# Mean Sensing Depth for Skin Hydration Measurement of the Epsilon Capacitance Contact Imaging System

Bob Imhof & Elliott Berg, Biox Systems Ltd, London, England

## Introduction

The most common method for measuring skin hydration uses contact sensors that respond to electrical capacitance. This works because capacitance increases with dielectric permittivity (***ε***) and ***ε*** for water is much higher than that of other components of skin. However, the sensors used in capacitance-based hydration instruments have a depth-dependent response, because the electric field produced by their electrodes penetrates into the material of interest by a distance that depends mainly on electrode geometry and material ***ε***. Furthermore, skin hydration is strongly depth-dependent, being relatively low near the surface of the Stratum Corneum (SC) and higher in the viable tissues below the SC. Given this complex depth dependence, it is generally unclear how the readings of such instruments can meaningfully be interpreted. The aim of this work was to characterise the sensing depth and its dependence on ***ε*** of the Epsilon capacitance imaging system (Biox Systems Ltd, England) in order to provide a meaningful comparison with the Corneometer (Courage & Khazaka, Germany), currently the most widely used capacitance-based hydration instrument.

## Method and Materials

The work used a new method for measuring sensing depth, which is illustrated in **Figure 1**.

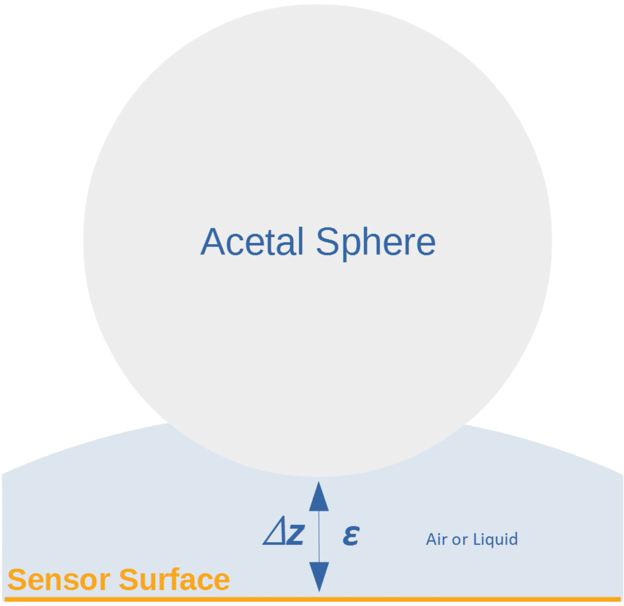


**Figure 1:** New method for measuring the sensing depth of the array sensor used in the Epsilon Model E100 capacitance imaging system.

An Acetal Sphere of 8mm diameter was mounted on a differential micrometer to provide control of the vertical distance $\Delta$**z** between the sphere and the sensor surface with sub-micron resolution. Depth-dependence in materials of different dielectric permittivity ***ε*** was measured by filling the space between the sphere and the sensor with either air or a liquid. The apparatus used the Epsilon in-vitro stand, fitted with higher than normal vertical posts to accommodate the sphere and its mounting. The differential micrometer was equipped with an adaptor sleeve so that it could be held stably in the standard tool holder of the in-vitro stand. A photograph of the set-up is shown in **Figure 2**.

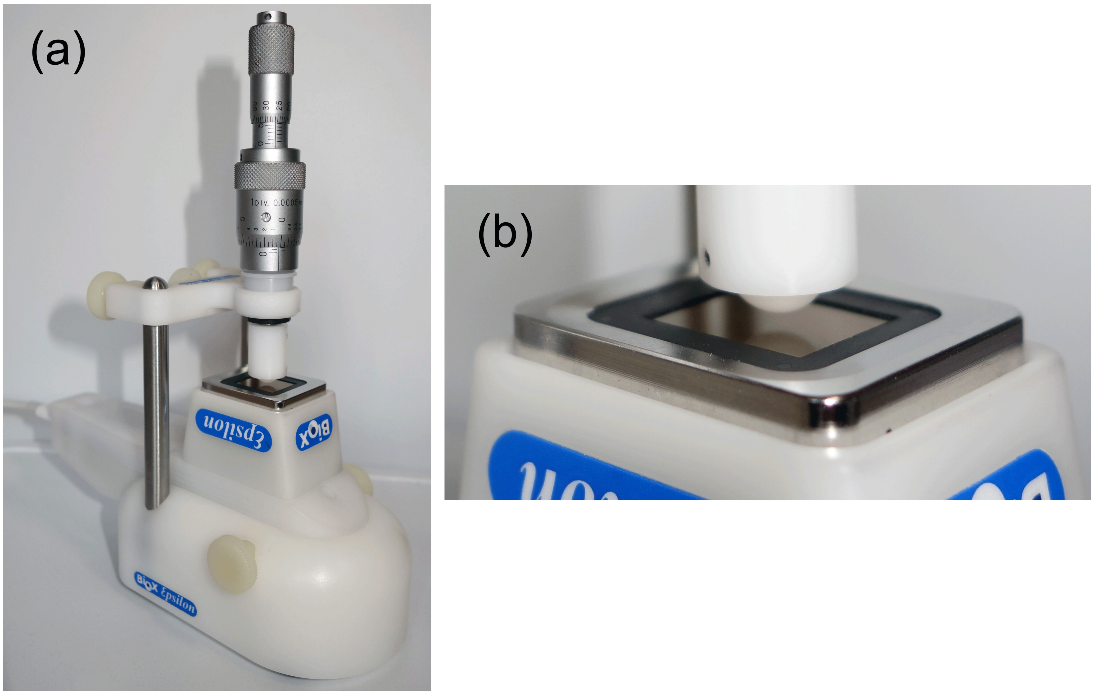


**Figure 2:** (a) Apparatus, (b) close-up view of Acetal sphere and sensor surface.

## Results

The micrometer was first adjusted to make light contact between the sphere and the sensor surface. Images were then recorded as the separation $\Delta \mathbf{z}$ was increased in increments of 1µm. Measurements were taken with both air and Propylene Glycol (PG) in the space between the sphere and the sensor. Image sequences for air and PG are shown in **Figure 3**.

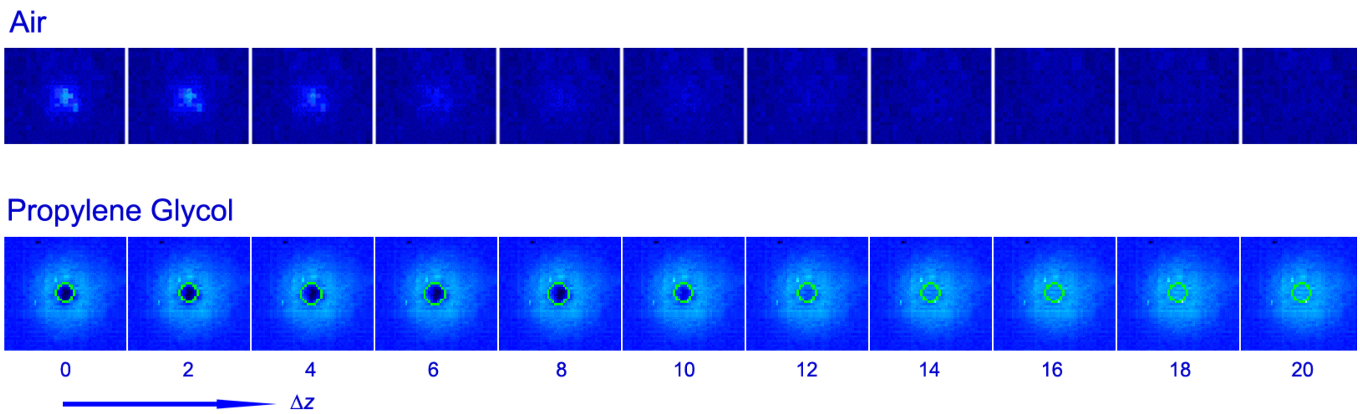


**Figure 3:** Image sequences shown in $\Delta \mathbf{z}$ increments of 2µm in air and PG. Note that the response in air decreases from bright to dark, but increases from dark to bright in PG. The reason is that air has a lower $\boldsymbol{\varepsilon}$ than the Acetal sphere, whereas the opposite is the case with PG.

The normalised response plotted in **Figure 4** was calculated from the mean $\boldsymbol{\varepsilon}$ within a circular region of interest of 8 pixel (400µm) diameter, centred on the initial point of contact, shown in the PG sequence of **Figure 3** by the green circles. The data of **Figure 4** are adequately represented by exponential functions with characteristic *1/e* sensing depths of 7.0µm and 3.8µm respectively for air and PG.

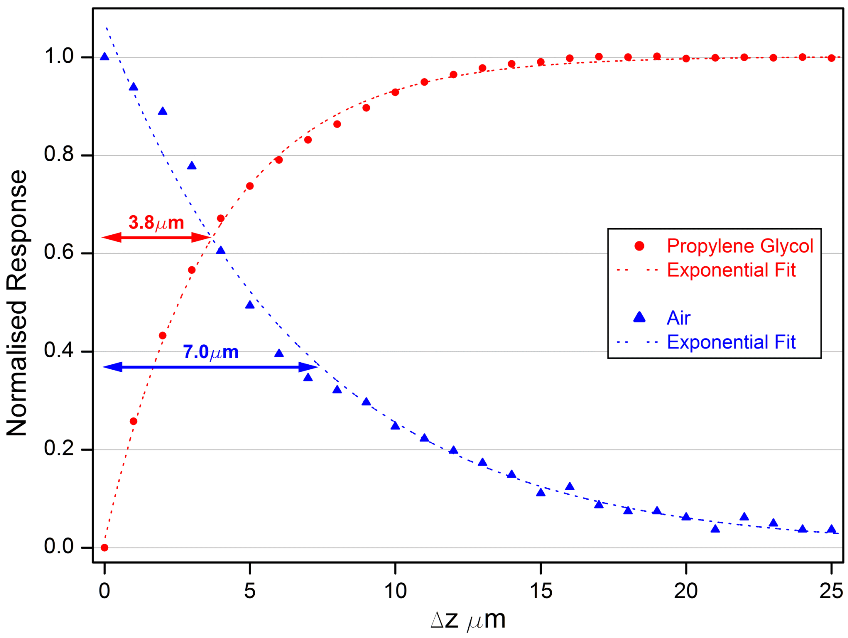


**Figure 4:** Normalised response with sphere-sensor separation **Δz**. Note that the response with PG increases with **Δz** because unlike air, PG has a higher dielectric permittivity (***ε***≈30, depending on water content) than the Acetal sphere (***ε***≈4).

## Epsilon v. Corneometer

Comparison with literature values of Corneometer sensing depth are difficult, because different authors use different measures of sensing depth. A summary is presented in **Table 1**, which includes a conversion to equivalent *1/e* characteristic depth to aid comparison.

**Table 1:** Summary of sensing depth data for the Corneometer and the Epsilon. The reported Corneometer measures are based on observed signal attenuation produced by layers of low ***ε*** plastic film placed between the sensor and filter papers soaked in either water or saline.

| Authors | Date | Instrument | Model | Material | Reported Attenuation | @ Reported Depth [μm] | *1/e* Equivalent [μm] |
|---|---|---|---|---|---|---|---|
| Courage [1] | 1994 | Corneometer | CM 820 | Plastic Film | 0.5 | 30 | 43.3 |
| Barel & Clarys [2] | 1997 | Corneometer | CM 825 | Plastic Film | 0.9 | 40 | 17.4 |
| Fluhr *et al* [3] | 1999 | Corneometer | CM 820 | Plastic Film | 0.95 | 45 | 15.0 |
| Fluhr *et al* [3] | 1999 | Corneometer | CM 825 | Plastic Film | 0.95 | 15 | 5.0 |
| Clarys *et al* [4] | 2011 | Corneometer | CM 820 | Plastic Film | 0.83 | 15 | 8.6 |
| Clarys *et al* [4] | 2011 | Corneometer | CM 825 | Plastic Film | 0.84 | 15 | 8.3 |
| Barel & Clarys [5] | 2014 | Corneometer | CM 825 | Plastic Film | 0.95 | 40 | 13.4 |
| This work | 2019 | Epsilon | E100 | Air | N/A | 7.0 | 7.0 |
| This work | 2019 | Epsilon | E100 | PG | N/A | 3.8 | 3.8 |

From these data it appears that the Corneometer Model CM 825 has a smaller sensing depth than the earlier Model CM 820, with averages of *1/e* equivalent sensing depths of 11.0μm and 22.3μm respectively. However, the uncertainties of these averages (CV = 50% and 83% respectively) are too large to confirm this. Given that the two models use the same capacitance sensor and that sensor geometry determines sensing depth, it is likely that they have the same sensing depth. But irrespective of this, it is clear that the sensing depth of the Epsilon is smaller than that of either model.

## Conclusion

These are preliminary results from a new method with sub-micron depth resolution. They show that the sensing depth of the Epsilon is (i) smaller than that of the Corneometer and (ii) well matched to the thickness of normal SC.

## References

**1.** W Courage. ***Hardware and Measuring Principle: Corneometer***. In: *Bioengineering of the skin: Water and the Stratum Corneum*. P Elsner, E Beradesca & HI Maibach, editors. 1st ed. CRC Press 1994. **14**, 171–5.

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**5.** AO Barel & P Clarys. ***Skin Capacitance***. In: *Non Invasive Diagnostic Techniques in Clinical Dermatology*. E Beradesca, HI Maibach & K-P Wilhelm, editors. Springer Verlag 2014. **33**, 357-66.