

Measurement of Skin Surface pH

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What Is Already Known?

- Skin surface pH has been measured since 1928.
- The planar glass electrode was first used in 1955 to measure skin surface pH and is still the most widely used method of measurement.

What Does This Text Add?

- Practical guidance for measurement of skin surface pH using the planar glass electrode is provided.

Abstract

The acidic nature of the skin surface was recognised more than a century ago and has been measured since 1928. Several non-invasive methods for measuring skin surface pH have been developed ever since and have contributed to our understanding of healthy and diseased skin. This chapter summarises the endogenous physiological, exogenous and environmental factors that influence skin surface pH and its measurement as well as the different measurement methods for skin surface pH, with specific

emphasis on the classic planar glass electrode method. Also, practical guidance for measurement of skin surface pH using the planar glass electrode method is provided. Adherence to practical skin surface pH measurement (method) guidelines with due consideration and practicable control of all factors that may affect skin surface pH will ensure credible pH measurement results in our continuous pursuit of understanding especially diseased skin.

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Although the acidic nature of the skin surface was recognised more than a century ago, the first significant study on skin surface pH was carried out in 1928 [1, 2]. With crude technology, Schade and Marchionini reported a skin surface pH between 3 and 5. It is now, 90 years since the concept of an “acid mantle” of the skin was introduced by Marchionini. The skin surface pH is normally acidic and ranges between 4.2 and 6.1 [3], while the body’s internal pH is near neutral. Historically, the physiological function of an acidic skin sur-

face pH was thought to provide protection (defense) against micro-organisms [4]. However, since the early 2000's the skin surface pH and maintenance thereof has been implicated in playing an important role in stratum corneum integrity and cohesion and the regulation of epidermal barrier homeostasis and antimicrobial defense mechanisms [4, 5]. Interest in the skin's pH is also attributed to numerous diseases affecting skin pH, including acne and eczema [4]. For example, persons with filaggrin mutations and atopic eczema have significantly higher skin pH values than individuals not carrying filaggrin mutations [6] (Danby and Cork, as well as Bigliardi, in this volume).

In chemistry, pH is defined as the $-\log [H^+]$ concentration of a pure aqueous solution. With skin surface pH measurement "apparent skin pH" is measured, since the skin is not an aqueous solution as H^+ ions are released by lipids and other compounds present on the skin into the water applied to the skin with the electrode [2, 7, 8]. Several non-invasive methods for measuring skin surface pH have been developed over the past 90 years. In this chapter, we summarise the factors that influence skin surface pH and its measurement as well as the different measurement methods for skin surface pH, with specific emphasis on the classic planar glass electrode method. Also, we provide practical guidance for measurement of skin surface pH in clinical and non-clinical settings using the planar glass electrode method. Given the simplicity of this instrument, skin surface pH can be monitored routinely as part of a skin health program.

Factors Influencing Skin pH and Its Measurement

Many endogenous physiological, exogenous and environmental factors influence skin surface pH (Table 1, Biro, in this volume). Published literature on these factors has been evalu-

ated by numerous publications in the past 15 years [2, 4, 7, 9–12] and should be consulted for extensive explanation of each factor. In brief, skin surface pH differs with age, anatomical position, circadian rhythm, the amount of sebum on the skin, skin moisture and sweating (caused by exertion/exercise). Skin diseases such as atopic dermatitis [4], ichthyosis [4], irritant contact dermatitis [12] and psoriasis [9] have been shown to alter skin surface pH (Danby and Cork, as well as Bigliardi, in this volume). The influence of ethnicity, gender and skin temperature is inconclusive, with some studies reporting an influence and others not.

Many exogenous factors such as occluded skin, exposure to skin irritants such as soaps and detergents, application of cosmetic products and skin washing affect skin pH. The influence of environmental season and temperature on skin pH appears inconclusive.

Measuring Methods

Skin surface pH was determined by colorimetric methods in the early part of the 20th century [2]. This involved the application of an indicator to the skin, recollection thereof in a tube and the color change measured with a colorimeter. Schade and Marchionini [1], credited for the first significant reporting of skin surface pH, used a gas chain bell electrode to measure skin surface pH. In 1930, foil colorimetry, a simplification of the above-mentioned colorimetric method was introduced, in which indicator-impregnated sheets of adsorbing strips were placed on the skin with water [13]. Also, the skin's barrier capacity was measured with the application of a highly diluted sodium hydroxide solution containing an indicator to the skin [14]. However, the development of glass electrodes responding to H^+ ions by McInnes and Dole in 1930 and the invention of the "acidimeter" by Beckman in 1934 paved the way for

Table 1. A summary of factors influencing skin surface pH (adapted from [2, 4, 7, 9–12])

| Factors | Parra and Paye [2], 2003 | Darlenski et al. [10], 2009 | Stefaniak et al. [7], 2013 | Ali and Yosipovitch [4], 2013* | Darlenski et al. [11], 2017 | Stefaniak and du Plessis [12], 2017 |
|------------------------|--------------------------|-----------------------------|----------------------------|--------------------------------|-----------------------------|-------------------------------------|
| <i>Endogenous</i> | | | | | | |
| Age | Yes | Yes | Yes | Yes | Yes | Yes |
| Anatomical position | Yes | Yes | Yes | Yes | Yes | Yes |
| Circadian rhythm | Yes | Yes | Yes | – | Yes | Yes |
| Ethnicity | Yes | Yes | Inconclusive | Yes | Inconclusive | Inconclusive |
| Gender | No | Inconclusive | Yes | – | Inconclusive | Inconclusive |
| Genetic predisposition | – | – | – | Yes | – | – |
| Sebum on skin | Yes | – | – | Yes | – | – |
| Skin health (diseases) | – | – | Yes | – | – | Yes |
| Skin moisture | – | – | – | Yes | – | – |
| Skin temperature | Yes | Inconclusive | – | – | – | – |
| Sweating/exertion | Yes | Yes | – | Yes | – | Yes |
| <i>Exogenous</i> | | | | | | |
| Occlusion | – | – | Yes | Yes | – | Yes |
| Skin irritants | – | – | Yes | Yes | – | Yes |
| Skin washing | Yes | – | Yes | Yes | – | Yes |
| Topical products** | Yes | – | – | Yes | – | – |
| <i>Environmental</i> | | | | | | |
| Season/temperature | Inconclusive | Yes | Yes | – | – | Inconclusive |

–, not reported; *, also in [6], **, including detergents, cosmetics and soaps.

the development and improvements of pH meters as it is known today [15]. The glass electrode with a flat (planar) measuring surface, devised by Ingold, was first used by Schirren (1955) to measure skin surface pH [16]. The planar electrode with one unit containing both the active and reference electrodes (also known as the “combined” electrode or “single glass rod measuring circuit”) is still the most universally method used today to measure skin surface pH (Fig. 1).

Though the focus of this chapter is on the planar electrode, it is worth mentioning that several other innovative methods for assessing skin surface pH have been developed and include the use of pH-sensitive fluorescent dyes followed by confocal laser microscopy, 2-photon fluorescence lifetime imaging or electron spin resonance imag-

ing [11, 17–21]. A pseudo-pH measurement is possible with in-vivo Raman micro-spectroscopy [11]. However, these methods have not gained general acceptance.

The Planar Glass Electrode Method

Instrumentation and Its Measurement Principles
Skin surface pH is most commonly measured using a planar (flat measuring surface area, diameter approximately 10 mm) glass electrode connected to a voltmeter. This method is known to be simple, non-invasive and reproducible [10]. Several of these electrodes from different manufacturers are commercially available today.

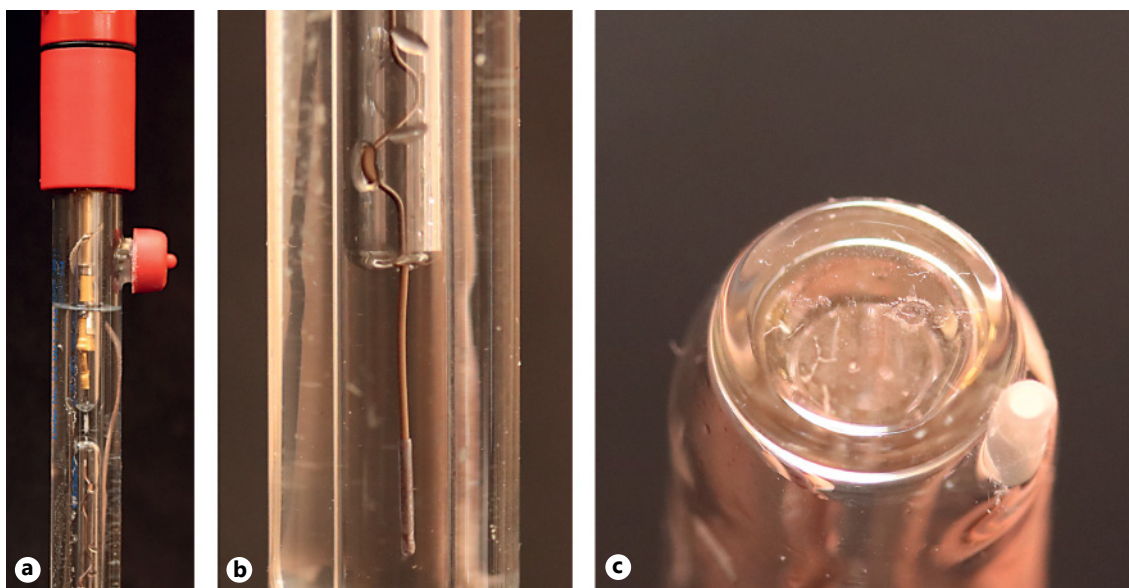


Fig. 1. Glass planar combined electrode for measurement of skin surface pH: view of combined electrode (a), close-up view of planar measurement surface (b and c).

Measurement Protocol

The purpose of this protocol is to provide guidelines for the reproducible measurement of skin surface pH with consideration of minimising the effect of endogenous (physiological), exogenous, environmental and instrumentation factors. Many of these guidelines are contained in the European Group on Efficacy Measurement of Cosmetics and Other Topical Products guidance for the in vivo assessment of skin surface pH [2] and two guidelines for the in vivo assessment of pH in non-clinical settings [7, 12]. Despite the latter proposing measurement of skin surface pH in non-clinical settings, such as workplaces, most of the guidelines provided are applicable to all measurements of skin surface pH.

For any health-related research involving human subjects, national and institutional research ethics requirements should be kept in mind and adhered to, if applicable. For ethics approval, the social and clinical value of the study, scientific validity, fair selection of subjects/participants and a favorable risk-benefit ratio should be justified.

Furthermore, participants should provide informed consent for participation and potential and enrolled participants should be treated with respect [22].

After informed consent is obtained, precise instructions should be communicated regarding acceptable skin-washing practices (using soaps), the use of topical products such as cosmetics and lotions and occlusion of measurement positions (some of which may even be considered part of the exclusion criteria for participation). It is recommended to avoid skin washing with water 2–3 h prior to measurement and up to 10 h when alkaline soaps are used [2]. If possible, measurements should be made 12 h after use of ointments, body lotions and other topical products are applied to the measurement area [23].

Handling and Storage of the Electrode (Probe)

The pH probe should always be handled in accordance to the instructions of the manufacturer. The pH electrode is delicate and should be handled with care, avoiding forceful contact with

hard objects [2, 7]. As noted earlier, the planar electrode utilizes both an active and a reference electrode. The level of the electrode solution (3 mol/L potassium chloride [KCl]) in the external reference electrode sheath should be verified regularly and supplemented if too low (the required minimum fill level may differ between manufacturers). During short breaks between measurements, the electrode measuring surface should be immersed in a KCl solution or in deionised water. For longer storage intervals, the protective electrode covering cap should be filled and regularly refilled with a KCl solution. After prolonged storage, the electrode should be immersed in a KCl solution for at least 12 h prior to use [2]. Any white KCl that may deposit around the membrane or externally on the electrode should be removed with distilled water [24].

Equilibration, Calibration and Use of the pH Meter

The rubber cap covering the lateral electrode-filling aperture should be lifted and immediately replaced once daily before measurements as to allow atmospheric pressure compensation [24]. Prior to use, the pH meter should be equilibrated for at least 20 min in the same room where measurements will be recorded [2, 7]. It is desirable to maintain room temperature between 20 and 22°C and the relative humidity between 40 and 60% to minimize sweating by the participant [2].

The pH meter must be calibrated in accordance to the instructions of the manufacturer [7, 12]; usually this implies calibration prior to use, but longer intervals may be prescribed based on the frequency of use and the age of the electrode [2]. With high frequency measurement, periodic verification against a standard buffer may also be required [7]. Calibration with at least 2 stable calibration buffers, usually at a pH of 4 and 7, should be performed.

Prior to measurement, the participant should be relaxed and acclimated for at least 20 min at the above-mentioned room temperature and rel-

ative humidity in order to avoid errors that could arise due to temperature and sweating [2]. Also, skin positions to be measured should not be occluded by clothing. Measurement of skin surface pH should be made on anatomical positions appropriate for the particular study design. In clinical settings, the standard anatomical position is the (mid) volar forearm. The skin on the measurement position may be wiped using a clean, dry, oil- and lotion-free tissue paper or filter paper to remove excess sebum or other residues [7, 12]. The use of water to clean the skin is not recommended, as it will influence the skin surface pH. The flat measuring surface of the pH electrode should be moistened with deionised water prior to it being applied to the skin (as to avoid contamination). The electrode should be held at a right angle to the skin and with gentle pressure applied in order to obtain optimal contact between the electrode's measuring surface and the skin surface [7]. Excessive pressure must be avoided, as it will most likely affect the extraction of material from the skin and expunge water between the electrode and the skin [2]. If possible, measurements should be performed by the same person, as to avoid inter-individual operator variability. Measurements should be recorded upon obtaining a stable signal (as is defined by the instrument manufacturer) [7, 12]. It is recommended to make 3 sequential measurements on the same anatomical position, each adjacent to the other. The lag-time between these sequential measurements should be as short as possible [7]. If more than one anatomical position is to be measured, it is recommended that all measurements on one anatomical position be completed before moving to the next position [7, 12]. If pH measurements are made at time intervals on a specific anatomical position, the area of measurement should be demarcated so as to ensure that all measurements are performed in exactly the same positions. Dermatological marking pens, photographs or templates may be used to demarcate measurement positions on the skin.

The electrode should also be regularly inspected between measurements for possible contamination with sebum and other substances, and if present, it should be eliminated [2]. Finally, if skin surface pH measurements are recorded in conjunction with other skin barrier function measurements, such as transepidermal water loss and skin hydration, skin surface pH should be measured last, as the water applied onto the skin with pH measurement will affect the other measurements [12].

Data Recording, Interpretation and Reporting

Modern skin pH metres report pH values with a precision of ± 0.01 to 0.1 units. A minimum dataset as described by Stefaniak et al. [12] should contain the following: (i) relevant endogenous (age, anatomical position, ethnicity, gender, observations on skin health, sebum and possible sweating) exogenous (skin hygiene/washing, possible occlusion of measurement positions and use of topical products) and environmental factors (record date, time and season); (ii) measurement conditions (acclimation time, temperature and relative humidity for pH meter and participants, pH electrode calibration and number of measurements); (iii) measurement results and variability thereof to at least 0.1 units (triplicate measure-

ments should ideally be reported as geometric mean, although most published literature reported arithmetic mean, but clearly stated it as such); and (iv) any relevant deviations from the study protocol or skin surface pH measurement guidance.

Conclusion

Skin surface pH measurements, with predominantly the planar glass electrode method was and is still pivotal in the assessment of healthy and diseased skin. Of utmost importance is adherence to published and given practical skin surface pH measurement (method) guidance with due consideration and practicable control of all endogenous, exogenous and environmental factors that may affect skin surface pH.

Disclaimer

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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