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DEVELOPMENT OF OSTEOPENIA IN THE FOURTH LUMBAR VERTEBRA DURING PROLONGED BED REST AFTER OPERATION FOR SCOLIOSIS

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Photon absorptiometry has proved to be a very accurate method for the determination of bone content (Cameron & Sorensen 1963). The wasting of skeletal mass during prolonged bed rest has so far been investigated in metabolic studies and by photon absorptiometry of peripheral skeletal parts such as calcaneus and the distal forearm (Deitrick et al. 1948, Rose 1966, Goldsmith et al. 1969, Donaldson et al. 1970, Vogel & Friedman 1970, Hulley et al. 1971, Hantman et al. 1973). These studies have been carried out on males. Females whose "physiological" loss of bone begins at an earlier age and proceeds at a more rapid rate are probably more susceptible to immobilization in bed, partly because their ability to regain lost bone is more doubtful (Harris & Heaney 1969, Nilsson & Westlin 1975).

The aim of this study was to follow the effect of prolonged bed rest on the bone mineral content of the fourth lumbar vertebra in a group of young females strictly immobilized in bed after operations for scoliosis.

MATERIAL

Thirteen females, 13–18 years old, all with idiopathic scoliotic deformities of the spine were studied. Subjects with any other disease which could interfere with bone metabolism were excluded. Preoperatively all had normal values for Ca/serum, P/serum, Ca/urine and P/urine. All were operated upon with correction, according to the method of Harrington, and posterior spinal fusion. Only patients with fusions above the fourth lumbar vertebra were included (Tables 1 and 2).

Seven of the patients, group A, were operated upon in two stages with an interval of fourteen days. At the first operation the Harrington rod was inserted on the concave side and the curvature corrected. At the second operation further correction and fusion were performed (Nordwall 1973). Six patients, group B, were

Table 1. Data and results. Group A patients.

Patient	Age (years)	Brace before operation (months)	Rod span and fusion length	Iliac apophysis (0–5)	Immobil. in bed (weeks)	Initial bone content of L_4	Bone content after immobil. L_4	Bone content change (%)	Weekly change of bone content (%)
MK	15	15	Th4–L2	5	6.0	11.54	10.05	−12.88	−2.15
AR	13	0	Th5–L1	4	5.6	11.76	8.60	−25.84	−4.82
IJ	16	0	Th6–L2	5	5.9	11.36	10.04	−11.67	−1.99
MS	16	0	Th2–Th11	5	5.6	9.09	8.09	−11.05	−1.98
MH	16	0	Th4–L2	5	6.6	12.56	11.23	−10.60	−1.61
BA	16	24	Th6–L3	5	6.3	8.41	7.63	− 9.24	−1.47
ML	15	0	Th6–L2	5	5.4	12.30	9.29	−24.76	−4.57

Table 2. Data and results. Group B patients.

Patient	Age (years)	Brace before operation (months)	Rod span and fusion length	Iliac apophysis (0–5)	Immobil. in bed (weeks)	Initial bone content of L_4	Bone content after immobil. L_4	Bone content change (%)	Weekly change of bone content (%)
AH	17	36	Th6–L2	5	3.4	12.26	11.45	−7.3	−2.17
AK	16	0	Th5–L1	5	4.3	11.62	11.47	−1.3	−0.28
BL	15	0	Th5–L1	4	3.0	9.72	9.34	−4.0	−1.33
LO	14	0	Th6–L1	0–1	3.3	8.82	8.16	−7.5	−2.24
HF	18	60	Th5–L2	5	4.0	10.61	9.84	−7.2	−1.62
LE	17	37	Th6–L1	5	3.1	9.63	10.01	+4.0	+1.26

operated upon in the same way, but with correction and fusion performed during the same operation.

After the operation(s) the patients were strictly immobilized in bed, in recumbency, usually supine. In both groups during the first five days, movements of the trunk in bed were permitted only with the full assistance of the nursing staff. Later on, the patients were permitted, after instruction, to roll themselves to either side. No external support was used until the patients were allowed to get out of bed, two (group B) to four (group A) weeks following the first or second operation, respectively.

The detailed postoperative mobilization program has been described earlier and is aimed to avoid as much as possible any strain on the back (Nachemson & Elfström 1973).

METHODS

Dual photon absorptiometry involves the use of two radionuclides, which emit gamma radiation with different energies (^{241}Am with 59.6 keV and ^{137}Cs with 662 keV). The radiation sources are so arranged that their gamma radiation passes through the object to be measured in a common collimated radiation beam (Figure 1). The transmitted gamma radiation is registered digitally with a scintillation detector—*both energies* simultaneously. The patient lies on a couch, which is moved in the transversal direction, and an electronic control unit enables intermittent scanning in steps of 4 mm. Transmission measurements are performed during preselected time intervals between the steps.

Both photon energies are exponentially attenuated by the object, the higher energy mainly by the Compton effect, the lower by both the Compton and photoelectric effects. In materials with higher atomic number than soft tissue, e.g. bone mineral, the photoelectric effect will dominate in the attenuation of the lower energy. This means that the lower energy will be relatively more attenuated than the higher when it passes a region containing bone. Application of the law of exponential attenuation to the case of the two energies will then give the bone mineral content in the units $g\,cm^{-2}$, denoted m_B. The amount of lean soft tissue can be eliminated mathematically. The existence of adipose tissue in the path of the beam will, however, introduce an error. The common scanning technique (Cameron & Sorensen 1963), and our method too, partly eliminate this error by measuring along a transverse path across the bone, continuously or intermittently. Plotting m_B versus the position x gives a so-called bone profile curve (Figure 2). Points outside the bone, on both sides, are selected to form end-points of a baseline above which the bone profile curve is integrated, yielding the bone mineral content in the units $g\,cm^{-1}$. This procedure gives a true correction if the adipose tissue is constant or varying linearly along the measurement path.

This is not quite true in our case, because the vertebra contains relatively large amounts of fatlike tissue. It is not possible to correct for this with the present method, but it is assumed that the error is constant when measuring the same vertebra in the same patient several times. The reproducibility should thus be unaffected by this source of error. A more detailed description of the theory and experimental technique has been presented elsewhere (Roos & Sköldborn 1974).

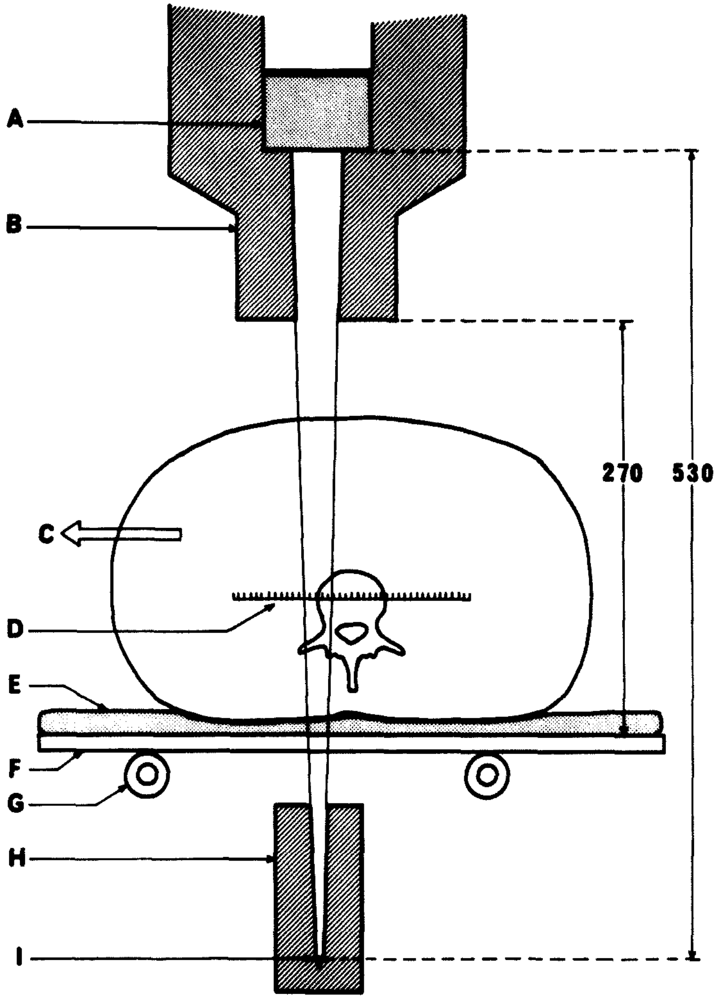

Figure 1. Diagram showing measurement procedure. A = scintillation crystal, B = lead collimator for the detector, C = patient's direction of movement, D = scale for demonstrating the successive measuring positions, E = polythene mattress, F = couch, G = ball bearing, H = container for the sources with collimation of emitted radiation beam, I = radiation sources. Distances are stated in mm.

Precision

The main cause of variation is the random nature of radioactive decay— the number of counts will vary according to the Poisson distribution. This variation will normally cause a coefficient of variation of about 3 per cent in the measurement result. Other variations may be attributed to the particular subject. They include all factors which cannot be reproduced exactly from one measurement to another,

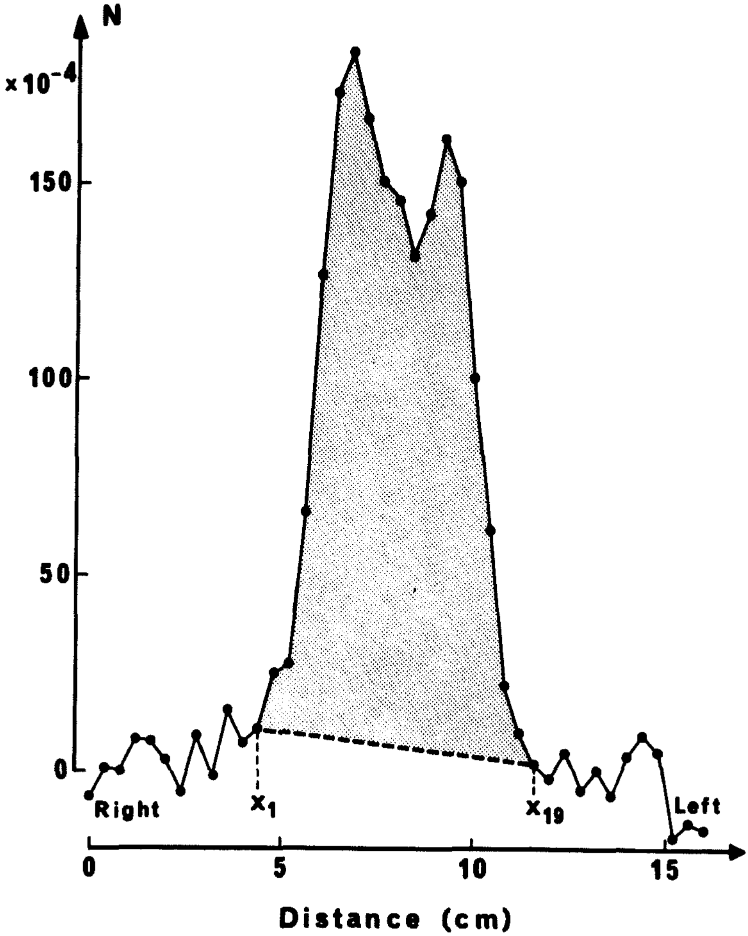

Figure 2. Bone profile curve showing bone content (N) as a function of measuring position for a normal subject. N is proportional to m_B.

e.g. adjustment variations or movements of the subject during the measurement. The combined error, the reproducibility, has been experimentally estimated by measuring four normal subjects ten times each and calculating the standard deviation of the results for each individual. The coefficient of variation varied in the range from 3.4 per cent to 5.7 per cent. The reproducibility of the method is thus considered to be better than 6 per cent (Roos & Sköldborn 1974).

Method of patient measurement

The patient lies in the supine position on the couch with flexed knees and hips. A special cushion placed under the knees provides the stability and the same angle

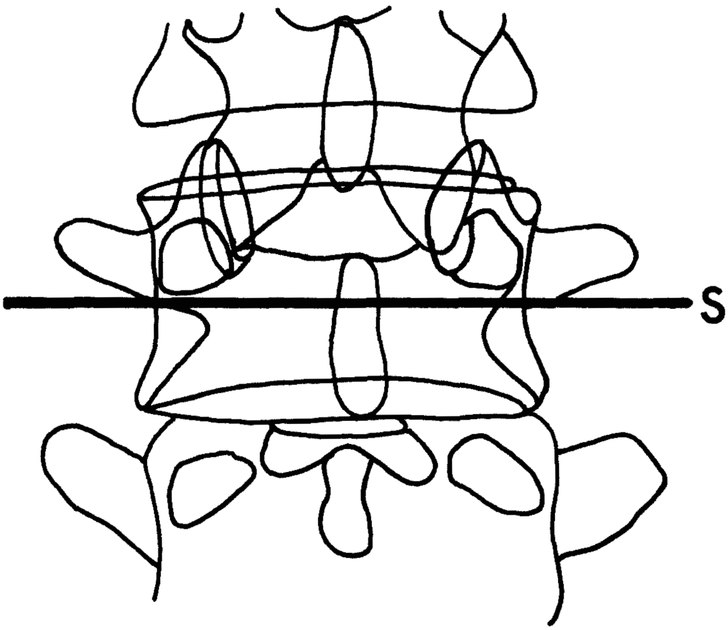

Figure 3. Posterior view of L_3 with the scanning path, S.

in the lumbar spine from one scanning to another. The fourth lumbar vertebra (the fourth free vertebra without any rib counted from cranial to caudal in the lumbar spine) is localized with an X-ray tube and image intensifier attached to the detector stand. The centre of the scanning track is placed at about 5 mm from the most cranial point of the projection of the spinous process of the vertebra (Figure 3).

FINDINGS

In group A (Table 1) all patients had had their menarche more than half a year prior to operation. All were near completion of bone maturity according to the iliac apophysis sign (Risser 1948) and their mean skeletal age (according to Gruelich & Pyle) was 15.5 years.

In group B (Table 2) all except LO had started to menstruate more half a year prior to operation. Mean skeletal age in this group was 16 years. LO was the only one who had more than 2 years left before reaching skeletal maturity.

In group A the weekly rate of bone mineral loss varied between 4.82 and 1.47 per cent. Mean monthly loss was 10.7 per cent in this group. In group B the weekly loss varied from 2.24 to 0.28 per cent. LE was an exception, showing a gain of bone content. This can reflect the error in reproducibility or, less probably, be a quite unexpected reaction to immobilization. Monthly loss in group B was 6.12 per cent with LE excluded and 4.24 per cent with LE included.

DISCUSSION

Prolonged bed rest as well as other kinds of immobilization result in disuse osteopenia. The absence of mechanical stresses upon the skeleton produces among other things a negative calcium and phosphorus balance and a decline in bone density, primarily because of an exaggerated bone resorption (Heaney 1962, Harris & Heaney 1969).

It is well known that osteoclasts, when resorbing bone, operate from a free surface. Consequently, cancellous bone with its high surface-to-bone volume ratio is lost faster with ageing and disease than cortical bone (Frost 1966). It also appears that the atrophy of the skeleton begins and is always more marked in the vertebrae than in the extremities (Frost 1966).

Metabolic studies have revealed a monthly loss of about 0.5 per cent of total body calcium during prolonged bed rest (Deitrick et al. 1948, Donaldson et al. 1970, Goldsmith et al. 1969, Hantman et al. 1973, Hulley et al. 1971, Issekutz et al. 1966). Immobilization in bed after spinal fusion, although not studied in a strict metabolic way, produced just about the same urinary losses of calcium (Millard et al. 1970). Photon absorptiometry has shown a loss of bone content in calcaneus at a much higher rate than in the distal forearm and even at a tenfold higher rate than compared to the total losses of body calcium (Hantman et al. 1973, Hulley et al. 1971, Vogel & Friedman 1970, and others).

The young women in this study showed a wide individual variation in bone content of the fourth lumbar vertebra already at the first scanning, irrespective of whether they had used Milwaukee braces before operation or not. As pointed out by others the great biological variation makes longitudinal studies of changes in bone content more valuable than cross-sectional studies (Dalén 1973).

The wide range of bone loss from the fourth lumbar vertebra suggests a rather individual susceptibility to immobilization. The highest rate of bone loss, in patient AR about 4.8 per cent weekly, was at an almost fourfold higher rate than previously seen in the calcaneus.

This study shows that, at least in this group of patients, during bed rest the loss of bone content in the lumbar spine is more extensive than in other investigated bones. However, it should be taken into account that the patients in this study were also subjected to a major surgical procedure involving bone tissue.

It has previously been demonstrated that after fracture the loss of bone mineral content is not confined to the injured bone only but also occurs in adjacent bones (Bauer & Carlsson 1955). Even if the lowest point of the fusion in twelve of the patients was two or more vertebrae above L_4 some part of the total bone loss might be of a post-traumatic type.

Children restitute their bone losses, at least after disuse osteopenia caused by immobilization after fractures (Nilsson & Westlin 1971). Young males and grown-up men restitute, at least to some extent, their bone losses, with known exceptions (Hantman et al. 1973, Hulley et al. 1971, Nilsson 1966). Women with immobilization after Colles' fracture show a tendency to normalize their bone density at about two years after the fracture episode (Nilsson & Westlin 1975).

Preliminary results from a parallel study of women with pathological osteoporosis reveal that at least four of the young women in this study have a bone content after immobilization in bed lower than that of some of the women with collapsed vertebrae.

Future measurements of the patients in the present study will reveal if the restitution of their vertebral mineral loss follows the pattern earlier seen in men and in other bones.

SUMMARY

The fourth lumbar vertebra was studied with dual photon absorptiometry in a group of young women immobilized in bed for 21 to 46 days after operation for scoliosis. Twelve out of 13 showed loss of bone content. The monthly loss in most patients highly exceeded earlier reported losses from other bones and significantly exceeded the methodological error.

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REFERENCES

Bauer, G. C. H. & Carlsson, A. (1955) Postfracture bone salt resorption studies in rats. *Acta orthop. scand.* **25**, 83.

Cameron, J. R. & Sorensen, J. (1963) Measurements of bone mineral in vivo. *Science* **142**, 230–232.

Dalén, N. (1973) *Bone mineral assay. Measuring sites; Clinical applications.* Thesis, Dept. of Medical Engineering, Karolinska Institutet, Stockholm.

Deitrick, J. E., Whedon, G. D. & Shorr, E. (1948) Effects of immobilization upon various metabolic and physiologic functions of normal men. *Amer. J. Med.* **4**, 3–36.

Donaldson, C. L., Hulley, S. B., Vogel, J. M., Hattner, R. S., Bayers, J. N. & McMillan, D. E. (1970) Effects of prolonged bed rest on bone mineral. *Metabolism* **19**, 1071–1084.

Frost, H. M. (1966) Bone dynamics in metabolic bone disease. *J. Bone Jt Surg.* **48**-A, 1192–1203.

Goldsmith, R. S., Killian, P., Ingbar, S. H. & Bass, D. E. (1969) Effects of phosphate supplementation during immobilization of normal men. *Metabolism* **18**, 349–368.

Hantman, D. A., Vogel, J. M., Donaldson, C. L., Friedman, R. J., Goldsmith, R. S. & Hulley, S. B. (1973) Attempts to prevent disuse osteoporosis by treatment with calcitonin, longitudinal compresison and supplementary calcium and phosphate. *J. clin. Endocr.* **36**, 845–858.

Harris, W. H. & Heaney, R. P. (1969) Skeletal renewal and metabolic bone disease. *New Engl. J. Med.* **280**, 193–259.

Heaney, R. P. (1962) Radiocalcium metabolism in disuse osteoporosis in man. *Amer. J. Med.* **33**, 188–200.

Hulley, S. B., Vogel, J. M., Donaldson, C. L., Bayers, J. H., Friedman, R. J. & Rosen, S. N. (1971) The effect of supplemental oral phosphate on the bone mineral changes during prolonged bed rests. *J. clin. Invest.* **50**, 2506–2518.

Issekutz, B. J., Blizzard, J. J., Birkhead, N. C. & Rodahl, K. (1966) Effect of prolonged bed rest on urinary calcium output. *J. appl. Physiol.* **21**, 1013–1020.

Millard, F. J. C., Nassim, J. R. & Woolen, J. W. (1970) Urinary calcium excretion after immobilization and spinal fusion in adolescents. *Arch. Dis. Childh.* **45**, 399–403.

Nachemson, A. & Elfström, G. (1973) Telemetry recordings of forces in the Harrington distraction rod. *Clin. Orthop.* **93**, 158–172.

Nilsson, B. E. R. (1966) Posttraumatic osteopenia: A quantitative study of the bone mineral mass in the femur following fracture of the tibia in man using Americium-241 as a photon source. *Acta orthop. scand.*, Suppl. 91.

Nilsson, B. E. & Westlin, N. E. (1975) Long term observations on the loss of bone mineral following Colles' fracture. *Acta orthop. scand.* **46**, 61–66.

Nilsson, B. E. & Westlin, N. E. (1971) Restoration of bone mass after fracture of the lower limb in children. *Acta orthop. scand.* **42**, 78–81.

Nordwall, A. (1973) Studies in idiopathic scoliosis relevant to etiology, conservative and operative treatment. *Acta orthop. scand.*, Suppl. 150.

Risser, J. C. (1948) Important practical facts in the treatment of scoliosis. *American Academy of Orthopaedic Surgeons' Instructional Course Lectures* **5**, 248.

Roos, B., Rosengren, B. & Sköldborn, H. (1970) Determination of bone mineral content in lumbar vertebrae by a double gamma-ray technique. *Proceedings of*

Bone Measurement Conference, AEC CONF 700515, p. 243, Atomic Energy Commision, Chicago.

Roos, B. & Sköldborn, H. (1974) Dual photon absorptiometry in lumbar vertebrae. I. Theory and method. Accepted for publication in *Acta radiol. Ther. Phys. Biol.*

Rose, G. A. (1966) Immobilization osteoporosis. A study of the extent, severity and treatment with bendrofluazide. *Brit. J. Surg.* **53**, 769.

Vogel, J. M. & Friedman, R. J. (1970) Mineral content changes in os calcis, ulna and radius induced by prolonged bed rest. *Proceedings of Bone Measurement Conference AEC CONF 700515,* p. 408, Atomic Energy Commission, Chicago.

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