Precision Skin Condition Monitoring with Skin Water Content and TEWL Measurements

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Introduction.

Stratum corneum (SC) hydration, generally referred to as skin water content, is important for its cosmetic properties and barrier function. SC hydration and transepidermal water loss (TEWL) are two key measurement indices used for SC characterisation and therefore skin condition monitoring. Previous studies have shown that capacitive imaging sensors, originally designed for biometrics applications, can be adapted for skin hydration imaging, surface analysis, 3-D surface profiling and skin micro-relief measurements [1-3].

In this paper, we present our latest study on precision measurement of skin condition using the AquaFlux condenser-chamber instrument for TEWL and the Epsilon capacitance-array sensor to measure hydration. The AquaFlux is a patented, condensing closed-chamber evaporimeter for skin transepidermal water loss measurement [4,5]. The Epsilon uses novel capacitance-based dielectric permittivity imaging technology to map and measure stratum corneum water content. Both devices are fully calibrated and exhibit high accuracy, high repeatability, and low noise. To simulate small variations in SC barrier properties, sunscreens with a range of protection factors were each applied to separate skin test sites and their effects were monitored over time. We will present the technical background, then the results and discussion, showing that precise measurement of TEWL and skin hydration can reveal otherwise undistinguishable changes in skin condition.

Further, with the Epsilon, we can measure skin surface hydration dynamically during occlusive contact to generate time-dependent greyscale occlusion curves. With the AquaFlux we can accurately measure TEWL to infer skin barrier function. Our previous studies have shown that skin occlusion hydration and TEWL measurement can yield further complementary information about skin properties. [6] The purpose of this study is to explore the feasibility of using precision skin measurement instrumentation to detect small differences between SC properties, with the longer term aim of developing a new SC barrier characterisation method that combines skin occlusion hydration imaging and TEWL.

Materials and Methods.

Figure 1 shows photographs and schematic diagrams of the Epsilon model E100 permittivity imaging system and the AquaFlux model AF200 TEWL instrument (both produced by Biox Systems Ltd, UK). The Epsilon is based on a 15.0x12.8 mm silicon Fujistu fingerprint sensor chip with an array of 256x300 integrated sensor pixels situated beneath a 1–2 μm thickness silicon carbide protective layer. Each pixel consists of a pair of capacitor electrodes, as depicted schematically in Figure 1(C). Pixel readouts have an 8-bit greyscale intensity resolution, representing the relative permittivity of a dielectric material in close proximity with a pair of electrodes, with 50 μm spatial resolution. When skin is placed in contact with the surface of the sensor, the dielectric is formed of the outer ~5 μm of the skin surface; specifically, its high-permittivity SC water content, because that's the extent of the fringing electric field emanating from each electrode pair. The AquaFlux uses the closed condenser-chamber measurement method. Its thimble-size cylindrical measurement chamber is open at the test-surface end and closed at the opposite end by means of a condenser with a constant surface temperature below the freezing point of water. This is illustrated in Figure 1(D) with the condenser acting as a water vapour sink while maintaining a controlled measurement environment. This arrangement enhances measurement repeatability and accuracy and provides real-time measurement validation. For comparison, an alternative TEWL device, the unventilated-chamber VapoMeter (Delfin Technologies Ltd, Finland), was also used in the study.

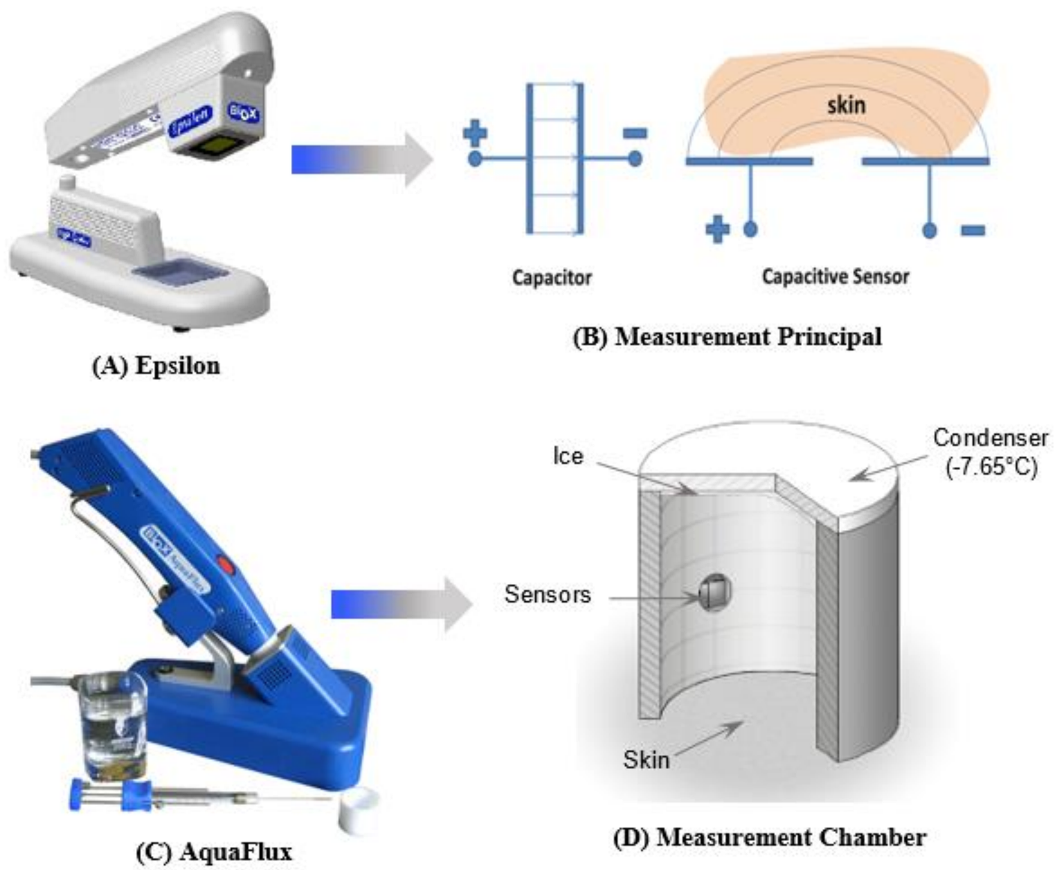


Figure 1. (**A**) Epsilon permittivity imaging system, and (**C**) AquaFlux (shown with droplet calibration tools). Diagram (**B**) is of pair of ordinary capacitor electrodes (left) shown opened up (right) to form one pixel of an array of 76,800 Epsilon coplanar capacitor pixels. Diagram (**D**) shows a cutaway view of a closed AquaFlux measurement chamber, with its protected sensors and water vapour collecting condenser.

All measurements were performed under normal ambient laboratory conditions of 20-21°C and 40-50% RH. Volar forearm skin sites were initially wiped clean with EtOH/H_2O (95/5) solution and the volunteers were acclimatized in the laboratory for 20 minutes prior to the experiments.

Three sunscreens of a popular brand with a SPF (Sun Protection Factor) of 20, 30 and 50+ were each applied to one of three test skin sites on the volar forearms of healthy volunteers; a fourth skin site was used as control, as illustrated in Figure 2. TEWL (transepidermal water loss) and skin water content measurements were performed before and after application of sunscreen. TEWL was measured using both AquaFlux and VapoMeter instruments, and skin water content was measured using the Epsilon permittivity imaging system. In each case, an average of 5 measurements was used.

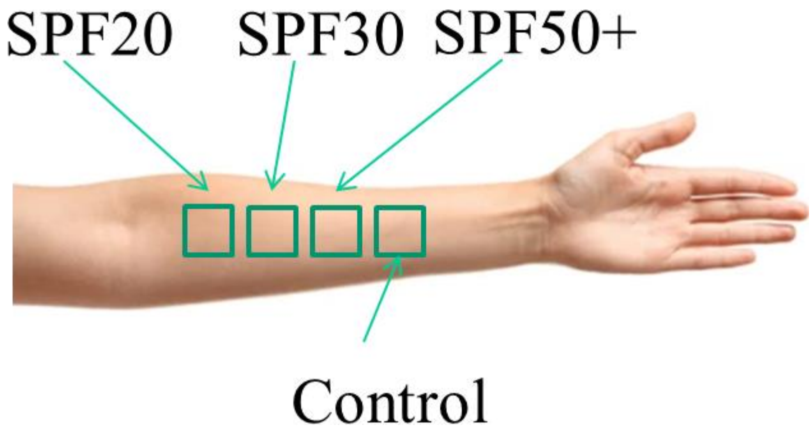
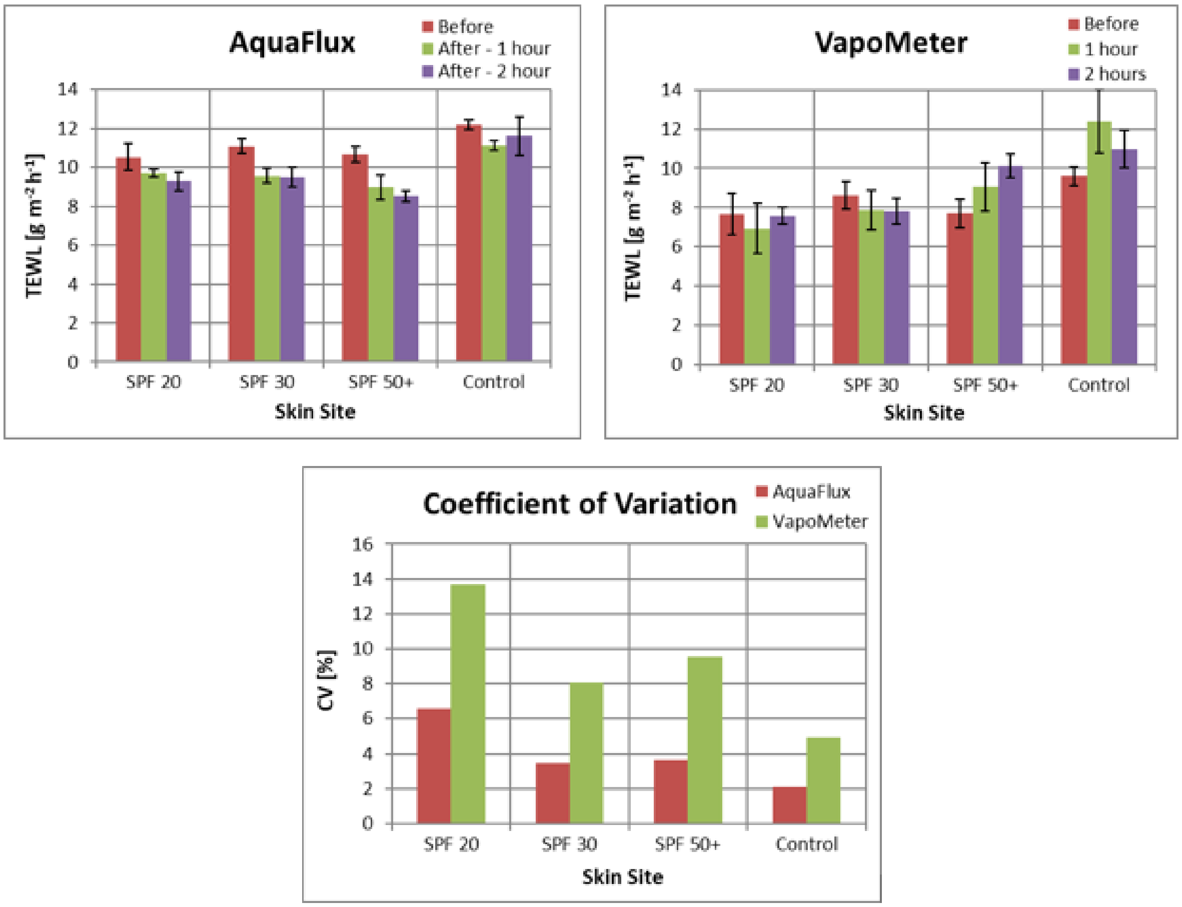


Figure 2. Four skin sites on the volar forearm. Three were test sites for sunscreen with SPF 20, 30 and 50+. The fourth skin site was chosen as control.

Results and discussion.

Figure 3 shows TEWL values of four volar forearm skin sites, before, 1 hour after, and 2 hours after the application of three different sunscreens. For the AquaFlux, Figure 3(A) reveals a consistent decrease in TEWL on all three skin sites after applying sunscreen, while the control site remained more or less unchanged. TEWL reduction was greatest during the first hourIn Figure 3(B), the VapoMeter TEWL values do not appear to indicate a pattern. This is likely due to larger instrumental coefficient of variation (CV) of the VapoMeter, as shown in Figure 3(C). CV is calculated as the ratio of standard deviation to mean measured TEWL value as a percentage, and represents a gaussian combination of skin heterogeneity, instrumental, and operator uncertainties.

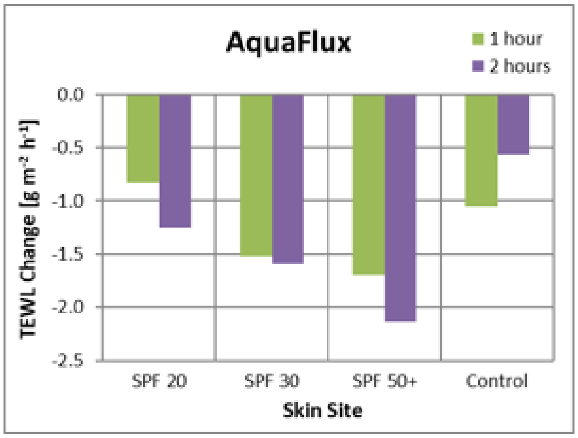
A B



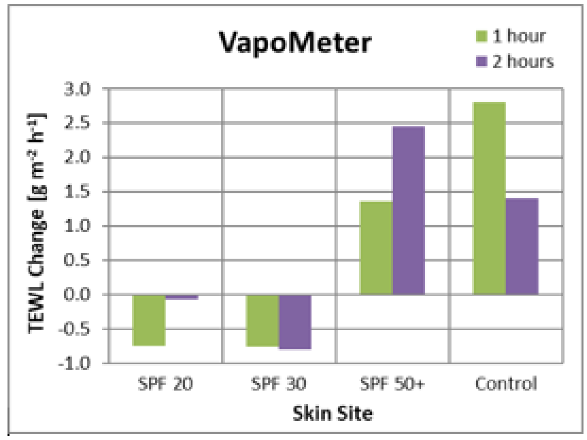
C

Figure 3. TEWL values of four volar forearm skin sites before and after applying sunscreen, measured by AquaFlux (**A**), VapoMeter (**B**). The error bars represent the standard deviations of five averaged repeat measurements per skin site. AquaFlux and VapoMeter measurement CVs are given for each skin site in (**C**).

Figure 4 shows how much the corresponding TEWL values change before, 1 hour after, and 2 hours after sunscreen application, measured with the AquaFlux and the VapoMeter. TEWL values decrease 1 hour after sunscreen application, and continue to decrease to a lesser extent 2 hours after, indicating a prolonged skin barrier function improvement lasting well beyond two hours. SPF 20, SPF 30 and SPF 50+ sunscreens appear similar in this respect. Of interest is the proportional decrease in TEWL with SPF number; SPF 20 decreasing the least and SPF 50+ the most. There is also a small change at the control site with time. The VapoMeter results, however, do not show any consistent trend.



A (AquaFlux TEWL Change)



B (VapoMeter TEWL Change)

Figure 4. Changes in TEWL values before and after sunscreen application, measured by AquaFlux (**A**) and VapoMeter (**B**).

Figure 5 below shows the corresponding Epsilon permittivity images before and after applying sunscreen. Before application, all four skin sites are relatively dark, indicating low water content. After one hour, the three skin sites with sunscreen applied became much brighter, probably attributable to the sunscreen's high-permittivity water content. The SPF 20 sunscreen image intensity increase indicates the highest moisture content, or a combination of sunscreen water and skin occlusion. Conversely, the SPF 50+ sunscreen image intensity increased the least, suggesting the lowest moisture content. The control site remained more or less the same throughout.

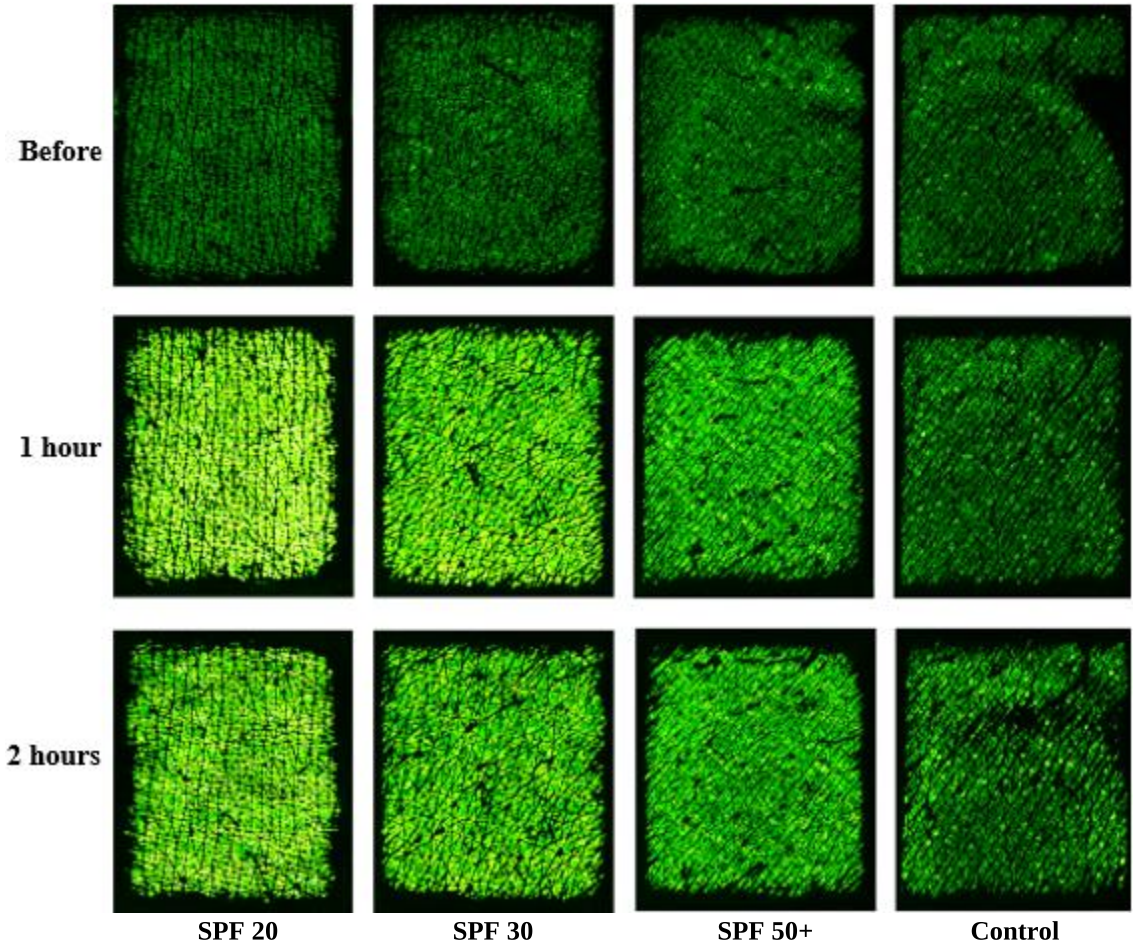
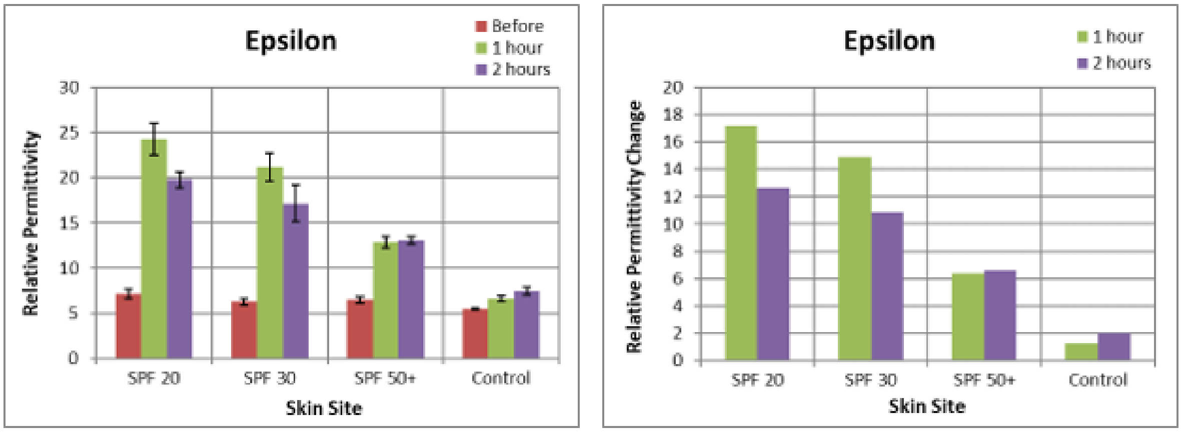


Figure 5. Epsilon permittivity images of four volar forearm test sites before, 1 hour after, and 2 hours after application of sunscreen. SPF 20, SPF 30, and SPF 50+ sunscreen was applied on three skin sites. The fourth skin site was used as control.

In order to improve the Epsilon measurement accuracy, a permittivity filter was applied to each image during post-capture analysis, such that pixels with relative permittivity values below 2 (air) and above 80 (water/salt solution) were eliminated. These filter settings remove the black regions, where there is poor skin contact with the sensor, as well as those with sweat gland activity. After filtering, the permittivity readouts are calculated as the mean of all remaining pixel values, correctly depicting hydration within the SC. Histograms of the analysed results corresponding to the images in Figure 5 are shown below in Figure 6, again indicating a proportional relationship, this time between hydration and SPF number.



A (Relative permittivity) **B (Permittivity change)**

Figure 6. Epsilon mean permittivity readouts of the four skin sites before, 1 and 2 hours after sunscreen application (**A**), and the corresponding change in permittivity at each site (**B**). Again, the error bars represent the standard deviations of five averaged repeat measurements per skin site.

Conclusion. We present our latest study on precision skin condition measurement using AquaFlux and Epsilon research grade instrumentation. The overall results demonstrate that the AquaFlux and Epsilon are capable of detecting, quantifying and discriminating between subtle changes in skin condition after the application of different sunscreens. The AquaFlux results show a small decrease in TEWL after sunscreen application compared to the control site, with SPF 50+ having the most effect and SPF 20 the least. Using an alternative closed chamber evaporimeter, the VapoMeter, the results were inconclusive. Epsilon measurements show a significant increase in skin water content after sunscreen application, with SPF 20 increasing the most and SPF 50+ the least.

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Conflict of Interest Statement. Ciortea, Bahman, and Berg are full time employees of Biox Systems Ltd, UK.

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