The Use of Tc-99m MDP Bone Scanning in the Study of Vascularized Bone Implants: Concise Communication

Paul Dee, Phillip G. Lambruschi, and John M. Hiebert

University of Virginia Medical Center and Hospital, Charlottesville, Virginia

The extent to which the nutrient artery alone is capable of maintaining bone growth in the immature animal was studied by excision and reimplantation of the upper tibia in two groups of puppies. In one group the reimplant was totally devascularized, and in a second group attempts were made to preserve the nutrient vessels to the reimplant. Technetium-99m methylene diphosphonate (Tc-99m MDP) was used to assess the effectiveness with which the nutrient circulation was maintained. With one exception the Tc-99m MDP scans proved to be reliable in indicating the potential for continued growth after reimplantation. It was found that the nutrient artery alone is capable of maintaining longitudinal bone growth in metaphyseal reimplants in immature animals. Complete devascularization results in cessation of growth. The Tc-99m MDP bone scan should prove of critical importance in the assessment of free vascularized transplants of immature bone.

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The development of microvascular surgery has allowed the transplantation of bone with preservation of the blood supply to the graft (*1–3*). The osteocytes in a nonvascularized bone graft undergo necrosis, with the probable exception of those in a very narrow superficial layer (*4,5*). The graft is then used as a scaffold or template for the reconstruction of bone by a process of "creeping substitution" by cells and vessels from the bed of the graft (*6*). Quite apart from disadvantages, such as inherent weakness during the period of substitution and a tendency toward nonunion, the nonvascularized bone graft lacks longitudinal growth potential. In a child, particularly in mandibular reconstructions, this is disadvantageous.

Microsurgery offers the potential of effecting the transplant of bone, including the metaphyseal/epiphyseal region, with at least partial preservation of its blood supply by isolation and grafting of the nutrient artery. Of critical importance, however, is the extent to which the nutrient artery alone can sustain the viability of the growth zone at the epiphyseal plate, thereby maintaining growth.

A developing long bone has a triple blood supply. A number of small periosteal arteries supply the periosteum and the superficial layers of the cortex. The nutrient artery enters the bone, usually in the middle third of the bone's shaft, then divides in the medulla into two arteries, which traverse the medulla to opposite ends of the bone. The nutrient arteries connect with both the medullary and cortical sinusoids and finally ramify in the central portion of the metaphysis. The outer side of the metaphysis is supplied by several metaphyseal arteries, which enter the bone near the growth plate. The epiphysis is supplied by the epiphyseal arteries, and there is no vascular connection across the growth plate itself. It is widely estimated that the central three fifths of the metaphysis is supplied by the nutrient artery while the two outer fifths are supplied by the metaphyseal arteries (*7*). There is, however, very considerable collateral potential between the metaphyseal arteries and the nutrient arteries.

The present study was designed to determine the ex-

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For reprints contact: Paul Dee, MD, Dept. of Radiology, Box 170, Univ. of Virginia Medical Center, Charlottesville, VA 22908.

tent to which the nutrient artery alone could sustain bone growth. Reliance was placed on Tc-99m MDP bone scanning to assess the effectiveness with which the nutrient artery supply was maintained. This was based on the assumption that uptake of the tracer is a function of an intact blood supply and the presence of metabolically active tissue in the metaphysis (*8,9*). The present paper examines the use of Tc-99m MDP scanning in assessing the viability of the metaphysis and the potential for growth after severance of all but the nutrient-artery supply to a long bone.

METHOD

Two groups of experimental animals were studied, both consisting of puppies of under 12 wk of age. Group 1 animals (four subjects) were used to evaluate the effect of deliberate total devascularization of a bone implant on growth of the implant. In this group the upper half of one tibia was completely excised, with total severance of the blood supply, then reimplanted and wired into position in the same bed. Group 2 animals (11 subjects) had the upper half of one tibia excised, with preservation of the nutrient artery's vascular pedicle, then reimplanted and wired into position. Longitudinal growth was measured by determining the separation between a sphere implanted in the upper tibial epiphysis and a wire ring placed on the lower portion of the reimplanted shaft (Fig. 1). In the contralateral limb, markers were placed similarly on the otherwise undamaged bone. Radiographs of the lower extremities were taken at fixed film-focus and object-film distances immediately following surgery and at 3, 6, and 9 mo following reimplantation. The bone scans were performed using 2–3 mCi Tc-99m MDP 1 wk following surgery, after the plaster casts had been removed. Follow-up scans were performed at the same time intervals as the radiographic examinations.

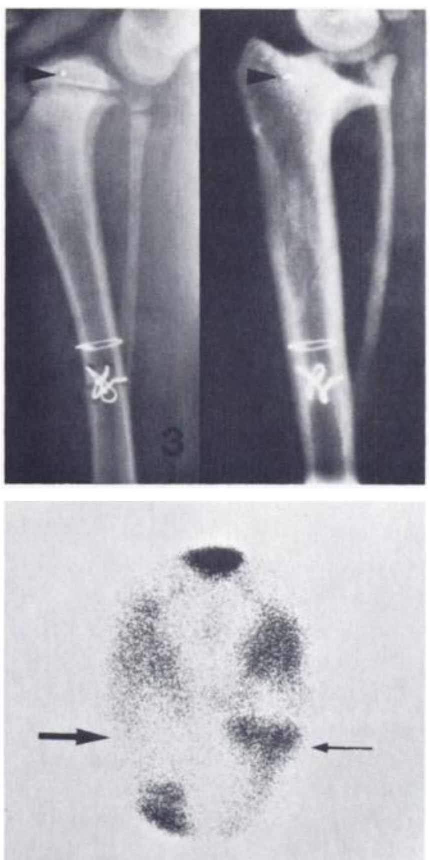

FIG. 1. Group 1 experiment (all vascular supply cut). Bone scan, 1 wk postoperative, shows absence of uptake in right upper tibia (large arrow) compared with normal uptake on control side (small arrow). Increased activity appears at osteotomy site on right. Radiographs taken immediately after operation (left) and at 9 mo (right) show complete failure of longitudinal growth (same scale, arrowheads mark sphere in epiphysis).

RESULTS

The bone scans were evaluated without foreknowledge of eventual growth and without knowledge of the group to which the animal was assigned.

In the immediate postsurgical examination (Fig. 1), the Group 1 animals all had complete failure of tracer uptake on the experimental side in the metaphyseal/epiphyseal region. This was to be anticipated in view of the total severance of blood supply on that side.

The Group 2 animals, in which preservation of the nutrient arterial blood supply was the object, presented a more complex breakdown of the initial scan ressults. Two of the animals showed complete failure of tracer uptake in the metaphyseal/epiphyseal region of the reimplant. Two others had equivocal scans in which some tracer uptake was apparent, although activity in metaphyseal/epiphyseal region of the reimplant was significantly reduced. The remaining seven subjects had apparently normal uptake in the metaphyseal/epiphyseal region of the reimplant (Fig. 2). (The difference in activity between the distal femora is due to positioning).

To avoid the use of absolute units, bone growth on the experimental side has been expressed as a percentage of growth on the control side (Fig. 3). The range of growth was from −14 to +126%, the latter representing actual overgrowth on the experimental side compared with the control side. The −14% represented not just failure to grow but actual shortening of the experimental side compared with the initial examination of this side. This was the result of severe avascular necrosis of the epiphysis, with resultant collapse of the epiphysis and migration of the marker sphere toward the marker wire.

In Fig. 3 the bone scan results are correlated with the relative bone growth. The Group 1 control animals showed a mean decrease in length of 6%, and this was associated with severe changes of avascular necrosis in the upper end of the reimplant (Fig. 1). In Group 2, the

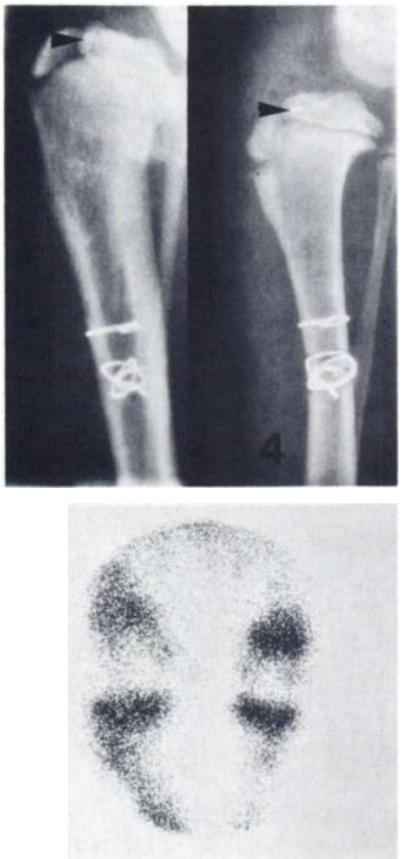

FIG. 2. Group 2 experiment (nutrient artery preserved). Anterior bone scan, 1 wk postoperative, shows tracer uptake in right upper tibia (experimental side). Radiographs taken immediately after operation (L) and at 9 mo (R) show that longitudinal growth has occurred (same scale, arrowheads mark spheres in epiphysis).

two animals with no tracer uptake in the metaphyseal/epiphyseal region of the reimplant both showed complete failure of bone growth on this side. The two animals with equivocal scans showed a mean growth of 11.5%. The seven animals with normal tracer uptake in the reimplant showed a mean growth of 63% with a range of 0–126% (Fig. 2). Review of the subject in this subgroup with total failure of growth indicated that the tracer uptake in the reimplant on the initial scan was unquestionably normal. It is possible that the nutrient artery supply was damaged, as the animal became mobile following removal of the cast 1 wk after surgery. If this subject is excluded from this subdivision of Group 2, the mean growth was 74% of the growth on the normal side.

DISCUSSION

Complete severance of blood supply to the upper half of the tibia in the immature animal results in cessation of bone growth and severe avascular necrosis of the growing end of the bone. On the other hand, if the blood supply can be maintained by the nutrient artery, there is potential for growth. The mean growth in the present

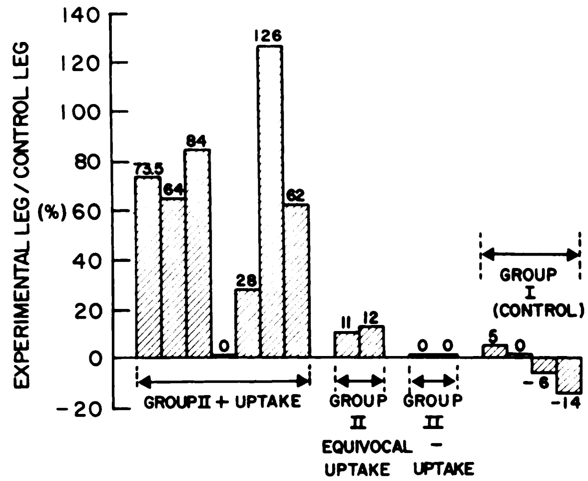

FIG. 3. Histogram correlating the Tc-99m MDP scan results with growth of corresponding reimplants, expressed as percentage of the growth in opposite (control) limb (control = 100%).

series, in those cases with scan evidence suggesting continuing perfusion and viability of the metaphysis, was 63% of normal for these animals. Some damage to the epiphysis/metaphysis presumably must have occurred to account for the disparity in growth between the two sides.

The bone scan proved a useful tool in interpreting the results in this series. The scan results in Group 1 occasioned no surprise, but it is clear that interpretation of the results in the experimental group would have been more complex had the scan results not allowed a further degree of subdivision in this group. The two cases with failure of uptake on the experimental side, and the two cases with equivocal scans, were presumed to have suffered a significant reduction in bone perfusion, probably total or near-total in the former and partial in the latter. The total failure of growth in the one pair, and the severe curtailment of growth in the other, support this concept. One result, however, in the experimental group is anomalous. Unquestionably one of the animals had an unequivocally normal scan 1 wk following surgery and yet showed total failure of growth.

Avascular necrosis of the epiphysis appeared inevitable. There is no vascular connection across the epiphyseal plate, and collateral pathways must have been in large part destroyed by the dissection. Nevertheless the most severe avascular necrosis occurred in Group 1 and could well have involved the metaphysis to a significant extent. The severity of the avascular necrosis is evidenced by the actual shortening of the reimplant in three of the four cases in this group. Damage to the epiphysis is far less critical than damage to the metaphysis in relation to bone growth. Damage to the metaphysis was less easy to document, but deformities due to uneven metaphyseal growth did occur and overall growth was diminished.

The radionuclide bone scan proved—with one notable exception—to be a reliable indicator of the potential for growth following the reimplantation experiments described. As previously stated, the bone scan indicates significant vascular perfusion of bone and the presence of metabolically active tissue in bone. It is not necessary to separate these functions. Perfusion and the presence of active bone cells are interrelated prerequisites for bone growth.

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