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Gamma-ray scattering for mandibular bone density measurement

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Abstract. There has been considerable interest in the measurement of bone density in the mandible, either to study bone resorption following tooth loss or to determine the relationship between mandibular and skeletal bone mineral density. Measurements mostly have been made on dental radiographs but more significant correlations between mandibular and skeletal bone density have been obtained when more sophisticated techniques have been used, such as quantitative CT and dual energy X-ray absorptiometry. The present work investigates the feasibility of using gamma-ray scattering measurements to estimate mandibular bone density. Using a phantom to simulate the jaw, an ^{241}Am source and a hyperpure germanium detector it is shown that bone density may be measured with a precision of about 1%.

The bone mineral density (BMD) of the mandible has been reported by a number of authors investigating both bone resorption following tooth loss and the relationship between mandibular BMD and skeletal BMD as an indicator of osteoporosis [1–12].

For the measurement of mandibular BMD to be considered as a predictor of osteoporosis, it is first necessary to establish whether there is a significant correlation between the mandibular BMD and that of skeletal sites. Quantitative CT (QCT), dual photon absorptiometry (DPA) and dual energy X-ray absorptiometry (DXA) as well as radiographic film have been used to study this relationship. In a review of published data, Horner et al [12] concluded that "the evidence from the literature in favour of the mandible being a useful indicator of the general skeletal bone status is mixed. It appears that significant correlations are obtained when more sophisticated analysis of the mandible, such as QCT, is used". Their own results where DXA was used to measure both mandibular and skeletal BMD also showed good correlation between the two sites.

The aim of the work reported here was to investigate the feasibility of using a gamma-ray scattering technique to give a measure of mandibular bone density. Both measurement precision and linearity *vs* density have been assessed. Potentially, such a technique offers a low dose, compact and relatively inexpensive means of indicating mandibular bone density compared with DXA and QCT. Gamma-ray scattering techniques have been previously used or investigated for the measurement of BMD in the heel as a predictor of skeletal osteoporosis [13–17].

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Scattering parameters

A number of workers [13–17] have proposed or used the measurement of the ratio of coherent to Compton scattered photons from irradiated bone or other tissues to determine information on the composition of that tissue. Because coherent scatter is very dependent on the atomic number of the scatterer, the ratio of coherent to Compton scatter is also dependent on the atomic number of the scatterer, varying approximately as Z^2 [18]. Similarly the coherent/Compton scattering ratio of a composite material, such as bone, containing many elements, is dependent on the atomic numbers of its component elements and their proportion in the material.

More recently, the sensitivity of the Compton scattering profile to the chemical composition of the scatterer has been suggested as an alternative method of characterizing bone tissue [19, 20]. These latter authors have compared the high energy tail of the Compton distribution with the region dominated by singly scattered Compton gamma-rays. The ratio measured is shown to be dependent on the concentration of K_2HPO_4 used to simulate varying BMDs.

This paper examines the potential of both of the above methods to give a measure of mandibular bone density for either bone resorption studies or as a predictor of osteoporosis.

Experimental arrangement

The experimental arrangement is shown schematically in Figure 1. A backscatter geometry was

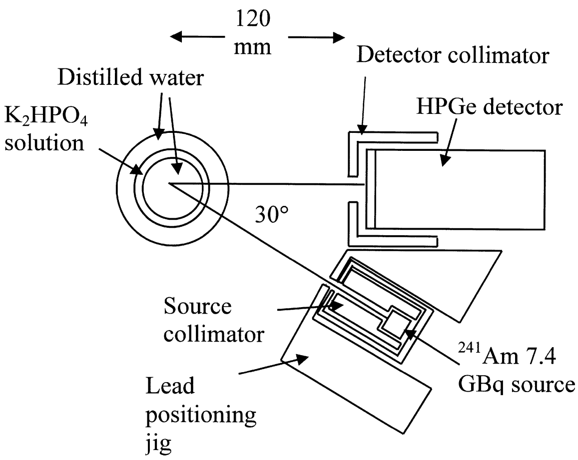

Figure 1. The experimental arrangement showing the ^{241}Am source, the jaw phantom and the HPGe detector.

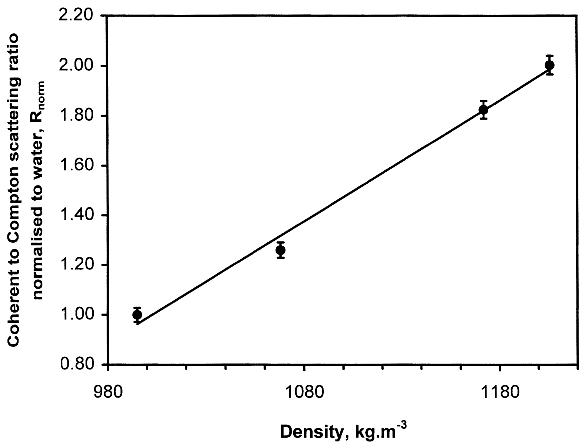

Figure 2. The variation in coherent/Compton scattering ratio with increasing density of the K_2HPO_4 solutions.

chosen for compactness and ease of set-up. A 7.4 GBq ^{241}Am source (5 mm diameter sphere) was collimated using a 5 mm diameter lead cylinder. A 32 mm diameter, 10 mm depth hyperpure germanium detector recorded the scattered photon spectrum. A 10 mm thick steel sleeve was fitted over the detector housing with a central 40 mm diameter hole exposing the detector.

To simulate the mandible a phantom was constructed of concentric thin-walled polypropylene cylinders as shown in Figure 1. The inner diameters of the cylinders were 54 mm, 74 mm and 90 mm, creating two concentric layers of 10 mm and 8 mm thickness surrounding the inner 54 mm diameter cylinder. The outer 8 mm layer was filled with water as a soft tissue substitute to a depth of 45 mm. Solutions of K_2HPO_4 were used as bone substitutes in the inner 10 mm layer to simulate the mandibular bone. The inner cylinder also contained water as a soft tissue substitute.

The phantom was irradiated with the inner 10 mm layer containing varying concentrations of K_2HPO_4 to a depth of 45 mm in the range 0–30 g K_2HPO_4 per 100 ml water simulating bone in the density range 1000–1200 kg m^{-3}. In this feasibility study the irradiation time was set at 1 h as in a practical instrument many sources could be arranged around the detector in the configuration shown in Figure 1, reducing the irradiation time proportionately. The measurement system focus was positioned at the phantom axis rather than at the "bone" layer to increase the count rate.

Results and discussion

Coherent/Compton scattering ratio

Figure 2 plots the variation of the measured coherent/Compton scattering ratio, R, against the density of the K_2HPO_4 solutions. The ratios are normalized to the value for water and the error bars show the standard deviation for each measurement. The line is the least-squares fit. If S is the slope of the plot then an uncertainty of ΔR on the measured ratio translates to a density uncertainty (ΔD) of $\Delta R/S$.

The average uncertainty in coherent/Compton ratio over the density range 1000–1200 kg m^{-3} is 2.5%. The measured slope is 0.005 m^3 kg^{-1} which results in a density uncertainty of about 1% when derived from a ratio measurement.

Compton profile ratios

Both MacKenzie [19] and Tartari et al [20] have suggested, as an alternative to the coherent/Compton scattering ratio, comparing the high energy tail of the Compton profile with the region dominated by singly scattered Compton gamma-rays. These authors have suggested slightly different energy limits for these ratios. MacKenzie [19] defined a ratio HP where the numerator is the integrated counts between 52 keV and 58 keV encompassing the high energy Compton tail, and the denominator is the integrated counts between 40 keV and 58 keV. Tartari et al [20] define a ratio R_k which results in summing over a slightly narrower portion of the high energy Compton tail.

Both parameters, HP and R_k are plotted in Figure 3 *vs* density of the K_2HPO_4 solutions. Again the ratios are normalized to that for water. A similar analysis to the above for the coherent/Compton scattering ratios gives an average density uncertainty of about 1% when derived from either the HP or R_k ratio parameter. This is similar to the uncertainty obtained for the coherent/Compton scattering ratio. Although the slopes of the plot are much less for the Compton profile ratio measurements, the statistical uncertainty is much less because of the increased counts in the Compton tail compared with the coherent peak.

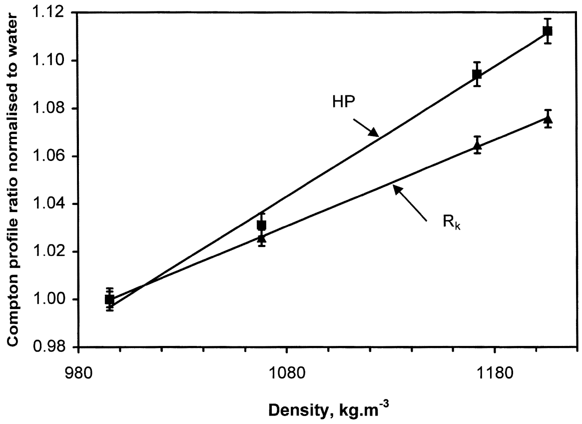

Figure 3. The variation of the parameters HP and R_k (see text) with increasing density of the K_2HPO_4 solutions.

Dose measurements

The absorbed dose at the surface of the phantom was measured using lithium fluoride (LiF) thermoluminescent dosemeters (Harshaw TLD 100) calibrated using a 100 kVp diagnostic X-ray beam. The dose at the phantom surface was 0.4 mGy per measurement which is similar to the skin dose received during dental radiography.

Conclusions

There has been considerable interest, reported in the last two decades [1–12], in the measurement of mandibular bone density either following tooth loss in bone resorption studies, or as an indicator of skeletal bone density. It has been shown that both coherent/Compton scatter ratio measurements and Compton profile measurements are sensitive to the density of K_2HPO_4 solutions in a jaw phantom giving a measurement precision of about 1% at densities near 1200 kg m^{-3}, typical of trabecular bone. In practice, patient positioning and anatomical variations would be expected to increase the measurement precision to nearer 3%. This is not as good as that achievable with QCT and DXA of between 1% and 2%, but is better than can be obtained from dental radiographs. Such scatter measurements might therefore offer low dose inexpensive alternatives to the use of dental radiographs in studies of mandibular bone density. As referred to in the introduction, because the technique gives a more precise density measurement than a dental radiograph, the results of such measurements would be expected to correlate more closely with skeletal bone status.

The aim of this work was to investigate the feasibility of using gamma-ray scattering measurements to estimate mandibular bone density. It is recognized that further work is required to provide information on other factors such as ease of use and costs of a complete system.

References

1. Henrikson PA, Wallenius K, Astrand K. The mandible and osteoporosis (2). Methods for determining mineral content of mandible and radius. J Oral Rehabil 1974;1:75–84.
2. Von Wowern N, Hjorting-Hansen E, Stoltze K. Changes in bone mass in rat mandibles after tooth extractions. Int J Oral Surg 1979;8:229–33.
3. Kribbs PJ, Smith DE, Chesnut CH. Oral findings in osteoporosis. Part II: Relationship between residual ridge and alveolar bone resorption and generalized skeletal osteopenia. J Prosthet Dent 1983;50:719–24.
4. Kribbs PJ, Chesnut CH, Ott SM, Kilcoyne RF. Relationships between mandibular and skeletal bone in an osteoporotic population. J Prosthet Dent 1989;62:703–7.
5. Kribbs PJ, Chesnut CH, Ott SM, Kilcoyne RF. Relationships between mandibular and skeletal bone in a population of normal women. J Prosthet Dent 1990;63:86–9.
6. Kribbs PJ. Comparison of mandibular bone in normal and osteoporotic women. J Prosthet Dent 1990;63:218–22.
7. Mohajery M, Brooks SL. Oral radiographs in the detection of early signs of osteoporosis. Oral Surg Oral Med Oral Pathol 1992;73:112–7.
8. Horner K, Devlin H. Clinical bone densitometric study of mandibular atrophy using dental panoramic tomography. J Dent 1992;20:33–7.
9. Klemetti E, Vainio P. Effect of bone mineral density in skeleton and mandible on extraction of teeth and clinical alveolar height. J Prosthet Dent 1993; 70:21–5.
10. Klemetti E, Vainio P, Lassila V, Alhava E. Cortical bone mineral density in the mandible and osteoporosis status in postmenopausal women. Scand J Dent Res 1993;101:219–23.
11. Klemetti E, Kolmakov S, Kroger H. Pantomography in assessment of the osteoporosis risk group. Scand J Dent Res 1994;102:68–72.
12. Horner K, Devlin H, Alsop CW, Hodgkinson IM. Mandibular bone mineral density as a predictor of skeletal osteoporosis. Br J Radiol 1996;69:1019–25.
13. Kerr SA, Kouris K, Webber CE, Kennett TJ. Coherent scattering and the assessment of mineral concentration in trabecular bone. Phys Med Biol 1980;25:1037–47.
14. Puumalainen P, Uimarihuhta A, Olkkonen H. A coherent–Compton scattering method employing an X-ray tube for measurement of trabecular bone mineral content. Phys Med Biol 1982;27:425–9.
15. Webster DJ, Lillicrap SC. Coherent–Compton scattering for the assessment of bone mineral content using heavily filtered X-ray beams. Phys Med Biol 1985;30:531–9.
16. Gigante GE, Sciuti S. A large angle coherent–Compton scattering method for measurement *in vivo* of trabecular bone mineral concentration. Med Phys 1985;12:321–6.
17. Shukla SS, Leichter I, Karellas A, Craven JD, Greenfield MA. Trabecular bone mineral density measurement *in vivo*: use of the ratio of coherent to Compton-scattered photons in the calcaneus. Radiology 1986;158:695–7.
18. Holt RS, Kouris K, Cooper MJ, Jackson DF. Assessment of gamma ray scattering for the characterisation of biological material. Phys Med Biol 1983;28:1435–40.

19. MacKenzie IK. An axially symmetric gamma-ray backscatter system for Du Mond spectrometry. Nucl Instr Meth 1990;A299:377–81.

20. Tartari A, Casnati E, Felsteiner J, Baraldi C, Singh B. Feasibility of *in vivo* tissue characterisation by Compton scattering profile measurements. Nucl Instr Meth 1992;B71:209–13.