(*Reprinted from Nature, Vol.* 197, *No.* 4862, *p.* 81 *only, January* 5, 1963)

Piezoelectric Effect in Bone

THERE is convincing evidence that bone has an orderly morphological and microscopic structure. This evidence is derived mainly from electron microscopy, ordinary histological preparations, and microradiography[1]. Such a structure, consisting essentially of apatite crystals embedded in an organic matrix, might be expected to exhibit piezoelectric properties, as in the case of many other multicrystalline structures.

This has been conclusively demonstrated by Fukada and Yasuda[2], who measured the piezoelectric constants of small specimens of compact bone cut from human and ox femurs. These authors conclude from the observed relationship between polarization and stress that the effect is truly piezoelectric, and they suggest that it results from the slipping of collagen fibres past one another.

We have observed the same stress-induced electrical effect in a number of whole bones from different anatomical sites and species, both in bending and compression modes. The bones were cleaned of soft tissue and periosteum, then placed in an ultrasonic cleaner with detergent and finally dried. Electrodes were painted on the bones with conductive paint (DuPont silver paint No. 4817), leads were attached to these electrodes and connected to a vibrating reed electrometer (Applied Physics Corporation model 31), the output of which was displayed on a chart recorder. To minimize electrical pickup the bone being tested was kept in a shielded box and stressed from the outside. Bones which were stressed by bending, such as human ribs or rabbit femurs, were clamped at one end and bent by applying a force normal to the other end. Shorter bones, such as a human toe phalanx, were stressed by applying known compressive forces lengthwise along the bone axis.

Our results may be illustrated by the following example: the ends of a human toe phalanx were squared off with a saw to permit uniform application of the compressive force. Two silver bands, spaced 12·7 mm apart, were painted completely around the mid-portion of the bone. The d.c. resistance between these electrodes was approximately 10^9 ohms. Sudden application of a static force resulted in a potential difference between the electrodes proportional to the stress and with a decay time of about 0·5 sec; the latter appeared to be characteristic not only of the electrical circuit constants but also of some mechanical property (relaxation phenomenon) of the bone. On releasing the stress the same voltage pulse appeared with opposite polarity. The magnitude of the effect was of the order of 0·3 mV/kg of applied force.

It has long been known that the architectural structure of bones depends to a large extent on the mechanical forces acting on them. The fact that surface charges appear on stressed bone may be the controlling factor in bone formation. The local electric fields resulting from such surface charges might be expected to influence the orientation and deposition of ions or polarizable molecules. As evidence for the effect of electric fields on bone formation, Yasuda *et al.*[3] showed that the development of callus in living bone could be induced by electrical energy. Similarly, Bassett[4] has influenced the direction of bone growth in tissue culture by means of electric fields, as well as by inhomogeneous magnetic fields.

MORRIS H. SHAMOS

Department of Physics,
New York University, New York.

LEROY S. LAVINE

Departments of Surgery, Orthopaedic Division,
Long Island Jewish Hospital,
New Hyde Park, and
State University of New York Downstate Medical Center,
College of Medicine,
Brooklyn, New York.

MICHAEL I. SHAMOS

Horace Mann School,
New York.

[1] McLean, F. C., and Urist, M. R., *Bone*, second ed. (Univ. Chicago Press, 1961).

[2] Fukada, E., and Yasuda, I., *J. Phys. Soc. Japan*, **12**, 1158 (1957).

[3] Yasuda, I., Noguchi, K., and Sata, T., *Proc. J. Bone and Joint Surg.*, **37**, A, 1292 (1955).

[4] Bassett, C. Andrew (private communication).

Printed in Great Britain by Fisher, Knight & Co., Ltd., St. Albans.