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FROM THE DEPARTMENTS OF RADIATION PHYSICS AND ORTHOPAEDIC SURGERY I, UNIVERSITY OF GOTHENBURG, SAHLGRENSKA SJUKHUSET, S-413 45 GOTHENBURG, SWEDEN.

DUAL PHOTON ABSORPTIOMETRY IN LUMBAR VERTEBRAE

Evaluation of the baseline error

B. O. ROOS, T. H. HANSSON and H. SKÖLDBORN

Dual photon absorptiometry is a method of determining the bone mineral content in lumbar vertebrae in vivo (ROOS & SKÖLDBORN 1974, ROOS 1975). The method is based on the following principles.

Two nuclides, ^{241}Am, with a gamma energy of 59.6 keV, and ^{137}Cs, with a gamma energy of 662 keV, are placed together under the examination couch. The patient lies on his back on the couch, which travels in the transverse direction. The collimated gamma radiation beam, which contains both photon energies, is absorbed and partly scattered by the patient's skeleton and soft tissue. The transmitted fractions are detected with a NaI(Tl)-detector placed in a frame over the patient. Stationary transmission measurements are performed at a series of points along a line transversally over the patient at the level of the third lumbar vertebra. The bone mineral mass, m_B, (in g/cm^2) is calculated for each measurement point and plotted as a function of the position, giving a bone profile curve. Integration over a subjective baseline between two end-points gives the bone mineral content in g/cm.

By means of dual photon absorptiometry, a two-phase system, e.g. bone mineral and lean soft tissue, can be solved in a stationary measurement. The attenuation for adipose tissue differs from that of lean soft tissue, causing a reduction of the registered bone mineral mass, m_B, at each individual measurement point (ROOS 1974). This systematic measurement error has also been observed and discussed in connection with the more common single photon absorptiometry technique (WOOTEN et coll. 1973, JUDY & VOGEL 1974). With both single and dual photon absorptiometry the scanning technique, with integration of the bone profile curve, is normally used to correct for a layer of fat which has a constant mass along the measurement path. The only influence of the fat in this case is a vertical shift of the bone profile curve.

Considerably more serious is the error caused by an inhomogeneous distribution of adipose tissue along the measurement path. A measurement path over L3 will generally pass through the caudal parts of the kidneys and thus the adipose capsules (Fig. 1). All measurement points on either side of the vertebra will be influenced by the adipose capsule; in the bone profile curve m_B in these areas will have a negative value. It is thus reasonable to assume that the end-points of the baseline (E_1 and E_2 in Fig. 1) will also have negative values (assuming that the fat in the adipose capsules of the kidneys is the only inhomogeneously distributed fat). After integration the bone mineral content will be overestimated by an amount which is approximately equal to the area A_3.

In order to test this hypothesis, a series of measurements on the bone mineral content in the third lumbar vertebra was carried out in a number of cadavers, using exactly the same technique as is

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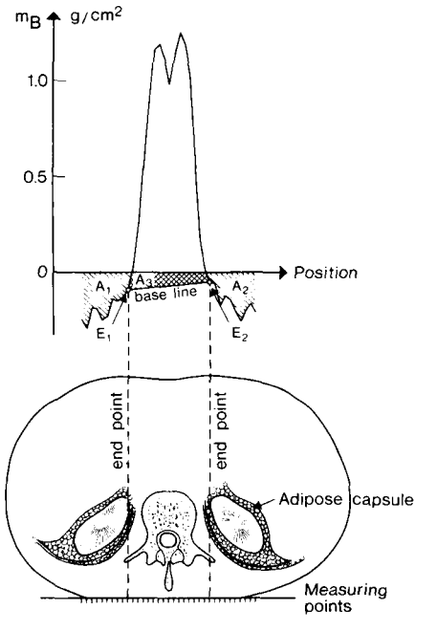

Fig. 1. Influence of inhomogeneous adipose tissue distribution along the measurement path. Negative values of bone mineral mass, m_B, due to influence of fat, form the areas A_1 and A_2. The integrated area between the end-points E_1 and E_2 represents the bone mineral content, which will be overestimated by the area A_3.

used in vivo. A segment of the lumbar spine, comprising vertebrae L2–L4, was then removed and measured under controlled conditions in a water-bath. The technique was the same as was previously used in determining the mineral content in vertebrae in relation to compressive strength (HANSSON et coll. 1979). The present report presents the results of measurements on lumbar vertebrae from 14 cadavers and analyses the difference between in vivo and in vitro measurements in order to be able to evaluate conclusions from biomechanical in vitro tests of compressive strength (HANSSON et coll.).

Table

The age, sex and bone mineral content in vertebra L3 in situ (BMC_1) and in vitro (BMC_2) and the difference between BMC_1 and BMC_2 in 14 cadavers

No.	Age	Sex	BMC_1	BMC_2	BMC_1–BMC_2
1	54	M	4.24	4.09	0.15
2	55	M	5.69	5.16	0.53
3	56	M	3.37	3.82	−0.45
4	59	M	3.78	3.47	0.31
5	59	M	4.87	4.54	0.33
6	60	M	3.71	3.81	−0.10
7	64	F	4.22	3.38	0.84
8	64	M	4.27	3.97	0.30
9	69	M	5.09	4.50	0.59
10	70	F	3.84	3.21	0.63
11	72	M	8.28	8.40	−0.12
12	74	F	2.96	2.50	0.46
13	74	M	5.79	5.67	0.12
14	75	M	4.50	3.61	0.89

Material and Methods

The material comprised 14 cadavers (54–75 years). The sex, age and results of the measurements appear in the Table. The only form of selection was exclusion of individuals who had died from malignancies or other diseases which might affect the skeleton. The most usual cause of death was myocardial infarction.

For the in situ measurements the cadaver was placed in the supine position on the examination couch and vertebra L3 located by fluoroscopy. Recordings were then made at 35 points along a measurement path transversally over L3. The measurement time was 0.7 min for each measurement point. The distance between the measurement points was 4 mm. The recording for each measurement point is designated m_B, the bone mineral mass in g/cm². m_B was plotted as a function of position, giving a bone profile curve (Fig. 1). The bone mineral content (BMC) was calculated from the bone profile curve as follows. The end-points were selected subjectively as the points lying closest to the profile curve over the vertebra which were projected free from bone. Normally, the full width at half maximum (FWHM) of the curve may be considered to represent the breadth of the vertebra, and the end-points fall about 12 mm outside FWHM. The area below the curve between the end-points is expressed by the following equation:

$$BMC=\left[\sum_{k=2}^{n-1} m_B^{(k)}-\frac{n-2}{2}(m_B^{(1)}+m_B^{(n)})\right]\times 0.4\ \text{g/cm}$$

where the end-points are numbered (1) and (n), and $m_B^{(k)}$ is the bone mineral mass at a point between the end-points. The bone mineral content measured in situ is designated BMC_1.

Vertebrae L2-L4 were removed in one piece at the autopsy and in vitro measurements then performed over L3 using the same method as was used in previous in vitro experiments on the compressive strength of vertebrae in relation to the bone mineral content (HANSSON et coll.), i.e. with the vertebra

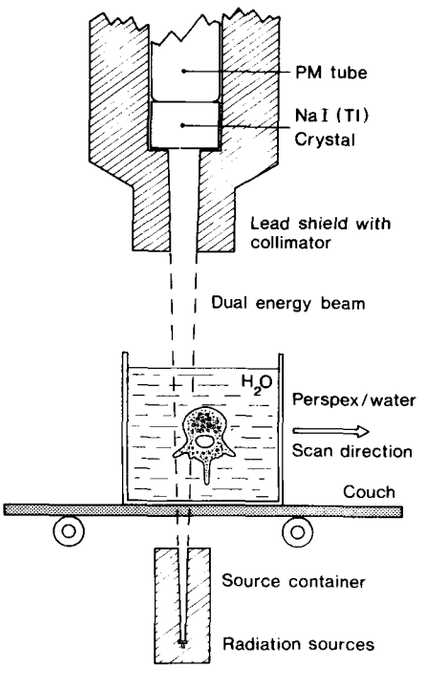

Fig. 2. Experimental set-up for in vitro measurement of lumbar vertebrae. The preparation (L2–L4) is fixed in a water-bath on the travelling examination couch and intermittent scanning is performed in the same way as in in vivo and in situ measurement.

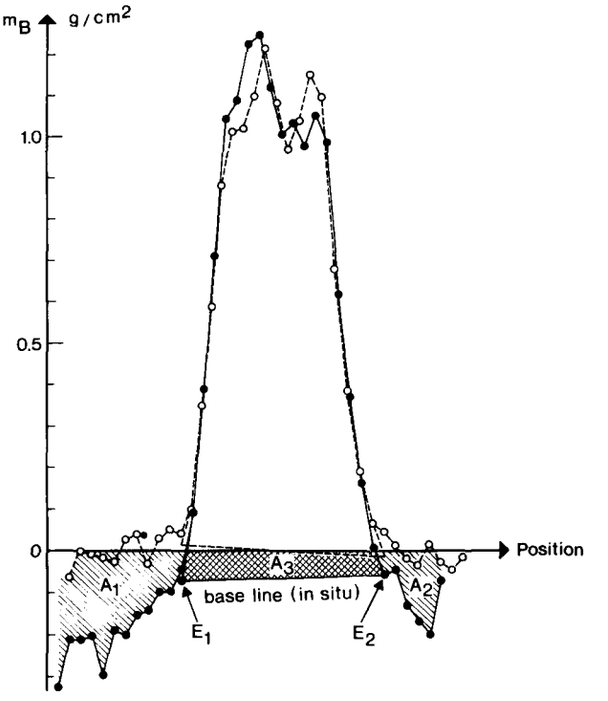

Fig. 3. Bone profile curves for measurement in situ (solid line) and in vitro (dashed line) for subject No. 2 in the Table. The two profile curves have been adjusted in the vertical direction in relation to the full width at half maximum of the curves. The adipose effect, designated A_3 in Fig. 1, was in this case 0.53 g/cm.

fixed in a water-bath as shown in Fig. 2. The measurements, profile drawings, end-point determinations and calculations of the mineral contents were made in the same way as in the in situ measurements. Measurement in vitro was considered to represent the bone mineral content of the vertebra without interference from adipose tissue. This value was designated BMC_2.

The difference between BMC_1 and BMC_2 was considered to represent the systematic error caused by erroneous positioning of the baseline. This difference was calculated for each vertebra and is given in the Table.

Examples of bone profile curves in situ and in vitro appear in Fig. 3.

Results

In the Table the BMC is given in g/cm. The subjects are listed in order of age. The Table shows BMC_1, BMC_2 and the difference between BMC_1 and BMC_2. It appears that the BMC difference varies from −0.45 (preparation No. 3) to 0.89 (preparation No. 14). The values of the BMC difference are fairly evenly distributed between these extreme values. It can thus not be assumed that the BMC difference is normally distributed and a non-parametric method of statistical analysis and evaluation of significance must be chosen. The sign test was chosen. The BMC difference in the Table has a median value of 0.32. According to the sign test, the median value is significantly greater than zero with the confidence interval (0.12; 0.59) at the confidence level 94.4 per cent.

The median value for BMC_1 is 4.39 (mean values for preparations Nos 8 and 14).

The median value for BMC_2 was 3.90 (mean value of BMC_2 for preparations Nos 3 and 8).

Discussion

The results thus confirm the hypothesis that in situ measurement (and thus also in vivo measurement) gives a significantly higher figure than is obtained on measurement of the same vertebra in vitro (confidence level 94.4%). This seems to be due to the fact that the end-points of the baseline are

systematically positioned too low during in vivo measurement due to interference by adipose tissue on either side of the vertebra.

A high correlation (r=0.86) between the bone mineral content of lumbar vertebrae and their ultimate compressive strength has previously been found in vitro (HANSSON et coll.). Comparison between biomechanical properties of vertebrae in vivo and in vitro implies important potential sources of error. The present results suggest that the bone mineral values in in vivo measurements systematically overestimate the mechanical strength of the vertebrae, the error being of the order to 250 N (HANSSON et coll.).

The differences between in vivo and in vitro measurements may have been influenced by the composition of the patient material. Most of the vertebrae examined belonged to men (11/14). The amount of fat around the kidneys in men is probably greater than in individuals with osteoporosis since short, slender elderly women dominate among the latter (SAVILLE & NILSSON 1966). The difference between the bone mineral content in vivo and the in vitro value in these individuals is thus probably smaller than was found in the present series (0.32 g/cm).

Based on the attenuation coefficients for adipose tissue, water and hydroxyapatite (ROOS 1974), the median difference of 0.32 g/cm may be calculated to correspond to a fat mass of just over 1.4 g/cm^2 at the end-points of the baseline.

SUMMARY

In connection with determination of the bone mineral content in the third lumbar vertebra by dual photon absorptiometry, the fat in the adipose capsules of the kidneys is assumed to cause erroneous positioning of the baseline, leading to overestimation of the bone mineral content. The bone mineral content in L3 was measured in *situ* (BMC_1) and *vitro* (BMC_2) in 14 cadavers. The difference between BMC_1 and BMC_2 was significantly greater than zero, the median value being 0.32 g/cm at the confidence level of 94.4 per cent. It is concluded that at correlation between bone mineral content and compressive strength in vitro, the in vivo strength is overestimated by about 250 N.

ACKNOWLEDGEMENT

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REFERENCES

HANSSON T., ROOS B. and NACHEMSON A.: The bone mineral content and ultimate compressive strength in lumbar vertebrae. Spine 4 (1979), 29.

JUDY P. F. and VOGEL J. M.: A method to estimate the error caused by adipose tissue in bone absorptiometry. *In:* Proceedings of the symposium on bone mineral determinations. Stockholm-Studsvik, 1974.

ROOS B. O.: Dual photon absorptiometry in lumbar vertebrae. Thesis, University of Gothenburg, 1974.

— Dual photon absorptiometry in lumbar vertebrae. II. Precision and reproducibility. Acta radiol. Ther. Phys. Biol. 14 (1975), 291.

— and SKÖLDBORN H.: Dual photon absorptiometry in lumbar vertebrae. I. Theory and method. Acta radiol. Ther. Phys. Biol. 13 (1974), 266.

SAVILLE P. D. and NILSSON B. E.: Height and weight in symptomatic postmenopausal osteoporosis. Clin. Orthop. 45 (1966), 49.

WOOTEN W. W., JUDY P. F. and GREENFIELD M. A.: Analysis of the effects of adipose tissue on the absorptiometric measurement of bone mineral mass. Invest. Radiol. 8 (1973), 84.