Development of Skin Measurement Instruments

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Abstract: The observation of skin changes has long been conducted with an emphasis on the visually identifiable and palpable lesions. However, because of the limitation of sensory evaluation, efforts have been made during the last 30 years toward the introduction of various types of instrumental measurement. Skin conditions that have conventionally been categorized as normal can now be classified into various types on the basis of numerical values. Achievements from such studies are widely utilized not only for the treatment of diseases, but also in the field of cosmetics. Of particular importance is the measurement of the barrier function of the stratum corneum in the outermost layer of the skin, as well as its water content. Such measurement enables us to perform numerical assessment of skin irritation and abnormal cornification. It also facilitates the quantitative evaluation of the action of topical drugs in softening and smoothing the skin surface. Skin color, surface topography, and stiffness can also be evaluated numerically. The magnified observation of the skin assists the differential diagnosis of malignant tumors. Recent developments are enabling us to perform in-situ non-invasive observation of the internal structures of the skin, eliminating the need for invasive biopsy and histopathological studies to some extent.

Key words: Barrier function; Biophysical measurement; Hydration state; Instrumental measurement; Skin; Stratum corneum

Introduction

Gross observation has been and is an essential part of the examination of skin in our routine practice. Descriptive dermatology has a long history, and experienced dermatologists are usually reputed for their capability in identifying subtle changes in the patient’s skin. Typically, the presence of a skin rash is obvious. A dermatologist makes a diagnosis by observing the characteristic morphology of the skin lesion, applies appropriate topical drugs, and confirms the disappearance of macroscopic lesions. The whole process of treatment
is performed with the naked eye. The use of instruments has traditionally been limited to the use of a magnifier by presbyopic physicians and the use of a microscope for mycological examination.

However, the field of dermatology is not limited to overt pathologic changes, but also shares a number of elements with cosmetic field. Even the skin of healthy individuals shows subtle variations in tone and the degree of softness, which are very difficult to describe verbally. Needless to say, the characteristics of diseased skin are much more diverse.

When we measure various characteristics of the skin using appropriate instruments, we find that the normal skin shows wide variations that are difficult to discern with the naked eye. It is now clear that there are even “invisible dermatoses,” which are conditions detected only by the use of instruments. What we see with the naked eye is not everything.

Reflecting this situation, there has been a movement toward the introduction of measurement instruments in dermatology and the development of skin biometry in the past quarter of a century. Specialized academic societies have been established and dedicated scientific journals have come into publication. Nowadays, more and more instruments are being used in our daily practice.

**Measurement of Skin Surface Properties**

The outermost layer of the skin consists of the stratum corneum, which functions as a barrier preventing the free passage of substances and maintains the suppleness of the skin. The stratum corneum is composed of corneocytes, which are dead epidermal keratinocytes commonly called scurf. The spaces among these cells are filled with intercellular lipids arranged in a special lamellar structure. The stratum corneum as a whole is a biologically produced membranous structure less than 20μm thick. The reason for the presence of the stratum corneum all over the human body surface is the basic need to retain water in the body living in a dry environment and warding off the invasion of microbes and other harmful substances.

As compared with the healthy skin, diseased skin looks whitish and is rough and dry to the touch. The stratum corneum of the skin showing such pathological appearance lacks sufficient barrier functions. Because it loses water to dry air and becomes hard and brittle, cracks develop on the skin surface as a result of body movement. This leads to the formation of hard, thick lumps of horny tissues called scales. From the standpoint of maintaining a beautiful, healthy skin, the moisture content of the stratum corneum is one of the major factors affecting the properties of both healthy and diseased skin, and this tissue is considered to be one of the most important targets of instrumentation in dermatology. In addition, this measurement is important to evaluate the effectiveness of topical drugs and skin care cosmetics.

1. **Measurement of the barrier function of stratum corneum**

Recently, it has become possible to examine *in situ* the barrier function of the stratum corneum using a non-invasive method called transepidermal water loss (TEWL) measurement. This method uses an electric hygrometer to measure the amount of water being lost slowly from the body through the stratum corneum.

Because the measurement is affected by perspiration, it is performed at an ambient temperature of 22°C or less and under conditions that cause no sweating. The skin with inflammatory conditions forming scales consistently shows high values of TEWL reflecting the loss of barrier function. A study using this measurement has revealed a loss of barrier function in the skin damaged by detergents, as well as in atopic xerosis (areas of skin in atopic dermatitis patients that are simply dry but have
no visible lesions). The situation differs in the xerosis of elderly people. While inflammatory skin lesions involve the formation of pathological stratum corneum and appearance of scales as a result of enhanced epidermal metabolism, the xerosis of elderly people is characterized by the presence of intact barrier function, and the dryness results from the lack of moisture supply from inside after moisture is lost to the dry air of winter. Despite the similar dryness in clinical appearance, the latter is characterized by the thick accumulation of the stratum corneum and reduced TEWL.

On the other hand, fresh scars, hypertrophic scars, and keloids with inflammation and fibrous tissue proliferation in deep layers of the dermis show a reduction of barrier function, even if no scales are observed. This is also the case with the topical applications of retinoic acid for photo-aging in the exposed skin areas of elderly patients and the oral use of retinoids for dyskeratotic dermatoses. Naturally, normal skin in different parts of the body shows different values of TEWL. The skin of the face and the external genitalia present high values of TEWL approximating those in skin lesions in other locations.

2. Measurement of hydration state of stratum corneum

Normal stratum corneum binds water and performs the important hydration (moisture retention) function for maintaining the softness and smoothness of the skin and allowing the unrestricted movement of the skin. A loss of this function may result in dryness, rough skin, and even the scales and cracks that frequently accompany skin diseases. Thus, the hydration state of the stratum corneum is a very important measure both for cosmetic scientists, who attempt to design fundamental cosmetics that would enhance the water content of a normal stratum corneum, and for dermatologists, who treat skin diseases by the use of topical drugs increasing the water content of an abnormal stratum corneum.

In 1980, the authors reported that we could perform in-vivo measurement of the hydration state of the stratum corneum surface instantly and non-invasively by the measurement of the high-frequency conductance or electric capacitance. Since then, many types of instruments based on this principle have been developed and used widely for diagnosis and the development of moisturizing agents and other topical drugs.

Along with the measurement of the barrier function of the stratum corneum, that of the hydration state of the stratum corneum provides the basis for the functional analysis of the stratum corneum. This measurement also should be performed at an ambient temperature of 22°C or less and a relative humidity of about 50% to avoid the influence of perspiration.

Among the parts of the body, the hydration value tends to be high in the face and the upper parts of the body, where sebum secretion is high, and low in the lower limbs. Elderly people who show a loss of hydration function of the stratum corneum often suffer from dryness in the lower limbs in winter, and this may lead to senile xerosis characterized by itchiness due to surface cracking. Normal individuals without skin rashes also show lower barrier function and higher TEWL of the stratum corneum in winter than in summer, when the same individuals are examined under the same conditions. This means that the skin in winter is more prone to dermatitis and aggravation of conditions such as atopic dermatitis.

The water content of the stratum corneum decreases when there are scales or crusts and increases promptly after the application of moisturizing agents. The oral use of retinoid for abnormal cornification and the topical use of retinoic acid for acne and photo-aging increase the softness of the skin within 1 or 2 weeks. The afore-mentioned keloids and fresh scars also show similar changes associated with the increase in the water content of the stratum corneum.
3. **Measurement of skin surface topography**

The most widely used method for detailed observation of skin surface topography seems to be the replica (microrelief) method. The surface topography of the skin is transferred to a soft nitrocellulose or silicone rubber material, transferred further from it to a resin or other appropriate material, and then observed under the light or electron microscope. Attempts have been made to visualize the surface topography in 2-dimensional representation and to achieve 3-dimensional reconstruction.

At present, specimens are usually observed under oblique light and the resulting shadows are read into an image analyzer connected to a computer, which calculates the area of detected shadows. For example, in Paget’s disease and mycosis fungoides, a type of T lymphoma, we can accurately define the borderline between the margin and normal tissues based on the difference in the form of minute wrinkles. 8)

**Measurement of Skin Color**

The measurement of the redness, whiteness, and pigmentation of the skin has been showing extremely remarkable progress. One of the most notable developments is Minolta Chroma Meter®, which has the capability to analyze skin tone based on hue, lightness, and chroma. With the convenience for routine use, it is fairly close to the ideal of instruments of this type. The facial skin of Japanese people shows a decrease in lightness (L*) and an increase in yellowness (b*) with the advancement of age. 9)

**Magnified Observation of Skin Surface**

The observation of the skin surface under a magnification of about 20× using a portable optical device called a dermatoscope facilitates the evaluation of superficial tumors, pigment lesions, and blood vessel network. It improved the accuracy of clinical diagnosis of seborrheic keratosis, solar lentigo, pigmented mole, basal cell carcinoma, and malignant melanoma, which often present difficulties in differential diagnosis. 9)

**Non-Invasive In-Vivo Observation of Microscopic Skin Structures**

While histopathological examination of the skin can be performed by simple procedures, it has a problem of scars remaining on the skin. The use of instruments enables us to conduct in-situ observation of microscopic changes in skin tissues. The construction of the skin can be examined by the use of high-frequency ultrasound. The numerical data of the hypertrophy and atrophy of the skin and the tumor location may be useful in assessing the extent of lesions or the effectiveness of treatment.

With respect to non-invasive observation of smaller structures, confocal laser microscopes are useful to examine the shallower layers of the skin, i.e., the epidermis and the papillary layer of the dermis. This method can provide information on the nature and thickness of corneocytes, nature of epidermal cells, and hemodynamics in capillary vessels. 10) However, in view of the fact that we have been accustomed to the observation of artifacts in HE stained histopathological specimens, the value of this method in the diagnosis of diseases has yet to be established.

**Identification of Substances in Skin Tissues**

Microdialysis is a method in which physiological saline is injected via a thick injection needle inserted intradermally or subcutaneously while the tissue fluid is recovered via another needle to analyze and identify substances occurring in it. This method enables us to analyze various substances in the tissue fluid sampled in real time and to study the roles and metabolism of these substances in normal and pathological skin. 11)
Measurement of Viscoelasticity and Stiffness of Skin

Cutometers are commercially available devices that comprehensively measure the mechanical and physical properties of the skin, such as extensibility and viscoelasticity. These instruments apply suction to the skin and measure its displacement and time to recovery. Because changes in the skin detected by this method reflect not only the hydration state of the stratum corneum, but also the thickness of epidermis, the extent of fibrous changes, the state of the dermal matrix, etc., it is necessary to understand the characteristics of each device and select appropriate models to suit the purpose of the study.

We recently developed a method of measuring skin stiffness with robotic tactile sensors and analyze it into superficial stiffness due to drying of the stratum corneum and deep stiffness reflecting fibrotic changes in the dermis.12)

Conclusion

Subjective observation that can be recognized only by the observer himself lacks reproducibility and reliability. The instrumental measurement of the living skin has been developed based on the idea of analytical science to understand skin conditions through analyzing instrumental measurement data. The application of biometry technology to the skin has enabled us to grasp numerically the properties of the skin that cannot be evaluated by the human senses. This approach has become essential to the understanding of not only the changes caused by skin diseases, but also the characteristics of normal skin reflecting age, sex, and anatomical location. With respect to normal individuals, we need to pay particular attention to the skin of elderly people, who represent an increasingly large part of our society. It is hoped that this approach will facilitate the measurement of the age-related changes in the skin and the scientific evaluation of the efficacy of treatment for aged skin.

REFERENCES

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