PET/CT Study of Temporal Variations in Blood Flow to the Femoral Head Following Low-energy Fracture of the Femoral Neck

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Abstract

Earlier studies on femoral neck fractures have assessed the blood flow in either the pre- or postoperative period and information is lacking regarding changes in vascular flow to the femoral head after injury. Sixty-two adults with low-energy intracapsular femoral neck fractures were studied prospectively. Mean patient age was 57.2 years (range, 45-82 years). All patients underwent positron emission tomography/computed tomography (PET/CT) prior to surgical intervention and 6 weeks after internal fixation. Internal fixation was done using cannulated cancellous titanium screws and serial follow-up radiographs were obtained (at monthly intervals for the first 3 months followed by 3 monthly intervals between radiographs up to 2 years). On the preoperative PET/CT, 13 patients showed intact vascularity, 31 showed total loss of vascularity, and 18 showed partial loss of vascularity of the femoral head. The 6-week postoperative PET/CT scan showed recovery of blood supply in 23 of the 31 patients with total loss of vascularity and 15 of the 18 patients with partial loss of vascularity of the femoral head. Eleven of 62 patients had total or partial avascularity at the 6-week postoperative PET/CT scan and all 11 patients showed evidence of avascular necrosis on plain radiographs at the end of 2 years. The association between the vascular status of the femoral head at 6 weeks and avascular necrosis at the end of 2 years was statistically significant ($P < .001$). This study shows that the femoral head undergoes temporal variations in blood flow following femoral neck fracture. Decreased or absent vascularity is seen in approximately 75% of the fractures and 80% of the femoral heads with initial vascular compromise seem to regain blood flow within 6 weeks. Thus, prognostication about vascularity based on single-point preoperative imaging is difficult. The 6-week postoperative PET/CT scan seems to be reliable in predicting the future status of the femoral head. However, decision making regarding hemiarthroplasty or internal fixation at the time of injury may have to depend on factors other than the preoperative vascular status of the femoral head.
Despite the advances in internal fixation techniques, nonunion and avascular necrosis (AVN) of the femoral head remain high on the list of complications following femoral neck fractures. Decrease in blood supply may contribute to both AVN of the femoral head and nonunion of the femoral neck. Probable contributory factors for AVN of the femoral head include intracapsular tamponade, fracture severity (Garden classification), quality of reduction and fixation, and delay in treatment after injury.\textsuperscript{1,2} The femoral head has been shown to be a hypovascular area even in normal states and injury may swiftly tip the balance toward avascularity.\textsuperscript{3}

The main focus of studies on vascular flow is on the prediction of AVN in femoral neck fractures. This knowledge would be useful for treatment selection in the acute setting (internal fixation vs hemiarthroplasty) and in counseling patients about subsequent interventions in the event of AVN. This is particularly true in low-energy fractures in physiologically older patients where the choice between internal fixation and prosthetic replacement of the femoral head is often difficult to make. Previous studies have not been able to reach a consensus regarding the prognostic value of the advanced imaging modalities used. They have reported either pre- or postoperative imaging and have not studied the blood supply in both the pre- and postoperative periods.\textsuperscript{4-15} The aims of the current study were (1) to assess the fluctuations in the vascular flow in the femoral head both before and after surgical intervention; (2) to determine the prognostic usefulness of the information in understanding the fate of the femoral head in the long term; and (3) to assess the effect of fracture displacement and the interval between injury and treatment on the vascularity of the femoral head.

**MATERIALS AND METHODS**

This was a prospective study of patients with intracapsular fracture of the femoral neck. Patients aged 45 years and older with low-energy fractures of the femoral neck were included in this study. Patients younger than 45 years and those with high-energy fractures following high-velocity accidents were excluded. Eighty-four patients underwent internal fixation of intracapsular fractures of the femoral neck between January 2009 and August 2011 in the authors’ hospital. Seventy-seven patients had low-energy fractures and were aged 45 years and older. Of the 77 patients, 6 declined to participate, and 7 could not be investigated because they underwent hemiarthroplasty because of the combination of advanced age and comorbid illness. Two patients who had internal fixation underwent total hip arthroplasty within 2 years of the index procedure due to highly symptomatic nonunion. Three men had a history of cigarette smoking.

Twenty-seven of the 62 patients were men and 35 were women. Mean patient age was 57.2 years (range, 45–82 years). Three patients had Garden type 1 fractures, 21 had Garden type 2 fractures, 29 had Garden type 3 fractures, and 9 had Garden type 4 fractures. Minimum follow-up period was 2 years (range, 2.5–4 years). Six of the 77 patients declined to participate and 7 could not be investigated because they underwent hemiarthroplasty because of the combination of advanced age and comorbid illness. Two patients who had internal fixation underwent total hip arthroplasty within 2 years of the index procedure due to highly symptomatic nonunion. Three men had a history of cigarette smoking.

Fifty-one patients underwent cannulated cancellous screw fixation of the fracture (closed reduction was performed for 45 patients and open reduction was performed for 6 patients). Eleven patients required open reduction and fixation with a dynamic hip screw along with a derotation screw (due to highly unstable fracture patterns). Permission from the hospital ethics committee was obtained prior to the study and written consent was obtained from the patients.
patients after explaining the nature of the study.

Preoperatively, all 62 patients underwent PET/CT scans to assess vascularity of the femoral head (Biograph MCF PET-CT; Siemens, Munich, Germany). The PET/CT scan was performed after hydrating the patient adequately and injecting a bolus dose of 370 MBq of F18 intravenously and performing the PET/CT scan 1 hour later. The PET/CT was repeated 6 weeks postoperatively for all patients. The femoral heads were stratified into 3 groups depending on the PET/CT scan findings: normal uptake of the contrast, partial uptake of the contrast (50% or less of the head takes up the contrast), and absent uptake of the contrast. Each scan was reported by 3 radiologists independently. Each radiologist reviewed the same scan on 2 separate occasions 1 week apart. Inter- and intraobserver correlations were obtained for the ratings. Intraclass correlation coefficients (ICCs) were obtained for both pre- and postoperative scan ratings.

Internal fixation was performed using 3 cannulated cancellous screws (inverted triangle configuration) or using a combination of sliding hip screws and derotation screws (in patients with higher Pauwels’ angle of the fracture and marked comminution of the posterior cortex of the neck). Care was taken to reduce the fracture as accurately as possible and open reduction was performed if the quality of closed reduction was not acceptable. Patients were followed up with plain radiographs at monthly intervals for the initial 3 months. Subsequently, radiographs were obtained once in 3 months for a minimum period of 2 years following the fracture. Radiographs were evaluated for evidence of fracture union and the presence of AVN of the femoral head. Changes of AVN were staged according to the modified Ficat and Arlet classification. The radiographs were reported independently by 3 radiologists. Statistical analyses were conducted using SPSS version 17 software (SPSS, Inc, Chicago, Illinois) and chi-square and Fisher exact tests were used for analysis.

RESULTS

On the preoperative PET/CT, 13 patients showed intact vascularity, 31 showed total loss of vascularity, and 18 showed partial loss of vascularity of the femoral head (Figure 1). The inter- and intraobserver correlations were excellent for both pre- and postoperative scans. The ICC was 0.89 (95% confidence interval [CI], 0.92 to 0.98; \( P \text{-value} < 0.01 \)) for the preoperative scans and 0.92 (95% CI, 0.94 to 0.98; \( P \text{-value} < 0.01 \)) for the postoperative scans. It is noteworthy that vascular changes were present in 49 of 62 patients on the preoperative scans. The 6-week postoperative PET/CT scans showed intact vascularity in all of the 13 femoral heads that had showed intact vascularity on the preoperative scans. Of the 31 femoral heads that showed total loss of vascularity on the preoperative scans, 23 showed reperfusion on the second PET/CT scan in the postoperative period. Of the remaining 8 femoral heads, 6 continued to remain avascular and 2 became partially perfused at 6 weeks postoperative. Of the 18 patients with preoperative partial vascularity, 15 had regained complete vascularity, 2 became avascular, and 1 continued to remain partially vascular at the end of 6 weeks (Figure 2).

At the end of the minimum 2-year follow-up period, all 11 (17.7%) femoral heads that were avascular and partially vascular at the 6-week PET/CT scan showed changes of AVN on plain radiographs (Figures 3-7). Eight femoral heads showed grade 2 changes, and 5 femoral heads showed grade 3 changes on the modified Ficat and Arlet grading. Nine of 62 patients had evidence of nonunion of the fracture on follow-up radiographs. The association between the vascular sta-
uss of the femoral heads on the 6-week postoperative PET/CT scan and the final outcome on radiographs after 2 years was highly significant ($P<.001$). The sensitivity, specificity, and predictive values of the preoperative PET/CT scan and 6-week postoperative PET/CT scan were calculated. For the preoperative PET/CT scan, sensitivity and negative predictive values were 100%, whereas specificity was 20% and positive predictive value was 18%. For the 6-week postoperative PET/CT scan, the sensitivity, specificity, and predictive values were 20%.

Internal fixation was performed within a mean of 10.5 hours after admission. Thirty-four patients in the study presented >17.2 hours after injury. No statistically significant association were found between the interval to surgery and AVN at final follow-up ($P=.374$). In addition, no statistically significant relationship was found between the Garden’s grading of the fracture and the final outcome ($P=1.00$).

**DISCUSSION**

Modalities used in the assessment of blood flow to the femoral head include isotope bone scan, magnetic resonance imaging (MRI) with and without contrast, PET/CT scan, perosseous phlebography, super selective digital subtraction angiography, intraoperative drilling of the femoral head to observe bleeding, observation of bleeding from the cannulated cancellous screws, and measurement of oxygen tension in the femoral head using polarographic oxygen electrodes. The purpose of the assessment of blood flow to the femoral head is to use the information for decision making on treatment options and for early understanding and communication of the prognosis to patients. Review of earlier studies shows that these purposes have not been served well by the single-episode imaging modalities performed either pre- or postoperatively.

Earlier studies that involved only preoperative imaging have reported that normal blood flow to the femoral head in the preoperative period was not associated with AVN in the postoperative period. However, decreased or absent blood flow in the preoperative period was not associated with postoperative AVN in all cases. Approximately 50% to 60% of patients with absent or decreased enhancement on contrast-enhanced MRI preoperatively did not develop AVN changes in the postoperative period. Kim et al$^2$ concluded that the role of the preoperative isotope scan was insignificant in influencing the choice of treatment options. In studies that involved only postoperative imaging, AVN developed when there were persistent abnormalities on the scan after 1 to 3 months postoperatively.$^{12,14}$

A problem with postoperative MRI in these patients is the occurrence of susceptibility artifacts that have been reported even with titanium implants. These artifacts interfere with accurate interpretation of the perfusion status. PET/CT imaging is not affected by the presence of either stainless steel or titanium implants and it is a dynamic, multi-planar imaging modality. The changes of devascularization, as well as the restoration of blood supply, are detected well on PET/CT. The cost of the imaging using F18 isotope is compa-

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**Figure 8:** Algorithm for the management of intracapsular fractures of the femoral neck in adults. Abbreviations: DCE-MRI, dynamic contrast enhanced magnetic resonance imaging; PET/CT, positron emission tomography/computed tomography.
rable to that of contrast-enhanced MRI. It has been used to assess the hemodynamics of uninjured pelvic bones in an earlier study. The PET/CT was done pre- and postoperatively in the current study.

Difficulty exists in immediate post-injury decision making and in the prediction of later prognosis because femoral heads showing partial flow may become revascularized through the undamaged posterior retinacular vessels. Boraiah et al have demonstrated the presence of extensive intraosseous anastomoses in the femoral head (between the superior retinacular arteries, inferior vicular artery, and the subfoveal plexus), which may contribute to delayed revascularization. In the current study, it was observed that decreased vascularity of the femoral head frequently followed fracture of the femoral neck (seen in approximately 77% of patients). Fortunately, revascularization of the femoral head also occurs frequently and was seen in 80% of the authors’ patients who had total avascularity and in 84.6% of patients who had partial vascularity on the preoperative PET/CT scan. The study’s results are in agreement with earlier studies regarding the revascularization potential of partially vascular femoral heads at the time of injury. The revascularization process seemed to occur within 6 weeks after injury.

The 6-week postoperative PET/CT scan was sensitive and specific in the prediction of AVN at the end of 2 years and this can be considered as a reliable prognostic tool. The study’s results differ from those of Kamano et al and Kaushik et al, who found that AVN occurred in all patients with poor enhancement on dynamic contrast enhanced MRI. Similar to Hirata et al, the current authors found that revascularization occurs in a significant percentage of totally avascular femoral heads. The sensitivity and negative predictive value of preoperative PET/CT scans were 100% when complete vascularity was seen, whereas the specificity and positive predictive value were low when either total or partial avascularity was observed. Thus, when the femoral head is seen to be completely vascular on the preoperative scan, it can be assumed with reasonable confidence that chances of later AVN are low. This information is especially useful when the patients present late and there is a dilemma over the viability of the femoral head. The current cohort of patients who presented late serves as a good example of the utility of preoperative scanning.

Not much controversy exists regarding the need for internal fixation and joint preservation in femoral neck fractures in young patients (those younger than age 45 years). It is also easier to decide in favor of arthroplasty in the elderly cohort of patients (those 65 years and older). However, patients between ages 45 and 65 years present a dilemma in decision making between internal fixation and arthroplasty due to their higher longevity than elderly patients. Hemiarthroplasty has been reported to carry significantly higher revision rates and lower functional outcomes, and in a few comparative studies conducted until now, total hip arthroplasty has been declared superior to hemiarthroplasty. Conversion of hemiarthroplasty to total hip arthroplasty has been reported to have complication rates approaching that of revision total hip replacements (THRs). Although the superiority of THR over hemiarthroplasty may be easily apparent in the elderly population, THR has its own drawbacks in younger patients. Reports from joint registries have shown poorer outcomes and higher revision rates with primary THR in patients younger than 60 years compared with the outcomes in older patients. Those who have argued in favor of arthroplasty have claimed lower reoperation rates and better functional outcomes following arthroplasty. However, factors such as blood loss, infections, and increased operating time, and prolonged hospital stay are observed more in the arthroplasty group. A recent comparative study showed that functional outcomes were higher in the arthroplasty group in the first year following the operation but the results became comparable from the second year onward. Another common argument is that osteoporosis in the physiologically older group affords poor purchase of internal fixation devices and increases the failure rates. However, in 1 study that objectively examined this claim, no correlation was found between bone mineral density and the clinical outcome of the fracture. The claim that arthroplasty is better in the presence of osteoporosis has also been challenged by the finding of Kobayashi et al that reduced bone density is an independent risk factor for implant loosening following primary total hip arthroplasty.

Considering the projected worldwide figure of 1.2 million intracapsular fractures of the femoral neck per year by 2025, failed arthroplasty for femoral neck fractures will be an onerous addition to the existing revisions of THR for primary arthritis of the hip. Hence, Bosch et al have argued in favor of internal fixation even in elderly patients. On the basis of the available facts, the role of internal fixation can be strongly supported in patients between 45 and 65 years old with intracapsular fractures of the femoral neck with good vascularity on the preoperative scans.

When total or partial avascularity are noted on the preoperative scan, decision making in the immediate post-injury period cannot be made only on the basis of viability of femoral head due to the possibility of revascularization of avascular and partially vascular femoral heads. Other factors need to be considered in the decision-making process, and in earlier reports these factors have included the Garden grade of the fracture, the time interval between injury and treatment, and, most importantly, the physiological age discussed recently by Forsh and Ferguson.

The current authors’ found no statistically significant association between Gar-
den grading of the fracture and AVN. This contrasts numerous earlier reports showing a significant relationship between the degree of fracture displacement and subsequent AVN. One possible reason could be the low incidence of Garden type 1 fractures in the current study. Papadakis et al showed that the posterior retinaculum was intact in almost all Garden type 3 fractures and the majority of Garden type 4 fractures, which refutes the widely held notion that blood flow is interrupted due to the anatomical disruption of the vessels in the posterior retinaculum. In the current study, no statistically significant association was found between the injury and treatment interval and AVN. Few earlier studies have reported decreased incidence of AVN when reduction and internal fixation was performed within 8 to 12 hours of injury. Other studies have found no significant difference in the AVN rates in patients undergoing early or delayed internal fixation. The current study offers a possible explanation for the discrepancy in the earlier observations, namely restoration of blood flow in many femoral heads following an earlier state of total or partial avascularity. Because this vascular behavior did not correlate with time since injury, it explains the lack of correlation between injury and treatment interval and AVN reported by other authors. However, prognostication at 6 weeks following injury can be made with reasonable confidence based on the findings of the 6-week postoperative PET/CT scan. The sensitivity and specificity of 6-week postoperative PET/CT scans were 100% in the current study.

Thus, when confronted with partially or fully avascular femoral heads, the reliability of Garden grading and the injury-treatment interval are not high in aiding decision making. The physiological age of the patient is probably useful in this regard, especially in patients between 45 and 65 years of age. If the patient has an avascular femoral head on the preoperative scan and is physiologically old (ie, has poor bone density, lower functional demands, comorbidities), arthroplasty is a better option. A physiologically young patient (ie, has good bone density, higher functional demands, and no comorbidities) with avascularity or decreased vascularity on the preoperative scan may be given the option of internal fixation and counseled regarding the probability of a second procedure in the event of nonunion or AVN. The information required for counseling is available as early as 6 weeks postoperatively using the PET/CT scan. This approach might lead to the avoidance of needless sacrifice of many femoral heads that may eventually be revascularized. When internal fixation is the chosen option, accurate reduction and stable fixation of the fracture are essential to minimize complications. In the presence of factors such as suboptimal bone quality, marked comminution of the posterior cortex of the neck, and high Pauwels’ angle, surgeons should have a low threshold for additional procedures, such as bone grafting and valgization osteotomy, to ensure union. These additional procedures are best done at the time of initial fixation to minimize the chances of reoperations. The current authors have presented an algorithm for primary management of femoral neck fractures in adults based on the recent recommendations by other authors and the findings of the current study (Figure 8).

**Conclusion**

To the authors’ knowledge, this is the first study on the use of PET/CT in the evaluation of femoral neck fractures. The femoral head undergoes temporal variations in vascular flow until 6 weeks after femoral neck fracture. A partial or complete decrease in blood flow was seen in approximately three quarters of the femoral heads after fracture, but revascularization occurred in 80% or more. The use of PET/CT was investigated in this study for the purpose of improving the accuracy of imaging, but any imaging modality that demonstrates the vascular status at 6 weeks can be used for this purpose. The advantage of PET/CT in the postoperative period is that it is not affected by the presence of ferromagnetic and non-ferromagnetic metallic implants. Prognostic information provided on imaging at 6 weeks after injury is useful because avascularity of the femoral head at 6 weeks is unlikely to improve further. In this study, neither Garden grading of the fracture nor the injury and treatment interval had a significant association with subsequent AVN of the femoral head. Thus, in the postoperative period, the physiological age of the patient should be considered along with the vascular status during decision making. Physiologically young patients between the ages of 45 and 65 years should be offered an option to save the native femoral head even in the presence of poor or absent blood flow due to the tendency to revascularization later. Further studies are worthwhile in this regard for accurate therapeutic categorization of patients.

**REFERENCES**

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