Dynamic MRI Positive Enhancement Integral Color Mapping in Femoral Neck Fracture

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Abstract

Introduction: The most important factor affecting the outcome of osteosynthesis is not the degree of displacement, but femoral head perfusion after femoral neck fracture. Classifications based on plane radiography including Garden’s classification cannot reflect perfusion of the femoral head. We estimated femoral head perfusion in patients with femoral neck fracture using dynamic magnetic resonance imaging positive enhancement integral color mapping (PEICM).

Materials and Methods: Subjects in this prospective study comprised 64 patients with femoral neck fracture. Mean age was 78 years. All patients underwent PEICM with a 1.5-T unit before surgery. The examination protocol included coronal fast spoiled gradient echo imaging (SPGR) of the femoral head before and after intravenous gadopentetate dimeglumine administration. The integral signal intensity value of each pixel was displayed as color mapping, with the highest value displayed as red and the lowest value as black. Color mapping was then classified into 3 grades: Grade 1, same color as unaffected side; Grade 2, darker than unaffected side; and Grade 3, black. Patients showing Grade 1 or 2 underwent osteosynthesis using 3 cannulated screws. Patients showing Grade 3 underwent primary hemiarthroplasty. Patients were followed for 6 months (median, 16 months; range, 6 - 38 months).

Results: Color mapping was classified as Grade 1 in 15 patients, Grade 2 in 32 patients and Grade 3 in 17 patients. Union was achieved without complications in 40 of 47 patients who underwent osteosynthesis (union rate, 85.1%). In the remaining 7 patients, late collapse occurred in 3 patients and non-union occurred in 4 patients. Histological studies of the extirpated femoral head from patients showing Grade 3 revealed avascular necrosis in 16 of 17 specimens.

Conclusion: PEICM is a reliable method for estimating femoral head perfusion in femoral neck fractures. Deciding therapeutic strategies based on the results of PEICM is valid.

Keywords: Femoral Neck Fracture; Dynamic MRI; Femoral Head Perfusion; Color Mapping; Osteosynthesis

Abbreviations
PEICM: Positive Enhancement Integral Color Mapping; SPGR: Fast Spoiled Gradient Echo Imaging; Gd-DTPA: Gadopentetate Dimeglumine; CCHS: Cannulated Cancellous Hip Screw; T: Tesla; sec: Seconds

Introduction
Femoral neck fractures have often been classified based on radiography. Pauwels divided femoral neck fractures into 3 types based on obliquity of the fracture line as shown on anteroposterior radiography [1]. Later, Garden proposed a classification system based on the degree of displacement of the fracture noted on prereduction anteroposterior radiography [2]. Recently, femoral neck fractures have often been classified according to the Arbeitsgemeinschaft fuer Osteosynthesenfragen/Association for the Study of Internal Fixation (AO/ASIF) classification and Orthopaedic Trauma Association (OTA) classification as international classifications. Based on these various classifications, internal fixation or replacement of the proximal femur has been performed.

Osteonecrosis of the femoral head and non-union may be the most important complications after osteosynthesis. In a report on 350 femoral neck fractures, Levi found the overall failure rate, including non-union, avascular necrosis and reoperation, for fractures treated using 3 parallel screws was 23/154 (15%) for Garden stage I/II fractures and 38/96 (40%) for Garden stage III/IV fractures [3]. Therefore, failure rates were lower for Garden stages I and II than for Garden stages III and IV. However, almost 60% of Garden stage III or IV femoral neck fractures treated with osteosynthesis healed without any complications. We thus think that the most important factor affecting the outcome of osteosynthesis is not the degree of displacement, but instead femoral head perfusion after fracture. Classifications based on plane radiography, including Garden's classification, cannot reflect perfusion of the femoral head.

Venography, bone marrow pressure measurements, iliac and femoral angiography, superselective digital subtraction angiography (DSA), and radionuclide scintigraphy have been used to assess viability and vascular supply of the femoral head after femoral neck fracture. These diagnostic techniques are not widely used because of unreliability, potential complications and technical difficulty. Conversely, the utility of magnetic resonance imaging (MRI) in evaluating the musculoskeletal system has been reported based on simplicity and the non-invasive nature of the modality [4]. However, Speer, et al. concluded that MRI is inadequate for determining viability of the femoral head after acute femoral neck fracture [5]. In contrast, Cova, et al. reported that gadolinium-enhanced dynamic MRI was valuable in evaluating bone marrow perfusion of the proximal femur in a dog model [6]. Lang, et al. also showed that contrast-enhanced MRI is useful for non-invasive evaluation of femoral head perfusion after femoral neck fracture [7]. Nakajima, et al. visualized perfusion of the femoral head as a color gradation according to the integral signal intensity value of gadolinium-enhanced MRI [8]. We therefore preoperatively estimated femoral head perfusion of patients with femoral neck fracture using dynamic MRI positive enhancement integral color mapping (PEICM). Therapeutic strategies for femoral neck fracture were then based on the results of PEICM. The purpose of this study was to evaluate the clinical usefulness of PEICM in patients with femoral neck fracture.

Materials and Methods
Patients
Subjects in this prospective study comprised 64 patients with femoral neck fracture (18 men, 46 women) who were admitted to our hospital between January 2005 and October 2007. Mean age of patients was 78 years (range, 55 - 96 years). Femoral neck fractures were classified according to Garden's classification, as Stage I (n = 5), Stage II (n = 15), Stage III (n = 32) or Stage IV (n = 12). Garden stage I and II were defined as undisplaced fractures, while Garden stage III and IV fractures were displaced fractures.

MRI Measurement of Femoral Head Perfusion
All patients underwent PEICM using a 1.5-T MRI system (Signa Twin Speed; GE Yokogawa Medical System, Tokyo, Japan) before surgery. Written informed consent was obtained from all patients before PEICM. The examination protocol included coronal fast spoiled...
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Gradient echo imaging (SPGR) before and after intravenous administration of gadopentetate dimeglumine (Gd-DTPA) application. A bolus of 0.2 ml/kg body weight was injected manually at a rate of 3 ml/s, followed by a rapid 20-ml saline flush. Scan parameters on pre- and post-contrast acquisitions were identical. Dynamic examinations of Gd-DTPA-induced enhancement were performed with T1-weighted SPGR and the following parameters: repetition time, 4.2 msec; echo time, 1.8 msec; flip angle, 20 degrees; matrix, 256 by 160; field of view, 40 cm; and coronal section thickness, 8 mm. Over a total time of 224 sec, SPGR sequences were repeated every 16 sec.

Recently, nephrogenic systemic fibrosis has been reported as a side effect of Gd-DTPA administration. Patients with serum creatinine levels > 1.5 mg/dl were thus excluded from this study [9].

PEICM was performed at a mean of 4.3 days (range, 0 - 18 days) after initial injury.

Color Mapping Classification

The integral signal intensity value of each pixel was displayed as color mapping. Color gradation was automatically adapted according to the integral signal intensity value. The highest value was displayed as red and the lowest value as black. Color mapping was then classified into 3 grades: Grade 1, same color as the unaffected side; Grade 2, darker than the unaffected side; and Grade 3, black (Figure 1).

![Figure 1: Color mapping was classified into 3 types according to shades of color. Red arrows indicate the affected femoral head. Left; Grade 1, Color is the same as the unaffected side. Middle; Grade 2, Color is darker than the unaffected side. Right; Grade 3, Color is black. Right, fractured side; Left, unfractured side.](image)

Treatment Protocol

All patients were immobilized in lower leg traction until surgery. Closed reduction was performed atraumatically with the hip on a traction table under adequate anaesthesia for Grade 1 and 2 patients. After satisfactory reduction was achieved under image-intensifier control, the fracture was fixed using 3 cannulated cancellous hip screws (CCHSs). Three parallel screws were inserted in the shape of a triangle to reach deep into the subchondral bone of the femoral head.

Patients showing Grade 3 underwent primary hemiarthroplasty. Konishiike., et al. reported on the use of dynamic MRI as a non-invasive technique for evaluating femoral head perfusion. They used dynamic MRI and compared the signal-intensity curve (dynamic curve) in the femoral head on the fractured side with that on the unfractured side. Femoral neck fractures were then classified into 3 types

according to the dynamic curve pattern. Perfusion of a femoral head showing a Type A curve might be normal, while a Type B curve pattern might indicate impaired perfusion but not total absence, and a Type C curve might indicate complete absence of perfusion [10]. Hirata, et al. reported that the union rate with Type A and B curves after osteosynthesis was 100% (17/17 cases). Conversely, union rate for Type C curve after osteosynthesis was 21.1% (4/19 cases) [11]. We thus could not select osteosynthesis for elderly patients with color mapping Grade 3, given the extremely low union rate.

Postoperative rehabilitation programs were the same for Grades 1, 2 and 3. Patients were allowed to sit on postoperative day 2. One week postoperatively, patients were allowed to walk using a walker or parallel bar under the supervision of the physiotherapist. Most patients were able to walk with 1 crutch or a cane within 6 weeks after operation. Patients were followed for minimum 6 months (median, 16 months; range, 6 - 30 months) after initial injury.

**Radiographic evaluation after surgery**

Plane radiography was performed immediately after the operation, 1 week after the operation and every month thereafter. Radiographic complications including late segmental collapse or non-union were noted.

**Histological evaluation**

Seventeen femoral heads of Grade 3 patients extirpated at the time of prosthetic replacement were immediately fixed in formalin, decalcified, sectioned and stained with hematoxylin and eosin. An experienced pathologist then evaluated the degree of femoral head necrosis.

**Statistical Analysis**

The chi-square test was performed with the union rates for patients with undisplaced fracture versus patients with displaced fracture. For statistical analysis, the p<0.05 level of significance was used.

**Results**

Color mapping showed Grade 1 in 15 patients, Grade 2 in 32 patients and Grade 3 in 17 patients. The 5 patients with Garden Stage I fractures included 2 patients with color mapping Grade 1 and 3 patients with Grade 2. The 15 patients with Garden Stage II fractures comprised 4 patients with color mapping Grade 1, 10 patients with Grade 2 and 1 patient with Grade 3. The 32 patients showing Garden Stage III fractures consisted of 7 patients with color mapping Grade 1, 14 patients with Grade 2 and 11 patients with Grade 3. The 12 patients with Garden Stage IV fractures included 2 patients with color mapping Grade 1, 5 patients with Grade 2 and 5 patients with Grade 3 (Table 1). As a result, 19 of 20 patients (95%) showing undisplaced fracture were considered to display color mapping Grade 1 or 2. Conversely, 28 of 44 patients (63.6%) showing displaced fractures displayed color mapping Grade 1 or 2. These results indicate that femoral head perfusion is often present even in displaced fractures of the femoral neck.

<table>
<thead>
<tr>
<th>Garden stage</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
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<tr>
<td>I</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>4</td>
<td>10</td>
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<td>III</td>
<td>7</td>
<td>14</td>
<td>11</td>
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<tr>
<td>IV</td>
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**Table 1:** The relationship between Garden’s classification and color mapping grading.

Nineteen of 20 patients (95%) showing undisplaced fracture were considered to display color mapping Grade 1 or 2. Conversely, 28 of 44 patients (63.6%) showing displaced fractures displayed color mapping Grade 1 or 2. These results indicate that femoral head perfusion is often present even in displaced fractures of the femoral neck.
Union was achieved without complications using CCHS placement in 40 of 47 patients (Figure 2).

**Figure 2:** Garden stage II and PEICM Grade 1. \(\text{a} \); Preoperative plain radiography showed undisplaced fracture. \(\text{b} \); Postoperative plain radiography showed that fracture united completely. \(\text{c} \); PEICM Grade 1. Circles within both femoral head indicate region of interest. The color of both femoral heads was almost the same. The color of affected femoral neck showed red because of post-traumatic blood flow increase.

Union rate after osteosynthesis was 85.1%, with late collapses occurring in 3 patients who showed color mapping Grade 2. Non-union occurred in 4 patients (color mapping Grade 1, \(n = 1\); Grade 2, \(n = 3\)) (Table 2 and Figure 3). Of these 7 patients, 6 underwent secondary hemiarthroplasties and another patient underwent removal of screws. Four of the 7 patients had vertical fractures of Pauwels Type III.

<table>
<thead>
<tr>
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<th>Grade 1</th>
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<tr>
<td>Union</td>
<td>14</td>
<td>26</td>
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<tr>
<td>Non-union</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Late Collapse</td>
<td>0</td>
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**Table 2:** Surgical outcome of osteosynthesis with 3 CCHSs. The union rate was 85.1%.

**Figure 3:** Garden stage IV and PEICM Grade 2. \(\text{a} \); Preoperative plain radiography showed displaced femoral neck fracture. \(\text{b} \); Postoperative plain radiography showed non-union and displacement of the femoral head. \(\text{c} \); The color of the femoral head of the affected side was darker compared with the opposite side.

The union rate for fractures treated with CCHS was 84.2% for Garden stage I and II fractures and 85.7% for Garden stage III and IV fractures. No significant differences in surgical outcomes of PEICM-based treatment were seen between undisplaced and displaced fractures (p < 0.4827, chi-square test).

Histological studies of the extirpated femoral head for cases with color mapping Grade 3 revealed extensive avascular necrosis in 12 of 17 specimens of the femoral head (Figure 4). Partially avascular necrosis was identified in 4 specimens, while no avascular necrosis was observed in 1 specimen.

**Figure 4:** Histological findings of the femoral head with PEICM Grade 3. a; Preoperative plain radiography showed displaced femoral neck fracture. b; Hemiarthroplasty was performed. c; The color of the affected side was black. d; Histological findings of the extirpated femoral head (×10). e; Histological findings of the extirpated femoral head (×100) showed osteonecrosis.

Among all 64 patients, 58 patients could walk after treatment. All 15 patients in color mapping Grade 1 could walk after treatment, while 30 of 32 patients in Grade 2 could walk. The remaining 2 patients could not walk because of preoperative senility and extreme muscle weakness of the limbs. Among 17 patients in Grade 3, 13 patients could walk, while 1 patient could not walk due to postoperative cerebral haemorrhage and 3 patients could not walk because of preoperative senility and extreme muscle weakness of the limbs.

**Discussion**

The number of patients with femoral neck fractures has been gradually increasing with the continued aging of society. Femoral neck fractures may be the most problematic when we consider resulting disabilities and medical cost. Proper and reliable treatment of this common injury should be performed to maintain health and vitality of the population and minimize medical expenses.
Patients with femoral neck fracture are usually elderly and often have many complications, such as heart disease, pulmonary disease, central nervous system disorder and osteoporosis. Less-invasive and more effective therapy is thus essential to achieving good results. In general, the surgical invasiveness of osteosynthesis with 3 CCHSs is lesser than that of hemiarthroplasty with implants. The most important factor that affects the outcome of treatment for femoral neck fracture is the degree of femoral head perfusion. If femoral head perfusion can be adequately maintained, the patient can undergo osteosynthesis. Before this trial, we had selected surgical procedures of osteosynthesis or primary hemiarthroplasty mainly based on the degree of fracture displacement according to Garden’s classification. Osteosynthesis had been performed for patients with undisplaced fractures and hemiarthroplasty had been performed for patients with displaced fractures. However, these therapeutic strategies were imprecise due to the dependence on Garden’s classification, which cannot reflect femoral head perfusion.

In addition, in terms of medical expenses, 3 CCHSs cost about $1000 and enhanced MRI costs about $200 in Japan. The total cost of osteosynthesis including PEICM is $1200. Conversely, the implant for hemiarthroplasty costs about $8000 in Japan. Osteosynthesis thus offers superior cost-effectiveness to hemiarthroplasty.

Reliable evaluation of the degree of femoral head perfusion is thus warranted, to permit accurate prognosis and better selection of the surgical procedure to be performed. Various trials have been described for the evaluation of femoral head perfusion. Superselective digital subtraction angiography has been proven to be effective in the investigation of arteries of the femoral head. Heuck., et al. reported a correlation between restricted vascularisation and manifest necrosis in 97% of cases [12]. However, this method may be hampered by complications such as infection, arterial dissection, thrombosis and arteriovenous fistulae.

Strontium 87m and technetium 99 polyphosphate scans have been used to detect avascular necrosis of the femoral head. However, these bone-seeking radioisotopes are picked up in various conditions, such as infection, tumor, osteoarthritis, avascular necrosis and fracture. Technetium 99m-sulphur-colloid scanning is specific for deficient or severely impaired circulation in tissues, including bone, and is reliable, accurate and simple to perform. Marvin., et al. reported that the accuracy of technetium 99m-sulphur-colloid scans as corroborated by histological findings and clinical results was 95% [13]. This method provides a qualitative rather than a quantitative evaluation of the circulatory status of the femoral head.

Technetium 99m-sulphur-colloid scanning offers an excellent method for demonstrating osteonecrosis after osteosynthesis, but is unable to predict ultimate viability of the femoral head within a few days after injury.

MRI is non-invasive and effective for use in diagnosing disorders of the musculoskeletal system. While providing precise information about morphological features of the femoral head, MRI does not show vascularity and is inadequate in assessing viability in the early post-traumatic phase.

Cova., et al. reported that gadolinium-enhanced dynamic MRI was valuable in evaluating bone marrow perfusion of the proximal femur in a canine model [6]. Performed after unilateral arterial embolisation of major femoral vessels, that study found significant differences in enhancement between embolised and control sides. A high correlation was noted between MRI data and blood flow measurements as evaluated by radioactive microsphere technique.

Lang., et al. also showed that contrast-enhanced MRI is useful for non-invasive evaluation of femoral head perfusion after femoral neck fracture [7]. In patients with osteonecrosis or interruption of blood supply shown on DSA, enhanced MRI showed absence of contrast enhancement in the femoral head, indicating impaired perfusion.

Konishiike., et al. reported on the use of dynamic MRI as a non-invasive technique for evaluating femoral head perfusion as mentioned above.

Nakajima, et al. visualised perfusion of the femoral head as color gradation according to the integral signal intensity value on gadolinium-enhanced MRI. They classified femoral neck fractures into 3 types as reported by Konishiike, et al. but according to color gradation [8]. We thus selected PEICM as an evaluation method for femoral head perfusion, basing our therapeutic strategy for dealing with femoral neck fracture on the results.

PEICM allows easy evaluation of femoral head perfusion and has demonstrated a high correlation between clinical and radiological results. In our study, most fractures with color mapping Grade 1 and 2 were treated successfully using osteosynthesis, and union rate was 85.1% (40/47 cases). Eighty-six percent of Garden Stage III or IV femoral neck fractures treated with osteosynthesis healed, even though displacement was present. Femoral head perfusion might be maintained even in displaced fractures because of a strong ligamentous band that contain the inferior retinacular artery. This ligamentous band may be strong enough to avoid rupture in some cases. Moreover, a thin membrane exists around the femoral head that might often remain intact. These anatomical characteristics could assist in preserving circulation to the femoral head.

Conversely, failure of osteosynthesis was seen in 7 fractures, including 3 with late collapse. Although the exact cause of late collapse was not clarified, we think the main cause may have involved microthrombosis after surgery. Other possible causes of late collapse include vascular damage during reduction and damage to the medullary microcirculation with the insertion of CCHSs. The other 4 fractures showed non-union, and 3 of these 4 fractures involved shear fractures of Pauwels classification Type III. In the literature, shear fracture with a vertical fracture line is more difficult to retain with internal fixation than more oblique fractures [14]. We think that a factor in these non-unsions was the increased shearing force at the fracture site. Another possible factor is technical failure of the surgery. In the remaining 1 case of non-union, the CCHSs did not reach into the deep subchondral bone.

Many reports have described union rates of femoral neck fractures. In 1976, Barnes reported union rates were 84% for Garden stage I and II and 72.4% for Garden stage III and IV [15]. Pauwels reported non-union and late collapse in 38% of their patients [1]. In our study, the union rate was 85.1%. We think the union rate in this series using PEICM was higher than described in other studies.

Hirata, et al. reported that 21% of Type C curve pattern fractures united without osteonecrosis. High intracapsular pressure blocks blood supply to the femoral head even if the vessels are not ruptured. Vessels may be kinked and the blood supply may appear absent because preoperative dynamic MRI is performed with the fracture unreduced. United fractures with Type C pattern without osteonecrosis might improve to a Type A or Type B pattern after surgery. Revascularisation from the femoral neck and surrounding soft tissue might also occur after surgery [11]. Histological study revealed that almost all femoral heads extirpated at surgery for patients with color mapping Grade 3 displayed femoral head necrosis. The union rate after osteosynthesis was 85.1% in this study. These results demonstrate that color mapping classification offers a good index for evaluating perfusion of the femoral head and predicting outcomes after femoral neck fracture.

**Conclusion**

PEICM is a reliable, less-invasive imaging modality for assessing femoral head perfusion after femoral neck fracture. Determining therapeutic strategies based on the results of PEICM is valid.

**Conflict of Interest**

We have no potentials conflict of interest with this paper.

**Bibliography**


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