

TRANSDERMAL ALCOHOL MEASUREMENT: A REVIEW OF THE LITERATURE

J.S. HAWTHORNE¹ AND M.H. WOJCIK²

ABSTRACT

The body of scientific literature on transdermal alcohol testing dates back almost 70 years. The first viable method enabling this knowledge appeared in the 1980s in the form of an alcohol “sweat-patch”. Recently, transdermal alcohol monitoring bracelets have been used to measure transdermal vapor alcohol. Based on published research in this field, one can conclude that measuring alcohol transdermally on a constant basis provides an effective screen for alcohol consumption and a reasonable approximation of the magnitude of that consumption.

RÉSUMÉ

L'essentiel de la littérature scientifique sur les analyses transdermiques de l'alcool remonte à près de 70 ans. La première méthode viable utilisant cette approche est apparue dans les années 1980 sous forme de «timbre-sueur». Des bracelets mesurant en continue l'alcool transdermique ont été récemment utilisés pour mesurer les vapeurs d'alcool s'évaporant à travers la peau. Les études publiées dans ce domaine démontrent que la mesure continue de l'alcool transdermique permet un dépistage de l'alcool consommé et une estimation approximative de l'ampleur de cette consommation.

INTRODUCTION

Alcohol testing by transdermal (i.e., through the skin) methods is relatively unknown compared to blood, breath, or urine testing. Over the past several years, products that use transdermal alcohol measurement to screen for alcohol consumption and estimate Blood Alcohol Concentration have appeared in the marketplace.

The purpose of this article is to examine the science of transdermal alcohol testing by summarizing the scientific literature previously published in this field. This literature documents research that dates back almost 70 years, and it provides a solid scientific foundation for the validity of transdermal alcohol testing.

EARLY RESEARCH

The fact that measurable amounts of ingested alcohol are excreted through human skin was first published in 1936 (1), when Nyman and Palmlov estimated that 1% of ingested alcohol is ultimately excreted through the skin. Little additional work was done in this field for 30 years subsequent to their original study. However, a number of papers were published in the 1960s and 1970s that pertained specifically to how the body processes drugs, alcohol, and non-electrolytes in the skin and sweat glands (2–5).

1. Chief Technology Officer and co-founder of Alcohol Monitoring Systems, Inc.
2. Vice President for Products for Alcohol Monitoring Systems, Inc.

SWEAT ALCOHOL ANALYSIS

The first concept that utilized transdermal alcohol testing was an alcohol “sweat-patch”. This patch was applied to the user’s skin for a period of several days, where it absorbed liquid sweat excreted through the skin. The patch was removed and analyzed using separate equipment in order to determine the amount of ethanol that each sweat-patch absorbed. These results were then tied to the consumption of alcoholic beverages.

A significant amount of research was performed with the sweat-patch between 1980 and 1984 (6–10). This research concluded that there was a statistically significant linear relationship between the concentration of ethanol in sweat and the average concentration of ethanol in blood (BAC³). Results of this testing were also 100% sensitive and specific, meaning the testing clearly differentiated drinkers from non-drinkers and had no false positives (6).

Further sweat-patch development led to simpler methods of quantifying the concentration of ethanol in sweat without using expensive laboratory equipment, such as a gas chromatograph. For example, the patch was placed in a sealed tube, and a fuel-cell-based portable breath tester was used to measure the alcohol concentration in the headspace above the patch. This established a reference point that was then compared to at least three “standard” ethanol solutions, including a zero, to provide an estimate of ethanol concentration. Researchers concluded that the method was sound (8). One of the technical difficulties with the sweat-patch was that the patch is susceptible to a potential for back-diffusion of ethanol from the patch back across the skin (9).

TRANSDERMAL VAPOR ALCOHOL ANALYSIS

While sweat-patch research focused on ethanol concentrations in liquid sweat, other research was conducted in the late 1980s that measured the ethanol concentration in vapors formed above the skin.

The amount of direct excretion of unchanged alcohol is approximately 1% in sweat and perspiration. Alcohol distributes throughout the body in relationship to each body part’s water content. “Insensible Perspiration” is the vapor that escapes through the skin when we sweat. It cannot be seen or detected within the normal confines of our olfactory system (nose). Generally, the water concentration in the skin is very low in relationship to other organs of the body. Thus, alcohol migrates last through the skin, resulting in a slightly slower - but ultimately complete - Blood Alcohol Curve (See Figure 1 for a more detailed view of the composition of the dermis/skin.).

Research at the Indiana University School of Medicine entailed placing polyethylene bags around the hands of human subjects, measuring ethanol in the insensible perspiration that accumulated in the bag, and comparing those measurements to fixed ethanol standards (11). This study concluded that, “Ethanol gas is readily excreted in insensible perspiration in sufficient quantities to allow reliable estimation of BAC.” The study further concluded that, “Henry’s Law applies to insensible perspiration in the same manner it applies to breath”, suggesting the possibility of a fixed-partition ratio between ethanol concentrations above the skin and BAC. This study was the first published research to note that ethanol concentrations above the skin had clear absorption and elimination phases that corresponded to BAC. In addition, the study noted a distinct, measurable lag between peaks “by as much as 25%”.

3. Blood Alcohol Concentration, or BAC, is the amount of alcohol per fixed unit of blood. It is usually defined as grams of ethanol per deciliter of blood (g/dL) or percent weight of ethanol per volume of blood (%w/v). For example, 0.05 g/dL is the same as 0.05%.

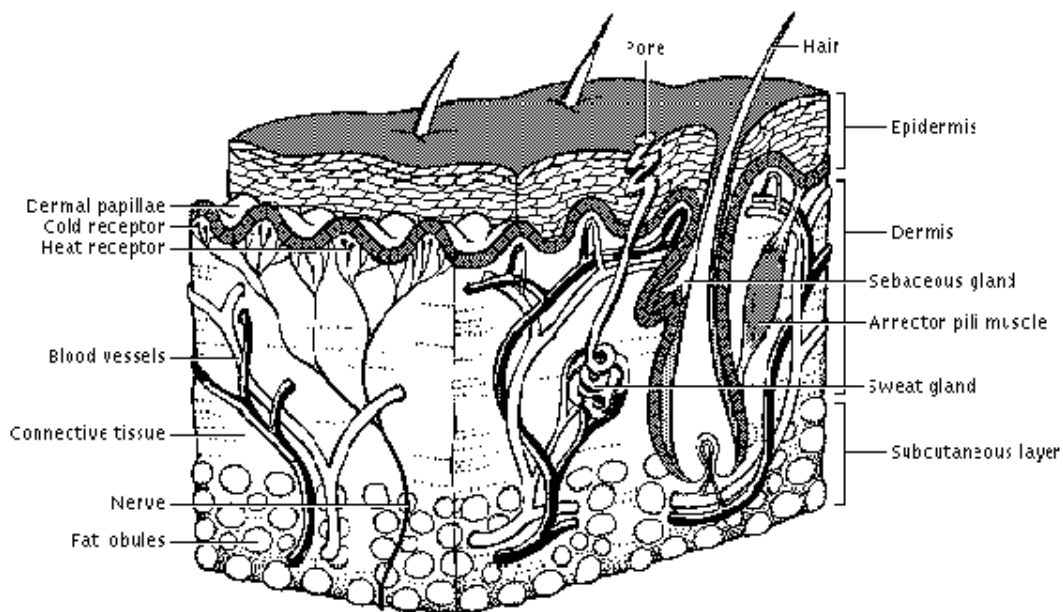


Figure 1. Cross Section of Human Skin.

A follow up study was later conducted at the Indiana University School of Medicine (12) to further study the possibility that a fixed-partition ratio exists between ethanol concentrations above the skin and BAC. This study concluded that the pharmacokinetic parameters for Transdermal Alcohol Concentration (TAC⁴) are essentially different from those of Breath Alcohol Concentration (BrAC⁵) and BAC, and that BAC could not be accurately estimated from TAC in the same manner as from BrAC. Therefore, detecting BAC using transdermal measurement methods should be regarded only as a screening method to establish continued abstinence.

Similar research was performed at the University of Toronto, also during the late 1980s. However, this research dispensed with the polyethylene bags and complex laboratory equipment and used a portable ethanol sensor, placed directly above the skin, to measure ethanol vapors excreted by both rats and humans (13,14). Like all prior studies, the University of Toronto researchers concluded that there was a very high correlation between ethanol concentration above the skin to both BAC and to BrAC. In addition, the study recorded distinct absorption, peak, and elimination phases in controlled dosage experiments. Finally, these researchers suggested that electrical signals triggered by high skin vapor ethanol concentrations could be used to activate a warning device for problem drinkers or law enforcement, and in fact, their crude device was probably the closest precursor to today's alcohol monitoring bracelets.

4. A variety of terms have been used by researchers to refer to the concentration of ethanol in both liquid sweat and insensible perspiration. We will standardize on Transdermal Alcohol Concentration, or TAC, and define TAC to be the measured transdermal ethanol concentration transformed by parameters that equate it to BAC.
5. Breath Alcohol Concentration, or BrAC, is the breath corollary to BAC. It is defined as grams of ethanol per 2100 deciliters of exhaled air. By definition, BrAC = BAC when assuming that 2100 dL of exhaled air contains the same amount of ethanol as 1 dL of blood. Although this 2100:1 ratio, called the partition ratio, varies from person to person, it is generally accepted to be the average value for the adult population.

TRANSDERMAL ALCOHOL BRACELETS

The 1990s ushered in a new era of measuring devices related to transdermal alcohol measurement, including development of the Wrist Transdermal Alcohol Sensor (WrisTAS™), by Giner, Inc., and the Secure Continuous Remote Alcohol Monitor® (SCRAM®) bracelet by Alcohol Monitoring Systems, Inc. (AMS).

In studies using the WrisTAS device (15,16,22), it was again found that TAC curves and BAC curves were highly correlated in both amplitude and shape, but that the onset of the TAC peak was delayed by 30 to 120 minutes. Thus transdermal alcohol measurements provided a noninvasive and continual method for estimating BAC that was comparable with estimates obtained from blood and breath, although delayed in time. This research also concluded that sober test subjects never produced a signal that could be interpreted as a drinking curve, and that transdermal ethanol testing showed great promise for assessment of alcohol consumption on a continuous and real-time basis.

Research was conducted using SCRAM Bracelets at approximately the same time initial WrisTAS research was published. SCRAM Bracelet results were entirely consistent with all published research. Particularly, it was concluded that there was sufficient volume of ethanol in insensible perspiration to reliably estimate BAC, that measured TAC curves were highly correlated with BrAC curves in both shape and magnitude, and that there was a distinct delay between peak BrAC and peak TAC (See Figure 2 for an example of BrAC to TAC delay). Subsequent research performed using the SCRAM Bracelet also resulted in estimating a TAC:BAC partition ratio. This equates TAC to BAC, on average. It is important to emphasize that this is an average value intended for practical use in determining if alcohol consumption has taken place and its approximate magnitude. The pharmacokinetics of transdermal alcohol are highly complex, and numerous sources of variation, both among different people and within the same person, have been documented in the published literature (5,12,16–18).

Beginning in 2002, the Michigan Department of Corrections (MDOC) began testing of the SCRAM Bracelet on offenders (19). MDOC personnel concluded that the “SCRAM System clearly meets the primary objective of accurately measuring alcohol consumption.” They also concluded that comparisons between TAC and BrAC measurements were accurate.

Further research using the SCRAM bracelet was recently conducted at the University of Colorado (20). This research was conducted in both a controlled laboratory environment and a community environment. The research concluded that, as described previously, the TAC curve is right-shifted from the BrAC curve, and that transdermal peaks occurred later and were lower. As with previous research, this research also concluded that transdermal testing produced no positive TAC curves unless the subjects were consuming alcohol. Through comparative analysis of BrAC results and TAC results the researchers in this study concluded that individual TAC results cannot be considered quantitatively equivalent to simultaneously obtained breath results, suggesting that transdermal testing is not a direct replacement for breath testing equipment.

As for applications of transdermal technology, the researchers concluded that although individual readings from the device cannot be considered equivalent to blood alcohol concentrations, on average the device does provide meaningful information about relative alcohol concentrations. In criminal justice programs, the device could be used as a method to qualitatively identify drinking episodes, to monitor drinking among alcohol dependent offenders to reduce recidivism, and to identify individuals in need of treatment. However, the device should not be used to approximate simultaneous blood alcohol concentrations such as used in charging an individual with driving under the influence.

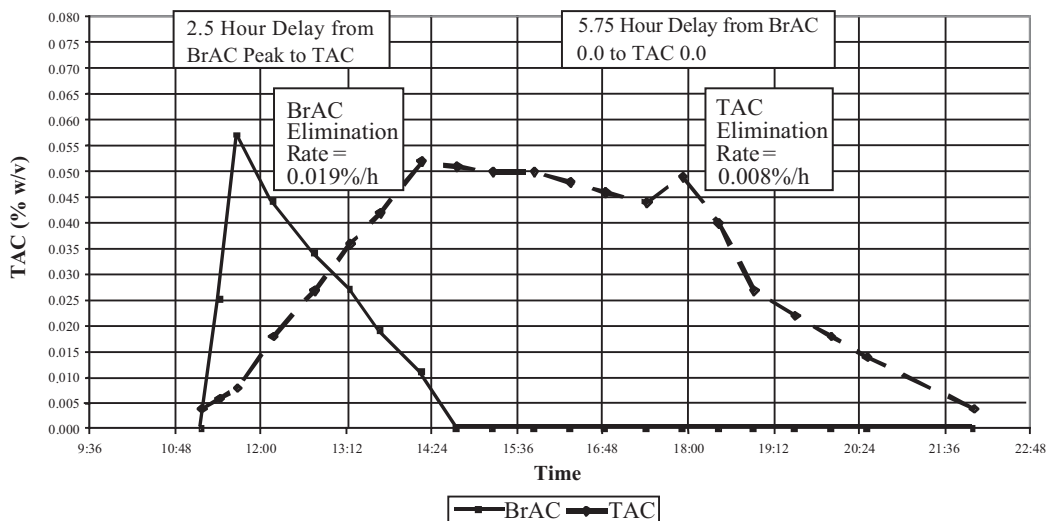


Figure 2. Example of delay between BrAC curve and TAC curve.

Another study was conducted at the University of Washington (21) in which a mathematical model of ethanol transport through the skin was developed and used in an attempt to determine the important factors governing the relationships between the BAC vs. time curve and the TAC vs. time curve. Additionally they evaluated the physiological limitations to interpretation of TAC. The model output data were qualitatively compared to actual study data (12,15,17), and it was concluded that the peak TAC was lower than the peak BAC, that the TAC curve was right shifted with peak delays of between 30 and 90 minutes, and that the TAC took up to 3 hours longer to reach zero than the BAC. They determined that the output sensitivity of the model was governed by the three model parameters describing the stratum corneum (solubility, diffusivity, and thickness) and the volume of gas above the skin. They also concluded that TAC measurements could not be quantitatively compared to BAC due to the many variations in the physiological variables of the skin, combined with the variations from BAC curves to TAC curves. Again this suggests that TAC measurements are not a direct replacement for BAC or BrAC measurements in terms of a quantitative real time result.

CONCLUSION

Transdermal alcohol measurement has a scientific foundation that dates back almost 70 years. Since that time, researchers have performed significant transdermal alcohol measurement research utilizing a number of different research techniques with very consistent results. Based on the published literature, one must conclude that: [1] ethanol is excreted through the skin in sufficient quantities to estimate BAC; [2] those who have not consumed alcohol do not produce signals that can be interpreted as a transdermal alcohol curve; [3] TAC is correlated with BAC in both magnitude and shape of the alcohol curve; [4] the TAC alcohol curve is right shifted from the BrAC alcohol curve and takes longer to reach zero; and [5] measuring TAC on a constant basis provides an effective screen for alcohol consumption and an approx-

imation of the magnitude of that consumption. The variability in the kinetics of ethanol transport through the stratum corneum and the variations between peak values of BAC and TAC dictate that today's transdermal devices can not directly replace a breath analyzer, but can semi-quantitatively identify drinking episodes in a continuous screening environment. Further research and improved modeling techniques of ethanol transport through the skin are required to obtain more quantitatively accurate transdermal results.

REFERENCES

1. Nyman E. and Palmlov A. The elimination of ethyl alcohol in sweat. *Skand. Arch. Physiol.* 1936; 74: 154-159.
2. Brusilow S.W. and Gordes E.H. The permeability of the sweat gland to nonelectrolytes. *Am. J. Dis. Child.* 1966; 112(4): 328-333.
3. Pawan G.L. and Grice K. Distribution of alcohol in urine and sweat after drinking. *Lancet.* 1968 Nov 9; 2(7576): 1016.
4. Johnson H.L. and Maibach H.I. Drug excretion in human eccrine sweat. *J. Invest. Dermatol.* 1971 Mar; 56(3): 182-188.
5. Scheuplein R.J. Permeability of the skin: a review of major concepts. *Curr. Probl. Dermatol.* 1978; 7: 172-186.
6. Phillips M. and McAloon M.H. A sweat-patch test for alcohol consumption: evaluation in continuous and episodic drinkers. *Alcohol Clin. Exp. Res.* 1980 Oct; 4(4): 391-395.
7. Phillips M. An improved adhesive patch for long-term collection of sweat. *Biomater. Med. Devices Artif. Organs.* 1980; 8(1): 13-21.
8. Phillips M. Sweat-patch test for alcohol consumption: rapid assay with an electrochemical detector. *Alcohol Clin. Exp. Res.* 1982; 6(4): 532-534.
9. Phillips M. Sweat-patch testing detects inaccurate self-reports of alcohol consumption. *Alcohol Clin. Exp. Res.* 1984; 8(1): 51-53.
10. Phillips M. Subjective responses to the sweat-patch test for alcohol consumption. *Adv. Alcohol Subst. Abuse.* 1984 Summer; 3(4): 61-67.
11. Brown D.J. A method for determining the excretion of volatile substances through skin. *Methods Find. Exp. Clin. Pharmacol.* 1985 May; 7(5): 269-274.
12. Brown D.J. The pharmacokinetics of alcohol excretion in human perspiration. *Methods Find. Exp. Clin. Pharmacol.* 1985 Oct; 7(10): 539-544.
13. Giles H.G., Renaud G.E., Meggiorini S. and Israel Y. New instrument using gas sensors for the quantitative analysis of ethanol in biological liquids. *Alcohol Clin. Exp. Res.* 1986 Oct; 10(5): 521-525.
14. Giles H.G., Meggiorini S., Renaud G.E., Thiessen J.J., Vidins E.I., Compton K.V., Saldivia V., Orrego H., and Israel Y. Ethanol vapor above skin: determination by a gas sensor instrument and relationship with plasma concentration. *Alcohol Clin. Exp. Res.* 1987 Jun; 11(3): 249-253.
15. Swift R.M., Martin C.S., Swette L., LaConti A., and Kackley N. Studies on a wearable, electronic, transdermal alcohol sensor. *Alcohol Clin. Exp. Res.* 1992 Aug; 16(4): 721-725.
16. Swift R.M. Transdermal measurement of alcohol consumption. *Addiction.* 1993 Aug; 88: 1037-1039.
17. Swift R. Transdermal alcohol measurement for estimation of blood alcohol concentration. *Alcohol Clin. Exp. Res.* 2000 Apr; 24(4): 422-423.
18. Buono M.J. Sweat ethanol concentrations are highly correlated with co-existing blood values in humans. *Exp. Physiol.* 1999 Mar; 84(2): 401-404.
19. Bock S. Michigan DOC runs beta test of new remote transdermal alcohol monitoring. *J. Offender Monitoring.* 2003; 16(1): 9-20.
20. Sakai J.T., Mikulich-Gilbertson S.K., Long R.J., and Crowley T.J. Validity of Transdermal Alcohol Monitoring: Fixed and Self-Regulated Dosing. *Alcohol Clin. Exp. Res.* January 2006; 30(1): 26-33.

21. Anderson J.C. and Hlastala M.P. The Kinetics of transdermal ethanol exchange. *J. Appl. Physiol.* October 2005; 100: 649–655.
22. Davidson,D., Camara P., and Swift R. Behavioral Effects and Pharmacokinetics of Low-Dose Intravenous Alcohol in Humans. *Alcohol Clin. Exp. Res.* October 1997; 21(7): 1294–1299.

