lazaro: Data collection (cadaveric dissections; measurements), Data analysis, Writing the paper.
C. E. Klinger: Data collection (cadaveric dissections; measurements), Data analysis, Writing the paper.
P. K. Sculco: Data collection (cadaveric dissections; measurements), Data analysis, Writing the paper.
D. L. Helfet: Data analysis, Writing the paper.
D. G. Lorich: Data analysis, Writing the paper.

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References


