Comments

Dermatology

Dermatology 2001;202:87–89

Received: October 2, 2000
Accepted: November 8, 2000

Facts and Myths about Electrical Measurement of Stratum corneum Hydration State

Ørjan G. Martinsen[a] Sverre Grimnes[a, b]

[a]Department of Physics, University of Oslo, and [b]Department of Biomedical and Clinical Engineering, Rikshospitalet, Oslo, Norway

Key Words
Skin hydration · Electrical susceptance · Single frequency · Cole plot · Measurement depth

Abstract
Some of the views presented in the chapter on 'Examination of stratum corneum hydration state by electrical methods' in *Skin Bioengineering – Techniques and Applications in Dermatology and Cosmetology* (Karger, 1998) are in strong disagreement with the results from basic research that has been conducted on skin impedance measurement over the last decades. This research has e.g. non-ambiguously shown that the frequency response of the stratum corneum does not obey the Cole equation and that measurement depth is strongly dependent on measurement frequency. One consequence of these findings is that multifrequency electrical measurements on stratum corneum are impossible to achieve in vivo with any electrode system known today. Hence, electrical measurements of stratum corneum hydration must be conducted at one single, low frequency.

The electrical measurement of stratum corneum hydration is an important and interesting field of research. Unfortunately, it is also a field where we have not been able to eliminate obsolete theories and information from our publications. Thus, a chapter on the topic in the otherwise excellent book *Skin Bioengineering: Techniques and Applications in Dermatology and Cosmetology* [1] published in 1998 only carried on this practice. Some of the views presented in the chapter on 'Examination of stratum corneum hydration state by electrical methods' are in strong disagreement with the results from basic research that has been conducted on skin impedance measurement over the last decades.

This research has e.g. non-ambiguously shown that the frequency response of the stratum corneum does not obey the Cole equation [2, 3]. In fact, the impedance of the stratum corneum does not even show any resemblance to a depressed circular arc when plotted in the complex impedance plane. Another important finding is that measurement depth is strongly dependent on measurement frequency [4–8]. The contribution from viable skin increases with increasing frequency and hence measurements done at different frequencies will not represent the same measured volume of the skin. There is consequently no doubt that multifrequency in vivo measurements on stratum corneum alone are impossible to achieve with any electrode system known today.

It is stated in the introduction that undamaged normal and even psoriatic human skin very accurately obeys the Cole complex impedance equation. Later, citing Yamamoto and Yamamoto [2], it is argued that each layer of keratin-filled cells in the stratum corneum also obeys the Cole equation. This is wrong. One of the major findings reported in this specific article by Yamamoto and Yama-

KARGER

Fax + 41 61 306 12 34
E-Mail karger@karger.ch
www.karger.com

1018–8665/01/2022–0087$17.50/0

Accessible online at:
www.karger.com/journals/drm

Ørjan G. Martinsen
Department of Physics, University of Oslo
PO Box 1048, Blindern
N–0316 Oslo (Norway)
Tel. +47 22856474, Fax +47 22856422, E-Mail ogm@fys.uio.no

moto is that the layers of the stratum corneum do *not* obey the Cole equation. If one plots the data given for the stratum corneum in the complex impedance plane, one will actually see a frequency response quite different from a depressed circular arc. Our own measurements confirm this [3]. It is however true that all skin layers together will produce a frequency response, which sometimes is found to resemble a depressed circular arc in the complex impedance plane. But the Cole equation is only one of many empirical equations that are able to mimic this behaviour. Not only the Cole distribution, but also any log-normal distribution of relaxation times will produce curves which are indistinguishable from depressed circular arcs [9]. One single Cole equation can consequently not be used as a proper model for any stratum corneum phenomena, including hydration state, since the stratum corneum alone does not obey the Cole equation.

Hence, anything in the book chapter that is related to using the Cole equation for the assessment of the stratum corneum hydration state is invalid. The arguments for basing hydration measurements on the Cole exponent m and the claims that one would need at least three frequencies in order to reproduce the frequency response of the stratum corneum are all defective since they are based on the same erroneous assumptions.

It is important to note that any multifrequency approach to measuring skin hydration in vivo will be ambiguous and misleading with any electrode system known today. For a typical concentric two-electrode system we found, by means of finite element calculations, that while viable skin represented about 10% of the measured impedance at 1 kHz, it represented about 90% of the impedance at 100 kHz [8]. It is therefore obvious that e.g. an instrument like the Skicon-200 [10], which measures at 3.5 MHz, does hardly measure in the stratum corneum at all but may be an interesting instrument for measuring reactions in viable skin. Furthermore, this important mechanism is evidently not taken into account when the author advocates using a frequency range tending towards the high-frequency limit of the dispersion for skin hydration measurements. Smaller and more closely separated electrodes decrease the influence from viable skin, however, and hence the Corneometer CM 825 [11] represents a reasonable endeavour to achieve isolated measurements on the stratum corneum at relatively high frequencies. Both electrode width and separation must however be small compared to the thickness of the stratum corneum in order to achieve this and the Corneometer is hence only suitable on rather thick stratum corneum like e.g. on the frictional surfaces [12].

Our suggested choice of low-frequency susceptance measurements for skin hydration assessment is also scrutinised in the book chapter. The author's arguments against the method are firstly that it – being a single-frequency method – fails to specify the impedance or admittance locus. This is of course irrelevant since the stratum corneum does not produce a depressed circular arc. Secondly the criticism is directed towards the possible influence by temperature and sweat duct filling on the measured values. This issue has been thoroughly investigated for many years in our group [3, 7, 8, 13–15]. In a recent article we discuss the matter and find the influence from viable skin and sweat ducts to be negligible even in the worst case of stratum corneum soaked in water and the impedance of the viable skin being very high [16]. The temperature coefficient for the susceptance is typically only –0.5% per degree Celsius [9] and since the low-frequency susceptance for the stratum corneum increases exponentially with moisture content [17], the temperature influence is also negligible in any practical situation. In the mentioned article we use the Cole equation together with a common four-component electrical model for the total skin (stratum corneum and viable layers) but we would like to emphasise that the conclusion of the paper is not dependent on any of these models. The author factorises and transforms our expression for the measured susceptance by introducing new parameters and then asks how we can be sure that the limit conditions are still met (i.e. still negligible influence from viable skin and sweat ducts). This is only misleading since undoubtedly, transformation or factorisation of an equation does not change the variable's dependence on the original parameters.

Despite the author's warning that the frequency dependence is far from simple, the fact that the low-frequency susceptance does not increase proportionally to the measuring frequency, as it would with an ideal capacitor, does not represent any problem when using susceptance as a parameter for skin hydration. The frequency dependence is totally irrelevant in this context. The relation between water content and susceptance is known and the measurements can be done with negligible influence from unwanted factors like temperature, sweat duct filling and viable skin. Based on our current knowledge on the electrical properties of human skin, low-frequency susceptance measurements prevail as the most correct technique for electrical measurements of skin hydration.

References

1 Elsner P, Barel AO, Berardesca E, Gabard B, Serup J (eds): Skin Bioengineering: Techniques and Applications in Dermatology and Cosmetology. Basel, Karger, 1998.

2 Yamamoto T, Yamamoto Y: Electrical properties of the epidermal stratum corneum. Med Biol Eng 1976;14:151–158.

3 Martinsen ØG, Grimnes S, Sveen O: Dielectric properties of some keratinized tissues. 1. Stratum corneum and nail in situ. Med Biol Eng Comput 1997;35:172–176.

4 Clar EJ, Her CP, Sturelle CG: Skin impedance and moisturization. J Soc Cosmet 1975;26: 337–353.

5 Leveque JL, De Rigal J: Impedance methods for studying skin moisturization. J Soc Cosmet Chem 1983;34:419–428.

6 Ollmar S, Nicander I: Information in multi-frequency measurement on intact skin. Innov Tech Biol Med 1995;16:745–751.

7 Martinsen ØG, Grimnes S, Karlsen J: Electrical methods for skin moisture assessment. Skin Pharmacol 1995;8:237–245.

8 Martinsen ØG, Grimnes S, Haug E: Measuring depth depends on frequency in electrical skin impedance measurements. Skin Res Technol 1999;5:179–181.

9 Foster KR, Schwan HP: Dielectric properties of tissues and biological materials: A critical review. Crit Rev Biomed Eng 1989;17:25–104.

10 Tagami H: Hardware and measuring principle: Skin conductance; in Elsner P, Berardesca E, Maibach HI (eds): Bioengineering of the Skin: Water and the Stratum corneum. Boca Raton, CRC Press, 1994, pp 197–203.

11 Courage W: Hardware and measuring principle: Corneometer; in Elsner P, Berardesca E, Maibach HI (eds): Bioengineering of the Skin: Water and the Stratum corneum. Boca Raton, CRC Press, 1994, pp 171–175.

12 Grimnes S, Martinsen ØG, Mørk C: Can skin hydration be estimated from electrical measurements? Skin Res Technol 1996;2:213.

13 Martinsen ØG, Grimnes S, Henriksen I, Karlsen J: Measurement of the effect of topical liposome preparations by low frequency electrical susceptance. Innov Tech Biol Med 1996;17: 217–222.

14 Martinsen ØG, Grimnes S, Kongshaug ES: Dielectric properties of some keratinized tissues. 2. Human hair. Med Biol Eng Comput 1997;35:177–180.

15 Martinsen ØG, Grimnes S, Karlsen J: Low frequency dielectric dispersion of microporous membranes in electrolyte solution. J Coll Interface Sci 1998;199:107–110.

16 Martinsen ØG, Grimnes S: On using single frequency electrical measurements for skin hydration assessment. Innov Tech Biol Med 1998; 19:395–399.

17 Martinsen ØG, Grimnes S, Nilsen SH: New measuring cells for absolute water content and electrical admittance of keratinised tissues. Med Biol Eng Comput 1997;35(suppl):348.