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Sequential scintimetry after femoral neck fracture

Methodologic aspects and prediction of healing complications

Forty-five patients with recent cervical hip fractures were included in a prospective, clinical, radiographic and sequential scintimetric study. Striking changes in radionuclide uptake over the entire hip region on the fracture side were found during the first 5 postoperative months. Fractures that healed without complications showed the highest relative femoral head uptake at 1 week and a peak value at 6 weeks, followed by a gradual decline at the subsequent examinations. Fractures with complications (redisplacement, nonunion, or late segmental collapse) showed a lower initial uptake and a more gradual increase and only a slight tendency towards increased uptake after 3 months. The accuracy in predicting nonunion with scintimetric examination alone is high both at 1 and at 6 weeks, and the accuracy is almost equally high with combined scintimetric, radiographic, and clinical assessment 3–5 months postoperatively.

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Introduction

In the scintimetric studies of cervical hip fractures, interest has been mainly focused on osteonecrosis as a cause of late segmental collapse (D'Ambrosia et al. 1976, Greiff et al. 1980, Lucie et al. 1981). However, nonunion often produces severe clinical symptoms, whereas this is not necessarily so in late segmental collapse (Kofoed & Alberts 1980, Svenningsen et al. 1984). Strömqvist et al. (1984a) and Holmberg & Thorngren (1984) studied the possibilities of ^{99m}Tc-phosphate scintimetry as a prognostic indicator of nonunion. Owing to different designs, their conclusions differed as to the optimal time for predicting healing complications.

We have assessed the accuracy of sequential scintimetry in predicting healing complications following nailing of cervical hip fracture.

Patients and methods

This prospective study comprised 45 patients (mean age 66 years, 36 women) with a recent cervical hip fracture. Patients with disorders of the contralateral hip and those with physical or mental disabilities that were liable to interfere with their participation in the follow-up program were excluded. Scintimetric, radiographic, and clinical examinations were done 1 week, 6 weeks, 3, 5, 8, and 12 months postoperatively, and a final radiographic and clinical examination 1 year later. The series included one Garden (1961) Type 1, 16 Type 3, and 28 Type 4 fractures. All the patients were operated on within 3 days after admission with closed reduction and fixation with multiple pinning according to Nyström (1944). Weight bearing was allowed from the first postoperative day.

Radiographic examination included standard AP and lateral views. Reduction of the fracture was defined as acceptable when the Garden alignment index was 155–185 degrees in both AP and lateral views, and ad latus displacement did not exceed one fourth of the diameter of the femoral neck (Kofoed & Alberts 1980); acceptable reduction was achieved for 38 of the 45 fractures. *Early redisplacement* was defined as loss of reduction with shortening and external rotation within 2 months postoperatively. *Nonunion* was defined as a visible fracture line or a continuing resorption of the femoral neck exceeding 10 mm at 12 months. *Late segmental collapse* was defined as deformity of the weight-bearing portion of the femoral head after fracture healing.

An intravenous injection of 400 MBq ^{99m}Tc methylene diphosphonate (^{99m}Tc MDP) was given and scintimetry was performed 3–4 hours later with the patient in the supine position and the hip joints in internal rotation. The distribution of the radionuclide was recorded anteriorly with 400,000 counts over the pelvis and the hip joints with a General Electric 400 T or 535 gamma camera equipped with a high-resolution large field 200 KeV parallel hole collimator. A Digital Equipment PDP 11/34 computer system with 64×64 matrix pictures was used for storage, display, and processing of the data. Numerical assessment of the radionuclide activity was performed by recording 3×3 pixel regions

of interest (ROI) corresponding to a 20×20 mm area located over the center of each femoral head and 2×2 pixel ROI located over each femoral neck. On the basis of the recorded average uptake per pixel, the ratio between the femoral head on the fracture side and the contralateral side (head/head ratio=HHR) and between the femoral neck on the fracture and contralateral sides (neck/neck ratio=NNR) was calculated.

The scintigrams were also examined visually, and the uptake over the center of the femoral head on the fracture side was compared with the corresponding area on the contralateral side and assessed as diminished, equal, enhanced, or markedly enhanced.

To evaluate the methodologic error in the quantitative assessment of radionuclide uptake, two separate and independent determinations of the ROI were made at 31 randomly selected recordings of radionuclide distribution. The methodologic error was expressed as the average difference in per cent of the mean of each ratio.

On the basis of the radiographic end results, the HHR limits at each of the postoperative scintimetric examinations permitting optimal discrimination between fractures resulting in union versus nonunion were selected. Using these fixed limits for the HHR, prognostic accuracy was determined by means of the following formula: true positive + true negative predictions/all cases (Sutherland et al. 1980).

Computerized analysis included the Mann-Whitney *U*-test and Kruskal-Wallis one-way analysis of variance, as well as Fisher's exact probability test.

Results

Radiography

Early redisplacement occurred in five fractures. Three of them were reoperated on with hip replacement after 2–4 months and consequently were excluded from further scintimetric examinations. One patient died 8 months after fracture, which already at that time showed signs of nonunion with a wide fracture line and sclerotic rounded-off fracture edges. Another patient sustained a femoral neck fracture on the intact side after 8 months; this patient was followed until death 13 months after the original fracture, which showed the same radiographic appearance as the previous patient. No redisplacement of the fracture had occurred in these 2 patients. The remaining 40 patients were given a final clinical and radiographic examination 2 years postoperatively; 31 fractures had united, 6 had nonunion, and 3 had segmental collapse between 8 months and 2 years after fracture. Two of the fractures with late segmental collapse had united within 5 months and one within 7 months.

Scintimetry

The most pronounced shifts in relative activity occurred within 5 months after fracture (Figure 1). Fractures that resulted in redisplacement or nonunion showed a fairly rapid increase in HHR between 1 and 6 weeks, followed by a gradual increase during the first year (Figure 2). Three cases of late segmental collapse showed only a slight increase in radionuclide uptake between 1 and 6 weeks; and after a peak value at 3 months, the HHR remained at an almost constant level. Fractures resulting in uneventful union, on the other hand, showed a different pattern. The initial value at 1 week was much higher than for nonunion and for late segmental collapse. A dramatic increase in HHR was found at the 6-week scintimetry, followed by a gradual decline in activity.

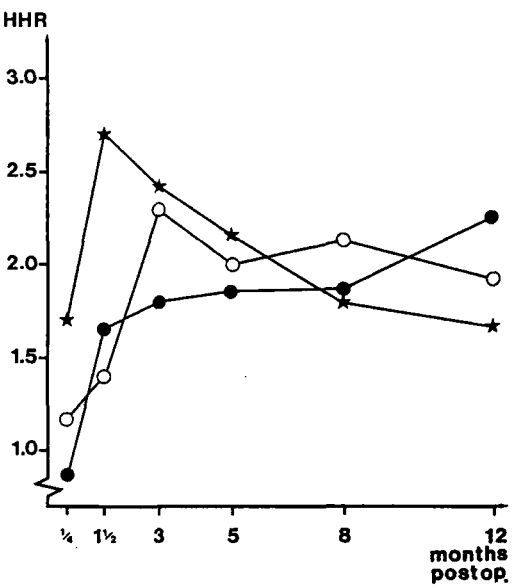

Figure 1. Head/head ratio (HHR) in sequential scintimetry in relation to time after internal fixation.

★ union (n 31).
● redisplacement/nonunion (n 11).
○ late segmental collapse (n 3).

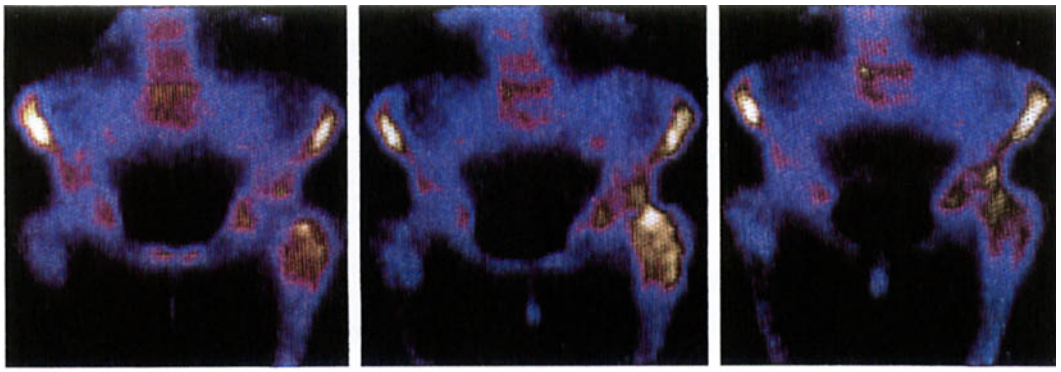

Figure 2. Left cervical hip fracture resulting in nonunion. Digital images performed at 1 week, 6 weeks, and 3 months after fracture. Head/head ratio at 1 week 0.8, at 6 weeks 1.8, and 3 months 1.7.

Higher HHR values (Mann-Whitney *U*-test) were found at the 1-week ($P<0.001$), 6-week ($P<0.001$), and 3-month ($P<0.05$) scintimetries for fractures that resulted in uneventful union as compared with those with complications. At the first postoperative scintimetry (Figure 1), the average HHR for fractures with uncomplicated union was 1.69. This was higher than for fractures with early redisplacement or nonunion with an average HHR of 0.88 ($P<0.05$, Kruskal-Wallis analysis of variance with multiple comparison). For fractures destined to late segmental collapse, the average HHR was 1.17, which did not differ from those with uncomplicated union. When scintimetry was repeated 6 weeks after fracture, the average HHR was 2.71 for union, 1.66 for nonunion, and 1.40 for late segmental collapse. The differences were significant not only for union versus nonunion, but also for union versus late segmental collapse ($P<0.05$).

A review was also made of the results of scintimetry in relation to radiographic findings in patients with persistent pain at weight bearing. The fractures with an unimpaired acceptable reduction resulting in uneventful healing, when compared with fractures with complications, had a higher HHR at 1 week ($P<0.05$ Mann-Whitney *U*-test), 6 weeks ($P<0.01$), 3 months ($P<0.05$), and 5 months ($P<0.05$). The two fractures with unacceptable reduction resulting in union had a higher HHR only at 1 week ($P<0.05$) and 6 weeks ($P<0.05$) when compared with fractures with unacceptable reduction and/or redisplacement resulting in nonunion or late segmental collapse.

Table 1. Number of fractures resulting in union or nonunion in patients with pain at weight bearing and unimpaired acceptable reduction of the fracture 1 week to 5 months postoperatively in relation to scintimetry (head/head ratio, HHR). Fisher's exact test

HHR	Union	Nonunion	*P*-value
1 week			
≥1.10	22	0	<0.001
<1.10	3	6	
6 weeks			
≥1.95	23	0	<0.01
<1.95	3	3	
3 months			
≥1.85	11	0	<0.01
<1.85	3	4	
5 months			
≥1.85	10	0	<0.01
<1.85	1	4	

Prognostic accuracy of scintimetry (Table 1). A high incidence of union was associated with an HHR above 1.1 at 1 week, 1.95 at 6 weeks, 1.85 at 3 months, and 1.85 at 5 months. The prognostic accuracy at the 1-week examination was 0.87 for combined scintimetric and radiographic assessment, as well as for scintimetry alone. At 6 weeks the accuracy was 0.87 for combined assessment and 0.89 for scintimetric assessment. At the examinations 3–5 months postoperatively, the prognostic accuracy was on the average 0.88 for combined radiography and scintimetry and 0.80 for scintimetry alone.

Femoral neck uptake. The total series showed a sharp increase in NNR between the first and the second scintimetry, followed by a decline at 3

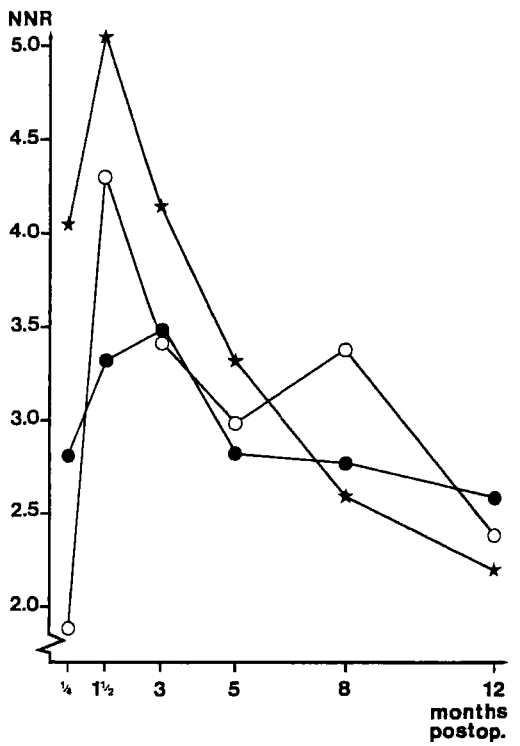

Figure 3. Neck/neck ratio (NNR) in sequential scintimetry in relation to time after internal fixation. For symbols, see Figure 1.

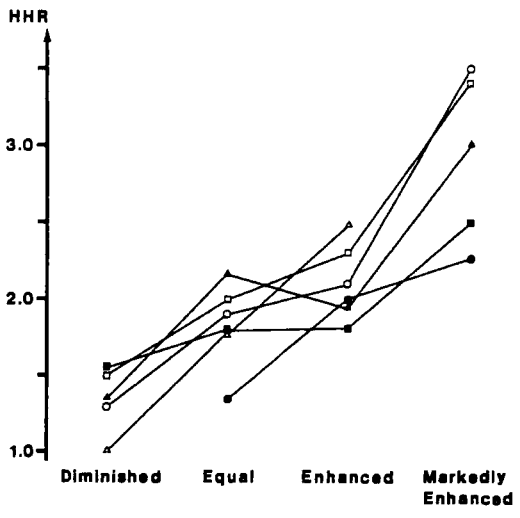

Figure 4. Correlation of qualitative (visual) and quantitative (head/head ratio=HHR) evaluation of ^{99m}Tc MDP uptake in the femoral head on the fracture side in relation to the contralateral side at 1 week △, 6 weeks □, 3 months ○, 5 months ▲, 8 months ■, and 12 months ● postoperatively.

months (Figure 3). These changes were more pronounced for fractures with uneventful union as compared with those with complications; a higher NNR was observed at 1 week ($P<0.01$) and at 6 weeks ($P<0.01$) for cases with uneventful fracture union when compared with cases with complications.

Methodologic error. The methodologic error in determining the radionuclide activity was 10 per cent for the HHR and 19 per cent for the NNR. Among fractures with nonunion or late segmental collapse, the error of the two ratios was respectively 11 and 25 per cent, and for fractures with uneventful healing 9 and 14 per cent; the differences between fractures with and without complications were not significant for either parameter.

Qualitative assessment. The qualitative (visual) and quantitative (HHR) evaluations of the relative radionuclide uptake of the femoral heads at the six radionuclide examinations were highly correlated ($r=0.56$; $P<0.001$, Figure 4).

The results of qualitative assessment of the scintigrams from the six postoperative examinations were also related to the healing course. For fractures resulting in uneventful healing, 13 out of 27 scintigrams at 1 week showed diminished radionuclide uptake over the femoral head on the fracture side, in contrast to 10 out of 12 for fractures with complications ($P<0.05$). At 6 weeks the corresponding findings were 1 out of 28 in contrast to 5 out of 12 ($P<0.01$), and at 5 months 0 out of 29 in contrast to 3 out of 9 ($P<0.01$). Visual assessment at the remaining scintimetric examinations yielded no statistical differences between the two groups.

Discussion

The marked early increase in radionuclide uptake demonstrated in the present study for fractures with an uneventful healing course may be explained by a relatively good vascular supply to the femoral head, permitting rapid initiation of a repair process and consequent radionuclide uptake following the damage caused by the nailing procedure to the bony trabeculae of the femoral head. The lower initial HHR in fractures destined to healing problems reflects a more severe initial vascular impairment.

Comparison of visual evaluation and numerical assessment of femoral head uptake showed a positive correlation, which confirms previous studies (Bauer et al. 1980, Strömqvist 1983, Holmberg & Thorngren 1984). When the uptake was visually judged as equal in the femoral head on the fracture side and on the intact side, the mean HHR was 1.73. This discrepancy should probably mainly be attributed to the surrounding acetabular activity. The findings of Greiff et al. (1980) suggest that visual assessment on an average of 6 and 11 weeks after fracture has prognostic value regarding subsequent development of late segmental collapse.

Quantification of radionuclide distribution and intensity is an objective method and therefore preferable to visual assessment (Bauer et al. 1980, Strömqvist 1983), which is confirmed by the present study. However, our findings suggest that a very low radionuclide uptake according to visual assessment from 6 weeks after fracture is indicative of future nonunion.

Femoral neck uptake in relation to subsequent union or nonunion has been studied by Oda et al. (1980) and Strömqvist et al. (1984a). Despite the somewhat discrepant results in comparison with the present study, probably mainly due to different intervals for scintimetry, we feel that our findings suggest intensive uptake over the fracture region during the first postoperative month to be a favorable prognostic sign. The neck/neck ratio (NNR) may therefore at 1 and 6 weeks be of value as a complement to the head/head ratio (HHR).

The methodologic error of radionuclide scintimetry was 10 per cent for the HHR in this study, which agrees with earlier studies here (Alberts et al. 1984). The larger error for the NNR indicates a greater difficulty in defining the location of the femoral neck on the display. Variations in degree of displacement and posterior comminution also seem to influence the magnitude of this error.

With regard to late segmental collapse, Strömqvist et al. (1984a) found that scintimetry could not distinguish between this complication and nonunion during the first year after fracture. Our series included too few cases with late segmental collapse to permit any definite conclusions.

In a scintimetric study (Alberts et al. 1986) of femoral head specimens removed at arthroplasty due to nonunion , it was found that an HHR<1.85 was indicative of markedly deficient femoral head vascularity. These findings may explain why a previous study (Alberts et al. 1984) showed that an HHR exceeding 1.85 more than 4 months after injury in patients with pain at weight bearing combined with adequate fracture reduction without subsequent redisplacement, as a rule, led to union, whereas an HHR below 1.85 combined with the same radiographic picture resulted in nonunion. Irrespective of the HHR value, unsatisfactory reduction and/or early redisplacement always resulted in nonunion. The prognostic accuracy in differentiating between union and nonunion in that study was found to be 0.86. The results of preoperative scintimetry reported by Holmberg & Thorngren (1984) indicate a prognostic accuracy of 0.94; those reported by Strömqvist et al. (1984a, 1984b) for scintimetry performed 1–2 weeks after internal fixation were 0.97 and 0.90, respectively. In the present study, the prognostic accuracy of both radiography and scintimetry, with respect to healing course, was evaluated for different time intervals after fracture. Scintimetry alone appeared to have great prognostic value 1 to 6 weeks postoperatively. Examinations at 3 and 5 months proved combined scintimetric, clinical, and radiographic assessment to have an almost equally high accuracy in predicting union. In selecting the arbitrary HHR limits for optimal prediction, the time interval between fracture and scintimetric examination must be taken into account.

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