ELECTRICAL ASSESSMENT OF TRABECULAR BONE DENSITY: THEORETICAL AND IN VITRO RESULTS

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INTRODUCTION: The assessment of bone density is an important aspect in the clinical management of osteoporosis and other metabolic bone diseases. Current methods rely on ionizing electromagnetic radiation, such as with dual energy X-ray absorptiometry. Alternative methods such as ultrasound have also been explored. The purpose of this study was to investigate the use of another means for assessing bone noninvasively, namely non-ionizing electrical measurements. The specific goal was to examine the relationship between density and electrical conductivity in trabecular bone.

MATERIALS AND METHODS: This study used both theoretical and *in vitro* experimental techniques. In the analytic portion, an idealized trabecular bone model consisting of a three-dimensional arrangement of identical beams or rods arranged as a cubic crystal was developed. Each rod had a square cross section of area d^2 and length ℓ. The rods were assumed homogeneous and isotropic with an electrical conductivity, σ_s, and the pores of the structure were assumed to be filled with a fluid of conductivity, σ_f. The theoretical electrical conductivity, σ_{THEOR}, associated with the overall trabecular bone model was evaluated as a function of the solid volume fraction, v, using Maxwell mixture theory [1].

The *in vitro* portion of the study used 13 human vertebral trabecular bone samples, prepared according to the protocol in [2]. Briefly, fresh vertebral bodies were harvested from cadavers, a two cm diameter cylindrical core was cut from the central portion of each body and the cortical shell at both ends was removed. The cores were defatted and then fully saturated with a saline solution with a conductivity of approximately $\sigma_f = 1.2\ \mathrm{Sm}^{-1}$. The samples were then measured in an electrical conductivity chamber, which consisted of a 2.2 cm diameter by 2.1 cm high plastic cylinder filled with the conducting fluid and a 1 cm diameter silver-silver chloride electrode (Type 4560, Nikomed, Doylestown, PA) fixed at one end. Each trabecular bone sample was lowered into the chamber until it was in contact with the fixed electrode. Another electrode identical to the first was then placed in contact with the top of the specimen. The impedance magnitude of each bone sample was then measured (Model 1260 Impedance Analyzer, Solartron Instruments, Hampshire, UK) at 10 kHz and normalized by the sample's length and area to obtain its electrical conductance, σ_{EXPER}. The bone apparent densities, ρ_a, were estimated by air drying the samples and dividing their dry weight by their total volume. The volume fractions of the bone samples were estimated from the apparent densities using the relationship $v = \rho_a/\rho_b$, where ρ_b was the density of the solid matrix, assumed equal to 1.5 gm/cc.

RESULTS: The theoretical electrical conductivity of the idealized trabecular bone model is given by

$$\sigma_{THEOR} = \frac{[\sigma_s^2 v + \sigma_f^2 (3-v)]\,(1-v) + \sigma_f \sigma_s (3+v)}{\sigma_s (3-3v) + \sigma_f (3+v)}$$

and the solid volume fraction is $v = b^2(3-2b)$, where $b = d/\ell$. Fig. 1 displays the theoretical and *in vitro* trabecular bone samples' conductivities, both relative to the fluid conductivity, σ_f. The conductivity of the solid phase was assumed to be negligible (*i.e.*, $\sigma_s \approx 0$) in the evaluation of σ_{THEOR}. The correlation of the conductance, σ_{EXPER}, with respect to the apparent density of the trabecular bone samples, was $R=0.94$ ($P<.001$).

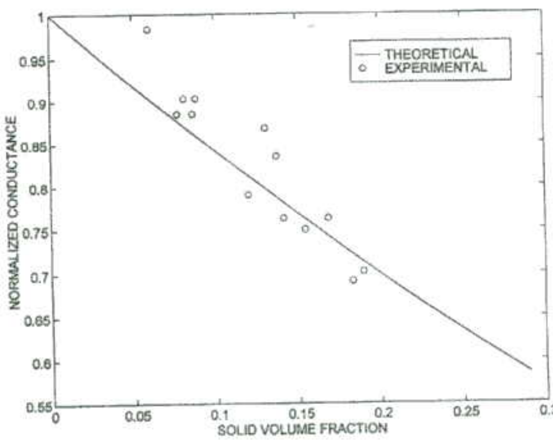

Fig.1. Theoretical and experimental conductivity data.

DISCUSSION AND CONCLUSION: A trabecular bone model was used in the analytical evaluation of its electrical conductivity. Although the model was highly idealized, there was good qualitative correspondence between the theoretical conductances and the conductances measured on human trabecular bone samples *in vitro*. There was also a high degree of correlation between the apparent density of the bone samples with measured electrical conductivity. Other researchers have not reported such high correlations, which may be due in part to their use of a more heterogenous group of bone samples with respect to architectural considerations or perhaps to use of samples with narrower density ranges [3]. The results presented here suggest that electrical measurements should be further explored as a potential means for noninvasively assessing bone.

REFERENCES:[1] Chiabrera A, Bianco B *Technical Report #CB001A*, CyberLogic, Inc., 1995. [2] Lin D *et al. Trans ORS 19*:408, 1994. [3] Saha S, Williams PA *Annals of Biomedical Engineering 17*:143, 1989.

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