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Diffusion theory analysis of transepidermal water loss through occlusive films

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Synopsis

It is shown that simple DIFFUSION THEORY dictates that the application of an OCCLUSIVE FILM on SKIN always results in a decrease in TRANSEPIDERMAL WATER LOSS (TWL), as expected intuitively. The basic inconsistency in a previous analysis, which seemed to predict the possibility of the opposite effect, is pointed out.

INTRODUCTION

In a recent paper in this Journal (1), a theoretical argument was advanced to demonstrate that an occlusive film, when applied to skin, may lead not only to increased hydration of the stratum corneum but, contrary to expectation, to a concurrent *increase* in the transepidermal water loss (TWL). The authors used their argument to explain some experimental data that seemed to indicate such an increased flux, and to caution against rejecting potential occlusive agents that exhibit this effect, since they may, nevertheless, be excellent in their ability to effect increased skin hydration. The authors went so far as to state that "this increase in TWL is evidence of increased skin hydration in the stratum corneum."

Although the analysis seemed sound at first sight, we had the distinct impression that the conclusion had to be in violation of some basic principles in transport phenomena. If not, some curious paradoxes could be envisaged (for example, insulating one's house could conceivably lead to a greater heat loss in wintertime). The question to be asked is whether introduction of an extra resistance in a transport process can cause a change in the original resistance that will not only nullify, but overcompensate for, the intrinsic effect of the added resistance. We believe that such an effect is, in general, impossible, although we shall prove it only, in a very simple way, for the system of an occlusive film on skin.

THEORETICAL

Let us consider the concentration (or activity) profile of water in the stratum corneum in the absence and presence of an occlusive film (Fig. 1). In both cases, the concentra-

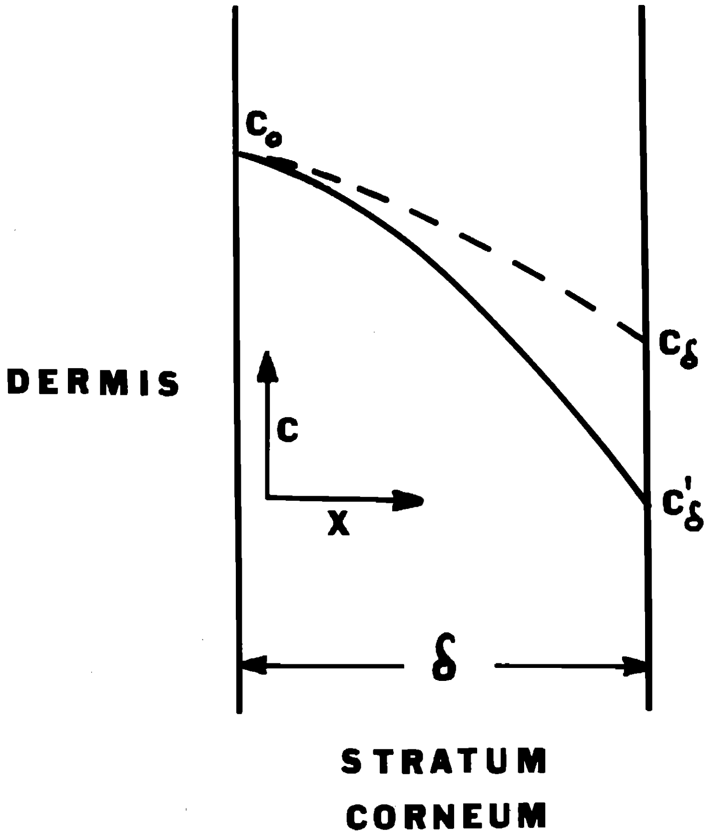

Figure 1. Concentration profile of water in the stratum corneum: solid line, nonoccluded case; dashed line, occluded case

tion at the dermis side equals c_o, which is determined by the constant activity of water in the dermis. In the nonoccluded case, the concentration drops to c'_δ at the outer surface ($x = \delta$), which is at equilibrium with the ambient atmosphere. Therefore, c'_δ is determined by the ambient water activity. In the occluded case, the concentration drops only to c_δ ($c_\delta > c'_\delta$), since part of the overall activity drop has to occur across the occlusive film (not shown in Fig. 1). Thus, the water content of the stratum corneum is indeed raised by the presence of an occlusive film, namely by an amount equal to the area between the two curves in Fig. 1.

It is an essential feature of Fig. 1 that the concentration profile is not linear, but curved as a result of the concentration dependence of the diffusion coefficient D(c). At any point in the corneum, the water flux is given by

$$J = -D(c)\frac{dc}{dx} \qquad (1)$$

or upon integration,

$$\int_0^\delta J\, dx = -\int_{c_0}^{c_\delta} D(c)\, dc \qquad (2)$$

In the steady state, J does not depend on x, so that

$$J\delta = -\int_{c_0}^{c_\delta} D(c)dc = \int_{c_\delta}^{c_0} D(c)dc \quad \text{(occluded case)} \tag{3}$$

and

$$J'\delta = -\int_{c_0}^{c'_\delta} D(c)dc = \int_{c'_\delta}^{c_0} D(c)dc \quad \text{(nonoccluded case)} \tag{4}$$

Hence, the difference in flux is given by

$$J' - J = \frac{1}{\delta}\left[\int_{c'_\delta}^{c_0} D(c)dc - \int_{c_\delta}^{c_0} D(c)dc\right] = \frac{1}{\delta}\int_{c'_\delta}^{c_\delta} D(c)dc \tag{5}$$

Since c_δ is always greater than c'_δ, and D(c) is greater than zero, the integral on the right-hand side will always be positive, whatever the form of D(c), which leads to the general conclusion that

$$J' > J \tag{6}$$

i.e., the occlusive film always results in a decrease in water loss rate, as expected intuitively.

As in (1), the assumption was made that the corneum thickness, δ, does not change as a result of increased hydration; however, we know that swelling does take place. This effect can only further increase the difference between J′ and J. It should be noted also that the use of activities instead of concentrations in the above analysis in no way modifies the result.

It is clear now where the analysis in (1) went astray. It assumes, and quite rightfully so (2), that the diffusion coefficient increases with increasing concentration of water in the corneum. However, in their analysis, the authors consider "D to be constant for each membrane, even though this may not be the case for nonuniformly hydrated stratum corneum." This basic internal inconsistency gives rise to the paradox.

It is not our intention to dispute the validity of the experimental data quoted in (1). But a different mechanism would have to be found to explain such findings. Other data exist that appear to violate the straightforward diffusion theory. For example, the maximum in the relationship between TWL and ambient relative humidity, as reported by Grice *et al.* (3) for the *in vivo* situation, cannot be explained this way. However, other *in vivo* (4), as well as *in vitro* (5,6), data do show the expected continuous increase of flux with increasing RH difference across the corneum. In this connection, it may be pointed out that *in vivo* measurements are notoriously variable and sensitive to extraneous influences.

CONCLUSION

A truly occlusive film, when applied to skin, can only reduce the rate of TWL. When the opposite effect is found in practice, the conclusion must be that the agent applied is not simply occlusive (i.e., inert) but must interact in a more complex way with the stratum corneum.

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