THE SCINTIGRAPHIC ASSESSMENT OF THE SCOLIOTIC SPINE AFTER FUSION

MICHAEL J. McMASTER, MALCOLM V. MERRICK

From the Edinburgh Scoliosis Unit, Princess Margaret Rose Orthopaedic Hospital, Edinburgh, and the Medical Radioisotope Department, Western General Hospital, Edinburgh

Scintigraphy using technetium-labelled methylene diphosphonate was performed on 110 scoliotic patients six months after an attempted fusion and the findings compared with those at exploration to detect the possible sites of pseudarthroses. The majority of patients (65 per cent) had a uniform uptake of isotope over the fused area and all but one had a solid fusion. A second group (35 per cent) had a more patchy uptake and eight of the nine patients with pseudarthroses were in this group. Pseudarthroses were detected as localised areas of increased uptake but there were also a number of false positives and scans that were difficult to interpret due to continuing new bone formation in immature fusions. In those scans performed after one year the pseudarthroses which had been missed were seen much more clearly in contrast to the diminished generalised activity in the fused area.

Methods of detecting pseudarthroses in the scoliotic spine after fusion have been mainly radiological, but unfortunately radiographs of the deformed spine are often difficult to interpret, and it is only when the curve has deteriorated that a presumptive diagnosis is made. In an effort to overcome this difficulty, and accurately to detect and repair pseudarthroses at an early stage, some surgeons have routinely surgically explored their fusions (James 1965). This diagnostic procedure, unfortunately, subjects a considerable number of patients with a solid fusion to an unnecessary operation. If an accurate non-operative method of detecting pseudarthroses at an early stage could be developed this would be of considerable value.

Scintigraphy using bone-seeking radioactive isotopes, which can be detected within the skeletal system by means of an external imaging device, is a long-established orthopaedic investigation (Bauer and Wendeburg 1959). This technique, which has been most widely used to detect skeletal metastases before they are visible radiographically (Sklaroff and Charkes 1968; Galasko 1972), has also been used to a lesser extent to study infective lesions of bone (DeNardo and Volpe 1966; Kemp *et al.* 1973), the healing of fractures (Wendeburg 1961) and the vascularity of the femoral head after subcapital fracture (McNeur 1970).

The recent introduction by Subramanian and McAfee (1971) of a new group of bone-seeking compounds labelled with the radioactive isotope tech-

netium ($^{99}\text{Tc}^m$) has resulted in a renewed interest in bone scanning. Technetium itself is not taken up by the skeleton but can be made to do so by chelating it with various phosphate-containing compounds (Castronovo and Callahan 1972; Subramanian *et al.* 1972; Yano *et al.* 1973). The phosphate compounds replace the phosphate groups on the surface of the hydroxyapatite crystals of bone but the exact mechanism of uptake is not completely understood (Jung, Bisaz and Fleisch 1973). It has, however, been shown that the concentration of the phosphate compounds in bone is non-specific and depends on the blood supply and the production of immature new bone, whatever the stimulus may be (Galasko 1975; Hughes *et al.* 1978). Of the various phosphate compounds available, the diphosphonates are thought superior because of their affinity for bone rather than for soft tissue and rapid clearance from the blood (Hughes, Jeyasingh and Lavender 1975; Subramanian *et al.* 1975).

The radiographic diagnosis of a bony lesion depends on a relative change in the amount of calcium within the lesion as compared to the surrounding bone. Often the changes have to be large and, in the case of a metastasis in a vertebral body, at least half of the trabecular structure must be destroyed before becoming visible radiographically. Therefore, when a pseudarthrosis develops in a spinal fusion it is very difficult to see it radiographically in the early stages, but the increased blood supply and localised osteoblastic response

M. J. McMaster, MD, FRCS, Consultant Orthopaedic Surgeon, Scoliosis Unit, Princess Margaret Rose Orthopaedic Hospital, Fairmilehead, Edinburgh EH10 7ED, Scotland.
M. V. Merrick, MSc, DMRD, FRCR, Consultant, Medical Radioisotope Department, Western General Hospital, Edinburgh EH4 2UX, Scotland.

Requests for reprints should be sent to Mr M. J. McMaster.

attempting to heal the lesion should theoretically be detected on a bone scan as an area of increased radioactivity.

To test this hypothesis we have carried out a prospective study to evaluate technetium bone-scanning as a diagnostic technique for the early detection of pseudarthroses before they become visible radiographically. A comparison was made between the scintigram and the findings at exploration six months after the attempted fusion. No similar investigation has as yet been published. Hannon and Wetta (1977) have carried out technetium bone-scanning on 11 scoliotic patients with longstanding pseudarthroses in their spinal fusions. These bone scans, however, were not performed until 11 to 97 months (average 45 months) after the attempted fusion and were found to be unhelpful in localising the pseudarthroses. There were no control patients with solid fusions and it was suggested that a developing pseudarthrosis might be more easily detected than an old well-established one.

CLINICAL MATERIAL

One hundred and ten patients with scoliosis who had a spinal fusion between April 1975 and December 1977 and who were thought to be possible candidates for a pseudarthrosis were subjected to both a technetium bone-scan and an exploration of their spine six months after the attempted fusion. Eighty-six of the spinal fusions and all of the explorations were performed by one of us (M.McM).

There were 83 girls and 27 boys whose ages at spinal fusion ranged from 8 to 25 years. Only one patient was over the age of 18 years and the average age of the remaining patients was 12 years 3 months. Sixty patients had an idiopathic scoliosis, 34 a congenital scoliosis and seven a paralytic scoliosis. Nine patients were in a miscellaneous group: three had neurofibromatosis, three Marfan's syndrome, one Ehlers-Danlos syndrome, one arthrogryposis and one was a metatropic dwarf. Ninety-six patients had a single structural curve of which 75 were thoracic, 15 thoracolumbar and six lumbar. There were 14 patients with double structural curves of which six were double thoracic, and eight had combined thoracic and lumbar curves.

Harrington instrumentation was used to correct the curves in 92 patients and a Risser localiser jacket was used in 18 patients. There were two methods of spinal fusion. The interfacetal technique of fusion described by Moe (1958) was used in all patients but in 86 there was an additional total decortication of the posterior spinal structures followed by an onlay of matchstick grafts of autogenous bone from the iliac crest.

METHODS

Six months after the attempted fusion the patients were admitted to hospital and their plaster jackets removed. A bone scan of the spine was performed and two days later the fusion was explored surgically.

Scintigraphic assessment. An intravenous bolus of 150 microcuries per kilogram of technetium-labelled methylene diphosphonate was given three hours before scanning with either an Ohio Nuclear Sigma 100 scanning gamma camera or a Clear multidetector scanner (Subramanian *et al.* 1973).

Surgical exploration. The technique of exploration and classification of pseudarthroses into definite, hairline and doubtful has been described by McMaster and James (1976). A definite pseudarthrosis is the most common type and presents as an irregular crevice filled with fibrous tissue (see Figs 8 and 19). The hairline pseudarthrosis is much less common and appears as a fine white fibrocartilaginous crack in an apparently solid fusion and is easily overlooked (see Fig. 12). A doubtful pseudarthrosis is an area in which the periosteum is more

adherent than in adjacent areas and the cortical bone appears soft. If this bone is curetted away a defective area in the cancellous bone is exposed. All three types of pseudarthrosis may extend completely across the fusion mass (bilateral pseudarthrosis) or only part of the way on either side of the curve (unilateral pseudarthrosis) with a solid bar of bone on the other side.

RESULTS

Operative findings

At exploration 103 patients were diagnosed as having a solid fusion and seven had pseudarthroses. Two patients thought to have a solid fusion later developed increasing deformity and required a further exploration 15 and 28 months after the attempted fusion: a single bilateral pseudarthrosis was discovered at the thoracolumbar junction of each patient which on histological examination was shown to be surrounded by reparative new bone formation. There was therefore a total of nine patients with pseudarthroses. The aetiology of these curves and the types and sites of the pseudarthroses are shown in Table I.

Scintigraphic findings at six months

The scintigraphic findings in the 110 spines six months after the attempted fusion could be separated into two groups (Table II): those with a uniform uptake of isotope and the remainder with a more patchy uptake over the fused area.

Fig. 1

Fig. 2

Figure 1—Scintigram six months after fusion in a 14-year-old patient with an adolescent idiopathic thoracic scoliosis. There is a uniform uptake of isotope in the fused area. Figure 2—The solid fusion found at the six-month exploration.

Uniform uptake of isotope. Seventy-one patients (65 per cent) had a uniform uptake of isotope in the area of the fused spine and all but one had a solid fusion. A typical example of this type of scintigram and the solid fusion found at exploration are shown in Figures 1 and 2. This spine was fused using the Moe interfacetal technique followed by a total decortication of the posterior spinal

hooks were found to be firmly embedded in bone. In 19 per cent of the spines there was a slightly greater uptake of isotope on the convexity of the curve as compared to the concavity. At exploration no difference could be detected in the quality of the fusion on either side of the spine.

The one patient (Case 1) in this group who had an

Table I. Operative and scintigraphic findings in nine patients with pseudarthroses

Aetiology of scoliosis	Cases	Pseudarthrosis		Bone scan diagnosis	
		Site	Type	At 6 months	After 1 year
Idiopathic adolescent	1	T9 -10 T10-11	Definite unilateral Definite bilateral	- -	
Juvenile	2	T11-12	Definite bilateral	-	++
	3	T12-L1	Hairline bilateral	-	++
Congenital	4	T12-L1	Hairline unilateral	+	
	5	L4 -5	Definite bilateral	+	
	6	T12-L1 L1 -2	Definite bilateral Definite bilateral	+	
	7	L3 -4	Definite bilateral	+	
Neurofibromatosis	8	L4 -5	Definite bilateral	+	
		L5 -S1	Definite bilateral	+	
Metatropic dwarf	9	T12-L1	Definite bilateral	+	
		L1 -2	Definite bilateral	+	

structures and an onlay of bone grafts. The fusion mass is seen to be smooth and uniform and the corresponding scintigram has a uniform uptake of isotope over the fused area. There was usually no difficulty in distinguishing these uniform scans from those with a more patchy

unsound fusion had a generally high level of radioactivity over the whole of the fused area without any localising features to indicate the site of the lesion.

Patchy areas of increased uptake. The second group of patients were those with patchy areas of increased uptake of isotope over the fused area. The 39 patients in this group accounted for 36 per cent of the total number of patients and all but one of the nine patients with pseudarthroses were in this group. These bone scans could be separated into two subgroups: those scans with generalised patchy areas of increased uptake and those with a more localised area. This distinction was not, however, always absolutely clearcut.

Generalised patchy areas. There were 27 patients in this subgroup accounting for 24 per cent of the total number of patients, and all but two had solid fusions. The pseudarthroses in these two patients were not diagnosed at exploration and were only detected when the curves began to deteriorate and required a second exploration. These patients (Cases 2 and 3) are presented in detail later.

In many of the patients with solid fusions the generalised patchy areas of increased uptake had a fairly regular pattern which occurred bilaterally in the region of the interfacetal joints at nearly every intervertebral

Table II. Scintigraphic findings at six months (110 patients)

Uptake of ^{99m}Tc -MDP in the fusion	Fusion technique		Total	Patients with pseudarthroses
	Interfacetal fusion alone	Interfacetal fusion with onlay grafts		
Uniform	8	63	71	1
Patchy				
Generalised	14	13	27	2
Localised	2	10	12	6

uptake over the fused area, but there were some minor variations. Often the outline of the Harrington rod could be seen superimposed over the fused area where the rod obscured the radiation given off by the underlying spine. In some scans there was a small area of increased uptake around the Harrington hooks but at exploration these

level (Figs 3 and 4). This pattern of bone scan was seen much more frequently in the spines that had been fused using only the interfacetal technique (54 per cent), than in those in which there had been an additional total decortication and onlay grafting (15 per cent).

Localised patchy area. Twelve patients had bone scans which showed either a single area of increased uptake or

a patchy area of increased uptake localised to one specific area of the fusion. These patients account for 11 per cent of the total number of patients and six of the nine patients with pseudarthroses were in this group (Cases 4 to 9). In all, the site of the localised area of increased uptake (see Figs 14, 16 and 18) corresponded to the site of the pseudarthrosis found at exploration.

Fig. 3

Fig. 4

Figure 3—Radiograph of a solid fusion in a patient aged 10 years 7 months with an infantile idiopathic scoliosis. Figure 4—Scintigram six months after fusion showing multiple patchy areas of increased uptake in the fused area.

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Case 2. Figure 5—Scintigram six months after fusion from T6 to L4 appearing uniform except for a few patchy areas of increased uptake on the convexity of the curve. Figure 6—Radiograph 15 months after fusion when the curve had increased 14 degrees due to a pseudarthrosis between T11 and T12 (arrowed). Figure 7—Scintigram at 15 months showing a very clearly demarcated area of increased uptake at this site. Figure 8—At exploration a bilateral definite pseudarthrosis was discovered.

Apart from the six patients with pseudarthroses in this group there were six other patients with localised patchy areas of increased uptake who did not have a pseudarthrosis. These patients were found to have a solid fusion with no macroscopic bony abnormality at the site of increased uptake.

Scintigraphic findings after one year

Spinal scintigrams were routinely performed on all patients six months after the attempted fusion, but a second bone scan was required for the two patients whose spines later began to deteriorate. In Case 2 the six-month bone scan showed a generally uniform scan with only a few patchy areas of increased uptake on the convexity of the curve (Fig. 5), but the scan performed after 15 months showed a very clearly demarcated area of increased uptake (Fig. 7) precisely localised to the site of the pseudarthrosis (Figs 6 and 8). In Case 3 the six-month bone scan showed generalised patchy areas of increased uptake (Fig. 9) whereas in the scan performed after 28 months the patchy areas had disappeared and the site of the pseudarthrosis (Figs 10 and 12) was now clearly shown as a single localised area of increased uptake (Fig. 11).

CASE REPORTS OF PATIENTS WITH PSEUDARTHROSES

Case 2. A girl with a juvenile idiopathic right thoracolumbar scoliosis which was diagnosed at the age of five years four months. At the age of 10 when the curve measured 17 degrees a Milwaukee brace was applied but the child resisted wearing it and by the age of 13 years 9 months the curve had deteriorated to 24 degrees. The curve was

reduced to 12 degrees in a localiser jacket and a posterior spinal fusion from T6 to L4 was then performed. Six months later the curve had deteriorated to 26 degrees but exploration revealed an apparently solid fusion. Scintigraphic assessment at this time showed patchy areas of increased uptake on the convexity of the curve (Fig. 5).

The patient was then placed in an underarm plaster for a further six months, after which there was a gradual loss of correction until at 15 months after the attempted fusion the curve measured 40 degrees. Radiographs showed increased wedging at the disc space between T11 and T12 (Fig. 6) and a scintigram showed a very marked increased uptake of isotope at the same site (Fig. 7). A second exploration revealed a bilateral definite pseudarthrosis (Fig. 8).

Case 3. A boy with a juvenile idiopathic right thoracolumbar scoliosis which was diagnosed at the age of five years eight months. A Milwaukee brace was applied at the age of six years seven months, when the curve measured 30 degrees, and worn until the age of ten years five months. The curve was corrected from 40 to 25 degrees in a localiser cast and a posterior spinal fusion was performed from T5 to L3. Six months later there was a seven-degree loss in correction but exploration revealed an apparently solid fusion. The scintigram showed generalised patchy areas of increased uptake (Fig. 9).

The patient was then placed in a Milwaukee brace for a further six months after which there was a gradual loss of correction until at 28 months the curve measured 52 degrees (Fig. 10). The spinal scintigram now showed a single area of greatly increased uptake at the level between T12 and L1 (Fig. 11). A second exploration revealed a bilateral hairline pseudarthrosis (Fig. 12).

Case 5. A girl with a congenital right thoracolumbar scoliosis which was diagnosed at the age of four months. The curve, extending from T6 to L5 and measuring 41 degrees, was due to a hemivertebra at L2. By the age of two years it had increased to 60 degrees and the child was placed in a Milwaukee brace until the age of nine years seven months when the curve measured 62 degrees. A posterior spinal fusion from T4 to S1 was performed with Harrington instrumentation correcting the curve to 40 degrees. This was a difficult fusion because of the abnormal and hypoplastic interfacetal joints on the concavity in the

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Case 3. Figure 9—Scintigram six months after fusion from T5 to L3 showing a few patchy areas of increased uptake of isotope over the fused area. Figure 10—Radiograph at 28 months when the curve had lost 27 degrees due to a pseudarthrosis between T12 and L1 (arrowed). Figure 11—Scintigram at 28 months showing a localised area of increased uptake at this site. Figure 12—At exploration a bilateral hairline pseudarthrosis was discovered.

Fig. 13

Fig. 14

Case 5. Figure 13—Radiograph six months after fusion from T4 to S1. A definite bilateral pseudarthrosis (arrowed) was found between L4 and L5 despite the radiological appearance of a solid bar of bone on the concavity. Figure 14—Scintigram showing bilateral localised areas of increased uptake at the site of the pseudarthrosis. The large laminar defect in the lumbar region is shown as a central area of diminished uptake.

Fig. 15

Fig. 16

Case 6. Figure 15—Radiograph six months after fusion from T7 to L4, showing two bilateral definite pseudarthroses (arrowed). Figure 16—Scintigram showing the two areas of increased uptake.

lumbar region. Six months later there was no loss in correction and the radiograph showed a solid bar of bone on the concavity (Fig. 13). The scintigram, however, showed an area of increased uptake (Fig. 14) and at exploration a single definite pseudarthrosis was found extending across the fusion mass between L4 and L5.

Case 6. A boy who was noted at birth to have a congenital scoliosis due to hemivertebrae at T12 and L1 and a congenital coxa vara with an associated short bowed left femur. At the age of three years he was fitted with a Milwaukee brace which he wore until the age of 11 years 6 months when the scoliosis measured 42 degrees. The spinal curvature was then corrected in a localiser cast and a fusion performed from T7 to L4. After the operation the scoliosis measured 18 degrees. Six months later it had deteriorated to 29 degrees (Fig. 15). The scintigram showed two areas of increased uptake of isotope, separated by colder areas (Fig. 16) and at exploration two definite bilateral pseudarthroses at adjacent levels at the apex of the curve were found.

Case 7. A girl with a congenital left thoracolumbar scoliosis which was diagnosed at the age of seven years five months. Her curve extended from the T9 to L3, measured 34 degrees and was due to a bony bar on the concavity at the apex of the curve. Treatment was immediately started in a Milwaukee brace which she wore until the age of nine years eight months when the curve had increased to 48 degrees. A posterior spinal fusion from T9 to L4 was performed with Harrington instrumentation correcting the curve to 42 degrees. Fusion was difficult because of the presence of a large laminar defect at the apex of the curve and hypoplasia of the interfacetal joints. Six months later there was a three-degree loss of correction (Fig. 17). The scintigram showed diminished uptake round the lower hook and just above this were two areas of increased uptake extending across the fusion mass at adjacent levels separated by a cold area (Fig. 18). Exploration revealed a single bilateral pseudarthrosis at the site of the cold area (Fig. 19).

DISCUSSION

Ideally the spinal scintigram should be capable of detecting a pseudarthrosis before it becomes visible radiographically. This would allow early repair before all external support had been removed, and so prevent subsequent loss in correction and prolonged treatment in plaster.

In this study the scintigrams were performed routinely six months after the attempted fusion. The majority of patients (65 per cent) had a uniform uptake of isotope over the fused area, and all but one of these had a solid fusion. The one patient with a pseudarthrosis had a high level of radioactivity over the whole of the fused area, without any localising features at the site of the defect. It is possible that this generalised increased uptake, due to continuing widespread new bone formation in a relatively immature arthrodesis, obscured any local increase due to the presence of the pseudarthrosis.

Another group of patients (24 per cent) had multiple patchy areas of increased uptake and all but two were found to have a solid fusion. In many of these spines the multiple patchy areas had a fairly regular pattern which occurred bilaterally at nearly every intervertebral level in the region of the interfacetal joints. The probable explanation for these areas of increased uptake is the greater rate of new bone formation at the sites of the healing interfacetal fusions in contrast to the surrounding relatively unreactive

Fig. 17

Fig. 18

Fig. 19

Case 7. Figure 17—Radiograph six months after fusion from T9 to L4 showing a single bilateral pseudarthrosis (arrowed) between L3 and L4. Figure 18—Scintigram showing the lower Harrington hook as an area of diminished uptake and just above this two areas of increased uptake extending across the fusion at adjacent levels separated by a cooler area. Figure 19—The single definite bilateral pseudarthrosis at the site of the cooler area.

bone. This conclusion is supported by the 54 per cent incidence of this type of scan in those spines fused using only an interfacetal fusion technique as compared to the 15 per cent incidence in those spines with an additional total decortication and onlay of autogenous bone grafts. After the latter technique there is widespread new bone formation, over all the posterior spinal structures, and this produces a more uniform scan which is more easily interpreted. Unfortunately, the multiple patchy areas of increased uptake make it impossible to exclude the presence of a pseudarthrosis.

A smaller number of patients (11 per cent) had either a single area of increased uptake or a localised patchy area of increased uptake on an otherwise uniform scan. A pseudarthrosis was found at the site of the abnormality seen on the bone scan in half of these patients. There were, however, six patients with solid fusions who also had a localised abnormality on the bone scan for which there was no obvious explanation. The presence of a localised area of increased uptake on the six-month bone scan is therefore highly suggestive of a pseudarthrosis but does not provide conclusive evidence.

Two patients had a second bone scan performed 15 and 28 months after the fusion attempt. Both scans showed a single area of clearly localised increased uptake in a fused area which otherwise showed very little generalised uptake. At re-exploration both spines were found to have a single pseudarthrosis, which had previously been missed, precisely localised to the sites of increased uptake seen on the second bone scans. Histological examination of the excised pseudarthroses

showed them to be surrounded by reparative new bone. Review of the routine six-month scans of these patients showed both to have patchy areas of increased uptake over the fused area without any localising features.

Of all the bone scans performed on the patients with pseudarthroses, the most precise information regarding the site of the pseudarthrosis was obtained from those scans performed after one year. In our opinion there are two reasons for this. First, in many patients, six months after fusion there is still a very high level of new bone formation throughout the fused area and only when this activity diminishes does the localised osteoblastic response attempting to heal the pseudarthrosis become visible on the bone scan. Secondly, there is increased movement at the site of the pseudarthrosis once all external support is removed, especially if there is no internal fixation. This movement may stimulate further new bone formation not unlike the hypertrophic callus which occurs at an unstable pseudarthrosis of a long bone. Harrington instrumentation was not used in either of the two patients whose pseudarthroses were diagnosed late and there was obvious movement and new bone formation at the site of the defects. If, however, one waits too long the localised osteoblastic response at the site of the pseudarthrosis will eventually subside. In Hannon and Wetta's (1977) series the scans were performed at an average of three years nine months after the fusion attempt, at a stage when the pseudarthroses were well established and presumably quiescent. It is therefore not surprising that the majority of their patients had negative scans.

This study has shown that a pseudarthrosis in a

scoliotic spine can be detected as a localised area of increased uptake on a bone scan using technetium-labelled methylene diphosphonate performed six months after an attempted fusion. Unfortunately there are also a number of false positives and scans that are difficult to interpret due to continuing generalised increased new bone formation in immature fusions.

Pseudarthroses are more clearly seen in scans performed after one year when the fusion mass has become more mature. The spinal scintigram should therefore be performed at a stage when the generalised activity in the fused area has diminished but not so late as to allow the pseudarthrosis to become quiescent. This unfortunately does not always allow an early diagnosis.

We are grateful to Mr Graham Ainslie of the Photographic Department, Princess Margaret Rose Orthopaedic Hospital, for the photographic work.

REFERENCES

- Bauer GCH, Wendeborg B. External counting of Ca^{47} and Sr^{85} in studies of localised skeletal lesions in man. *J Bone Joint Surg [Br]* 1959;**41-B**:558-80.
- Castronovo FP Jr, Callahan RJ. New bone scanning agent: $^{99\text{m}}\text{Tc}$ -labeled 1-hydroxy-ethylidene-1, 1-disodium phosphonate. *J Nucl Med* 1972;**13**:823-7.
- DeNardo GL, Volpe JA. Detection of bone lesions with the strontium-85 scintiscan. *J Nucl Med* 1966;**7**:219-36.
- Galasko CSB. Skeletal metastases and mammary cancer. *Ann R Coll Surg Eng* 1972;**50**:3-28.
- Galasko CSB. The pathological basis for skeletal scintigraphy. *J Bone Joint Surg [Br]* 1975;**57-B**:353-9.
- Hannon KM, Wetta WJ. Failure of technetium bone scanning to detect pseudarthroses in spinal fusion for scoliosis. *Clin Orthop* 1977;**123**:42-4.
- Hughes S, Jeyasingh K, Lavender JP. Phosphate compounds in bone scanning. *J Bone Joint Surg [Br]* 1975;**57-B**:214-6.
- Hughes S, Khan R, Davies R, Lavender P. The uptake by the canine tibia of the bone-scanning agent $^{99\text{m}}\text{Tc}$ -MDP before and after an osteotomy. *J Bone Joint Surg [Br]* 1978;**60-B**:579-82.
- James JIP. Correction and fusion for scoliosis. *J Bone Joint Surg [Br]* 1965;**47-B**:587-8.
- Jung A, Bisaz S, Fleisch H. The binding of pyrophosphate and two diphosphonates by hydroxapatite crystals. *Calcif Tissue Res* 1973;**11**:269-80.
- Kemp HBS, Johns DL, McAlister J, Godlee JN. The role of fluorine-18 and strontium-87m scintigraphy in the management of infective spondylitis. *J Bone Joint Surg [Br]* 1973;**55-B**:301-11.
- McMaster MJ, James JIP. Pseudarthrosis after spinal fusion. *J Bone Joint Surg [Br]* 1976;**58-B**:305-12.
- McNeur JC. Observation on radioactive phosphorus uptake in high fractures of the femoral neck. *J Bone Joint Surg [Br]* 1970;**52-B**:393.
- Moe JH. A critical analysis of methods of fusion for scoliosis. *J Bone Joint Surg [Am]* 1958;**40-A**:529-54.
- Sklaroff DM, Charkes ND. Bone metastases from breast cancer at the time of radical mastectomy. *Surg Gynecol Obstet* 1968;**127**:763-8.
- Subramanian G, McAfee JG. A new complex of $^{99\text{m}}\text{Tc}$ for skeletal imaging. *Radiology* 1971;**99**:192-6.
- Subramanian G, McAfee JG, Blair RJ, Mehter A, Connor T. $^{99\text{m}}\text{Tc}$ -EHDP: a potential radiopharmaceutical for skeletal imaging. *J Nucl Med* 1972;**13**:947-50.
- Subramanian G, Blair RJ, Kallfelz EA, Thomas FD, McAfee JG. $^{99\text{m}}\text{Tc}$ -MDP (methylene diphosphonate): a superior agent for skeletal imaging. *J Nucl Med* 1973;**14**:640.
- Subramanian G, McAfee JG, Blair RJ, Rosenstreich M, Coco M, Duxbury CE. Technetium-99m-labeled stannous imidodiphosphate, a new radiodiagnostic agent for bone scanning: comparison with other $^{99\text{m}}\text{Tc}$ complexes. *J Nucl Med* 1975;**16**:1137-43.
- Wendeborg B. Mineral metabolism of fractures of the tibia in man studied with external counting of Sr^{85} . *Acta Orthop Scand* 1961;Suppl **52**:1-79.
- Yano Y, McRae J, Van Dyke DC, Anger HO. Technetium-99m-labeled stannous ethane-1-hydroxy-1,1 diphosphonate: a new bone scanning agent. *J Nucl Med* 1973;**14**:73-8.