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PATIENT AND FRACTURE EVALUATION

Part of "38 - FEMORAL NECK FRACTURES"

Epidemiology and Etiology

Approximately 280,000 hip fractures occurred in the United States in 1998. The National Osteoporosis Foundation reported that in 1995 health care expenditures totaled $8.7 billion for the treatment of osteoporotic hip fractures, representing 63% of the cost for treating all osteoporotic fractures (259) and 43% of the cost for all fracture care (71). More than 500,000 annual hip fractures are projected by the year 2040, and the cost of treatment for these patients is expected to rise to $16 billion per year (71).

Fractures of the femoral neck occur in two different patient populations. A very small group (3% to 5%) are young patients subjected to high-energy trauma, usually motor vehicle crashes and falls from a height. The remainder occur in the elderly population, and approximately 90% of these injuries are the result of a simple fall from the standing position. Hedlund and colleagues (132), in a study of over 20,000 hip fractures, demonstrated the age-specific incidence of hip fracture doubles every 5.6 years after age 30 in women, reaching 18 fractures per 1,000 per year in women over 85 (Fig. 38-2). Progressive osteoporosis is generally believed to be the primary force driving the increased incidence of hip fracture in the elderly, and hip fracture patients have been shown to have lower bone mineral densities than age-matched controls (286).

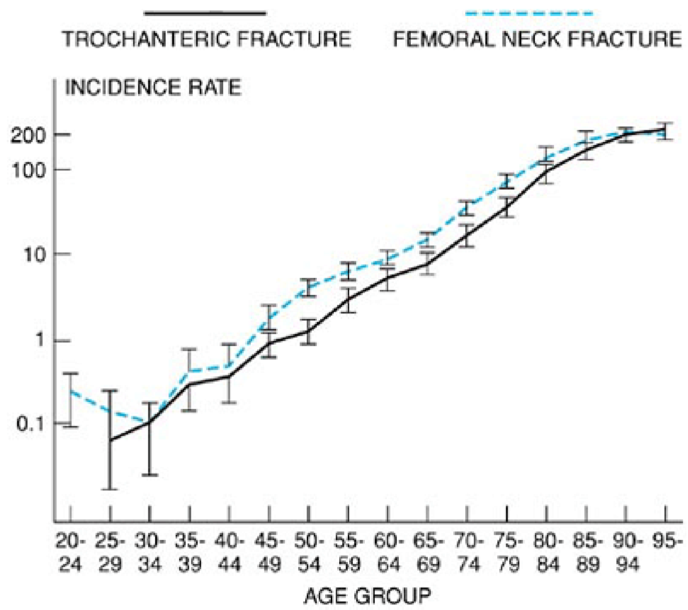

FIGURE 38-2. Age-specific incidence of femoral neck and intertrochanteric fractures in Swedish women. The rate increases exponentially, appearing linear on this semilogarithmic plotting. (Adapted from Hedlund R, Lindgren U, Ahlbom A. Age- and sex-specific incidence of femoral neck and trochanteric fractures. An analysis based on 20,538 fractures in Stockholm County, Sweden, 1972–1981. *Clin Orthop* 1987;222:132–139, with permission.)

Many reports have documented that patients with femoral neck fractures are different from those suffering intertrochanteric fractures. Koval et al. (172) demonstrated that intertrochanteric fracture patients were older, more likely to be homebound, and dependent on others for their activities of daily living (ADLs) than their counterparts with femoral neck fractures. Meta-analysis of other series have confirmed these findings, showing intertrochanteric fracture patients are “physiologically older” and demonstrate a more severe and generalized bone loss (24,213).

Risk Factors for Falling

Aitken's (3) 1984 study was the first to posit that the fall is the major cause of the fracture, and the degree of osteoporosis might

determine only the type of hip fracture. The risk of falling also increases with age; the rate approximately doubles between 65 and 85 years of age. During this same time, however, the risk of hip fracture increases nearly 100-fold. Although it is estimated that only 2% of falls in the elderly lead to hip fracture, trochanter-impacting falls to the side have a much higher likelihood of resulting in a hip fracture, increasing the risk tenfold in one prospective study of witnessed falls in nursing home patients (131). As patients age, walking velocity decreases. An otherwise healthy 65-year-old who stumbles will have enough momentum to fall forward, and will tend to land on her knees or outstretched hand. An 85-year-old who loses her balance is generally moving much slower, and will tend to simply buckle and fall to the side, impacting directly on the hip (70). Of patients who could recall the mechanism of their femoral neck fracture, 76% recalled falling to the side in Jarnlo and Thorngren's (153) review from Lund, Sweden.

Epidemiologic data from the United States, Scandinavia, and the United Kingdom suggest that the increase in incidence of hip fractures cannot be fully explained by the increase in the elderly portion of the population (38,265). In an often-cited paper, Cummings and Nevitt (70) hypothesize that other age-related neuromuscular changes increase the risk that a fall will lead to a hip fracture, and that these factors in combination may explain the increased risk for fracture that is seen with aging. In this theory, a hip fracture will only occur if four conditions are met (Fig. 38-3): the orientation of the fall must lead to an impact at or near the hip; protective responses such as grabbing for a countertop or extending an arm are inadequate or too slow to reduce the potential energy of the fall; the soft tissues around the hip are unable to absorb adequate energy; and the bone strength is inadequate to tolerate the remaining forces that reach the hip. Many, if not all, of the hip fracture risk factors are better understood within this context.

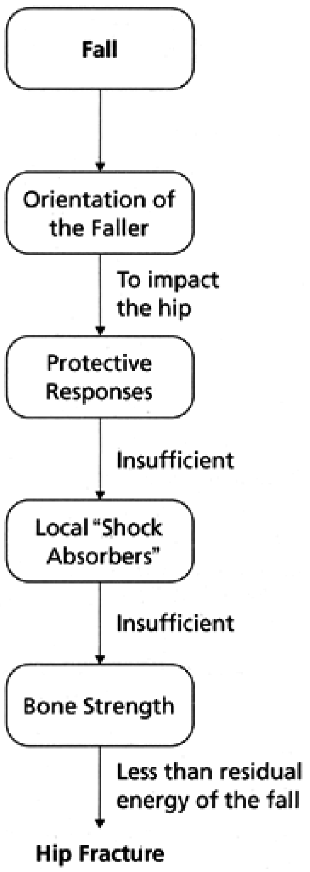

FIGURE 38-3. According to Cummings, a hip fracture will occur following a fall only if four specific defenses fail. (Adapted from Cummings SR, Nevitt MC. A hypothesis: the causes of hip fractures. *J Gerontol* 1989;44:M107–111, with permission.)

Deterioration of general medical condition and many of the illnesses associated with aging have been linked to risk of hip fracture (Table 38-1). Schroder et al. (270) found that a previous femoral neck fracture increases the risk by at least a factor of 5 for a contralateral hip fracture (typically of the same type). Residence in a nursing home, confusional states, frailty, psychomotor loss (Parkinson's disease, prior stroke, paresis, or weakness) and vision loss have all been shown to increase the risk of hip fracture (125,153,271). Many studies have suggested a connection between various medications and hip fracture. Some medicines may predispose the patient to fall or inhibit protective responses (antihypertensives, sedatives) while others may decrease bone stock or cause muscle atrophy (corticosteroids, anticonvulsants, laxatives, thyroxine) (244,271). Alcohol increases the falling risk and may also influence bone density (253), and smoking has been shown to increase fracture risk (180,186). Body weight is also predictive; those patients with a lower body mass index are more likely to fracture their hips (185).

Nonmodifiable
Previous fracture as an adult
Caucasian race
Advanced age
Female sex
Dementia
Poor health
Potentially modifiable
Tobacco use
Low body weight (<127 lb/58 kg)
Estrogen deficiency
Low total (lifelong) calcium intake
Inactive lifestyle
Recurrent falls
Impaired eyesight despite correction
Alcoholism

Modified from *Physician's guide to prevention and treatment of osteoporosis.* Washington, DC: National Osteoporosis Foundation, 1998:8.

TABLE 38-1. OSTEOPOROTIC FRACTURE RISK FACTORS

Factors that influence peak bone mass tend to be directly related to the risk of subsequent fracture. A lesser level of physical activity in middle age has repeatedly been demonstrated to be associated with an increased incidence of hip fracture later in

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life (18,37,222). Elderly populations in urban settings appear to be at higher risk than those in rural areas, perhaps attributable to living conditions or exercise patterns (273). Depending on the population examined, the female-to-male ratio for femoral neck fracture varies between 1.7 to 1 and 4.5 to 1. Race is strongly predictive of hip fracture risk. Hip fractures rates for South African blacks were reported to be one-tenth those of their countrymen of Western European descent (287). In the United States, white females are at most risk, followed by white males, black females, and black males (123,136).

Osteoporosis

Given the pivotal role of osteoporosis in the epidemic of hip fractures in the elder population, there is great interest in defining, treating, and ideally preventing the progression of this process. In 1970, Singh and colleagues (280) published an index of osteoporosis based on their interpretation of the trabeculation patterns of the proximal femur demonstrated on an anteroposterior pelvic radiograph that was correlated to iliac crest biopsy findings in 35 patients. Based on this very limited sample—only half of the patients had hip fractures, and only two were older than 70 years of age—a six-tiered system was developed as the classification standard for osteoporosis (Fig. 38-4). The reliability, interobserver reproducibility, and research utility of this classification has subsequently been shown to be quite poor (97,164,171,284). Perhaps without justification, the Singh index is nonetheless used extensively as a fast, inexpensive screening tool for preoperative decision making regarding the level of osteoporosis. Examination of this index against more technologically advanced methods has demonstrated a fairly high sensitivity (90%), but a low specificity (35%) for the identification of osteoporosis (212).

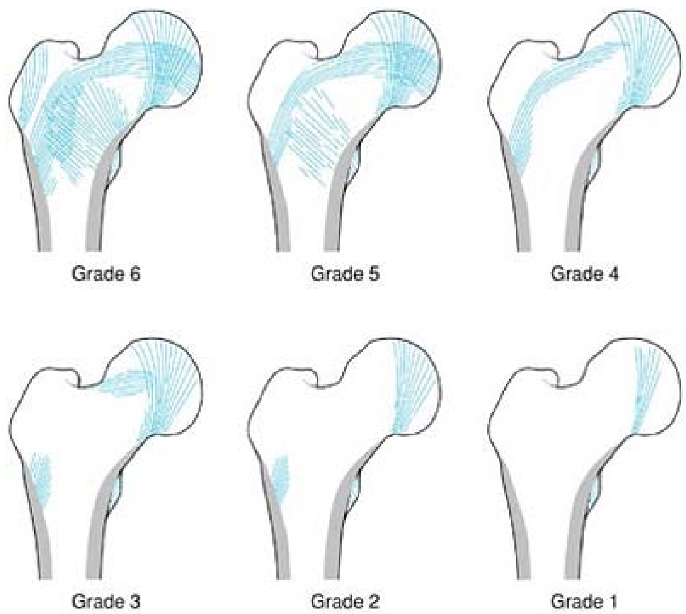

FIGURE 38-4. Singh's Index grades osteopenia from normal (grade 6; all trabecular groups are visible) to definite (grade 3; thinned trabeculae with a break in the principal tensile group) to severe (grade 1; only the primary compressive trabeculae are visible, and they are reduced) based on the ordered reduction in trochanteric, tensile, and ultimately primary compressive trabeculae. The grade is determined from a true AP projection of an intact proximal femur. (Adapted from Singh M, Nagrath AR, Maini PS. Changes in trabecular pattern of the upper end of the femur as an index of osteoporosis. *J Bone Joint Surg* 1970;52A:457–467, with permission.)

The current yardsticks for osteoporosis grading are photon absorptiometry and quantitative computed tomography (CT). Absorptiometry entails passing a photon beam through the skeletal segment and measuring absorption. The absorption from single beam cannot distinguish between bone and soft tissue, so the differential between two energy peaks is used in dual energy x-ray absorptiometry (DEXA) to accurately determine the mineral

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content of the bone. Absorptiometry has been used to measure bone density at the proximal or distal radius, lumbosacral spine, proximal femur, or calcaneus, but absorptiometry of the proximal femur seems to demonstrate the closest relationship to trabecular mineral content in the hip and appendicular osteoporosis (19,97). The predictive value of this test for femoral neck fractures is questionable, however, as Eriksson and Widhe (97) demonstrated no significant difference between the proximal femoral DEXA in women suffering femoral neck fractures and age-matched controls. Quantitative CT has also been utilized in some centers as a measure of bone mineral content, but has not proven to be directly linked to the risk of hip fracture (103).

Currently, medical treatment to retard and possibly reverse osteoporosis can involve four different drugs: calcium supplementation (usually with vitamin D also), estrogen, calcitonin, and the alendronates. Adequate calcium intake is perhaps most important during growth and young adulthood when bone mass is accruing, and should be 1,200 to 1,500 mg/day. It should be maintained at 1,000 mg/day in the elderly (46). A randomized trial comparing calcium vs. placebo demonstrated that daily supplementation with calcium and vitamin D_3 reduced by 43% the risk of hip fracture in 1,683 postmenopausal women followed for 18 months. Bone density was shown to be increased in the treated group (55). It has been demonstrated that postmenopausal women on estrogen replacement therapy have a decreased incidence of femoral neck fractures when compared to controls (168,185). The Osteoporotic Fractures Research Group prospectively followed nearly 10,000 nonblack women over 65 years of age and found estrogen particularly effective in reducing hip fractures in patients over 75 years old. Estrogen replacement therapy for postmenopausal women was most effective if started within 5 years and continued for 10 years (50). Although estrogen replacement decreases the risk of cardiovascular disease and has numerous other physiologic benefits, it can increase the risk of breast and endometrial cancer.

For those patients with contraindications to estrogen therapy, calcitonin can be considered. This hormone, which can be self-administered as a nasal spray, decreases bone resorption. Bisphosphonates also inhibit osteoclastic bone resorption. Alendronate, a third-generation highly active bisphosphonate that does not inhibit mineralization, has been approved by the Food and Drug Administration for treating osteoporosis. Black and co-workers (29) have shown a 51% reduction in the rate of hip fracture in patients with low bone mass and a documented vertebral fracture treated for 2 years with alendronate. This drug must be taken on an empty stomach with a large glass of water to optimize absorption, and patients should remain upright for at least 30 minutes after ingesting to avoid esophageal irritation. Thiazide diuretics, although not an approved treatment for osteoporosis, can protect bone loss and maintain total body calcium levels by impairing urinary calcium excretion. Two clinical studies have demonstrated a decrease in hip fracture rates for patients on thiazides versus control populations (181,260).

Brunetti and Einhorn (46) feel that selective estrogen receptor modulators (SERMs) may be a potent future weapon in the medical arsenal for treating osteoporosis. SERMS aim to deliver the positive effects of estrogen replacement to the skeletal sites without the increased risk of endometrial and breast malignancy associated with nonselective estrogen analogues. However, presently these authors recommend calcium supplementation for all patients and alendronate as the treatment of choice for women with osteoporosis. Estrogen is preferred if there is an increased risk of cardiovascular disease (46).

Fall Prevention

With the assumption that a fall is a prerequisite event to fracture, the most direct approach to preventing hip fractures is to prevent falls. Identifying those at risk of falling is therefore a key to prevention. According to Tinetti et al. (323), one-third of study patients over 75 years old suffered a fall during a 1-year study period. Of those falling, one-fourth were injured and 6% fractured. Risks for fall, in order of severity, included sedative use, cognitive impairment, disability in the lower extremities, presence of palomental reflex (positive extrapyramidal sign), and abnormalities of gait. Careful management of prescription medications, maximizing visual acuity, efforts to maintain muscular tone and balance, and modification of the home environment to minimize hazards are generally considered the key interventions easily achieved (1). A prospective controlled study of elderly community ambulators at risk for fall has demonstrated that adjustments in medications, behavioral instructions, and exercise programs can significantly reduce the incidence of falls in patients at risk (322). General health improvement measures such as tobacco and alcohol reduction, as well as exercise regimens to maintain bone mass, are indicated for virtually all seniors (183,252).

A final method for protecting the at-risk population is physically padding the hips of those people felt to be at the greatest risk. A single randomized study in nursing home patients in the U.K. demonstrated a significant reduction in the incidence of hip fracture among those residents wearing padded hip protectors versus controls, but noncompliance was problematic (184).

Diagnosis

Mechanism of Injury

In the elderly population, femoral neck fracture usually results from a fall from a standing position. There have been three proposed explanations for the mechanism of injury of femoral neck fractures in the elderly. The first mechanism is a fall directly onto the lateral aspect of the greater trochanter (70). This mechanism may also account for the valgus impaction that is seen in some instances. The second mechanism is lateral rotation with a sudden increase in load. With the head fixed in the acetabulum, an external rotation of the planted lower extremity relative to the torso forces impaction of the posterior neck along the acetabulum. This mechanism was described by Garden (112) and would account for the posterior comminution observed in 70% of displaced fractures by Scheck (269). The third possible mechanism is the sudden but spontaneous completion of a fatigue fracture that precedes and causes the fall. Freeman and co-workers (108) have shown that the highest concentration of trabecular microfractures occur in the subcapital area, and that these increase dramatically, regardless of activity level, when bone density

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falls to osteoporotic levels (bone density less than 0.5 g/cm^3). They saw large numbers of healing trabecular fractures adjacent to the fracture in specimens taken at the time of hemiarthroplasty. This mechanism, which presumably corresponds to the development of stress fractures in younger, healthier bone exposed to excessive loads, is the ultimate outcome of the insufficiency fracture in the elderly population. Interviewing these elderly patients often does not yield a clear recall of the sequence of the hip pain and the fall. Questioning patients and studying the mechanisms experimentally has not yielded a definitive answer (342). In practice, femoral neck fractures probably result from each mechanism, and the differences have little or no influence on management.

Femoral neck fractures in the younger population occur in an entirely different environment and are caused by high-energy trauma, typically in a fall from a height or a motor vehicle accident. The resulting degree of bony displacement and soft tissue injury is much higher. The presumed mechanism for these injuries is through the axial loading of the distal femur (or the foot, if the knee is extended). The force is transmitted to the femoral neck and a shear fracture occurs at the transition point from the axial to the transverse alignment of the skeleton (256,318). If the hip is abducted and the head well contained in the acetabulum, a neck fracture occurs, if it is adducted, a fracture dislocation may be more common. Unlike the elderly with a hip fracture, whose presenting complaint and exam usually make the diagnosis self-evident, in the young victim of blunt multiple trauma a diagnosis of hip fracture is frequently subtle and must be actively excluded. Other more clinically obvious skeletal or neurologic injuries can prevent the acquisition of a complete history or the performance of a thorough exam of the hip. A high index of suspicion, based on the known mechanism of injury and strengthened by identifying concomitant fractures of the patella, femur, or pelvis, may be the primary means of making the diagnosis. Only 3% to 6% of femoral shaft fractures are associated with ipsilateral femoral neck fracture (340), but the timely diagnosis of this problem is critical. One-third of femoral neck fractures in the presence of an ipsilateral shaft fracture are initially missed (262,314).

History and Physical Examination

Displaced femoral neck fractures result in an instantaneous onset of hip pain that renders the patient unable to ambulate. Nondisplaced or impacted fractures will usually give the patient significant pain but in some cases the patient may be able to continue to walk. The cause of the fall must be established, to rule out any cardiac, neurologic, or syncopal etiology. Similarly, the past medical history is paramount, with emphasis on identifying morbidities that may influence perioperative medical and anesthetic management. A complete assessment of the patient's preinjury ambulatory status, functional independence with ADLs, cognitive status, and any history of prior degenerative hip pain will be critical in determining the optimum surgical treatment and the patient's postoperative rehabilitation and disposition regimen.

The degree of shortening and rotation of the lower extremity witnessed on physical exam will vary with the degree of displacement of the femoral neck fracture, and is often noticeably less pronounced than with intertrochanteric fractures. The patient may also have localized tenderness and swelling about the hip. A careful visual inspection of the soft tissues about the hip will identify the occasional decubitus breakdown or abrasion that may influence surgical timing and approach. A complete motor, sensory, and vascular exam of the affected extremity must be documented or noted as unobtainable if the patient is not cooperative. If the patient is cooperative and there is hip tenderness but the diagnosis of fracture is uncertain, we like to take the hip through a gentle range of motion, paying particular attention to the extremes of rotation. If there is a significant increase of pain, the likelihood of fracture increases. Similarly, gentle axial loading of the foot with the knee extended can help separate soft tissue tenderness from fracture and can be useful. Finally, a thorough physical survey should be performed to identify any additional sites of musculoskeletal trauma. Particular attention should be paid to the wrists and shoulders in the elderly population, as unsuccessful attempts to break a fall will result in upper extremity fractures in 5% to 10% of patients (153).

Diagnostic Imaging

An anteroposterior (AP) radiograph of the pelvis should be obtained, preferably with the patient's legs internally rotated. This view allows the hips to be compared and the Singh index of osteoporosis estimated from the uninjured side (280). A cross-table lateral of the affected hip is always obtained by flexing the uninjured hip and knee 90 degrees (this leg can rest on the x-ray machine) and aiming the beam into the groin, parallel to the floor and perpendicular to the femoral neck, not the shaft (Fig. 38-5). This allows orthogonal assessment of the femoral neck without the painful and possible injurious manipulation of the effected hip required for a “frog-leg” lateral view. A good lateral radiograph will demonstrate the entire femoral head and neck clearly to allow correct assessment of the angulation and displacement in the anterior/posterior plane as well as the degree of posterior neck comminution. With an incomplete or nondisplaced femoral neck fracture, the diagnostic workup may be confounded initially by normal radiographs. If a femoral neck fracture is suspected but not clearly identified on the AP pelvis radiograph, obtain a dedicated “coned down” AP view of the hip with the extremity in gentle traction and internally rotated 15 degrees. This effectively removes beam parallax and exposure compromises inherent with a pelvic radiograph. Additionally, it positions the long axis of the neck medial to the trochanters and perpendicular to the radiographic beam, thus greatly facilitating identification of subtle cortical and trabecular interruptions.

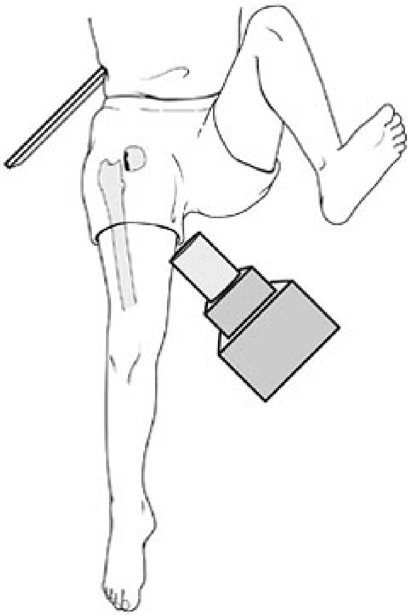

FIGURE 38-5. A cross-table lateral view of the affected hip is obtained by flexing the uninjured hip and knee 90 degrees and aiming the beam into the groin, parallel to the floor and perpendicular to the femoral neck (not the shaft). This allows orthogonal assessment of the femoral neck without the painful and possible injurious manipulation of the effected hip required for a “frog-leg” lateral view.

Despite thorough initial workup, plain radiographs may be normal or equivocal in up to 8% of patients presenting with acute hip pain suspected of having hip fractures (192). CT scanning can be diagnostic and is particularly helpful when the patient's symptom level or size prevents obtaining good plain radiographs. Because of its high sensitivity, radionuclide bone scan has been used to make the diagnosis of the initially occult fracture (100). Frequently a delay has been recommended to increase the sensitivity of the study, but in one large series, two of the five false negatives were performed at more than 60 hours after the trauma (192). Therefore, delaying this procedure more than

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12 hours from injury may not substantially increase sensitivity. The statistical sensitivity and specificity of bone scan for all femoral neck fractures was found to be 85% and 99%, respectively, but in one study of hip fractures with initially equivocal x-rays bone scan was even more impressive, with 98% sensitivity and 99% specificity (138).

In a study by Rizzo and co-workers (263), patients with hip pain and suspicion of fracture underwent magnetic resonance imaging (MRI) with T1-weighted coronal sections within 24 hours of admission and bone scan within 72 hours. MRI identified 37 hip fractures, of which 36 had positive bone scans. Other reports have also demonstrated a superior sensitivity with MRI over bone scan (79,99). Given the decreasing cost and relative ease of obtaining an MRI at many medical centers, this may now be the study of choice to assess occult femoral neck fracture. Because of the increased radiation, cost, and limitations of a laminar tomography study, it appears no longer indicated if other modalities are available.

Classification

For a fracture classification system to be useful, it must be fairly simple and easily applied. It should allow treating physicians to exchange information regarding either individual cases or series of fractures for collaboration and for study. In other words, it must be concise and reproducible. Additionally, a system should be a guide for the surgeon's treatment algorithm. Lastly, a fracture classification should be prognostic for long-term outcome, based on the initial radiographic presentation. With femoral neck fractures in particular, classification should help predict the risk of nonunion and AVN, the two most common complications that can dramatically influence outcome. The most widely used classification is the system outlined by Garden (110) in 1961, a classification scheme based on the AP radiograph that recognizes four different types of femoral neck fracture (Fig. 38-6). Garden shared the opinion of Linten (198) that the various fracture patterns were simply stages of displacement from the same mechanism. He described the trabecular angle or “alignment index” on the AP radiograph as the angle subtended between the primary compressive trabeculae of the head and the axis of the shaft (normal is 160 degrees), and used it to assist classification. A stage I fracture is in valgus alignment with at least the lateral aspect of the neck impacted into the head, and the alignment index is increased. The stage II fracture is complete but nondisplaced, with no evidence of impaction or change in the trabecular angle. Garden's stage III pattern is defined as a displaced femoral neck fracture, where some bone-to-bone continuity is maintained between the two fragments and the trabecular angle is decreased. Complete disassociation of the head from the neck is the hallmark of the stage IV fracture. In this fully displaced configuration, the head tends to realign itself with the acetabulum, and the primary compressive trabeculations on both sides of the joint appear parallel on the AP projection, occasionally giving the illusion of restoring the alignment index, although the neck is invariably foreshortened.

FIGURE 38-6. The Garden classification of femoral neck fractures. Type I fractures can be incomplete, but much more typically they are impacted into valgus, and retroversion **(A)**. Type II fractures are complete, but undisplaced. These rare fractures have a break in the trabeculations, but no shift in alignment **(B)**. Type III fractures have marked angulation, but usually minimal to no proximal translation of the shaft **(C)**. In the Garden type IV fracture, there is complete displacement between fragments and the shaft translates proximally **(D)**. The head is free to realign itself within the acetabulum, and the primary compressive trabeculae of the head and acetabulum realign *(white lines)*.

Interobserver agreement has been demonstrated to be poor when using the complete Garden classification (106). In this respect, it fails to meet criteria for a good fracture classification system. However, there is little interobserver variability when the type I and II groups are combined, and compared to a group that includes Garden type III and IV fractures. Many authors and clinicians advocate a binary use of the Garden classification (91,248). The treatment algorithm, as well as the risk of nonunion and AVN, are so similar within each of these groups (types I and II vs. types III and IV) that subclassifying them is probably an unnecessary division. The Garden type I and II fractures are grouped and referred to as "nondisplaced" femoral neck fractures, and Garden's type III and IV fractures are called "displaced" femoral neck fractures. A criticism of the classification is that it does not consider the lateral x-ray view. Substantial retroversion and posterior neck fragmentation, each of which can impact prognosis, are not seen well on the AP image. Thus, fractures classified as nondisplaced are often, in fact, mildly displaced.

As part of the initiative to create a universal fracture classification system, the AO/Orthopaedic Trauma Association (OTA) fracture classification may also be used for femoral neck fractures (225,236). In this alphanumeric system, all femoral neck fractures are coded into the 31B type (femur, proximal segment, intracapsular metaphysis), and then further grouped and subgrouped (Fig. 38-7). Although the universality, specificity, and alphanumeric aspects of the classification are major advances, it is not intuitive, and interobserver reliability is generally low (particularly at the subgroup diagnostic level) (31). It has yet to achieve widespread use (8).

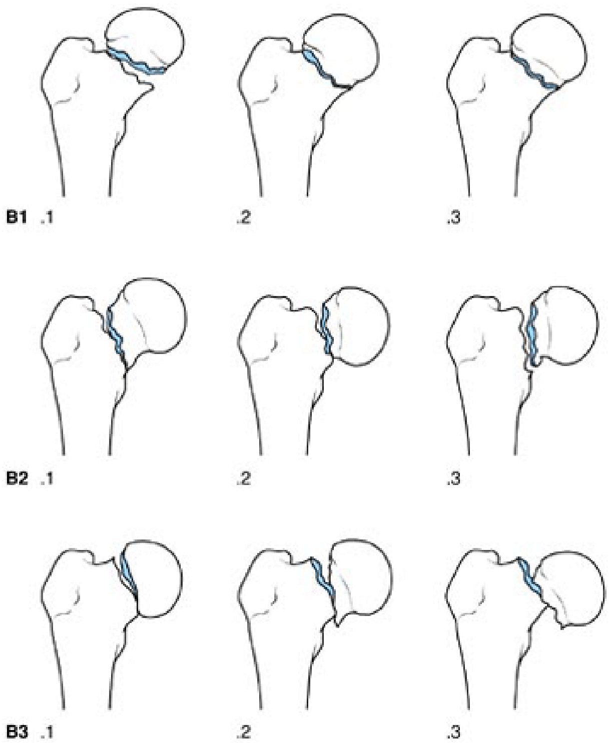

FIGURE 38-7. The AO/Orthopaedic Trauma Association (OTA) classification for femoral neck fractures. The B1 group fracture is a non- to minimally displaced subcapital fracture. The B2 group is transcervical fractures through the middle or base of the neck, and the B3 group includes all displaced, nonimpacted subcapital fractures. Subgroups further specify fracture geometry. The diagrams represent common *examples* of the defined fracture pattern. To effectively use this system, the text of the classification must be read and applied. (Adapted from Müller ME, Nazarian S, Koch P, et al. *The comprehensive classification of fractures of long bones*. New York: Springer-Verlag, 1990:118.)

A third fracture classification, and the oldest of the three, is

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that of Pauwels (251). This system defines three types based on the angle of obliquity of the femoral neck fracture line as seen on the AP radiograph. The mechanical basis behind the classification is that the higher angle fractures have a poorer prognosis, because as the fracture orientation becomes more vertical, joint reaction forces tend to shear rather than compress the fracture, leading to healing problems. For the most part, the literature demonstrates that the preoperative assessment of Pauwels' angle is not predictive of union or AVN (39,48). As Garden (110) pointed out, this classification appears to be of little use in the elderly population, as the obliquity of the fracture line rarely varies. It is applicable for the high-energy mid-cervical femoral neck fractures suffered by the younger population, but its predictive value is controversial, and efforts to save the femoral head will be made in all cases in these patients anyway. Although a critical measurement in planning an osteotomy for femoral neck nonunion, the utility of the Pauwels classification for acute fractures has rightly been called in to some question.

Unusual Fracture Patterns

Stress Fractures

Stress fractures are thought to be secondary to cyclic loading and so-called microtrauma that exceeds the bone's reparative

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ability. These injuries have been noted most often in patients doing endurance training, such as soldiers and distance runners, but also in the amenorrheic adolescent athlete and in the severely osteoporotic patient (81,87,109,330,331). They are termed fatigue fractures when occurring in normal bone exposed to excessive repetitive loads, and insufficiency fractures when osteoporotic or other weakened bone fails under normal daily activities.

Stress fractures may be difficult to diagnose, given the variable presentation, lack of acute trauma, and delayed radiographic findings. When presenting with a stress fracture, the patient may complain of pain in the groin, perhaps radiating to the knee, which is exacerbated by, but not limited to, times of exertion. A history of recently increased levels of exercise is common but not necessary. The pain may characteristically be worse the longer the exertion is continued and may be relieved somewhat with rest. Patients may or may not complain of night pain, and the injury may occur bilaterally. Johansson and co-workers (157) demonstrated the potentially disastrous effects of delayed diagnosis, including displacement and AVN. If initial plain radiograph workup is negative and the symptoms persist, a bone scan or MRI is the study of choice to establish the diagnosis (92). Decreased marrow signal will be seen at the site of the fracture on MRI T1-weighted images, and evidence of perifracture edema may or may not be present (Fig. 38-8) (80,189). Devas (81) first subdivided these fractures into two groups based on location and fracture morphology. Tension fractures begin on the superior neck and extend transversely; they have a relatively high risk of displacing and are typical in the elderly. Compression-type fractures are seen on the inferior cortex, and usually resolve with modified weight bearing. Fullerton and Snowdy (109) further refined the classification and added a third category for the displaced stress fracture. Prophylactic stabilization with activity restriction appears most appropriate for tension fractures, whereas activity modification alone is adequate for compression injuries, provided the patient is compliant (87). Rarely, major deformity of the neck shaft angle is the cause and not the result of the stress fracture, and treatment must incorporate a corrective osteotomy to achieve bony union (330).

FIGURE 38-8. A 58-year-old renal transplant patient presented with a 2-week history of atraumatic bilateral hip pain. Routine radiographs were considered nondiagnostic. A technetium 99m (Tc-99m) bone scan was read as negative for avascular necrosis (AVN); the increased uptake at both femoral necks was not reported **(A)**. Ten days later, magnetic resonance imaging (MRI) was performed and revealed subcapital femoral neck insufficiency fractures bilaterally. T1-weighted views show low signal at the fracture line and intermediate surrounding signal **(B)**. The T2-weighted (fat suppressed) sequence shows diagnostic perifracture edema **(C)**. Impaction at the left fracture line can be clearly seen.

Pathologic Fractures

A femoral neck fracture in a young person with minimal trauma or in an elderly person with presence of a lytic lesion should immediately raise suspicion of potential pathologic process. If pathologic lesion is evident, a skeletal survey or technetium (Tc-99m) bone scan may be indicated prior to operative fixation to assess for other sites of impending pathologic fracture or to help define a primary site. The history from a patient who suffers a pathologic femoral neck fracture may reveal recent weight loss and an antecedent local pain that was dismissed up until the time of acute fracture. The most common sources for metastasis

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to the femoral neck are breast and multiple myeloma (25). Once the metastatic workup has been completed, patients will benefit from the pain relief and functional improvement offered by internal fixation or proximal femoral arthroplasty (25,182). Lane et al. (182) devised the following criteria as the indications for prophylactic fixation of pathologic lesions in the femoral neck: (a) painful lytic lesion greater than 50% of the cross-sectional diameter of the bone; (b) painful lytic lesion involving a length of cortex greater than or equal to the cross-sectional diameter of the bone or greater than 2.5 cm in axial length; and (c) pain that is unresponsive to radiation therapy (182). Postoperative radiation therapy to all local bony sites is usually indicated in metastatic disease but may vary based on the nature of the primary, and may be found to interfere with osseous healing if pathologic fracture has already occurred.

Surgical/Applied Anatomy

Osseous and Capsular Anatomy

The neck shaft angle of the adult femur in both sexes averages 130 degrees with a standard deviation of 7 degrees. Average femoral anteversion is 10 degrees with a standard deviation of 7 degrees. There is moderate interracial and intergender variations in these averages. The femoral head is two-thirds of a sphere with an axis that is usually, but not always, parallel to the neck axis (occasionally there is some retroversion of the head on the neck). Articular cartilage depth is 4 mm thick along the superior weight-bearing portion, tapering in thickness to 3 mm near the equator of the joint (137). The trochanters project posteriorly to the neck, which originates slightly anteriorly to the midcoronal plane of the shaft. If the lesser trochanter appears in profile on radiographs, the femoral shaft is externally rotated. Understanding

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these relationships is critical to ensure correct assessment of the reduction and accurate placement of internal fixation.

The internal trabecular structure of the proximal femur was first described by Ward in 1838. In accordance with Wolff's law, trabeculations arise along the lines of force to which the bone is exposed. In the femoral neck and intertrochanteric region cancellous trabeculations form from the transition of the shaft cortex into metaphyseal cancellous bone. Primary compressive and tensile trabeculations pass through the neck and are separated by an area of sparse cancellous bone labeled Ward's triangle (Fig. 38-9). When mechanically tested in cross section, the cancellous bone of the hip has increased stiffness along these weight-bearing trabeculations and it is significantly reduced in Ward's triangle and in the intertrochanteric region (44). This nonhomogeneous pattern of bone density and stiffness is particularly apparent in the osteoporotic patient and is important to appreciate when trying to establish fixation (Fig. 38-10). A dense buttress of bone in the coronal plane, the calcar femorale, extends proximally from the posteromedial portion of the femoral shaft distally and deep to the lesser trochanter (Fig. 38-11 and Fig. 38-12) (122,130). The calcar is a key support in providing strength to the femoral neck, but does so from this vertical position at the shaft-neck transition. It has been frequently misidentified as the medial cortex at the intersection of the neck and shaft.

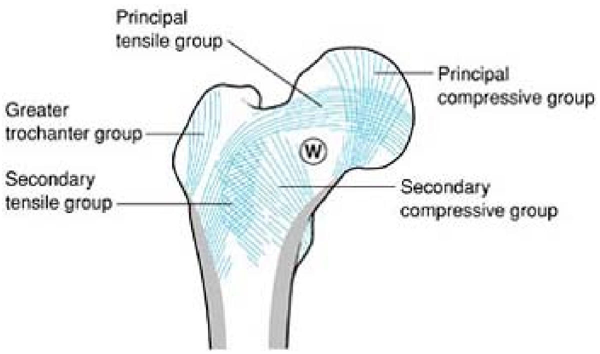

FIGURE 38-9. Diagrammatic representation of the major trabecular groups of the proximal femur. The markedly osteopenic area surrounded by the primary and secondary compressive trabeculae and the primary tension group is known as Ward's triangle *(W)*. (From Singh M, Nagrath AR, Maini PS. Changes in trabecular pattern of the upper end of the femur as an index of osteoporosis. *J Bone Joint Surg* 1970;52A:457–467, with permission.)

FIGURE 38-10. Comparative computed tomography (CT) scans of a femoral neck fracture sustained by a young person who fell from a height **(A)** and an elderly person who tripped and fell **(B)**. Note the variations of bone density in the femoral head of the osteoporotic patient (the primary compressive trabeculations can be appreciated on the intact hip) and the virtual absence of cancellous bone in the neck (Ward's triangle).

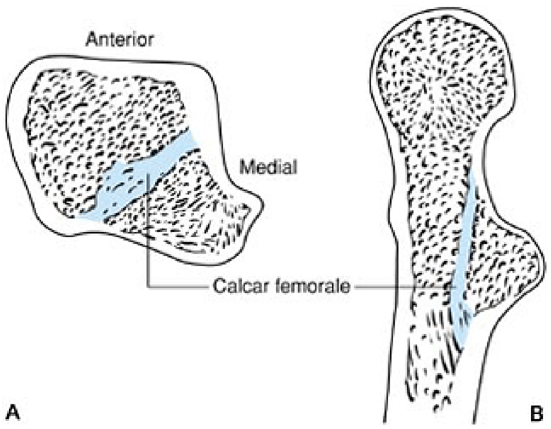

FIGURE 38-11. A dense buttress of bone running in the coronal plane, the calcar femorale is seen in a transverse section at the level of the lesser trochanter **(A)** and in a sagittal section of the proximal femur **(B)**. It originates from the posteromedial portion of the femoral shaft just distal and deep to the lesser trochanter. The calcar radiates proximally both laterally through the cancellous tissue into the greater trochanter, and medially, where at its superiormost extent it fuses with the posterior cortex of the femoral neck. (Adapted with permission from Harty M. The calcar femorale and the femoral neck. *J Bone Joint Surg* 1957;39A:625–630.)

FIGURE 38-12. The dense bone of the calcar femoral *(open arrows)* can be seen on the externally rotated femoral shaft of this completely displaced femoral neck fracture.

The capsule of the hip joint originates from the acetabular rim, immediately adjacent to the acetabular labrum (a triangular-shaped fibrocartilaginous lip that deepens the osseous acetabulum), and it inserts onto the femoral neck. Anteriorly, it is thickened by the iliofemoral ligament, one of the strongest ligaments in the body, and inserts on the intertrochanteric line. Posteriorly, the capsule is much thinner and inserts irregularly along the middle and distal aspects of the neck, forming projections, or retinaculae, that are easily seen during capsulectomy, and

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through which the subsynovial but extraosseous blood supply to the head arrives. This intraarticular environment leaves the entire anterior femoral neck and the majority of the posterior neck covered by a synovial membrane. Deep to the synovium, periosteum devoid of a cambium layer covers the neck, which is why periosteal callus is not seen and healing of femoral neck fractures depends entirely on endosteal proliferation from living bone (137).

Because of the orientation and relative strength of the anterior ligaments, the capsule tightens in extension and internal rotation and tends to effectively expand with mild flexion and external rotation. Intracapsular pressure rises with internal rotation, extension, and abduction (292).

Vascular Anatomy

Given the high incidence of AVN and nonunion after femoral neck fracture, the blood supply to the femoral head has been the focus of a great deal of study. Although the varying nomenclature is confusing, the anatomy has been well defined. The exceedingly high-quality injection studies of Trueta and Harrison (326) demonstrated that the primary intraosseous blood supply within the femoral head comes from the terminal branches of the medial femoral circumflex artery, vessels that they termed the lateral epiphyseal arteries. In their 15 best injections, these vessels (usually two to six in number) supplied more than two-thirds of the femoral head in 14 specimens, and more than half in the others. Invariably, the superolateral head, the area where collapse is usually seen, was supplied exclusively by these vessels (Fig. 38-13). The artery of the ligamentum teres, a branch of the obturator artery, provides a variable secondary contribution to the head (termed medial epiphyseal artery by Trueta), ranging from negligible to up to almost one-half of the epiphysis.

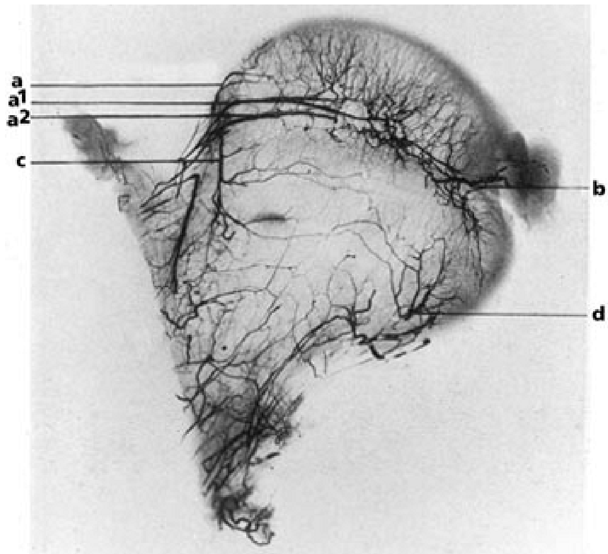

FIGURE 38-13. Angiogram of thick coronal section of one of Trueta's femoral head specimens injected with barium. The lateral epiphyseal arteries (also known as the ascending cervical arteries and labeled *a*, *a1*, and *a2*) supply the majority of the femoral head, the medial epiphyseal artery (also called the artery of the ligamentum teres and labeled *b*) can also contribute. There is no contribution to the blood supply of the head from the metaphyseal arteries (*c* and *d*). Fractures involving the entrance site of the lateral epiphyseal arteries are at high risk for healing complications (61). (From Trueta J, Harrison MHM. The normal vascular anatomy of the femoral head in adult man. *J Bone Joint Surg* 1953;35B:442–460, with permission.)

The extraosseous vascular anatomy of the proximal femur was well described in 1950 by Howe and co-workers (144) after their dissection of 40 specimens. The medial femoral circumflex artery usually originates from the profunda femoris and runs posteriorly between the iliopsoas and pectineus, along the base of the femoral neck, extracapsularly, proximal to the lesser trochanter. It supplies the obturator externus, running along its inferior border, deep to the quadratus femoris to reach the posterior femoral neck. It emerges in the interval between the quadratus and obturator externus and invariably gives off branches to the posterolateral surface of the greater trochanter at this level. The vessel passes superficial to the tendon of the obturator externus before diving deep to the tendinis insertions of the obturator internus and gemelli, where it is protected by the overhanging tip of the greater trochanter. The terminal branches of the medial femoral circumflex vessel (Trueta's lateral epiphyseal arteries) pierce the superolateral capsule and run deep to the synovial reflection before entering the femoral head just distal to the articular junction. The lateral femoral circumflex also originates from the profunda femoris, then runs laterally over the iliopsoas. Here it sends branches out to supply the anterolateral muscles as well as along the intertrochanteric line, nourishing the capsule, anterior femoral neck, and greater trochanter. There is little to

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no direct contribution to the femoral head blood supply from the lateral femoral circumflex artery.

Crock (69) and subsequently Chung (59) contributed to the understanding of the vascular anatomy of the proximal femur with a conceptually simple description and improved terminology. In this model, extra- and intracapsular arterial rings are connected by ascending cervical vessels (Fig. 38-14). The extracapsular arterial ring of the femoral neck is formed primarily by large branches of the medial femoral circumflex (posteriorly) and the lateral femoral circumflex on the anterior surface. Arising from this ring at regular intervals are the ascending cervical branches, which run proximally on the neck. Anteriorly, these pierce the capsule at the intertrochanteric line, whereas posteriorly they pass beneath the retinaculae of the capsule and run deep to the synovial reflection toward the articular surface, where a second arterial ring is at least partially reconstituted, the subsynovial intraarticular ring. Although the cervical ascending arteries are seen to occur intermittently along the entire circumference of the femoral neck, by nearly all accounts it is the ones situated superolaterally (Trueta's “lateral epiphyseal arteries”) that are dominant in supplying the femoral head (276).

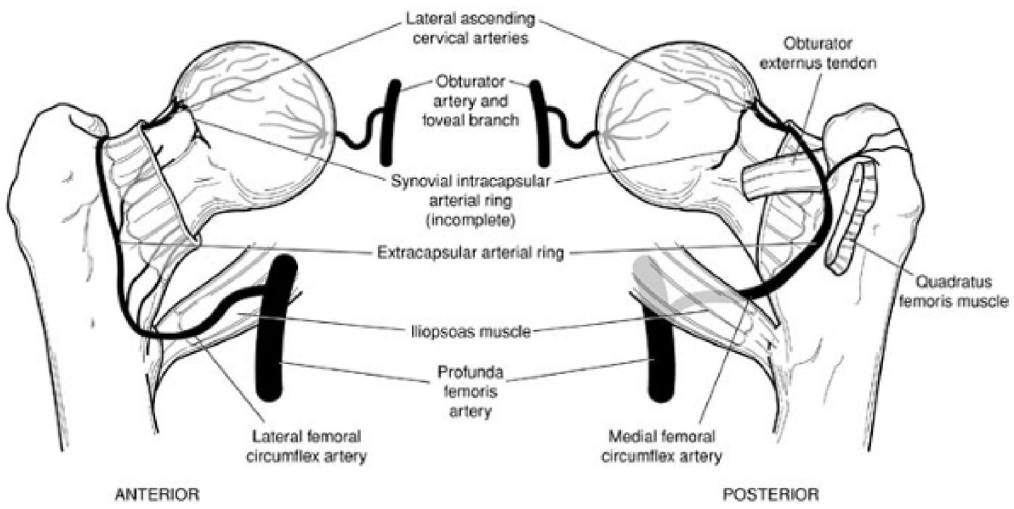

FIGURE 38-14. The arterial anatomy of the proximal femur. The lateral ascending cervical arteries provide the blood supply to the majority of the femoral head. Foveal vessels may supply a varying area directly adjacent to the insertion of the ligamentum. There is little to no direct contribution to the head from the anterior vessels.

Pathophysiology

Fractures of the femoral neck degrade and disrupt femoral head perfusion in multiple ways. Displaced cervical fractures must disrupt all intraosseous supply from the neck, leaving only surviving subsynovial ascending cervical arteries and contributions from the ligamentum (if present) to nourish the head. Total or near-total necrosis was present in 64% of injected femoral heads in Sevitt's (275) autopsy study of 25 patients with femoral neck fractures. Another 20% were partially necrotic. Small areas of viability were noted in the subfoveal area when the ligamentum was intact. Catto (49) performed histologic examinations on 109 femoral heads at least 16 days after femoral neck fracture. All had evidence of vascular damage, but the amount of necrosis was variable. Osteocytes remained visible in ischemic areas up to 3 to 4 weeks from fracture. The superior area of the head was invariably most involved, and the subfoveal area was frequently spared, consistent with Sevitt's findings. Several fractures appeared to be healing despite having heads with significant necrosis. This occurred by invasion of vessels across the fracture line and the ligamentum. Although necrotic bone had no change in radiodensity, femoral head revascularization often showed increase density due to new bone deposition.

The level of the neck fracture as well as the direction and amount of displacement influence the vascular insult. In Claffey's (60) study of injected, experimentally fractured femoral necks taken at necropsy, the critical lateral ascending cervical arteries were always disrupted at their entrance to the bone when the fracture involved the most proximal aspect of the superior neck. However, with more distal fractures, he noted that the typical proximal displacement and lateral rotation of the shaft tends to spare the vessels by pealing them off the neck, allowing displacements up to one-half the diameter of the head without putting tension on these critical vessels. In a follow-up radiographic review of 176 femoral neck fractures, he noted that osteonecrosis developed in all 24 fractures that definitely involved the entry point of the ascending cervical vessels, and only ten of the remaining cases.

In an angiographic study, Mussbichler (226) noted that half of his patients with femoral neck fractures had a disturbed posterior medial circumflex circulation prior to reduction. Of 12 angiographies done during reduction, five demonstrated a restoration of the posterior circulation. In those cases that eventually went on to AVN, there was no angiographic refilling of the superior retinacular vessels after reduction. Strömqvist et al. (303) used pre- and postoperative Tc-99m bone scanning to show that the reduction and fixation of femoral neck fractures could improve or worsen compromised blood supply to the femoral head. This seems to suggest that for at least many fractures, fracture displacement and instability put the vessels at risk, but do not necessarily destroy them. Dalen and Jacobsson (72) obtained quantitative bone scans on patients with neck fractures prior to reduction and could find no correlation between the amount of perfusion and the severity of the displacement.

All neck fractures bleed into the capsule, and depending on capsular integrity, elasticity, and blood volume, can create a tamponade effect, further limiting femoral head perfusion. Although 11% to 40% of displaced neck fractures will disrupt the capsule (68,85,293), in most fractures a hemarthrosis develops. Numerous investigators have demonstrated this and most have documented significantly elevated pressures within the capsule (34,68,140,211,309,338). In 1972, Arnoldi and Linderholm (13)

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published their findings of intraosseous pressure tracings in the presence of hip fracture; 52% of acute femoral neck fractures showed abnormal flow blood in the head, and 29% showed pulseless tracings. Of interest, interruptions in the venous drainage were demonstrated more commonly than interruptions in the arterial supply. In a dog femoral neck fracture model, Woodhouse (341) demonstrated that an intracapsular pressure of 50 mm Hg occluded femoral head blood flow. Despite appropriate reduction and fixation, AVN developed in all dogs where this pressure was maintained for 12 hours, but not in those where capsular pressure was only transiently elevated. More recently, using laser Doppler flowmetry, Swiontkowski and co-workers (316) demonstrated a significant decrease in femoral head blood flow with intracapsular pressures beneath central venous pressure levels. Crawfurd et al. (68) measured intracapsular pressures in fresh femoral neck fractures and found most to be high enough to embarrass circulation. Interestingly, recordings were more than double for Garden I and II fractures than for Garden III and IV patterns. The probable explanation for this finding is disruption of the capsule and relief of pressure in the higher-grade fractures. It is postulated that tamponade may be the source of the low but not absent rate of osteonecrosis observed in these nondisplaced fractures (309).

The relationship between intracapsular hematoma, pressure, and blood flow to the head has been thoroughly studied by Strömqvist and associates (309). Examining nondisplaced fractures (where arterial disruption would be unlikely) with documented increased intracapsular pressures, they demonstrated decreased femoral head perfusion by quantitative Tc-99m bone scanning. Following joint decompression, 70% of the heads with decreased flow returned to normal levels. They concluded that tamponade may cause reversible femoral head ischemia (338). Other authors have not shown percutaneous aspiration as an effective means to alter intracapsular pressure (85). All investigators have noted that, due to the orientation and strengths of differing aspects of the hip capsule, internal rotation and extension decrease capsular volume and necessarily increase pressure, whereas external rotation, mild flexion, and abduction can lower pressure to near normal and normal levels. Melberg et al. (220) found pressures significantly elevated only during reduction maneuvers, and therefore felt tamponade could only be an uncommon cause of AVN.

The anatomic and vascular factors described above are responsible for the high likelihood of healing problems seen following attempted repair of displaced femoral neck fractures. Redisplacement and nonunion rates of 33% and radiographic evidence of AVN in 16% was noted in a recent meta-analysis of reports concerning displaced femoral neck fracture (204). Although surgeons cannot control the initial insult, they are not powerless to modify the outcome of femoral neck fractures. If the head is to be salvaged, treatment should take into account the numerous impediments to reestablishing blood flow. The extremity should be maintained in gentle flexion and external rotation preoperatively to avoid traction on the remaining blood supply, and to minimize the effects of a potential capsular tamponade. As soon as possible, an atraumatic reduction and stabilization should be performed to realign and protect the retinacular vessels that have survived the initial fracture. Fixation should be anatomic and rigid to maximize the surface area available for endosteal healing and creeping substitution in the event of areas

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of osteonecrosis. Finally, capsular decompression at the time of surgery to exclude tamponade as a potential source of continued compromised perfusion should be encouraged. Although strong clinical support for the efficacy of capsulotomy in reducing the incidence of symptomatic osteonecrosis remains lacking, the capsular pressure and femoral head perfusion data that are available, as well as the simplicity and low morbidity of anterior capsulotomy, argue for its routine use (13,34,68,309,316,338,341).