THERMO-CURRENTS IN HUMAN BONE

S. HARIDOSS
Department of Physics, Indian Institute of Technology, Madras
and
T. ROBERT BULLARD
Department of Physiology, Christian Medical College, Vellore, Tamil Nadu

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Thermo-currents after electrification are observed in human bone when it is heated in short circuit conditions from room temperature ($\sim$ 300 °K) to 650 °K. Measurements are made both along the original long axis of the bone and perpendicular to the axis. Thermo-currents also appear '*de novo*' without any electrification. The results suggest an electret property of the bone.

INTRODUCTION

MASCARENHAS in his pioneering work in the early ninteen seventies provided evidence to suggest that bone behaves as an electret (Mascarenhas, 1970, 1973). '*De novo*' or spontaneous thermo-currents in exercised bone without previous electrical treatment have also been observed (Liboff & Frost, 1974). The present investigations on human femur provide additional evidence supporting the electret-like effect in bone and in addition describe spontaneous current thermograms similar to those of Liboff and Frost (1974) but in a higher temperature range (300–650 °K) with higher recorded currents (10^{-9}–10^{-10} amps).

EXPERIMENTAL

Bone samples, cut both parallel and perpendicular to the bone axis, were obtained from various regions along the midshaft of adult human femur and were machined to a size of 5 $\times$ 5 $\times$ 2 mm^3 as described by Becker and Brown (1965). Samples of bone apatite alone were prepared by refluxing bone samples with ethylene diamine (EDA) at a temperature of 80 °C for 10 hours (Williams & Irwin, 1954) while demineralisation in other samples was accomplished by prolonged agitation in 10 per cent Formic acid. The latter procedure is reported to have little or no deleterious effect on the collagen matrix (Morris & Benton, 1956).

The experimental apparatus (Fig. 1) consisted of a sample chamber whose temperature could be varied by an external heater. The sample was mounted inside the chamber and an iron constantan thermocouple fixed near to the sample was used to monitor the temperature. The entire assembly was shielded to avoid external pick-up. The short circuit current in the sample was measured with a Keithley 610 °C electrometer coupled to a servogor recorder.

Two different types of experiments were performed. One was the measurement of thermally stimulated discharge current (TSDC) which consisted of measuring the

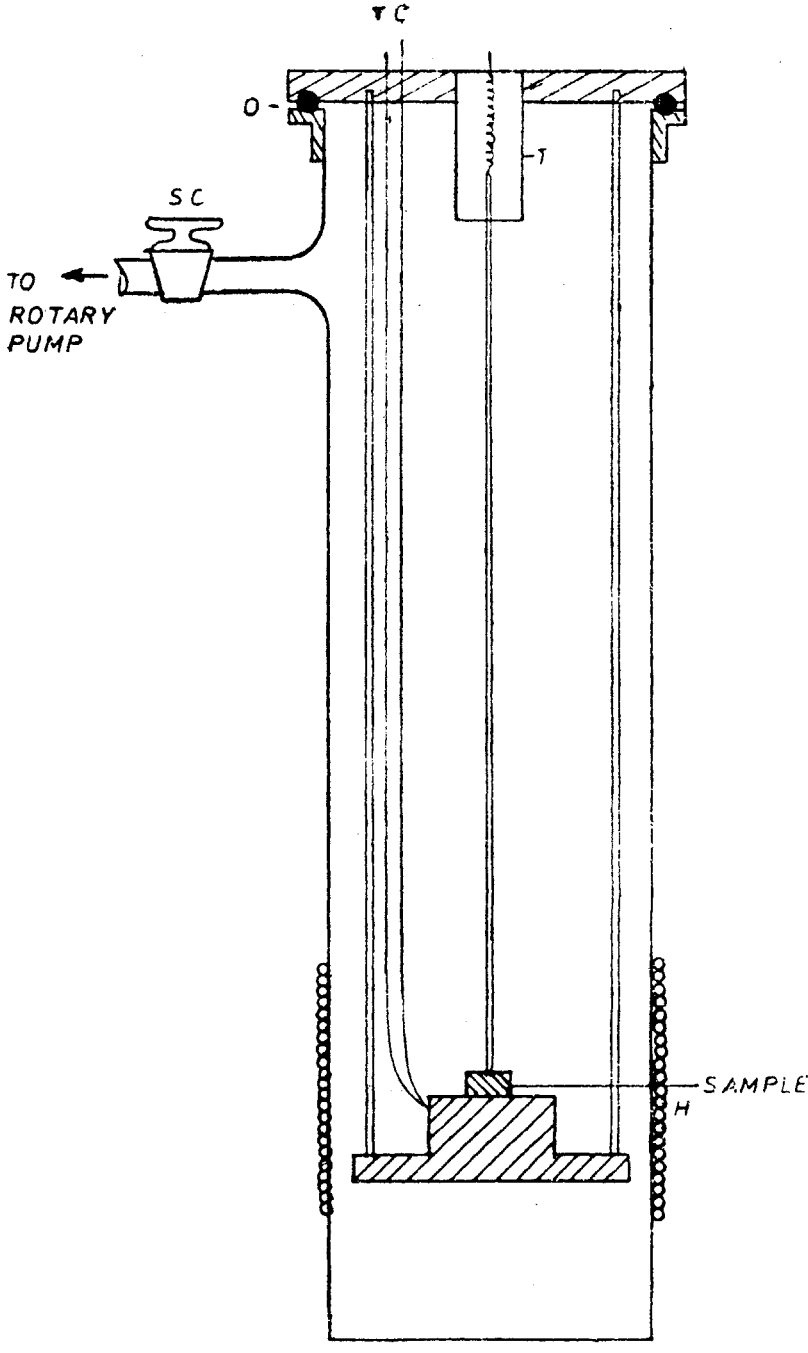

FIG 1. Schematics of the experimental set up.

short circuit current after polarising the sample. In the second type of experiment spontaneous currents (SC) without electrifying the sample, were measured. These SC currents were large to be accounted for by the phenomenon of contact electrification. Also the measurements were taken with sufficient care to avoid any signal due to peltier effect.

Results

(*a*) *TSDC Thermograms* — Electrification of the bone samples was carried out at different temperatures and with different electric fields. After removal of the field, the sample was short-circuited across the electrometer and the temperature was increased at a linear rate.

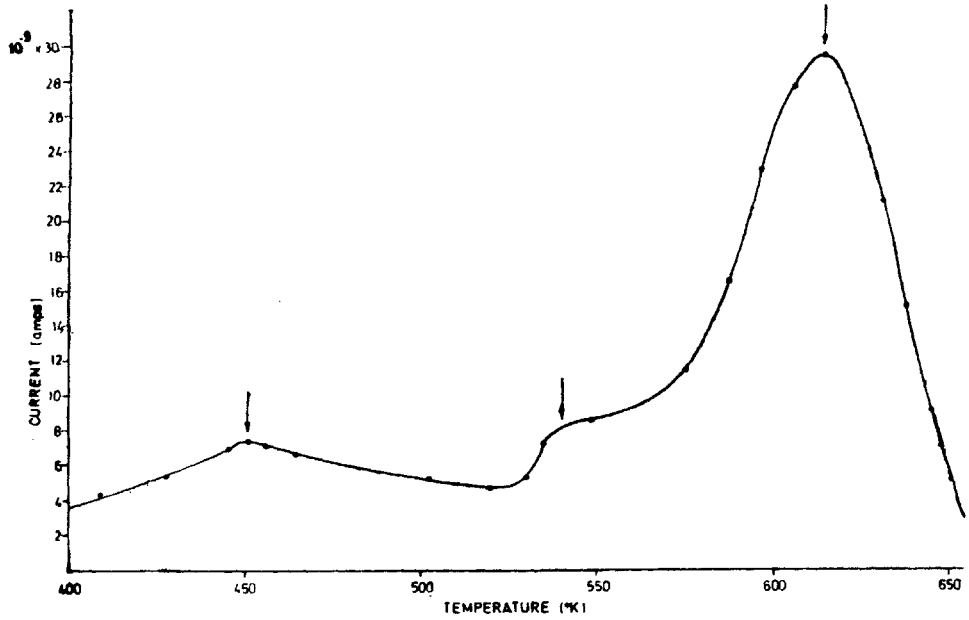

FIG. 2. TSDC in bone sample (field along bone axis) Specimen Thickness=1mm, Area=25mm.² Heating rate=9.35°/min, Vp=400V, Tp=385 °K, tp= 1hr.

TABLE I

TSDC data for bones

Samples	T_P (°K)	Peak Positions (°K)	Heating rate deg./min
Bone Sample	385	450, 540, 613	9.35
Bone Sample	445	495, 624	12
Bone Collagen	385	490, 562, 615	10
Bone Apatite	385	—	10

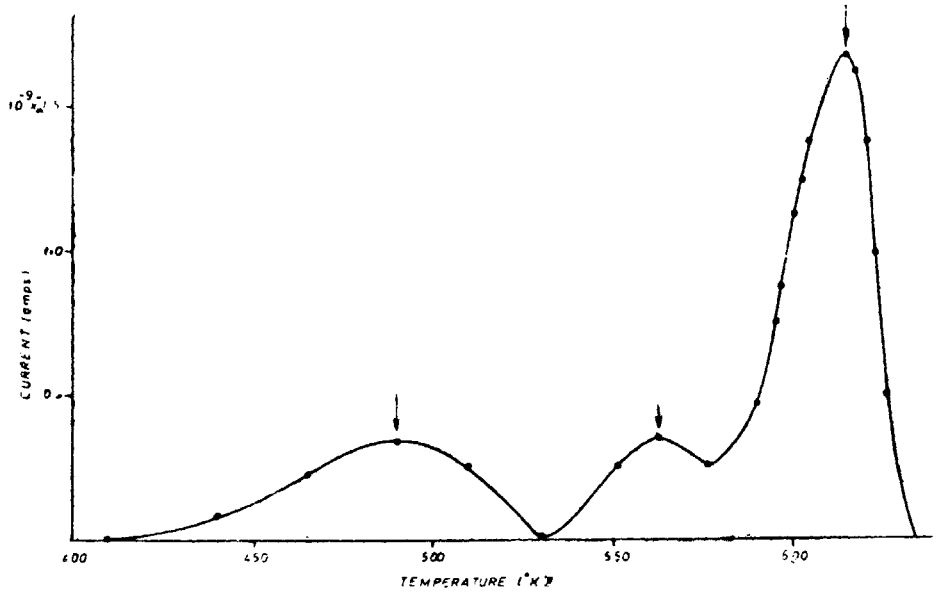

FIG. 3. TSDC in bone collagen (field along bone axis) Specimen Thickness=1mm, V_p, = 200 V, Area=16 mm², T_p = 385°K, Heating rate=10°/min, t_p =1 hr.

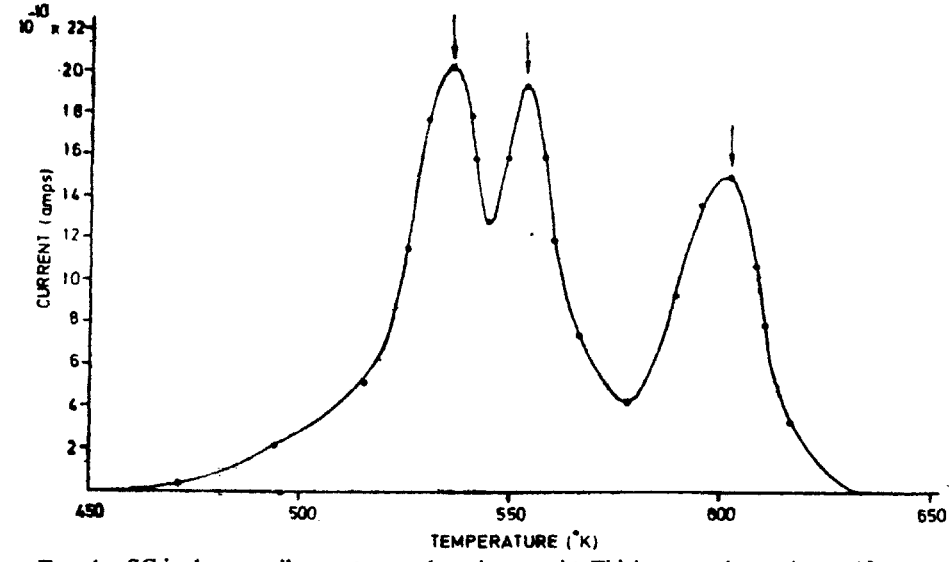

FIG. 4. SC in bone collagen (meas. along bone axis) Thickness = 1mm, Area=18mm, Heating rate 10°/min.

Typical TSDC spectra for bone and collagen samples, and conditions under which these were recorded are shown in Figs. 2 & 3. Thermograms shown in these figures were obtained when the electric fields were applied and measurements made parallel to the bone axis. No current peaks were observed in TSDC thermograms in which the fields and measurements were perpendicular to the bone axis. Samples

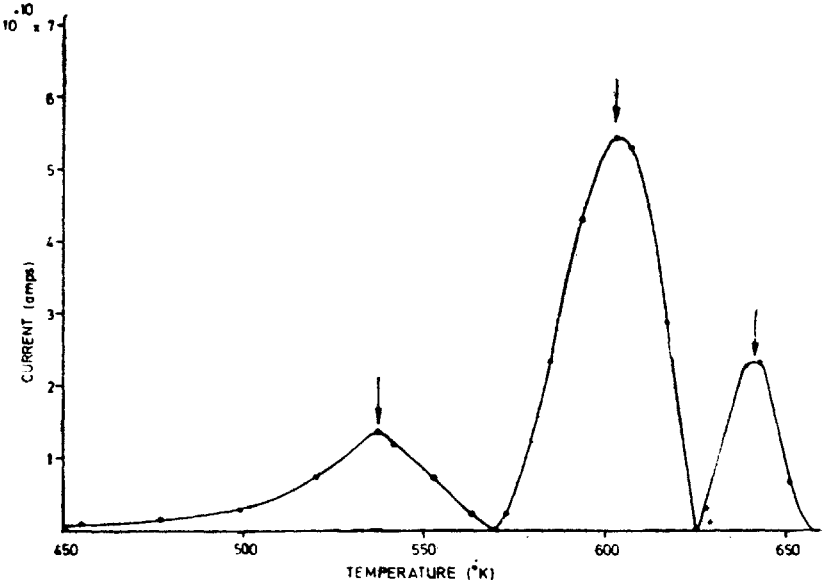

FIG. 5. SC in bone sample (measured along bone axis) Thickness=2.3 mm, Area=17.1 mm², Heating rate=10° min.

TABLE II
SC data for bones

Sample	Meas. Direction	Peak Position (°K)	Heating rate deg./min.	Remarks
Bone Sample	$\parallel^{l}$ bone axis	538, 604, 642	10	Sign reversal
,,	,,	583, 638	14	,,
,,	$\perp^{r}$ bone axis	536, 615, 638	16	No Sign reversal
Bone Collagen	$\parallel^{l}$ bone axis	536 554, 602	10	,,
,,	$\perp$ bone axis	555, 584, 616	10	,,
Bone Apatite	$\parallel^{l}$ $\perp^{r}$ bone axis	—	10	—

treated so as to remove collagen showed no current peaks in their TSDC spectra whether fields and measurements were perpendicular or parallel to the bone axis. Table I summarises the TSDC data obtained.

(*b*) *SC Spectrum* — Samples with no prior electrification were also found to generate electricity when heated. Typical SC spectra for bone and collagen samples are shown in Figs. 4 & 5 and Table II summarises the SC data obtained. It should be noted that in contrast to the situation in TSDC thermograms there were always current peaks observed in SC spectra when measurements were made perpendicular as well as parallel to the bone axis. Again, samples treated so as to remove collagen demonstrated no current peaks.

Different heating rates altered the number of current peaks of bone samples in

both TSDC and SC spectra and also resulted in current sign reversals in SC thermograms. Demineralised bone sample (collagen) showed 3 peaks in the SC spectra in similar position in both parallel and perpendicular measurements.

Discussion

Samples treated so as to remove collagen did not show current peaks in either TSDC or SC thermograms while normal or demineralised samples, which contained collagen, did show these peaks. Collagen, therefore, appears to be a necessary component of the sample structure for the current peaks to be observed. That the component for polarisation storage in bone is related to the protein phase has also been reported by Mascarenhas (1974).

It is interesting to note that SC thermograms reveal current peaks when measurements are done perpendicular and parallel to the bone axis while TSDC thermograms reveal these peaks only with parallel measurements. It appears that the orientation of the sample (i.e., its collagen fibers) plays some role in its electrical output although from these data it is difficult to determine how it does so. Also it can be observed that the peaks appear far above the poling temperature. Higher poling temperatures could not be tried as collagen degrades at temperature > 473 °K. Therefore, it can only be said that the phenomenon observed is not exactly the thermo-electret where one expects the discharge peaks at and around the region of poling temperatures, but it is more the modulation of the crosslinking of collagen fibres by the electric field.

It is also difficult to explain the appearance of SC peaks in human bone. The following two possible explanations are, however, suggested : (1) Collagen molecules have a permanent electrical moment in the direction of the longitudinal axis and behave as an electrical analog of a magnet (Athenstaedt, 1970). The SC spectra observed can be related to the disordering of dipoles as the biopolymer melts and crosslinks. A similar explanation was offered to describe why thermocurrents appeared *de novo* in alpha-Keratin (Menefee, 1974). (2) Secondly, the Costa Ribeiro effect (a phenomenon in which charge separation occurs accompanying the phase changes in dielectrics (Gross, 1954) may be involved. A bioelectrical phenomenon by which charges may become trapped within the organic matrix during the crystal growth of ionic crystals or naphthalene crystals could be sought as an explanation to the SC spectra.

Although these results do suggest an electret-like nature of bone it is by no means definite. An electret implies a prior electrification at an elevated temperature. But a possible physiological mechanism for electrification while simultaneously raising the effective temperature of bones *in vivo* is difficult to conceive and whether the electret effect is important *in vivo* remains to be seen.

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