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ASSESSMENT OF FRACTURE HEALING IN MAN BY SERIAL ^{87m}STRONTIUM-SCINTIMETRY

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"Primary bone healing" after rigid osteosynthesis of fractures occurs by direct bridging of the anatomically reduced fracture line by regenerating Haversan systems (Schenk & Willenegger 1967). Provided rigidity of fixation is sufficient, there is no visible callus formation on the radiograph, and it can be difficult to determine when the fracture has consolidated (Wieser 1964). This process of "primary bone healing" is morphologically very different from that found in fractures treated by classical conservative immobilization methods.

Radionuclide tracer methods for studying benign skeletal conditions in man have been widely used (Bauer & Wendeberg 1959, Wendeberg 1961, Bessler 1967, Bauer 1968, Segmüller et al. 1970, Fueger et al. 1971). The short-lived bone-seeking radionuclide ^{87m}Strontium (^{87m}Sr) is now easily available. Due to its short physical half-life (2.8 h), frequent repeat measurements are feasible with little radiation risk to the patient.

In this study we have performed repeat quantitative ^{87m}Sr-uptake measurements (scintimetry) at the fracture site over several months in the same patient, in order to answer the following questions:

How does radionuclide uptake vary in conservative and operative treatment of normally healing fractures of the lower leg?

Do tracer methods allow early detection of non-uniting fractures?

The first radionuclide uptake studies in fractures in man were done with ^{85}Strontium ($T\frac{1}{2}$ 65 d). Bauer & Wendeberg (1959) demonstrated increased uptake of ^{85}Strontium (^{85}Sr) by fractures of the femur and tibia in man. After a single injection of radionuclide, the uptake ratio, fractured: intact leg increased with time. They emphasized the fact that a high uptake does not necessarily mean a high rate of fracture healing, as resorption of mineral might be as high as accretion.

In a series of 51 patients with lower leg fractures, Wendeberg (1961) performed quantitative radionuclide uptake measurements (scintimetries) after a single injection of ^{85}Sr. He compared the data on different patients, and showed that ^{85}Sr-uptake reached a peak five to ten months after fracture and that it remained higher than on the controlateral side up to nine years after the accident. He found no correlation between clinical healing and accretion rate. There was no difference in uptake between normally healing fractures and delayed or non-union.

Increased ^{85}Sr-uptake by the reactive as well as the atrophic type of non-union of the lower leg was demonstrated by Segmüller et al. (1970). Bessler (1967) thought that increased ^{85}Sr-uptake at the site of intertrochanteric osteotomies of the hip was a sign of delayed union.

It seems difficult to judge fracture healing by a single radionuclide uptake measurement. The long physical half-life of ^{85}Sr (65 d) does not allow repeat measurements at intervals shorter than five to six months. This interval is too long, considering the fact that the question of allowing weightbearing in lower leg fractures arises after three to five months. Some authors have therefore tried to do repeat uptake measurements of the short-lived radionuclide ^{87m}Sr in fractures. After daily intraperitoneal injection of ^{87m}Sr and uptake measurement at the site of lower leg fractures in rats, Myers & Olejar (1963) found the increase in uptake to reach its maximum after two weeks.

Fueger et al. (1971) studied ^{87m}Sr-uptake by lower leg fractures on serial scintigraphies in man. They concluded that a locally increased uptake over the fracture was a sign of normal healing, whereas diffusely increased uptake in the whole lower leg was a sign of delayed union. A persistently high uptake was considered to be a sign of non-union or infection.

Few authors have compared radionuclide uptake by fractures in conservative and operative treatment. In the rabbit, Falkenberg (1961) showed that ^{85}Sr-uptake in nailed osteotomies of the radius was lower than in unnailed osteotomies. Fueger et al. (1971) reached the same conclusions by using ^{87m}Sr in rabbits, and found the increase in uptake to last longer in unnailed than in nailed osteotomies. In man, he found the ^{87m}Sr-uptake in conservative treatment to be higher and to reach its maximum earlier than after stable osteosynthesis.

Accurate data on ^{87m}Sr-uptake by normally healing fractures based on repeat quantitative uptake measurements in the same patient are still missing. The aim of this paper is therefore to establish a normal

^{87m}Sr-uptake curve against time for lower leg fractures in patients treated by conservative and operative methods.

MATERIAL AND METHODS

The study included 10 patients aged between 20 and 65 years. They all had transverse, oblique or short spiral fractures of the middle or lower third of the tibial diaphysis.

Four of the fractures were treated conservatively by axial traction using a transcalcaneal Steinmann pin for two to three weeks followed by immobilization in a long leg cast for 11 to 17 weeks. Partial weightbearing was allowed after removal of the cast, full weightbearing three to five weeks later. All fractures had healed within less than 23 weeks.

Stable osteosynthesis was achieved by means of an A.O.-compression plate in six fractures. Four fractures united sufficiently to allow full weightbearing within 12 to 20 weeks. Two fractures developed non-union.

For each scintimetry, the patient was injected intravenously with 1 mCi ^{87m}Sr. The length of both tibiae was divided into 10 equal segments. Three hours after injection, the patient was placed supine and the legs held in position by sandbags. Duplicate uptake measurements were made over each segment of both tibiae by means of a Mecaserto MO4 scintillation scanner equipped with a 3×3 inch NaI-crystal shielded by a 37-hole focussing collimator and connected to a scaler. The detector was repositioned between the two measurements. The counting rates were corrected for background activity, physical decay of ^{87m}Sr, and absorption by plaster, which had been measured to be about three per cent for an average thickness of plaster of Paris. For each segment, the uptake ratio, fractured: intact leg was calculated. The average ratio of the five segments closest to the fracture was called *fracture uptake ratio.* It is independent of the injected dose.

Scintimetries were done at 3, 11, 20 and 28 weeks after accident in conservative treatment and at 3, 12, 20 and 30 weeks after osteosynthesis in operative treatment. Absolute changes in ^{87m}Sr-uptake by the fracture in consecutive scintimetries were expressed by means of the fracture uptake ratio.

RESULTS

The mean fracture uptake ratios in normally healing fractures are shown separately for conservative and operative treatment in Figure 1.

With *conservative treatment*, uptake ratios increased over a 28-week observation period. This increase was specially marked at the time of starting weightbearing (11th to 17th week).

With *osteosynthesis*, uptake ratios decreased slightly over a 30-week observation period. There was a slight rise in uptake at the time of starting weightbearing (12th to 20th week).

Regression analysis showed the difference in slope between the two curves to be highly significant ($P < 0.001$).

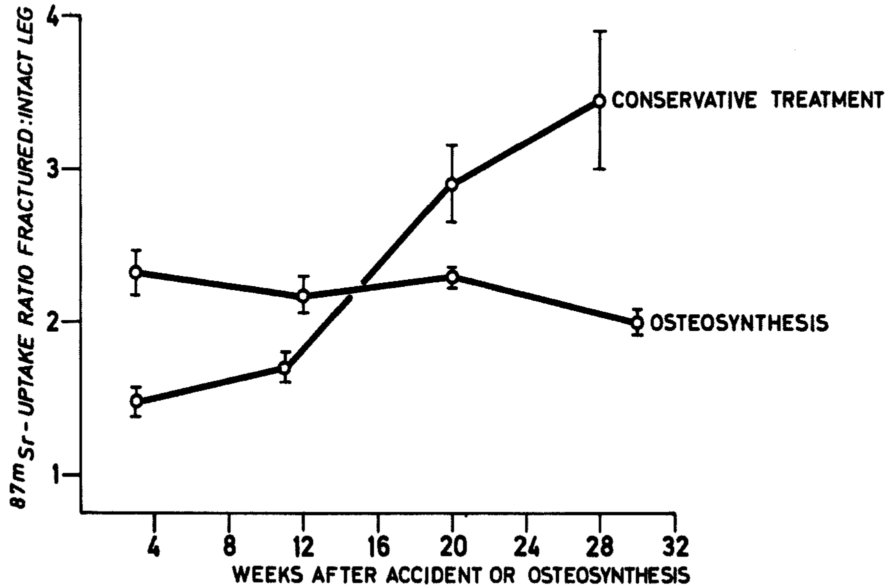

Figure 1. Average ^{87m}Strontium-uptake ratios in eight normally healing fractures. For each curve the data are based on measurements in four fractures. The end markings represent one standard deviation for each mean.

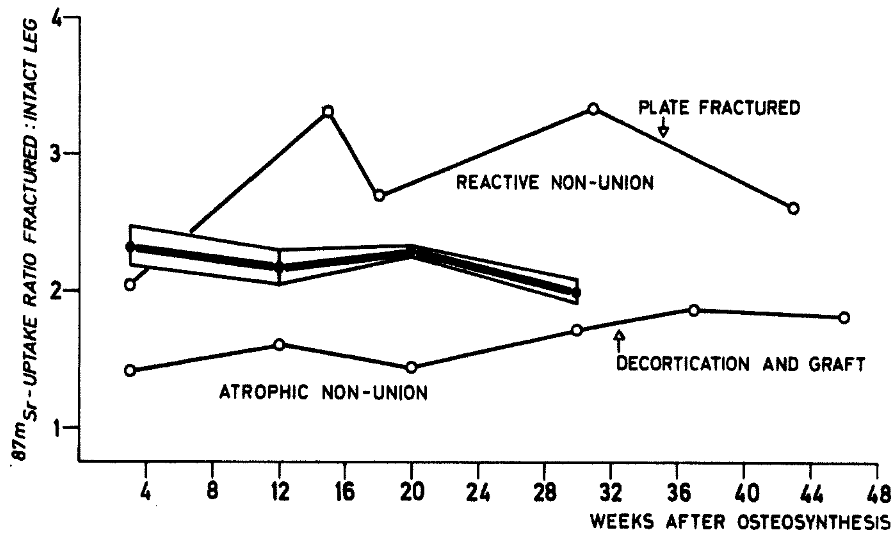

Figure 2. ^{87m}Sr-uptake ratios in lower leg fractures treated by compression plate. The middle curve represents mean and one standard deviation of ^{87m}Sr-uptake ratios in four normally healing fractures. A case of reactive (upper curve) and one of atrophic (lower curve) non-union show a marked and early departure from the normal uptake curve.

Two operated fractures developed non-union. Their uptake ratios in relation to the uptake ratios of normally healing operated fractures are shown in Figure 2. Radionuclide uptake in a case of reactive non-union was abnormally high. Weightbearing was allowed after 24 weeks despite clinical signs of instability and the high uptake ratios. The plate broke five weeks later. The uptake ratio dropped after the plate had been removed and the fracture had started to unite. In a case of atrophic non-union, uptake ratios remained abnormally low from the start, but increased slightly after decortication and cancellous bone grafting had been performed at 32 weeks.

DISCUSSION

Fracture healing in conservative treatment and after stable osteosynthesis are two fundamentally different processes (Schenk & Willenegger 1967). This difference is reflected by the shape of the ^{87m}Sr-uptake curves in lower leg fractures. With conservative treatment, callus formation and remodelling is accompanied by an increasing ^{87m}Sr-incorporation into the fracture during the first 28 weeks. After stable osteosynthesis, direct bridging of the fracture line is reflected by a constant if not diminishing ^{87m}Sr-uptake at the fracture site. Increased bone remodelling after starting weightbearing is reflected in both types of treatment by a rise in ^{87m}Sr-uptake.

In normally healing fractures, the degree of ^{87m}Sr-uptake varies little from patient to patient. This is demonstrated by the small standard deviation of the uptake ratios shown in Figure 1.

In non-union, the shape of the curve as well as the uptake ratios are very different from normal (Figure 2). In a case of atrophic non-union, persistently low uptake was noted, whereas in a case of reactive non-union, uptake was well above normal. It is striking that these changes in ^{87m}Sr-uptake appeared as early as three weeks after operation in the case of atrophic non-union and 15 weeks in the case of reactive non-union.

Serial ^{87m}Sr-scintimetry alone cannot determine the moment when weightbearing may be allowed. However, it seems reasonable to assume that if ^{87m}Sr-uptake corresponds to the values seen in normal fracture healing, weightbearing can be allowed after the usual number of weeks.

Serial ^{87m}Sr-scintimetry is an indication of the healing potential of fractures. Marked departure from the normal values should be interpreted as incipient non-union. The classical treatment of non-union is decortication of the fracture region and cancellous bone grafting, or osteosynthesis by a compression plate alone. When clinical or radiographic suspicion of incipient non-union exists, it should be possible to apply this treatment earlier on the basis of serial ^{87m}Sr-scintimetry than on the classical basis of clinical signs and radiography.

Serial ^{87m}Sr-scintimetry thus could be developed into a useful method for cases where doubts exist as to the healing prognosis of lower leg fractures.

SUMMARY

Serial quantitative ^{87m}Strontium-uptake measurements (scintimetry) were performed in 10 lower leg fractures in man during the first 28 weeks after trauma. Four fractures were treated conservatively and united within less than 23 weeks. ^{87m}Sr-uptake by these fractures rose throughout the investigation period. Four other fractures were treated operatively by an A.O. compression plate and united within less than 20 weeks. Their ^{87m}Sr-uptake diminished slightly over the observation period. For both methods of treatment, uptake values varied little from one patient to another. In two cases of non-union, early marked departure from the ^{87m}Sr-uptake values found in normal fracture healing was noted. Serial ^{87m}Sr-scintimetry is therefore thought to be a method which could be developed into a useful tool for early detection of incipient non-union.

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