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Piezoelectricity in hydrated frozen bone and tendon

THE piezoelectric property of connective tissue may play a role in regulating the patterns of tissue growth[1]. Most piezoelectric measurements, however, deal with dried tissue[2–4]. Observations of stress-generated voltages from hydrated connective tissue are generally insufficient to establish that the voltages are of piezoelectric origin, because of complications resulting from streaming potentials and electrode effects[5–7]. A report of the nonexistence of piezoelectricity in hydrated collagen at room temperature[8] has been criticised[9]. Use of the converse effect is most desirable in studying biological piezoelectricity[9], but for hydrated tissue the high electrical conductivity of water interferes with the establishment of an electric field inside the sample[2,4]. We therefore hydrated and then froze our connective tissue samples taking advantage of the reduced conductivity of ice compared with that of water. Our results establish the existence of the piezoelectric effect in bone and tendon under physiological conditions of moisture, but at a non-physiological temperature (– 25° C).

We used femurs and Achilles tendons of cows, aged 3 to 4 yr when slaughtered. Samples approximately 10 × 5 × 3 mm, oriented to display the piezoelectric coefficient d_{14}, were prepared and measured by the converse effect.

Measurements on dry bone and tendon were made at 24° C after drying the samples at 100°C for 24 h. Samples were fully hydrated by immersing in saline at 24° C for 24 h then after hydration, they were frozen at –25° C for 24 h and then measured at –25° C. The small dimensional changes in bone following hydration were ignored, whereas the corresponding changes for tendon were not negligible and therefore the dimensions of the frozen tendon samples were used to compute their hydrated piezoelectric coefficients.

The results (Table 1) show that hydrated frozen bone and tendon are piezoelectric. The effect of both freezing and hydrating is to reduce the magnitude of d_{14} by about a factor of two for bone and a factor of eight for tendon. About half of the decrease for tendon can be accounted for on the basis of the volume increase which accompanies hydration.

Table 1 Piezoelectric coefficients (d_{14}*) and standard deviations of bovine bone and tendon.

	Dry (at 24° C)	Hydrated (at –25° C)
Bone	5.45 ± 0.82 (22)	2.9 ± 0.6 (7)
Tendon	86.6 ± 18.4 (4)	10.2 ± 2.8 (7)

Numbers in parentheses indicate number of samples measured.
* $\times 10^{-9}$ c.g.s. e.s.u.

Whatever structural changes result from the incorporation of water by collagen, the piezoelectric property is relatively unaffected at –25° C. In view of the marked stability of collagen as determined by piezoelectric measurements[4,10], it seems unlikely that an increase to physiological temperatures would produce structural changes so drastic as to destroy the piezoelectric property. The preceding paper[11] presents evidence which supports this contention.

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