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

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DB Dill’s 1930’s observations of humans working in desert heat made him skeptical of the high sweat chloride concentrations reported in the literature (11). At fault, he surmised, were methods of sweat collection which “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 DL Costill’s, work (6) (with the added control of ion-free clothing and toweling). In 1953, Kleeman simultaneously determined sweat electrolyte concentrations in arm-bags and via WBW (20). Kleeman’s group used the recently developed flame photometer to measure sodium and potassium concentrations as well as chloride. They found that arm-bag collection, which prevented evaporation, always gave significantly higher concentrations of all three ions than those obtained via WBW. Consistent with Dill’s thinking, Kleeman suggested that wet skin alters the composition of sweat.

In this note I hypothesize that aqueous solutions remaining on skin, including sweat, leach electrolytes from the skin’s outermost layer, the Stratum Corneum (SC). Consequently, concentrations of the sweat electrolytes sodium, potassium, chloride and lactate 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. I will therefore refer to it as ‘faux sweat.’

Three lines of evidence support this leaching hypothesis: (1) anomalously high concentrations of potassium and sodium in small volumes of ‘faux sweat;’ (2) direct observations of urocanic acid and urea leaching, as well as incidental observations of electrolyte leaching into aqueous solutions on the surface of skin and (3) current models of SC behavior as a function of its water content.

ANOMALOUS ELECTROLYTE 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 (6, 9). Sweat potassium concentration, however, stays relatively constant, regardless of sweat rate (6, 7, 10), level of acclimatization (6, 7, 8, Armstrong cited in 1), or an individual’s
accompanying sodium concentration (4, 10, 15). Moreover, WBW sweat potassium concentrations are about 4 mEq·liter⁻¹ (4, 5, 6, 7, 8, 10, 15, 23), a physiological significant value -- namely that of plasma potassium concentration. Small volumes of ‘faux sweat,’ on the other hand, yield high potassium concentrations (3, 12, 20, 21, 24, 29), sometimes exceeding 50 mEq·liter⁻¹ (24). Similarly, in the case of sodium, Verde (29) reported concentrations greater than plasma sodium concentrations (140 mEq·liter⁻¹) in very small volumes of ‘sweat.’ Leaching explains the high concentrations observed for small sweat volumes: a certain amount of SC leachate divided by a small volume of leaching solvent yields a high quotient.

Electroneutrality in ‘faux sweat’ is preserved by leaching of chloride and lactate. These, the predominant anions of sweat (10), are also present in the SC (13, 22, 26, 30). Patterson (23) simultaneously collected ‘sweat’ from eleven local sites and via WBW. Their data (Table 1), for a wide range of concentrations, shows the sum of sodium plus potassium molar concentrations to be approximately equal to that of chloride plus lactate.

LEACHING OF UROCANIC ACID, UREA AND ELECTROLYTES

In separate experiments, two entities have been directly observed to be leached into sweat. Brusilow (2) demonstrated that urocanic acid is not present in sweat and that earlier reports of its presence were based on the artifactual error caused by leaching. Indeed, urocanic acid (and its parent molecule histidine) are known constituents of the water soluble group of entities in the SC collectively called Natural Moisturizing Factor (NMF) (27). Gordon (14) showed via ¹⁴C labeling that urea, a known constituent of both sweat and NMF, “dissolves” from the epidermis into sweat, leading to sweat urea concentrations higher than plasma concentrations.

Tanaka’s work with sweat electrolyte collection incidentally demonstrates electrolyte leaching (28). These investigators gently 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 and found
them to contain significant quantities of sodium, potassium and chloride. For example, they report a potassium concentration of 4 µEq·liter⁻¹ in the forearm “blank”, from which it can readily be calculated that the 2 ml solution contained 8 nmol potassium. This represents 10 nmol·cm⁻² of surface skin (the cylinder was 1.0 cm in diameter), or about 1% of the available SC potassium as calculated from Verissimo’s data (30). 

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). Integral to this barrier function is its water content, which changes as a function of the ambient concentration of water vapor (26). NMF, whose highly hygroscopic substances represent 10% of the SC’s dry weight (27), is responsible for the SC’s rapid absorption of atmospheric water. While the prime constituents of NMF are the amino acids of proteolyzed Filaggrin, including urocanic acid (27), the electrolytes sodium, potassium, chloride and lactate are also significant mole fraction constituents (13, 22, 30).

When the SC water content is relatively small, the water is bound and immobile (18). When, however, the water content exceeds about 33%, water mobility greatly increases (17, 18). The SC water has “melted” (18) and ionic mobilities have also increased (16). In this system, ions can diffuse to the SC surface and into an aqueous solution on the skin surface.

IMPLICATIONS

First: because ‘faux sweat’ electrolyte concentrations are higher than those of true sweat, they always 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). Secondly: reports of entities not present in interstitial fluid but observed in ‘sweat’ must be re-evaluated. Thirdly: ‘sweat’ potassium concentrations greater than
plasma potassium concentrations are indicative of leaching for both local and WBW reports. Fourthly: 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. Fifthly: the Pilocarpine Sweat Test (QPIT), diagnostic for Cystic Fibrosis, is based on a well-characterized defect in sweat duct chloride re-absorption (25). By simultaneously measuring potassium concentration and keeping the skin dry during sweat collection, it may be possible to increase this test’s reliability.

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 is interstitial fluid, secreted essentially intact into the secretory coil (references cited in 25), and rendered hypotonic in the duct by absorption of just two entities, sodium and chloride. Thus are conserved the two entities essential to the maintenance of extracellular fluid osmolality, and therefore of plasma volume.
REFERENCES


