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SWEAT ETHANOL CONCENTRATIONS ARE HIGHLY CORRELATED WITH CO-EXISTING BLOOD VALUES IN HUMANS

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SUMMARY

This study compared the concentration of ethanol, both absolute and relative to water content, in sweat and blood. Ten male volunteers consumed approximately 13 mmol (kg body weight)$^{-1}$ of ethanol. Blood and sweat samples were collected approximately 1, 2 and 3 h following ingestion. Sweat was collected following pilocarpine iontophoresis using an anaerobic technique that prevented ethanol evaporation. In addition, the water content of sweat and blood samples was determined. The correlation between sweat and blood ethanol, expressed in mmol l^{-1}, was $r = 0{\cdot}98$. The slope of the relationship was 0·81. When corrected for the water content in each sample, and expressed as mmoles per litre of water, the correlation remained very high ($r = 0{\cdot}97$) while the slope increased to 1·01. These results suggest that rapid and complete equilibrium of ethanol occurs across the sweat gland epithelium.

INTRODUCTION

Following consumption in humans, ethanol diffuses rapidly and uniformly throughout the existing total body water (Pawan & Grice, 1968; Loeppky *et al.* 1977; Dubowski, 1982*a*,*b*). However, there is no existing sweat pool in resting humans (Lloyd, 1962). Rather, sweat is formed in eccrine glands as needed via secretion (Quinton, 1983). These facts beg the question of whether the ethanol concentration of sweat is equal to that found in other body water spaces. Nyman & Palmlov (1936) reported that sweat ethanol concentration was only 81 % of that found in blood. More recently, Brusilow & Gordes (1966) found that sweat ethanol, in both humans and cats, was approximately 90 % of that found in plasma. Therefore, these studies would suggest that the sweat gland epithelium is not completely permeable to ethanol and thus has a reflection coefficient for ethanol greater than zero. However, neither study measured both the ethanol and water concentrations of their samples. It is well known that variability in the solid content of body fluids will affect their ethanol concentration. Thus it has been strongly suggested that the concentration of ethanol in any body fluid should be expressed in terms of the actual water content of the specimen analysed (Pawan & Grice, 1968).

The purpose of this study was to compare the concentration of ethanol, both absolute and relative to water content, in sweat and blood. The results may have both physiological and forensic medicine applications.

METHODS

The subjects for the study were 10 male volunteers. The mean (± S.D.) age, height and weight for the group was 26 ± 2 years, 179 ± 10 cm and 81 ± 8 kg, respectively. Each read and signed an approved

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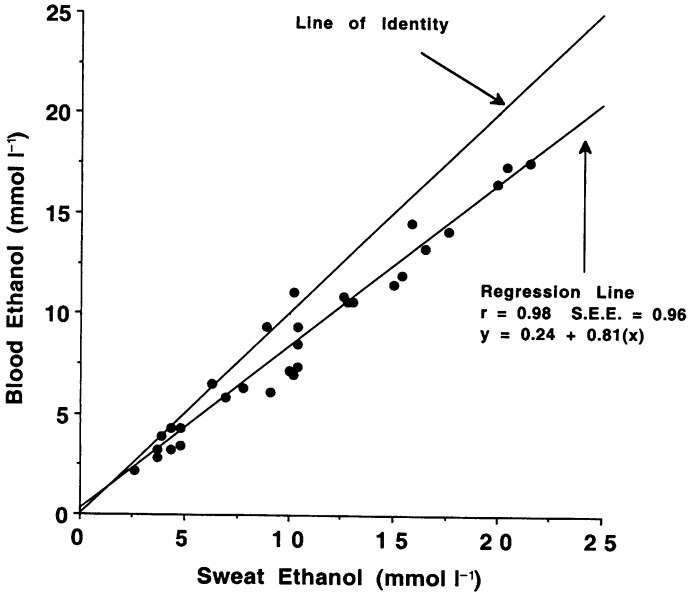

Fig. 1. The correlation of sweat *vs.* blood ethanol concentration, expressed in mmol l^{-1} of sample.

informed consent form prior to testing. No subject had consumed any ethanol for at least 24 h prior to testing, but no other dietary controls were imposed.

Each subject consumed approximately 13 ± 2 mmol (kg body weight)$^{-1}$ (i.e. 0·8–0·9 g kg^{-1}) of ethanol diluted to a 15 % solution with fruit juice within a 30 min period of time. Blood and sweat samples were collected approximately 1, 2 and 3 h following the start of ethanol ingestion.

Sweat was harvested from an approximately 7 cm^2 area on the flexor surface of the forearm for 15 min immediately following pilocarpine iontophoresis using a Macroduct sweat collector (Wescor, Logan, UT, USA). The rate of evaporation from the open end of the spiral capillary tube of the Macroduct is nil (0·16 $\mu l\ h^{-1}$) (Webster, 1983). Pilot data showed a 97 % recovery when Microduct collectors were spiked with an 18 mmol l^{-1} ethanol standard (Sigma) for 15 min. The iontophoresis current was fixed at 1·5 mA (i.e. approximately 0·2 mA cm^{-2}) for 5 min. Pilocarpine nitrate was delivered via reagent-impregnated discs (Pilogel, Wescor) (Buono & Sjoholm, 1988). Blood was collected from prewarmed, free-flowing, fingertip punctures into heparinized capillary tubes (Dubowski, 1982*a*, *b*) at the mid-point of each sweat collection period. Blood and sweat samples were immediately placed into airtight plastic vials and stored at 4 °C. Within 24 h, water and ethanol concentrations were measured, in duplicate, in each sample. Ethanol was measured using an enzymatic technique (alcohol dehydrogenase, Sigma). The procedure had an intraclass test re-test reliability of 0·99, and a coefficient of variation of 2·1 %. Water concentration was measured by drying each sample to constant weight according to the procedures outlined by Ohira *et al.* (1977).

The correlations between sweat and blood ethanol concentration, both absolute (mmol l^{-1}) and relative to the water content of each sample (mmol (l water)$^{-1}$) were determined using the Pearson product moment procedure.

RESULTS

The correlation between sweat and blood ethanol (expressed in mmol l^{-1}) is presented in Fig. 1. The two variables demonstrated a significant linear relationship with $r = 0·98$. Furthermore, the slope of the relationship was 0·81. Thus, across all concentrations tested, blood ethanol concentration averaged 81 % of that found in sweat.

The correlation between sweat and blood ethanol, corrected for water content in each sample (expressed in mmol (l water)$^{-1}$) is presented in Fig. 2. The correlation remained very high with $r = 0·97$, but the slope of the relationship increased to 1·01.

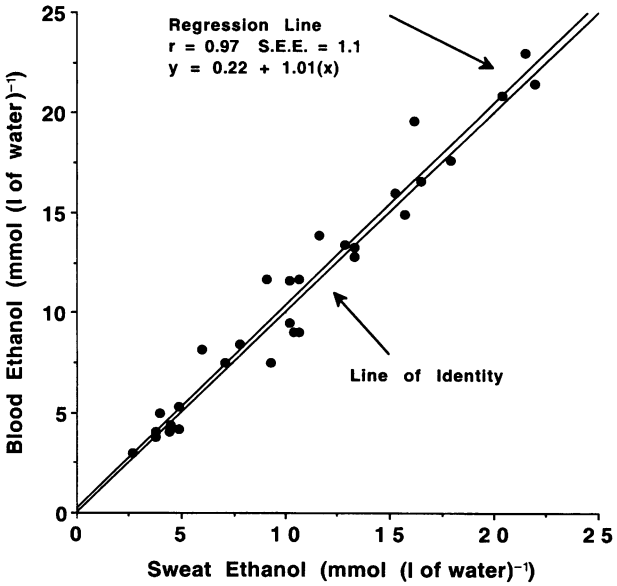

Fig. 2. The correlation of sweat *vs.* blood ethanol concentration, corrected for water content of each sample and expressed in mmol l^{-1} of water.

DISCUSSION

The results of the current study suggest that blood ethanol can rapidly equilibrate with sweat. Figure 1 shows that blood and sweat ethanol concentrations are highly correlated ($r = 0{\cdot}98$), with a slope of 0·81. However, water content of blood, in humans, is approximately 80 % (Ohira *et al.* 1977), while sweat is approximately 98 % water. Thus, one would predict that if equilibration occurred the blood *vs.* sweat ethanol relationship should have a slope of approximately 0·80, which agrees favourably with the 0·81 slope reported in Fig. 1.

As seen in Fig. 2, when sweat and blood ethanol concentrations were corrected for water content, the slope of the relationship increased to 1·01. This finding suggests that ethanol equilibrates rapidly between sweat and blood.

However, the above results do not fully agree with previous studies. Nyman & Palmlov (1936) were probably the first to compare sweat and blood ethanol concentrations. In that study, sweat was produced by having the subjects sit in a steam bath (approximately 50 °C) following which the sweat droplets that appeared on the skin were collected into glass capillary tubes. The authors identified several methodological concerns which included water vapour condensation on the skin which could dilute the sweat, and evaporation of ethanol prior to collection due to the high ambient temperature. Both of these phenomena would decrease the sweat ethanol concentration and may explain why the reported sweat ethanol was only 81 % of that found in blood.

They did attempt to collect sweat while the subject's arm was confined up to the axilla in a tightly closed glass cylinder, the free end of which was completely fitted around the arm by means of a rubber cap. Knowing the dead space of the cylinder and making an estimate of the evaporation partition coefficient between sweat and air, they hypothesized that the 'real' concentration of ethanol in sweat should be about 15 % more than whole blood. Their theoretical estimate, made over 60 years ago, is consistent with current results which show

that, on a volume for volume basis, sweat ethanol concentration is approximately 19 % more than whole blood.

More recently, Brusilow & Gordes (1966) reported that sweat ethanol, in both humans and cats, was approximately 90–95 % of that found in plasma water. This value is somewhat higher than that previously reported by Nyman & Palmlov (1936). Specifically, Brusilow & Gordes (1966) collected their sweat samples under a mineral oil vapour barrier, thus reducing the potential of ethanol evaporation prior to collection. They also expressed their plasma ethanol concentrations as millimoles per litre of water by dividing all samples by 0·93 (i.e. an assumed constant for the water content of plasma). The dose of ethanol used in their study was very small, and only produced a mean plasma ethanol concentration of 2·6 mmol l^{-1}. By comparison, peak blood ethanol concentrations in the current study approached 20 mmol l^{-1}.

The methodology used in this current study eliminates many of the problems associated with earlier studies. As previously mentioned in the Methods section, the Macroduct collectors greatly reduce the ethanol evaporation problem. Furthermore, in the current study, the water content of blood and sweat samples was measured, eliminating the need to use an 'assumed' value.

In conclusion, the current study found that sweat and blood ethanol concentrations are highly correlated (Fig. 1). In addition, when expressed as mmoles per litre of water (Fig. 2), they are also proportional to each other. These results suggest rapid equilibrium of ethanol across the sweat gland epithelium.

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