

# Bioengineering Analysis of Water Hydration\*

The water content of the stratum corneum (SC) influences almost every biophysical property measurable at the skin surface. Water hydration can be measured using the plastic occlusion stress test (POST) or the water sorption-desorption test (WSDT). Like the WSDT, POST provides dynamic information on skin hydration, even on nonvisible skin damage (see sidebar). However, the POST requires a complex mathematical approach to analyze the decay curves and decay constants.<sup>1</sup>

**Sorption-desorption is a different phenomenon from transepidermal water loss (TEWL), although both are characterized by interactions between water and skin.**

A simpler technique to noninvasively measure the in vivo kinetics of skin interaction with exogenous water is the WSDT.

## The Water Sorption-Desorption Test

The WSDT uses bioengineering instruments to measure electrical parameters that represent the skin hydration state as an electrical capacitance or conductance reading.<sup>2</sup> This technique minimizes the subjectivity involved in obtaining the data, allowing for greater accuracy and reproducibility than visual scoring methods.<sup>3</sup>

Sorption-desorption is a different phenomenon from transepidermal water loss (TEWL), although both are characterized by interactions between

water and skin. Unlike the former, TEWL measures the movement of endogenous water, while the sorption-desorption test determines skin hydration after the application of water.<sup>4</sup>

The WSDT method involves hydrating the skin with water and then observing the subsequent dehydration activity by means of serial recording with electrical instruments. Commonly used tools are the corneometer<sup>a</sup>, the skin surface hygrometer<sup>b</sup> and the dermaphase meter<sup>c</sup>, which measure capacitance, conductance and impedance-based capacitance, respectively.<sup>5</sup>

The corneometer measures capacitance in arbitrary units, the surface hygrometer expresses conductance in microsiemens (also known as micro-mho, the reciprocal of microohm), while the dermaphase meter uses picofarads or DPM units to express impedance-based capacitance (Table 1).<sup>6</sup> The three parameters relate directly to the skin surface hydration state, relying on an increase in the dielectric constant that occurs as the SC is hydrated. As the dielectric constant increases, impedance decreases while both the conductance and capacitance increase.<sup>7</sup>

**Testing methods:** The use of the corneometer, surface hygrometer or dermaphase meter in the WSDT follows a similar procedure (Figure 1).

First, a baseline electrical measurement is taken with the instrument before the skin is hydrated. This reading corresponds to the prehydration

<sup>a</sup> Corneometer CM820, ACA DERM, Menlo Park, Calif., USA. Corneometer is a trademark registered to Courage + Khazaka Electronic GmbH.

<sup>b</sup> Skicon 200, IBS, Hamamatsu, Japan

<sup>c</sup> Nova DPM 9003, Nova Technology Corp., Gloucester, Mass., USA

Column editor, Howard I. Maibach, M.D., is Professor of Dermatology, University of California School of Medicine, San Francisco, California. His laboratory has been interested in and has published extensively on dermatopharmacology and dermatotoxicology.



Christine M. Lee is a research associate with the Department of Dermatology at the University of California, San Francisco, and the author of several papers. She currently is finishing her medical degree at the University of California, San Diego.

state (PHS). Next, the skin surface is hydrated with distilled water for a defined period of time, usually less than 1 min. The skin then is blotted dry with sterile gauze, and the electrical capacitance or conductance is recorded again, giving a peak value. Peak measurement represents the hygroscopicity or the ability of the SC to take up (sorb) water.<sup>8</sup>

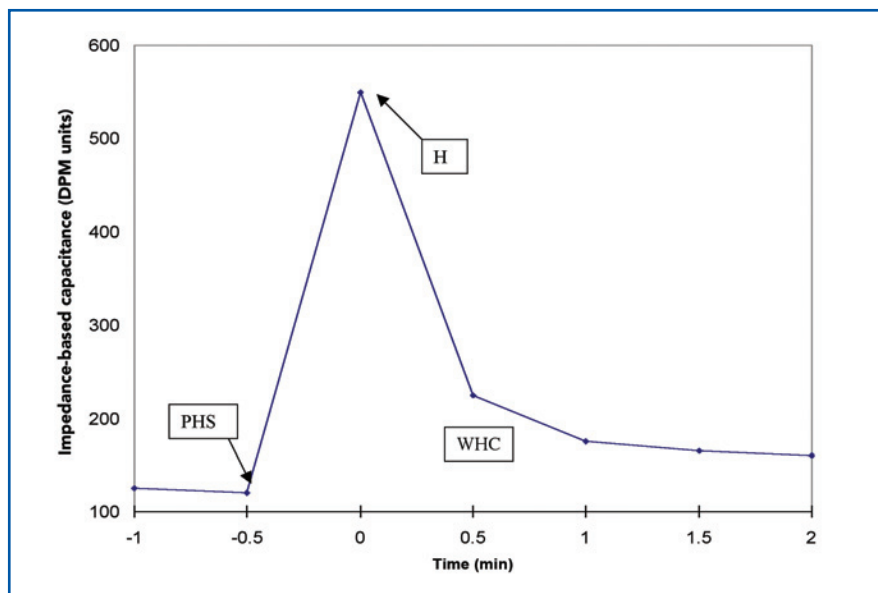
## THE PLASTIC OCCLUSION STRESS TEST

In POST, a plastic chamber is sealed firmly to the skin surface to induce an occlusion, increasing the water content underneath the chamber. When the occlusion is removed, the excess water on the skin starts to evaporate, and is defined as skin surface water loss (SSWL). The SSWL plotted over time yields a decay curve that provides information such as the stratum corneum's water-holding capacity and degree of hydration.<sup>1</sup>

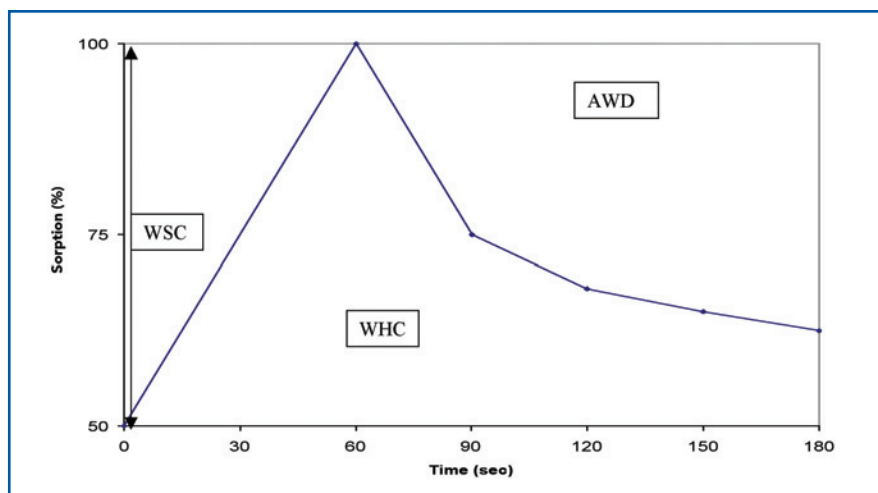
**Table 1. Instruments for sorption-desorption test studies**

Instrument	Electrical parameter measured	Measuring unit
Corneometer	Capacitance	Arbitrary unit (a.u.)
Surface hygrometer	Conductance	$\mu\text{S}/\mu\text{mho}$
Dermaphase meter	Impedance-based capacitance	Picofarad, DPM unit

\*Adapted from CM Lee and HI Maibach, Bioengineering analysis of water hydration: An overview, *Exog Dermatol* 1(6) 269-275 (2002), with permission from S Karger AG, Basel



**Figure 1. Sorption-desorption test curve with traditional hydration parameters**  
 PHS = prehydration state  
 H = hygroscopicity  
 WHC = water capacity  
 Data taken from Treffel and Gabard in Ref. 10.



**Figure 2. Sorption-desorption test curve with newly proposed parameters**  
 WSC = water-sorption capacity, which is the difference between the capacitance value at 60 sec and at 0 sec (prehydration state)  
 AWD = accumulated water decay, measured by the area above the desorption curve  
 WHC = water-holding capacity, calculated from the area under the sorption-desorption curve  
 Data taken from Pellacani and Seidenari in Ref. 11.

Subsequent measurements are taken at time intervals ranging from 20 to 30 seconds (s) for a period of 2 min, yielding the desorption curve as the electrical conductance values rapidly fall to values lower than basal.<sup>3</sup> Repeating the readings allows for a dynamic evaluation of water hydration, rather than a simple, steady-state analysis. Because the SC naturally is poor

in water, it has the ability to sorb water more or less rapidly depending on the skin condition, after which it experiences a subsequent tendency toward desorption. The biochemical makeup of the intercellular space in the SC, especially the low content in polar lipids and the abundance of neutral lipids and ceramides, may explain the barrier function exhibited by the

SC when polar and hydrophilic substances are applied onto the skin.<sup>3</sup>

**Dynamic parameters:** Hydration kinetics are better described using dynamic parameters such as the water-holding capacity (WHC) or the ability of the SC to retain water opposing a dehydration process (desorption).<sup>9</sup> This parameter is represented by the area under the graphed curve of the capacitance versus time, calculated using the trapezoidal method.<sup>10</sup> Among the many factors that influence the WHC of the SC are the following: the depth of the survey level carried out on the SC, the thickness of the SC, the survey area, the lipid component, and the presence of pathological conditions.<sup>3</sup>

To better describe the SC hydration kinetics, Pellacani and Seidenari<sup>11</sup> proposed two new hydration parameters: the water-sorption capacity (WSC), equal to the peak sorption (hygroscopicity) minus the PHS; and the accumulated water decay (AWD), which corresponds to the percentage of water released from the SC throughout the desorption phase (Figure 2).

The WSC and AWD can be beneficial because the WHC does not sufficiently assess the hydration dynamics during different phases of the hydration test for different skin conditions. For instance, applying urea-containing products on the skin increases the WHC, but applying irritants such as sodium lauryl sulfate (SLS) also increases it.<sup>10</sup> The increase in the former case is attributed to hydrophilic molecules holding water coming from both the surface and the deeper epidermis, while the increase in the latter is due to the impairment of the cutaneous barrier, allowing water to penetrate more easily into the SC.<sup>12</sup> The two new parameters would more precisely describe whether endogenous or exogenous factors lead to the increase in WHC.

## Effects of Moisturizers

Treffel and Gabard<sup>10</sup> investigated the effects of creams and lotions on skin hydration with the dermaphase meter to measure impedance-based capacitance, yielding values in arbitrary DPM units. With the cream and lotion study, an increase in PHS, hygroscopicity and WHC

was observed. Since both the cream and lotion were oil-in-water formulations, they caused an increase in the hydration parameters because they contained water. Moreover, the lotion contained 4% urea, contributing to the water-retention effect, which led to an increase in the WHC. The water-retention effect is measured by an increase in PHS and WHC after the application of urea-containing products, with hydrophilic molecules holding water coming from the surface.<sup>13</sup>

### Effects of Irritants

The WSDT also was used to determine the effects of SLS on skin hydration properties. Treffel and Gabard<sup>10</sup> found that the WHC increased after applying irritants due to the impairment of the cutaneous barrier, allowing water to pass through the SC more easily. As a result, the WHC does not sufficiently describe the dynamics of water accumulation and release because it does not consider the different testing situations.<sup>11</sup>

The findings suggest that for instances where either urea or SLS was used, the SC accepts external water quicker than if neither substance were applied. However, urea is able to enhance the SC's water-holding capacity, whereas SLS reduces it. In the application of both the moisturizer and irritant, it appears that the binding sites or binding capacity of the SC for water were increased, but for urea, additional water retained in the SC was released slowly, while additional water in SLS was not retained and released easily.<sup>10</sup> The long application time of SLS may have caused structural modifications to the lipid bilayer, inducing damage to the skin barrier,<sup>14</sup> which reduces the water-retention effect.

### Testing Limitations

The corneometer, surface hygrometer and dermaphase meter bioengineering instruments used in the studies enabled researchers to measure hydration parameters that characterize water

movement and barrier function of the SC. However, each instrument has its limitations. The surface hygrometer and dermaphase meter lack sensitivity in skin conditions described as very dry, and the corneometer lacks some sensitivity at high levels of hydration.<sup>5</sup>

**Accuracy:** Since the three devices all use different calibration procedures, comparing the accuracy of the different readings is impossible because an inter-instrumental standard currently is unavailable.<sup>5</sup> In the meantime, intra-individual hydration readings are used to obtain coefficient of variation (CV) values to estimate the repeatability of the hydration measurements.

**Repeatability:** The surface hygrometer has a high CV (20%), so only large variations in the hydration state can be reported in a significant way. Small variations do not reach statistical significance due to the high CV.<sup>5</sup> Increasing the number of measurements and averaging the results will alleviate this problem.<sup>15</sup>

**Table 2. Conversion between electrical measurement units**

Units compared	Correlation coefficient	Conversion equation
DPM (x) / a.u. (y)	r = 0.97	y = 0.156*x + 32
DPM (x) / μS (y)	r = 0.96	y = 1.708*x - 205
μS (x) / a.u. (y)	r = 0.89	y = 0.081*x + 52

Data taken from Clarys et al. in Ref. 5.

On the contrary, studies show that the dermaphase meter and corneometer have relatively low CVs for repeatability (5% and 7%, respectively). However, because the surface hygrometer is based on a high-frequency conductance (3.5 MHz),<sup>16</sup> the results show more prominent changes than those of the corneometer, which uses low-frequency capacitance (500 Hz). Like the surface hygrometer, the dermaphase meter uses high-frequency measurements (1 MHz),<sup>16</sup> so both devices measure the free or slightly unbound water in the SC within the superficial part of the epidermis.<sup>15</sup>

**Reproducibility:** The CV for reproducibility was highest in the surface hygrometer, having a mean value of 88%, indicating that the measurements are highly variable depending on circumstances. The mean CV for the dermaphase meter was 20%, and the corneometer CV was 14%. Lower CVs are considered more desirable because there is less variability in reproducibility.<sup>5</sup>

**Correlation:** Clarys et al.<sup>5</sup> found high degrees of correlation among the different instruments: r = 0.96 between dermaphase meter and surface hygrometer, r = 0.97 between dermaphase meter

and corneometer, and r = 0.89 between corneometer and surface hygrometer. This finding shows that the different units are almost linearly related, so linear equations can be derived to approximate the conversion between the DPM unit, the arbitrary units and the microsiemens (Table 2).

### Conclusions

The water sorption-desorption test is a useful tool used to measure the dynamic hydration of the skin and the stratum corneum's water-holding properties. The measuring instruments currently available are the corneometer, the surface hygrometer, and the dermaphase meter. Although these instruments provide researchers with useful information regarding SC hydration dynamics, the lack of a standardized measuring unit makes it difficult to compare between studies. However, there are significant degrees of high correlation between the three instruments.

While the conversion equations in Table 2 give only an estimate of relationship between the units, they demonstrate the possibility of finding a standardized unit to express the conductance, capacitance and impedance-based capacitance. Therefore, a need exists for the standardization of the electrical units to improve the bioengineering assessment of water

hydration in the superficial skin layer among different studies.

In the interim, appropriate experimental design, such as multiple treatments with the subjects as their own control (rather than parallel groups), has provided valuable insights.

*Reproduction of all or part of this column is strictly prohibited.*

Visit our Article Archives online to purchase this article.

**References**

Address e-mail to CT\_Author@allured.com.

1. E Berardesca and HI Maibach, The Plastic Occlusion Stress Test (POST) as a model to investigate skin barrier function, In *Dermatologic Research Techniques*, HI Maibach, ed, Boca Raton: CRC Press (1995) pp 179–186
2. G Borroni, C Zaccone, G Vignati, GP Vignoli, E Berardesca and G Rabbiosi, Dynamic measurements: Sorption-desorption test, In *Bioengineering and the Skin: Water and the Stratum Corneum*, P Elsner, E Berardesca and HI Maibach, eds, Boca Raton: CRC Press (1994) pp 217–221
3. LK Pershing, S Bakhtian, ED Wright and TM Rallis, Differentiation of involved and uninvolved psoriatic skin from healthy skin using noninvasive visual, colorimeter and evaporimeter methods, *Skin Res Technol* 1 140–144 (1995)
4. FA Okah, RR Wickett, K Pompa and SB Hoath, Human newborn skin: The effect of isopropanol on skin surface hydrophobicity, *Pediatr Res* 35 443–446 (1994)
5. P Clarys, AO Barel and B Gabard, Non-invasive electrical measurements for the evaluation of the hydration state of the skin: Comparison between three conventional instruments—the Corneometer, the Skicon, and the Nova DPM, *Skin Res Technol* 5 14–20 (1999)
6. F Distanto and E Berardesca, Hydration, In *Bioengineering and the Skin: Methods and Instrumentation*, E Berardesca, P Elsner and HI Maibach, eds, Boca Raton: CRC Press (1995) pp 5–11
7. Y Masuda, M Nishikawa and B Ichijo, New methods of measuring capacitance and resistance of very high loss materials at high frequencies, *IEEE Trans Instr Meas* 29 28–36 (1980)
8. H Tagami and K Yoshikuni, Interrelationship between water-barrier and reservoir functions of pathologic stratum corneum, *Arch Dermatol* 121 642–645 (1985)
9. E Berardesca and HI Maibach, Effect of nonvisible damage on the water-holding capacity of the stratum corneum, utilizing plastic occlusion stress test (POST), In *Current Topics in Contact Dermatitis*, Frosh PJ, ed, New York: Springer (1989) pp 554–559
10. P Treffel and B Gabard, Stratum corneum dynamic function measurements after moisturizer or irritant application, *Arch Dermatol Res* 287 474–479 (1995)
11. G Pellacani and S Seidenari, Water sorption-desorption test and moisture accumulation test for functional assessment of atopic skin in children, *Acta Derm Venereol* 81 100–103 (2001)
12. T Agner and J Serup, Sodium lauryl sulphate for irritant patch testing—A dose-response study using bioengineering methods for determination of skin irritation, *J Invest Dermatol* 95 543–547 (1990)
13. P Treffel and B Gabard, Measurement of sodium lauryl sulfate-induced skin irritation, *Acta Derm Venereol* 76 341–343 (1996)
14. JL Leveque, J de Rigal, D Saint-Leger and D Billy, How does sodium lauryl sulfate alter the skin barrier function in man? A multiparametric approach, *Skin Pharmacol* 6 111–115 (1993)
15. P Agache, S Mary, P Muret, AM Matta and P Humbert, Assessment of the water content of the stratum corneum using sorption-desorption test, *Dermatology* 202 308–313 (2001)
16. H Tagami, Quantitative measurements of water concentration of the stratum corneum in vivo by high-frequency current, *Acta Derm Venereol Suppl* 185 29–33 (1994) **C&T**