We performed dynamic MRI of the femoral head within 48 hours of injury on 22 patients with subcapital fracture of the neck of the femur and on a control group of 20 of whom ten were healthy subjects and ten were patients with an intertrochanteric fracture. Three MRI patterns emerged when the results between the fractured side and the contralateral femoral head were compared. In all of the control group and in those patients who had undisplaced fractures (Garden stages I and II), perfusion of the femoral head was considered to be at the same level as on the unaffected side. In patients with displaced fractures (Garden stages III and IV) almost all the femoral heads on the fractured side were impaired or totally avascular, although some had the same level of perfusion as the unaffected side. We conclude that dynamic MRI, a new non-invasive imaging technique, is useful for evaluating the perfusion of the femoral head.

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The choice between internal fixation and arthroplasty after a fracture of the femoral neck should be based on the perfusion and viability of the femoral head. Currently, it is usually determined by applying the classification of Garden or by the patient’s age.

Venography, measurement of the pressure in the bone marrow, radionucleide scintigraphy, and superselective digital subtraction angiography have been recommended to assess and predict the viability and vascular supply of the head of the femur after fracture of the neck. These procedures are neither effective nor widely used because of their unreliability, potential complications and technical difficulty.

We have used dynamic MRI for the assessment of perfusion of the femoral head in 22 patients, and compared the signal-intensity curve (dynamic curve) in the head on the fractured side with that of the opposite, normal head and of 20 control subjects.

Patients and Methods

We carried out dynamic MRI on 42 subjects who had not taken corticosteroids or other substances which might have caused avascular necrosis. Four men and 18 women had subcapital fractures of the neck of the femur. Their mean age was 71 years (33 to 92). Ten patients with intertrochanteric fractures (1 man, 9 women) and ten healthy subjects (2 men, 8 women) acted as a control group. The mean age of the patients with an intertrochanteric fracture was 70.8 years (34 to 95) and that of the healthy subjects was 62.6 years (43 to 78). The age differences were not statistically significant. All healthy subjects were informed of the experimental procedures before giving consent. The fractures of the femoral neck were classified into two groups of Garden stage I and II (three undisplaced fractures) and Garden stage III and IV (19 displaced fractures).

Dynamic MRI was carried out within 48 hours of injury using a 1.0 Tesla superconducting scanner (Magnetom Impact System; Siemens AG, Erlangen, Germany). A two-dimensional fast, low-angle shot (FLASH 2D method with fat saturation) with a repetition time of 100 ms, an echo time of 6.6 ms and a flip angle of 75° was used. The coronal plane was chosen for imaging through both femoral heads and the greater trochanters. Sequential gradient-echo images were obtained, alternately at the third level, with one signal averaging; the thickness was 8 mm, the matrix 154×11503,256, and the field of view 35 to 45 cm. The acquisition time for each image was 15 s.

The paramagnetic contrast agent, Gd-DTPA (0.1 mmol/kg body-weight), was injected into a brachial vein over two to four seconds. Bilateral regions of interest (ROI) of 1010 pixels were chosen in the femoral head and the greater trochanters. The signal intensity of the ROI was plotted against time. The enhancement ratio (ER), as a function of...
time after injection of Gd-DTPA, was calculated as the percentage increase in signal intensity by the formula:

$$ER = \left( \frac{SI - SI_0}{SI_0} \right) \times 100\%$$

where $SI_0$ is the baseline signal before and $SI$ the signal intensity after injection.

Peak enhancement occurred after 200 seconds and therefore the enhancement ratio after 200 seconds ($ER_{200}$) and relative enhancement ratio ($RER$) were calculated using the equation:

$$RER = \frac{SI'_{200} - SI_0}{SI_{200} - SI_0}$$

where $SI'$ is the signal intensity of the fracture site and $SI$ the signal intensity of the unaffected side.

**Results**

Three types of dynamic curve pattern emerged after comparing the fractured head with the unaffected side. In type A the curve of the fractured side was considered to be at the same level as that on the unaffected hip, in type B it was lower than that on the unaffected side with an RER <0.5, and in type C no curve was recorded on the fractured side with an RER <0.1 (Fig. 1).

The average $ER_{200}$ was 0.55 ± 0.26 in the normal group (healthy subjects, unaffected side of intertrochanteric fractures and neck fractures) and 0.56 ± 0.16 in the intertrochanteric fractures (Fig. 2).

The mean RER was 0.76 ± 0.14 in the control group. All subjects in the control group were type A, as were patients

![Fig. 1](image1)

Diagrams showing the three types of curve pattern when perfusion in the fractured side (solid line) was compared with that on the unaffected side (patterned line) (see text).

![Fig. 2](image2)

The $ER_{200}$ for normal healthy subjects (○) and for patients with intertrochanteric (△), undisplaced (▲) and displaced fractures of the neck (●).

![Fig. 3a](image3a)

Figure 3a – A radiograph of a 56-year-old man with a type-A displaced fracture. Figure 3b – Perfusion of the femoral head on the fractured side was considered to be at the same level as that of the unaffected hip.

![Fig. 3b](image3b)
with an undisplaced fracture. Of the patients with a dis-placed fracture three were type A, five type B and 11 type C (Figs 3 and 4).

Discussion

Although radio-isotope bone scanning and MRI are excel-lent methods for demonstrating osteonecrosis several months after fixation of a fracture, there is no technique which is able to predict the ultimate viability of the femoral head within a few days of injury. Superselective digital subtraction angiography demonstrates a high correlation between clinical and radiological results, and in one series of patients with fracture of the femoral neck, osteonecrosis of the head subsequently developed in 97% of patients with an impaired blood supply as shown by this method. The technique, however, is invasive and difficult to use clinically.

MRI is currently the most sensitive non-invasive method for detecting osteonecrosis of the head of the femur, but unenhanced MRI is inadequate in assessing viability in the early post-traumatic phase. The interval between the onset of ischaemia and of definite abnormalities, as shown on unenhanced MR images, may be several months. Contrast-enhanced MRI may be useful for non-invasive evaluation of perfusion of the head after fracture of the neck. Dynamic MRI may allow early detection of abnormal blood flow in the bone marrow, as has been shown by the results from dog models before and after embolisation of major arteries supplying the proximal femur. We used dynamic MRI to compare the level of perfusion of the fractured side and the unaffected hip in a clinical setting.

We found that there were cases in which perfusion of the femoral head in displaced fractures (type B) was impaired, but not totally absent. This may show that one or two of the arteries of the proximal end of the femur could still be intact, and that prosthetic replacement may not be required.

Since the absolute values for the parameters assessed vary with the patients’ age, the quantity of Gd-DTPA or the MRI system, we calculated an enhancement ratio. The perfusion of the femoral head was considered to be intact in the unaffected side and therefore we suggest that our classification and the relative enhancement ratio may be useful for patients with fracture of the femoral neck.

There are two potential sources of blood supply to the head after a displaced fracture of the neck of the femur. The residual uninjured vessels may be sufficient to sustain the femoral head, or revascularisation from the neck of the femur or surrounding soft tissues may occur before there is architectural failure. Decreased perfusion itself does not indicate that avascular necrosis will occur. A longer follow-up is necessary to determine further the relationship between our classification and subsequent late segmental collapse.

Dynamic MRI may be a useful new non-invasive imaging technique for evaluating perfusion of the head of the femur and in defining the appropriate treatment for a fracture of the neck.

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