Acoustical Detection of Senile Osteoporosis. (30722)

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Osteoporosis is a condition characterized by a shift in the anabolism-catabolism equilibrium of bone toward increased catabolism. In senile or post-menopausal osteoporosis, the equilibrium shift appears to be associated with increased bone resorption(1). This may be caused by defective adjustment of the body to a low calcium diet and defective intestinal absorption of calcium(2).

Routine radiographic techniques under optimal conditions cannot detect osteoporosis until at least 30% deossification of trabecular bone occurs(3). At this advanced stage, it is difficult to reverse or even arrest the deossification. In many cases, the bone is so weakened by the deossification that the first evidence of osteoporosis is a fracture, often across the neck of the femur(4).

Theory. Although osteoporosis is usually observed first in the pelvis, lumbar spine, and femur, it is a phenomenon generally occurring throughout the skeletal system(5). Therefore, a detection scheme utilizing a bone such as the ulna would be useful in detecting senile osteoporosis.

As an approximation, one may assume the ulna to be a bar which is mass loaded on the proximal end by the olecranon and coronoid processes and surrounded by a damping medium. The harmonic solution of the equation of motion of this system will yield FL=KC. In this equation, F is the resonant frequency of the ulna, L is the ulnar length, C is the speed of sound in the ulna, and K is a proportionality constant based on geometrical considerations. Since $C = \sqrt{\gamma/\rho}$, where ρ is the mean density of the ulna and γ is the elasticity (Young's modulus), and since elasticity is a function of density ($\gamma = \gamma(\rho)$), the speed of sound is a function of density ($C = C(\rho)$). Therefore, the product of resonant frequency and length is a function of density ($FL = \Phi(\rho)$)(6).

Apparatus. The experimental apparatus used in this investigation is shown in Fig. 1,

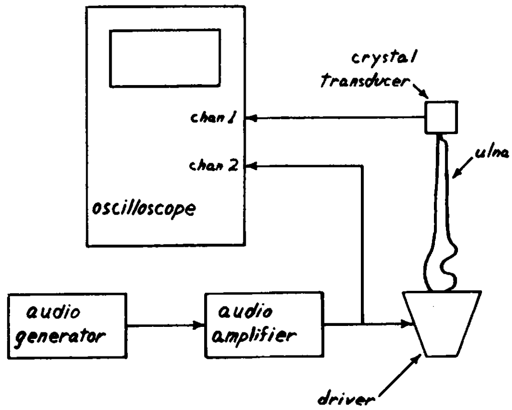


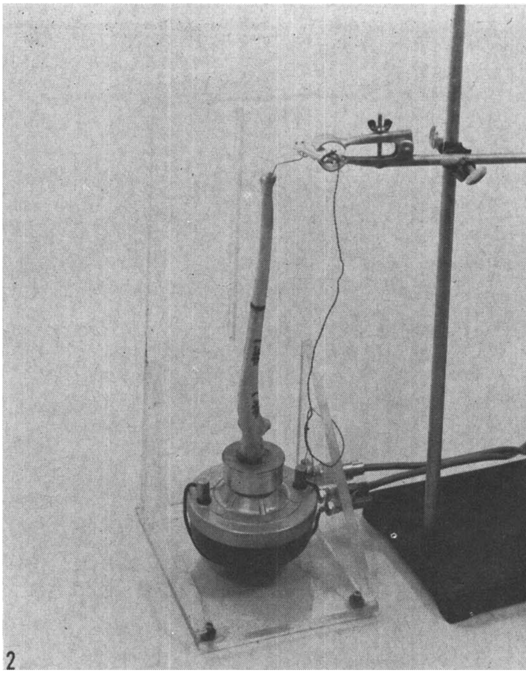
FIG. 1. Experimental apparatus: block diagram.

2, and 3. The audio generator provides a constant amplitude variable frequency sinusoidal voltage for the power amplifier. The output of the amplifier is connected to the driver located at the olecranon process. The crystal transducer located at the styloid process is connected to the oscilloscope. The generator frequency is varied until the output voltage of the crystal pickup is at a maximum. This frequency of maximum amplitude response is, to a close approximation, equal to the resonant frequency (F).

Results. The function $\Phi(\rho)$ was emperically determined using 6 excised ulnas of various densities. First, the lengths and densities of the bones were measured. The resonant frequency was then determined for each ulna. As shown in Fig. 4, FL was a monotonically increasing function of density.

After one obtains a graph of FL *versus* ρ, one may determine the density of the ulna *in vivo* by measuring its length and resonant frequency. However, it is easier from a clinical point of view to use FL directly as a measure of bone degeneration instead of converting it to density and then comparing the density to established norms.

FL was measured for 35 osteoporotics, 41 suspected osteoporotics, 16 diabetics and 105



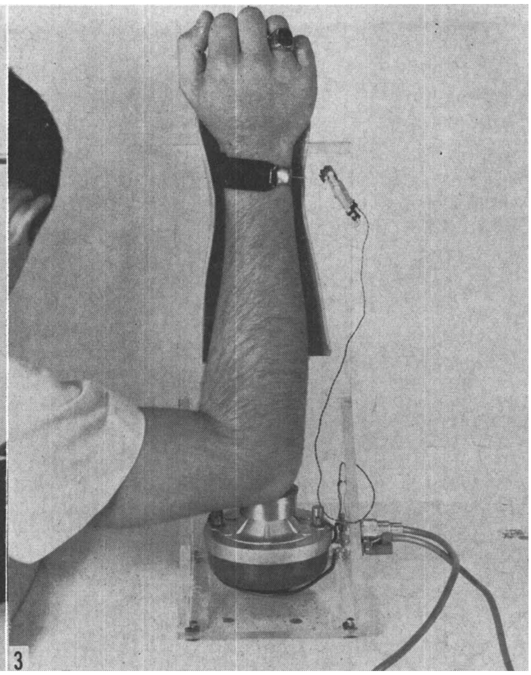


FIG. 2. Details of excised ulna support. Fig. 3. Details of arm support.

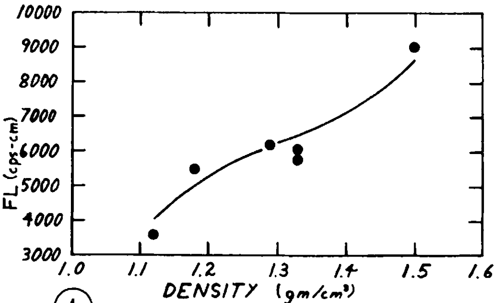
normal subjects. Normal subjects were by definition those subjects with no history of bone or joint abnormality, diabetes or other metabolic disease. To reduce the possibility of undiagnosed osteoporotics being included in the control groups, the control males had to be less than 66 years old, and the control females had to be less than 46 years of age. Normal subjects ranging in age up to 70 years were included in the study. Diabetic patients were studied because they often develop osteoporosis. The suspected osteoporotics were elderly non-diabetic patients who had been immobilized with rheumatoid arthritis, CVAs, etc. and could therefore be suspected of having osteoporosis even though no definite diagnosis had been made. The osteoporotic patients were those with definite radiographic signs of osteoporosis and/or those who suffered fractures with minimal trauma(7). Fig. 5 and Table I summarize the results of the clinical investigation. The curve of FL *vs* age for male subjects is irregular and probably reflects the small sample size. As seen in Table I, the diabetics and suspected osteoporotics fell between the normal subjects and the osteoporotics with respect to FL. This is consistent with the assumption that some but not all of the suspected osteoporotics and diabetics were in fact osteoporotic.

A discriminant value of FL was selected to provide maximum separation of normal subjects from osteoporotic subjects. This discriminant was selected in such a way that the

TABLE I. FL (cps-cm).

	Males	Females	Males & females
Controls	6154 ± 292 (36)	6231 ± 211 (48)	6198 ± 173 (84)
Normals	6173 ± 285 (37)	5934 ± 193 (68)	6018 ± 160 (105)
Diabetics	5109 ± 553 (3)	2964 ± 295 (13)	3366 ± 333 (16)
Suspected osteoporotics	4259 ± 398 (16)	3865 ± 296 (25)	4019 ± 237 (41)
Osteoporotics	3590 ± 1090 (3)	2729 ± 160 (32)	2803 ± 170 (35)

Ranges refer to standard deviation of mean.
No. of subjects in each category is enclosed in parentheses.



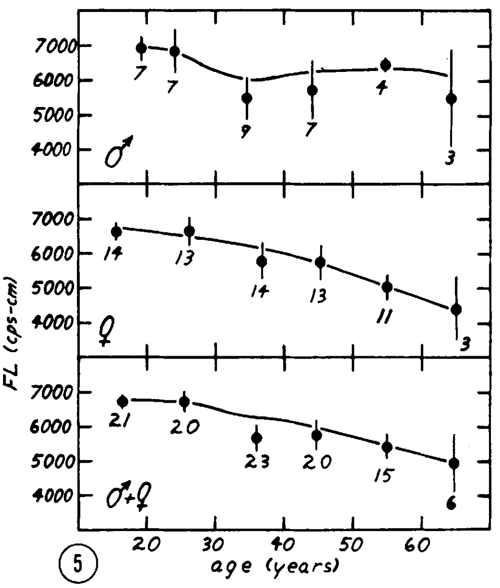


FIG. 4. FL and density.

FIG. 5. FL and age for normal subjects. The subjects were divided into age groups of one decade (11-20 years, 21-30 years, etc.) and the mean age, mean FL, and standard deviation of the mean was calculated for each age group. Numbers adjacent to each point refer to number of subjects in that particular age group. Range bars enclose ± one standard deviation of the mean.

square root of the sum of the squares of the percent incorrect diagnoses was minimized. The RMS incorrect diagnoses value was minimized (1.40%) with a discriminant of 3836 cps-cm. The discriminant gave the diagnosis matrix shown in Table II. A chi square analysis gave a probability of less than 1/100,000 that the relationship between FL and osteoporosis is due to chance ($\chi^2 = 71.33$).

TABLE II. Diagnosis Matrix for 119 Subjects.

	Acoustical diagnosis	
Clinical diagnosis	Normal	Osteoporotic
Normal	76	8
Osteoporotic	4	31

Discriminant = 3836 cps-cm, $\chi^2 = 71.33$.

Conclusions. The large difference between the values of FL for the osteoporotic and the normal subjects suggests that the acoustical method is more sensitive than the radiographic method. If one conservatively assumes that L can be measured to ± 1.0 mm and that F can be measured to ± 5.0 cycles per second, FL is accurate to ± 150 cm per second or about 2.5%. Reference to Fig. 4 indicates that this accuracy in FL will allow determination of bone density with an accuracy of about ± 3%. Compared to the 30% decrease density required for detection by the radiographic technique, the acoustical technique offers a large increase in sensitivity.

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