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Bone Sodium and Na^{22} Exchange: Relation to Water Content.* (25208)

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Reported values for sodium content of bone and for radiosodium exchangeability have shown considerable variation. Part of this variability is the result of age effects(1,2,3), for sodium content increases and exchangeability declines as animals become older. There still remains to be explained the variations noted among adult animals and men(1, 3,4,5). This report presents data on sodium content and radiosodium exchangeability for normal bone in a number of species, and demonstrates that the observed values fall into a regular pattern when allowances are made for variations in bone water content.

Materials and methods. The samples studied represent specimens of marrow-free bone obtained from normal animals. Human bone samples were obtained from subjects undergoing surgery, or from the autopsy room; none of the subjects suffered from disturbances of electrolyte metabolism. The human bone samples cover an age span from the 900 g premature infant to the adult, and those for the cat and rat from weanling to adult. The pigs were about 2 months old, the armadillo and fish of unknown age. The frogs ranged in weight from 3 to 85 g. A number of skeletal sites are represented: rib, skull, humerus and radius-ulna for the cat, pooled long bones of the rat, frog femur and tibia, pig and veal femur, armadillo rib, radius-ulna, and external bony plate, and rib, ilium, and long bones in man. Except for veal bone, all samples represent only the cortical portion. The human tooth samples† represent one each of a normal erupted, a normal unerupted, and a hypoplastic adult specimen. Enamel and dentin were carefully separated with the aid of a diamond grinding wheel. The teeth and veal bone had been frozen prior to analysis; all other samples of bone, including the goosefish (*Lophius americanus*),‡ represent fresh specimens. A number of bones were analyzed from this latter species, a marine teleost. Radiosodium^{22} was administered by the intravenous route to normal cats, and by the intraperitoneal route to normal rats, in a dose of 5 μc per 100 g body weight. Two hours later the animals were killed and samples of blood and bone removed for analysis. After removal of periosteum and marrow the bone samples were cut into small bits with an orthopedic rongeur, and dried *in vacuo* at 65°C. Fat was removed by ether extraction at room temperature, and the dry fat-free bone ground to a coarse powder in a mortar. Aliquots of this powder were then ashed in a muffle furnace at 525°C, and the ash taken up in 2N HCl. Sodium analyses were made either by a previously described column chromatographic technic(6) or by applying appropriate corrections to flame photometric readings of the ash

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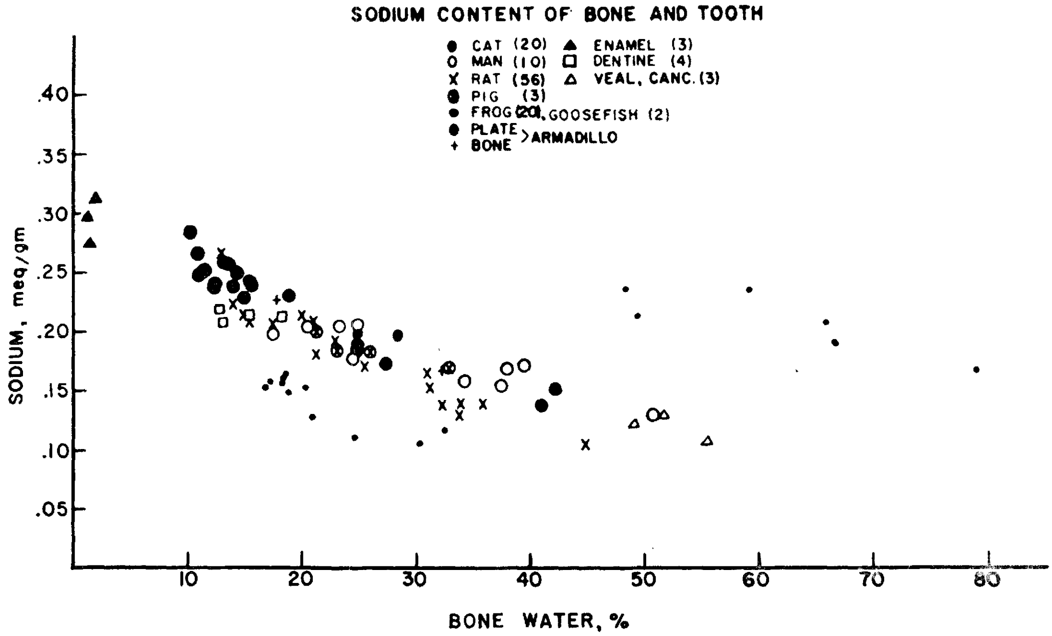

FIG. 1. Plot of sodium content against water content for various species. Number of animals indicated in parentheses. Values for the frog (•) lie below, and those for the goosefish (•) above the general curve. Samples of human bone depicted here all contained less than 5% fat.

solutions. $Radiosodium^{22}$ activity in bone ash solution and serum was determined in a scintillation counter, with appropriate correction for resolving time.

Results. Fig. 1 illustrates data for sodium content as a function of water content in the various species. In mammals there is an inverse curvilinear relationship between these two variables which is independent of species or skeletal site. It is of interest that such tissues as armadillo plate and human dentin conform to this general pattern, and that values for dental enamel are in fair agreement. Cancellous bone values can also be included.

It is evident that values for the 2 nonmammalian species do not conform to the general trend for mammals. These 2 species were deliberately chosen for analysis because they exhibit serum sodium concentrations far removed from the normal mammalian level of approximately 140 meq/l. In the 20 frogs we studied, where it is to be seen that bone sodium values fall distinctly below the general curve, the average serum sodium concentration was 110 meg/l. In the 2 goosefish, where bone sodium content is very high, serum sodium concentration averaged 194 meq/l. It would thus appear that bone sodium content reflects the concentration of this ion existing in extracellular fluid during bone formation. This contention is supported by previous studies(7) showing a reduction of bone sodium content in young rats fed a low sodium diet, with resultant hyponatremia.

One further discrepancy concerns a number of human bone samples containing large amounts (8-50% by weight) of ether-extractable material. These data, which have been omitted from Fig. 1, occupy positions well above the general curve for mammals when sodium and water contents are calculated on a fat-free basis. Samples containing 15% water, for example, have about 0.27 meq Na/g instead of the expected 0.24 meq/g; at the 30% water value these become 0.23 and 0.16 meq/g, respectively. Interestingly enough, the discrepancy is reduced somewhat when the calculations are made on a fat-containing basis.

In Fig. 2 radiosodium exchangeability is plotted against bone water content for the 2 species we have studied thus far. Here too there appears to be a relationship between these 2 variables, exchangeability mounting

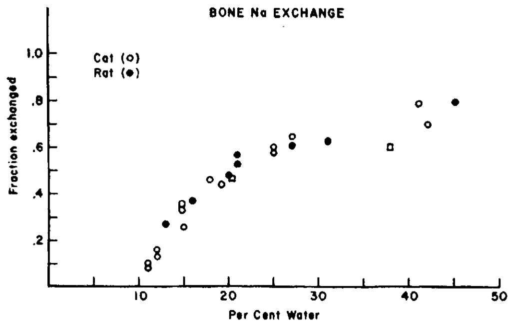

FIG. 2. Plot of radiosodium exchangeability against bone water content. Data for the cat represent individual samples, (cortical bone—○, cancellous—□; those for the rat averages of 3-11 animals.

as bone water increases. A similar phenomenon has been reported for radiophosphorus (8) and radiobromide(9). Fraction exchanged is calculated as the ratio bone: serum specific activity 2 hours following injection of radiosodium^{22}.

Discussion. The relationships depicted here provide a means of systematizing data on sodium content and radiosodium exchange in normal bone, and may prove useful in evaluating experiments involving a net change in bone composition. The conclusions of others (4,5) that bone sodium content varies from one skeletal site to another must be re-evaluated in the light of our findings; close inspection of the data from each of these reported studies also reveals an inverse relationship between sodium and water content. The previously reported effect of age(1,2,3) on bone sodium content may merely reflect age changes in water content. Of interest is the correspondence between tooth and bone and such unusual structures as armadillo plate, a fully calcified tissue. Cancellous bone exchange is in keeping with its water content. The observations of others(10) that radiosodium exchange in dentin exceeds that of enamel is also consistent with our findings.

The aberrant values noted for human bone samples of high fat content are difficult to interpret. A review of the individual data of Agna *et al.*(4) (Knowles, personal communication) reveals a similar phenomenon. Technical difficulties in removing such large amounts of fat may be at fault, though there is also the possibility that the supporting tissue associated with skeletal fat actually contributed a certain amount of extracellular electrolyte. This latter contention is supported by the finding of a higher chloride content in the high fat samples. For 10 samples containing less than 5% fat, the average Cl content was 0.029 meq/g fat-free wet weight, while that of the 11 high fat samples averaged 0.048 meq/g.

Finally, our data on frogs and fish can be offered in support of the hypothesis of Neuman and Neuman(11) that bone sodium content is a function of the extracellular fluid concentration of this ion.

Summary. 1) A study of marrow-free bone in a number of mammals reveals that sodium content is inversely related to water content. This relationship holds for a number of skeletal sites, and for dental structures. 2) Studies of 2 species with aberrant serum sodium values suggests that bone sodium content also varies, in direct fashion, with serum sodium content. 3) Radiosodium exchangeability of bone is also a function of bone water content.

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