

VIEWPOINT |

Sweat electrolyte concentrations obtained from within occlusive coverings are falsely high because sweat itself leaches skin electrolytes

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D. B. DILL'S (12) 1930s observations of humans working in desert heat made him skeptical of the high sweat chloride concentrations reported in the literature. At fault, he surmised, might be methods of sweat collection that "restricted opportunity for evaporation" (p. 763). For this reason, he developed whole body washdown (WBW) methods, which became de rigueur in his, and later in D. L. Costill's, work (7). In 1953, Kleeman et al. (20) pursued this issue by simultaneously determining sweat electrolyte concentrations in arm bags and as obtained via WBW. At their disposal was the recently developed flame photometer, which added the capability for measuring sodium and potassium concentration to that for chloride. Just as Dill had suspected, Kleeman et al. found that the arm bag method, in which evaporation was prevented, always gave significantly higher concentrations of all three ions than those obtained via WBW. Thinking along Dill's thread, they suggested that wet skin alters the composition of sweat.

In this note I hypothesize that aqueous solutions remaining on skin, including sweat, rapidly leach electrolytes, including sodium, potassium, and chloride, from its outermost layer, the stratum corneum (SC). Consequently, concentrations of sweat electrolytes obtained from within an occlusive covering are artifactually high. The fluid within the covering becomes something other than the sweat that emerged from the sweat duct and was deposited on the skin. It will therefore be referred to as "faux sweat."

Three lines of evidence support this leaching hypothesis: 1) anomalously high concentrations of potassium in small volumes of faux sweat (similar data exist for sodium); 2) a direct demonstration of the leaching of urocanic acid into aqueous solutions on the surface of skin; and 3) current models of SC behavior as a function of its water content.

ANOMALOUS POTASSIUM CONCENTRATIONS IN FAUX SWEAT

When evaluated by WBW, sweat sodium and chloride concentrations increase as a function of sweat rate for an individual at a particular state of heat acclimatization (7, 10). Sweat potassium concentration, however, stays relatively constant, regardless of sweat rate (7, 8, 11), level of acclimatization (7, 8, 9, Armstrong cited in Ref. 1), or an individual's accompanying sodium concentration (5, 11, 15). WBW sweat potassium concentrations are, moreover, at a physiologically significant value, namely that of plasma potassium concentration—~4 meq/l (5–9, 11, 15, 23). Small volumes of faux sweat, on the other hand, yield high potassium concentrations

(4, 13, 20, 21, 24, 29), sometimes exceeding 50 meq/l (24). Leaching explains this observation: a certain amount of SC potassium is leached into the volume of leaching water. If that volume is small, then the resulting concentration can be quite large.

This phenomenon has also been observed for sodium (29). Verde et al. (29) discarded samples collected from the palm of the hand because of the small volume of sweat, but noted nonetheless that the concentrations occasionally exceeded sodium's plasma concentration (140 meq/l).

LEACHING OF UROCANIC ACID AND ELECTROLYTES

In the early 1950s, urocanic acid was reported to be a constituent of sweat (cited in Ref. 2). Subsequently, Brusilow and Ikai (2) demonstrated that this was an artifactual error, arising from its "elution" from skin. Indeed, urocanic acid (and its parent molecule, histidine) are known constituents of the water soluble group of entities collectively called natural moisturizing factor, or NMF (27).

Tanaka et al.'s (28) work with sweat electrolyte collection provides evidence of electrolyte leaching. These investigators pressed an open-ended glass cylinder containing 2 ml distilled water against skin for one minute to collect sweat electrolytes. Prior to exercise, and hence prior to sweating, they collected "blank" samples. Their blanks nonetheless contained significant quantities of sodium, potassium, and chloride. For example, they report a potassium concentration of 4 $\mu\text{eq/l}$ in the forearm blank, from which it can readily be calculated that the 2 ml solution contained 8 nmol potassium. If the source of this potassium was the SC, this represents $10 \text{ nmol} \cdot \text{cm}^{-2}$ of surface skin (the cylinder was 1.0 cm in diameter) and is consistent with Verissimo et al.'s (30) measurements of potassium's abundance in the SC. More specifically, from Fig. 3 of the cited reference, it can be calculated that potassium's abundance in the SC is $\sim 10^3 \text{ nmol} \cdot \text{cm}^{-2}$. Thus the amount of potassium in Tanaka's cylinders represents $\sim 1\%$ of the available SC potassium ($10/10^3 \text{ nmol} \cdot \text{cm}^{-2}$)—a reasonable amount to have been leached in the 1 min of extraction by distilled water in the cylinder.

CHANGING NATURE OF THE STRATUM CORNEUM WITH INCREASING WATER CONTENT

The SC serves as a barrier to the entry of harmful entities into skin, as well as to excessive loss of water from the skin (17). Its barrier function varies with its water content, which is

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estimated to be 20–30% (3). Its water content is dependant on the ambient concentration of water vapor (26). This variability is due to the presence of a group of highly hygroscopic and water-soluble substances, NMF, which constitute up to 10% of the SC's dry weight (27). While the prime constituents of NMF are the amino acids of proteolyzed Filaggrin (27), sodium, potassium, and chloride are also significant mole fraction constituents (14, 22, 30).

When the water content of the SC is relatively small, the water is essentially bound and immobile (18). When, however, the water content exceeds ~33%, the SC resembles a polymeric hydrogel (17, 18). The water in this system has “melted” (18) and ionic mobilities approach those of electrolytes in bulk water (16). Thus skin surface water and SC water become part of a continuous aqueous solution, with a thermodynamic tendency for the water soluble ions in the stratum corneum to be homogeneously distributed throughout the resulting solution.

IMPLICATIONS

First, because faux sweat electrolyte concentrations are higher than those of true sweat, they extrapolate to overestimations of electrolyte loss in sweat. Therefore they are not suitable for mass-balance studies, nor for recommendations concerning electrolyte intake for workers or athletes in heat, nor for speculation as to the possible role of sodium loss in the etiology of exercise-associated hyponatremia (EAH). Second, reports of other entities' presence in sweat must be re-evaluated if analysis was of faux sweat. Third, “sweat” potassium concentrations greater than plasma potassium concentrations are indicative of leaching and hence also indicative of artifactually high sodium and chloride concentrations. Fourth, if skin can be kept dry through the period of sweating, perhaps by using wicking material to absorb sweat, it may be possible to obtain reliable estimates of local sweat electrolyte concentrations. Fifth, the Pilocarpine Sweat Test, diagnostic for cystic fibrosis, is based on a well-characterized defect in sweat duct chloride reabsorption (25). By simultaneously measuring potassium concentration and keeping the skin dry during sweat collection, it may be possible to increase this test's reliability.

Finally, the leaching hypothesis is consistent with a straightforward model of sweating and sweat (25). Sweating delivers water, a powerful coolant when it evaporates, to the skin. The source of sweat water is interstitial fluid, secreted essentially intact into the secretory coil, and rendered hypotonic in the duct by absorption of just two entities, sodium and chloride. Sodium and chloride, essential to the maintenance of extracellular fluid osmolality, are thus conserved.

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