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DIAGNOSTIC USE OF ^{85}STRONTIUM IN THE PREOPERATIVE EVALUATION OF NON-UNION

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Bone-grafting procedures have received universal acceptance in the treatment of non-union (Phemister 1914, Lexer 1924, Albee 1930, Witt 1952, Merle d'Aubigné 1959, Harris et al. 1965, Compere et al. 1966, Hanson & Eppright 1966, Lange 1967, Rogers 1968). Some diversity of opinion still exists as to the type of grafting material appropriate in a given case and to the best grafting technique (Boyd et al. 1965, Rogers 1968). While bone-grafting alone has been used ever since Lexer and Albee, an increasing number of orthopaedic surgeons over the last 20 years have preferred a combination of bone-grafting and internal fixation by metallic implants. Standard bone-plates were used at first, then intramedullary nailing became a standard procedure for a number of pseudarthroses (Lambotte 1913, Kuentscher 1949/1954, Boyd et al. 1965). Stabilization by external compression devices was favoured in France and in Switzerland (Hoffmann 1951, Greifensteiner 1953, Ricklin 1957, Mueller & Allgoewer 1958). Interfragmentary compression by a special plate was first used by Danis (1949). Many authors now use the AO-compression plate designed by Mueller (1963) (Boyd et al. 1965, Cech & Stryhal 1967).

Two main principles have always governed the treatment of non-union: (A) stabilization and (B) stimulation of osteogenetic activity.

The first argument is of a biomechanical nature, i.e. forces acting on the fragments should be eliminated to achieve full immobilization of the zone of disturbed fracture-healing. Remarkable progress has been made in recent years concerning firm and lasting stabilization of fragments by means of accurate intramedullary nailing and by the correct application of compression plates (Mueller 1963, Mueller et al. 1965, Segmueller 1966). Fixation provided by cortico-cancellous grafts alone, however, must be supplemented by plaster-casts. Functional treatment and weight-bearing is, therefore, not allowed, though it would seem to be essential in the presence of already impaired function of the extremity.

The second principle concerns the pathophysiology of bone repair at the fracture-site. The osteogenetic activity at the site of non-union was always believed to be poor and an osteogenetic stimulus was therefore considered to be essential in the operative treatment of non-union. There is, however, little information about the actual osteogenetic activity of any given stage in the development of delayed union or non-union.

Judet has demonstrated the presence of extensive vascularization of the bone at the so-called zone of sclerosis at the bone ends (Judet & Judet 1960, Judet et al. 1958). The resection of the "sclerotic" bone ends, advocated especially by German authors, was no longer advised by Judet nor by Burrows (1940), Phemister (1947), and Delangénière (1920) before him. These authors were against the disturbance of the fibrous union of the fragments. According to their findings intermediary fibro-cartilagenous tissue would calcify readily upon application of a small subperiosteal bone-graft and additional external fixation by plaster cast. In experimental non-union in the dog, Schenk (1968) has shown that blood supply is abundant in the area surrounding non-union and that numerous vascular sprouts approach the main line of pseudarthrosis very closely. Rhinelander et al. (1968) demonstrated an extremely dense vascular network in the callus surrounding delayed union of displaced fractures in dogs. Trueta (1967/1968), in accordance with many previous workers, pointed out the essential role of capillaries in the process of new bone formation. It would therefore seem that biological conditions in the "usual" type of clinical non-union are rather favourable to new bone formation and that correction of the biomechanical factors alone could suffice for the requirements of normal bone repair. In recent years much clinical evidence has been accumulated lending support to the assumption that operative stabilization without additional bone-grafting leads to successful healing in many cases. Infected non-union as well as pseudarthroses with bone defects present additional problems and are not dealt with in this paper.

In the preoperative evaluation of clinical non-union a lack of information about the osteogenetic capacity of the tissue at the site of non-union is obvious. This means that in addition to the conventional X-ray pictures more information about the functional state of the bone repair process is needed. The uptake of tracers such as ^{47}Ca and ^{85}Sr in human tibial and femoral fractures was studied by Bauer and Wendeberg in 1959 and 1961 (Wendeberg 1961, Bauer & Wendeberg 1959, Bauer & Ray 1958). They found a rapid uptake of ^{85}Sr in the fracture region during the first hour post-injection. This, according to the authors, indicates a rich blood supply to the fracture area and a rapid exchange of mineral salts between body fluids and callus. Two weeks after injection of ^{85}Sr, most of the isotope has been incorporated into the skeleton by actual accretion, i.e. mineralization of osteoid matrix. It is the purpose of this paper to make available for special problems in the clinic the experimental bone-seeking tracer studies of Bauer & Wendeberg (1961). The clinical evaluation of osteogenetic activity in non-union does not depend on absolute values of local mineral metabolism. However, the relative mineral accretion rates in areas of disturbed bone repair could well be used in determining the actual state of activity of osteogenetic tissue.

External Counting Techniques Used in this Clinical Study

In this clinic ^{85}Sr, ^{87m}Sr, and ^{47}Ca are used as bone-seeking tracers for diagnostic work-up of patients with bone lesions. Recording is done by scanning and external counting techniques. Scanning has proved to be superior (both clinically and in preliminary investigations on a laboratory model simulating conditions in bone) for determinating the extent of the lesion. When scanning is used alone, ^{87m}Sr is preferred for its short half-life. External counting by scintillation detectors allows for repeated counting in the early equilibration phase, as well as days or weeks thereafter. In studying bone-repair this is of great advantage. Cylindrical collimators and conic collimators are not used in this investigation.

A modified technique with the 1-inch scintillation detector has been tested and compared with other techniques. In locations where the bone-covering soft tissue layer is thin (lower legs) this technique permits essential dosage reduction of the tracer substance (5–10 μCi ^{85}Sr) and is therefore applicable in young patients. A detailed description of the technique is in preparation.

In this pilot study on osteogenetic activity in non-union, counting

Figure 1a.

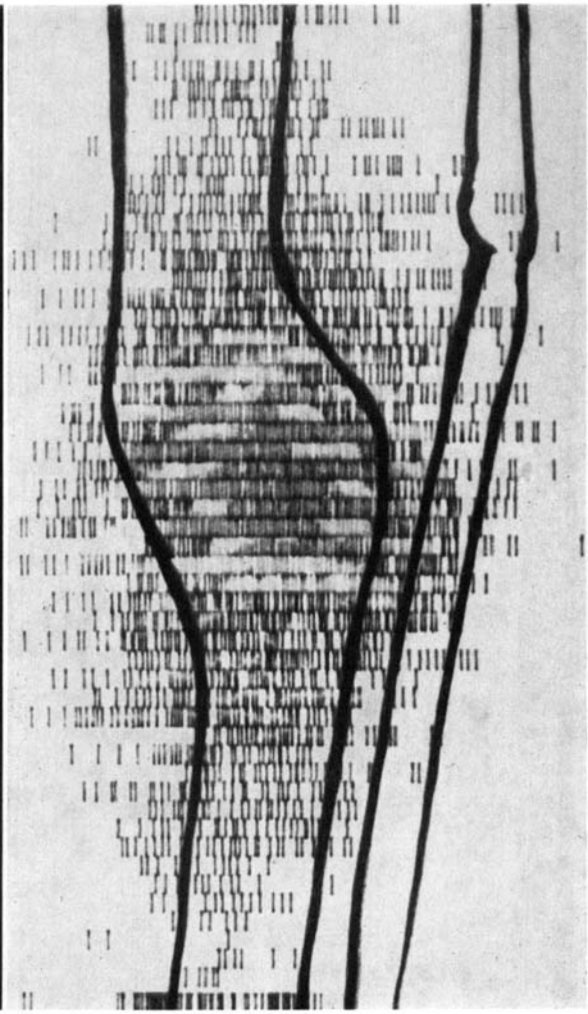

Figure 1b.

Figure 1a. Non-union of tibia, 18 months after open fracture. Radiologically no increase of callus formation for the last 8 months.
Figure 1b. Colour-scan, 2 days following ^{85}Sr administration, demonstrating marked increase of tracer uptake at the site of non-union.

has been done at 30 min., 1 hr, 2hrs (3 hrs), 24 hrs, 48 hrs, 96 hrs, and 1 week following intravenous administration of the tracer. Six anatomically corresponding locations over the tibia were chosen and their distances exactly measured. The principle underlying this work is

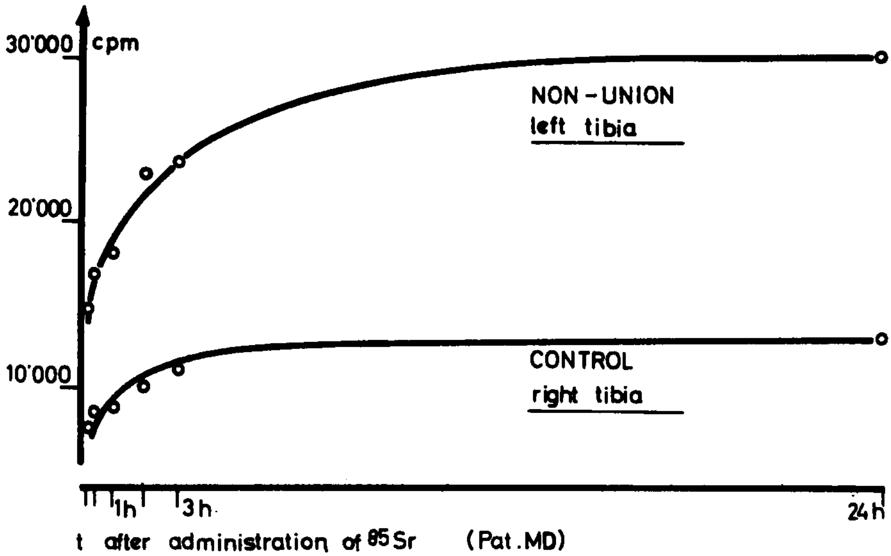

Figure 2. ^{85}Sr uptake at the site of non-union (9 months after fracture) of the left tibia, and at the same location on the right tibia, as point of reference. First counting 15 min. after intravenous administration of 13 μCi of ^{85}Sr. The difference in uptake is at its maximum immediately following injection.

direct comparison of activity of the diseased extremity with the control side. Therefore, correction of counting rates for decay and comparison with standard samples are not considered necessary.

CLINICAL CASES

In Figure 1, X-ray and photoscan of a case of non-union are presented. Active callus formation is demonstrated by the conventional roentgenogram, and a considerable early uptake of ^{85}Sr (colour-scan) gives additional proof of greatly increased mineral metabolism at the site of disturbed bone repair. This finding of early active ^{85}Sr (or C^{++}) exchange between body fluids and callus tissue reflects a large exchangeable calcium space on the basis of a rich blood supply to the site of non-union. This would be in accordance with the histological findings on experimental non-unions (Judet & Judet 1960, Judet et al. 1958, Schenk 1968, Rhinelander et al. 1968).

The rapid tracer uptake in the very early phase of equilibration in the body fluids is also shown in Figure 2. The difference of the counting rate between diseased tibia and control tibia in the same individual

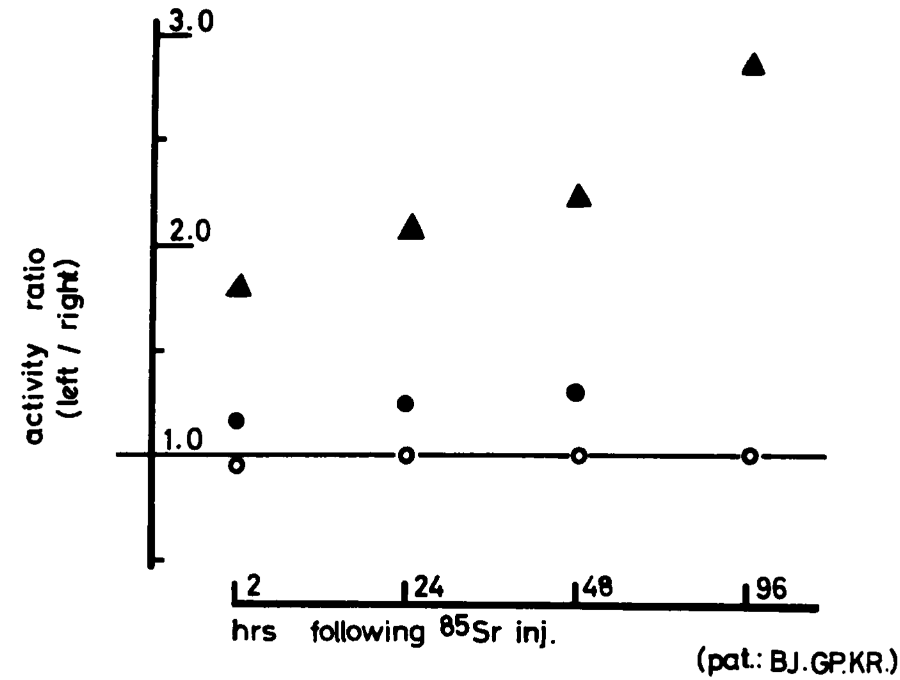

Figure 3. The activity ratio of 3 clinical cases with fracture of the lower leg.

▲: *Non-union of left tibia (8 months after injury). Radioactivity is persistently high over the bone lesion, the ratio therefore increases from 2.15–2.7 within 4 days.*
●: *Delayed union of left tibia (5 months following fracture), radiologically poor callus formation. Radioactivity shows little increase compared with normal (ratio 1.15–1.3).*
○: *Fracture of left tibia (8 years prior to investigation) fully consolidated. Activity ratio remains unchanged at unity (1.0 ± 0.05).*

is almost at its maximum within the first three hours following injection. The early rapid uptake of the bone-seeking isotope can be well demonstrated by either method: Colour-photoscan with ^{85}Sr or ^{87m}Sr and external counting by scintillation detector using ^{85}Sr.

In our experience there are marked differences of ^{85}Sr uptake in different types of non-union. In Figure 3 the activity ratio (left/right tibia) of three cases is shown. Case 1 (▲) represents a very active type of pseudarthrosis (Figure 4), 9 months following injury, with an activity ratio of 2.15 at 2 hrs, increasing to 2.7 four days following intravenous injection of ^{85}Sr. The X-ray of Case 2 (●) is characterized by no callus formation at all (Figure 5). The activity rates, however, recorded at the site of non-union, still demonstrate a moderate increase

Figure 4. *Figure 5.*

Figure 4. X-ray of Case ▲ in Figure 3, taken immediately after intramedullary nailing of non-union. Moderate callus formation 9 months after injury. Uptake of ^{85}Sr at the site of the non-union (Figure 3), however, is high.

Figure 5. X-ray of 5-month-old fracture shows little callus formation. Tracer uptake, slightly elevated, is shown in Figure 3, Case ●.

of ^{85}Sr uptake, compared with the control side. No increase of tracer uptake is recorded in Case 3 (○) at the site of a healed-lower leg fracture 8 years after injury (Figure 6). Activity ratio remains at unity in an early recording and also in late recordings.

Figure 6. X-ray of Case ○ in Figure 3, healed fracture 8 years after injury. Bone remodelling seems to be complete. No increase in tracer uptake.

DISCUSSION

Even though scintigraphic studies are not meant to give a quantitative answer to the question of local mineral metabolism of bone, they clearly show a heavily increased local activity at the site of pseudarthrosis immediately after injection. These findings point to the fact of a larger exchangeable calcium space at the site of disturbed bone healing as compared to the control side. Such rapid local mineral exchange during an early equilibration phase is indicative of a rather rich local blood supply. The marked increase in new bone formation, expressed by the late activity ratio (non-union/control side), allows the assumption that local osteogenetic capacity is not lost but increased. As Bauer pointed out, this gives no right to assume that fracture-healing will therefore occur. The rate of local bone resorption might be as active as new bone formation, which means that there would be no net gain of new bone tissue at all. However, as discussed earlier, clinically we are interested in the actual osteogenetic capacity of the tissue rather than in quantitation of new bone formation, in order to answer the long-standing question of whether the fibro-cartilaginous "scar-tissue" of the non-union is of so-called poor quality.

In our present clinical investigation we have been impressed by the fact that in different types of non-union remarkable differences in ^{85}Sr uptake are recorded. In Figure 3, two of our cases are presented, demonstrating clearly the range of difference in tracer uptake at the fracture site. The recordings of the clinical cases investigated in our study lie between these extreme values of a case of maximum increase and one of slight increase in radioactivity. We therefore consider the external ^{85}Sr counting technique a valuable parameter in the preoperative evaluation of the functional state of pseudarthrosis. As a diagnostic procedure this technique provides the clinician with a more rational approach to the question of whether he has to deal with poor osteogenesis or whether the only aetiological factor of non-consolidation in any given case is merely a mechanical one.

SUMMARY

The clinical evaluation and classification of non-union of long bones is generally based on conventional roentgenograms. The questions of the local vascularization and the new bone-forming capacity of the intermediary fibro-cartilaginous tissue is not answered by this source of information. By means of early photoscanning and/or early external counting technique as well as late external counting of ^{85}Sr with the aid of a scintillation detector, we have a parameter of local mineral metabolism for the evaluation of local osteogenetic capacity of non-union.

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