Cutometer®

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Hristo Dobrev

29.1 Introduction

The human skin possesses a complex structure and various functions which ensure the entity between the organism and the environment. Mechanical properties of the skin are of major importance for its protective function. They vary in accordance with age, sex and body sites, in some physiological and pathological skin conditions, and change due to different external and therapeutic influences. Considerable progress in the quantification of the skin mechanical functions had been achieved for the past 20 years through the introduction of modern non-invasive bioengineering methods and devices which provide the researchers with objective, quantitative, sensitive and reproducible measurements in vivo.

The Cutometer® (Courage + Khazaka Electronic GmbH, Cologne, Germany) is a well-recognized commercial device for measurement of the biomechanical properties of the skin. In this chapter, based on our own experience and review of the literature, we aimed to present the practical application of the Cutometer® method.

29.2 Measuring Equipment and Principle

29.2.1 Equipment

The Cutometer® is designed as separate or combined device.

1. The Cutometer® SEM 575 (Fig. 29.1), which is the successor of the Cutometer® SEM 474, is an independent device that includes two basic parts [7, 9, 40, 70].
   - Main unit, a metal housing containing vacuum pump with pressure sensor and microelectronics. The load of the vacuum (negative air pressure), the rate of its increase or decrease, the duration of suction (on time) and relaxation (off time) and the number of measuring cycles during one measurement can be defined through the Cutometer® software. The resolution of applied pressure is equal to 1 mbar.
   - Measuring probe, a handheld probe containing suction head, optical measuring system and microelectronics. The suction head is centred in the probe and has a standard circular aperture of 2-mm diameter (test area of about 3 mm^2). Optional probes with apertures of 4, 6 and 8 mm are available on request. The measuring system inside the probe head is noncontact and consists of a light source (light-emitting diode) and a light recipient, as well as two opposing glass prisms, which project the

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Fig. 29.1 Cutometer® SEM 575 (With permission from Courage and Khazaka GmbH, Cologne, Germany)

light from emitter to recipient. The changes of the infrared light beam intensity during the measurement are converted into millimetres (from 0 to 3.0 mm) and calculated with a resolution equal to 2 μm. The measuring probe is connected to the main unit through an air tube and an electric cable. During the measurement, it is held perpendicularly to the skin surface under constant pressure ensured (provided) by an elastic spring. The calibration data are stored in the memory of each probe which allows fast and easy exchange of probes with different apertures.

2. The Cutometer® MPA 580 (Fig. 29.2), that is currently available, combines the vacuum box for the Cutometer® with the built-in Sebumeter SM 815 and modular Multi Probe Adapter System which makes possible to connect up to 4 additional measuring probes as well as an ambient condition sensor. The Cutometer® Dual MPA 580 (Fig. 29.3) is the last generation device that allows the connection of two Cutometer® probes (with different diameters) at the same time.

29.2.2 Principle

The measuring principle of the Cutometer® is based on a suction method that consists of the measurement of vertical deformation of the skin surface after application of vacuum (Fig. 29.4) [7, 9, 40, 70].

Fig. 29.2 Cutometer® MPA 580 (With permission from Courage and Khazaka GmbH, Cologne, Germany)

Fig. 29.3 Cutometer® Dual MPA 580 (With permission from Courage and Khazaka GmbH, Cologne, Germany)

A defined negative air pressure is applied perpendicular to the skin through the opening of the probe for a selected time period. The evaluated skin surface is sucked into the aperture of the probe, and the resulted vertical deformation is measured by the optical measuring system inside the probe. The changes of light intensity are proportionally related to the penetration depth of the skin and are displayed on the monitor as curves in a coordinate system (extension/time or pressure/extension).

29.3 Software

The Cutometer® is designed for operation with an IBM-compatible PC via USB port. The last version of the Windows software allows storage of various data regarding the volunteer, date and time of experiment, skin area, external temperature and relative humidity, type of probe used and mode of measuring technique. The obtained

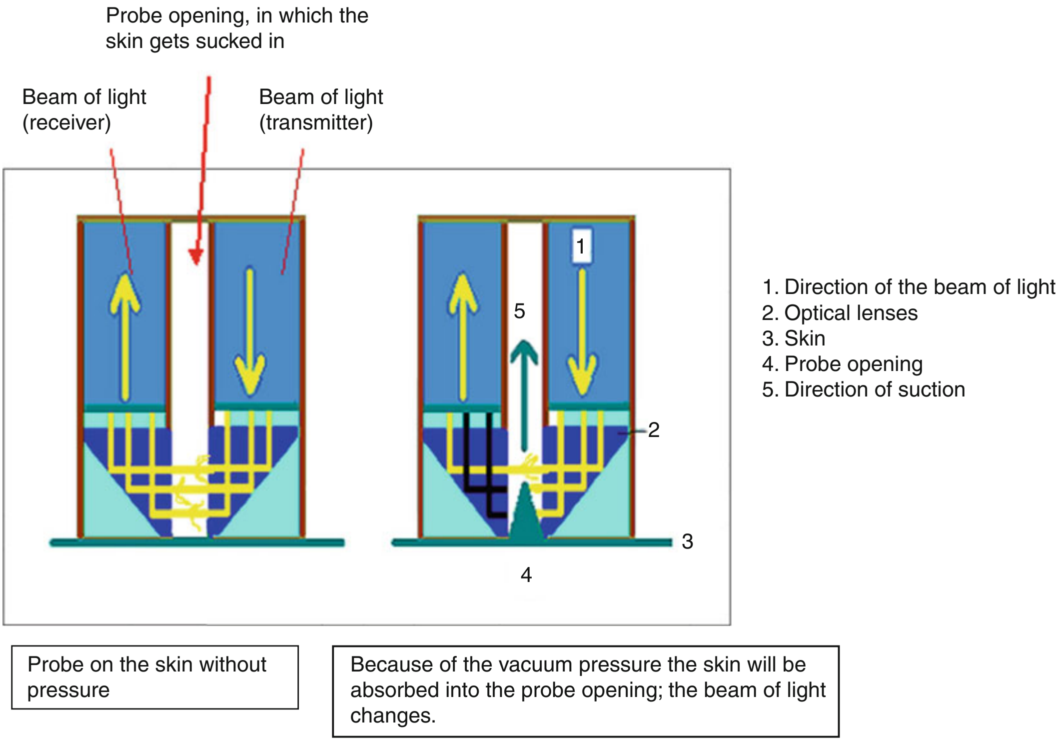


Fig. 29.4 Schematic view of the measuring system within the Cutometer® probe [56] (With permission from Courage and Khazaka GmbH, Cologne, Germany)

results are automatically calculated and displayed as curves and values [56].

The Cutometer® measuring cycle consists of suction phase and relaxation phase. It can be applied once or several times. The following parameters of the measurement can be exactly defined by the software:

- Pressure. The load of the air-negative pressure (vacuum) can be chosen between 20 and 500 mbar.
- Rate. The rate of increase or decrease of the air-negative pressure can be selected between 10 and 100 mbar/s.
- On-Time. The time when the air-negative pressure is applied (suction interval) can be chosen between 0.1 and 60 s.
- Off-Time. The time when the air-negative pressure is applied no longer (relaxation interval) can be chosen between 0.1 and 60 s.
- Repetition. The number of measuring cycles (suctions) included in one measurement can be varying between 1 and 99.
- Pre-Time. This function allows setting a short interval between pressing the start key and the beginning of the measurement.
- Preconditioning Time. This function allows (in the strain–time mode) to pretension the skin by applying a preliminary suction during a short time (0.1 s) before the real measurement is carried out.

The most used settings include air-negative pressure between 400 and 450 mbar, on-time and off-time intervals between 2 and 5 s and repetitions between 1 and 10.

29.3.1 Measuring Techniques

There are two measuring techniques available [7, 9, 56]:

1. In the strain–time mode, the deformation of the skin (in millimetres) is showed as a function of time (in seconds). This mode is mostly used in research studies.

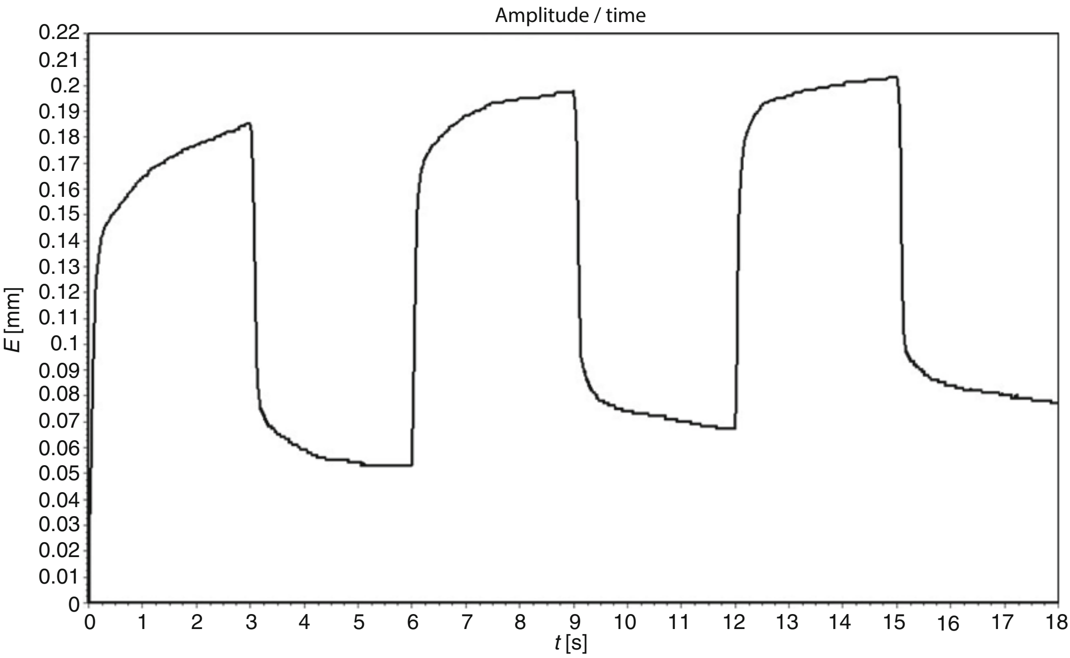


Fig. 29.5 An example of a curve obtained in mode 1 (*E*/*T* mode; extension/time)

2. In the stress–strain mode, the deformation of the skin (in millimetres) is showed as a function of the vacuum (in millibar).

29.3.2 Measuring Modes

There are four measuring modes available based on different combination of the measurement parameters [7, 9, 56].

29.3.2.1 Mode 1: Measurement with Constant Negative Pressure (–)

The measurement cycle consists of suction and relaxation phases. During the first phase, the skin is drawn into the probe with constant negative pressure set under “Pressure” within the interval set under “On-Time”. In the second phase, the negative pressure is switched off, and the relaxation of the skin is determined within the interval set under “Off-Time”. With the command “Repetition”, the number of measuring cycles can be chosen. The skin deformation is displayed as a function of time (Fig. 29.5). The measurement mode 1 is most important and is predominantly used for research studies in the field of dermatology and cosmetics.

29.3.2.2 Mode 2: Measurement with Linear Increase and Linear Decrease in Negative Pressure (/\)

The measurement cycle consists of three phases. At the start, the negative pressure is zero. During the first phase, the skin is drawn into the probe with linearly increasing negative pressure set under commands “Pressure” and “Rate” in the menu “Parameter”. This phase is succeeded by linearly decreasing negative pressure. In the last phase, the skin properties are evaluated when no negative pressure is applied for an interval set under “Off-Time”. With the command “Repetition” the number of measuring cycles can be chosen. The skin deformation can be displayed both as a function of time (Fig. 29.6a) and as a function of negative pressure (Fig. 29.6b).

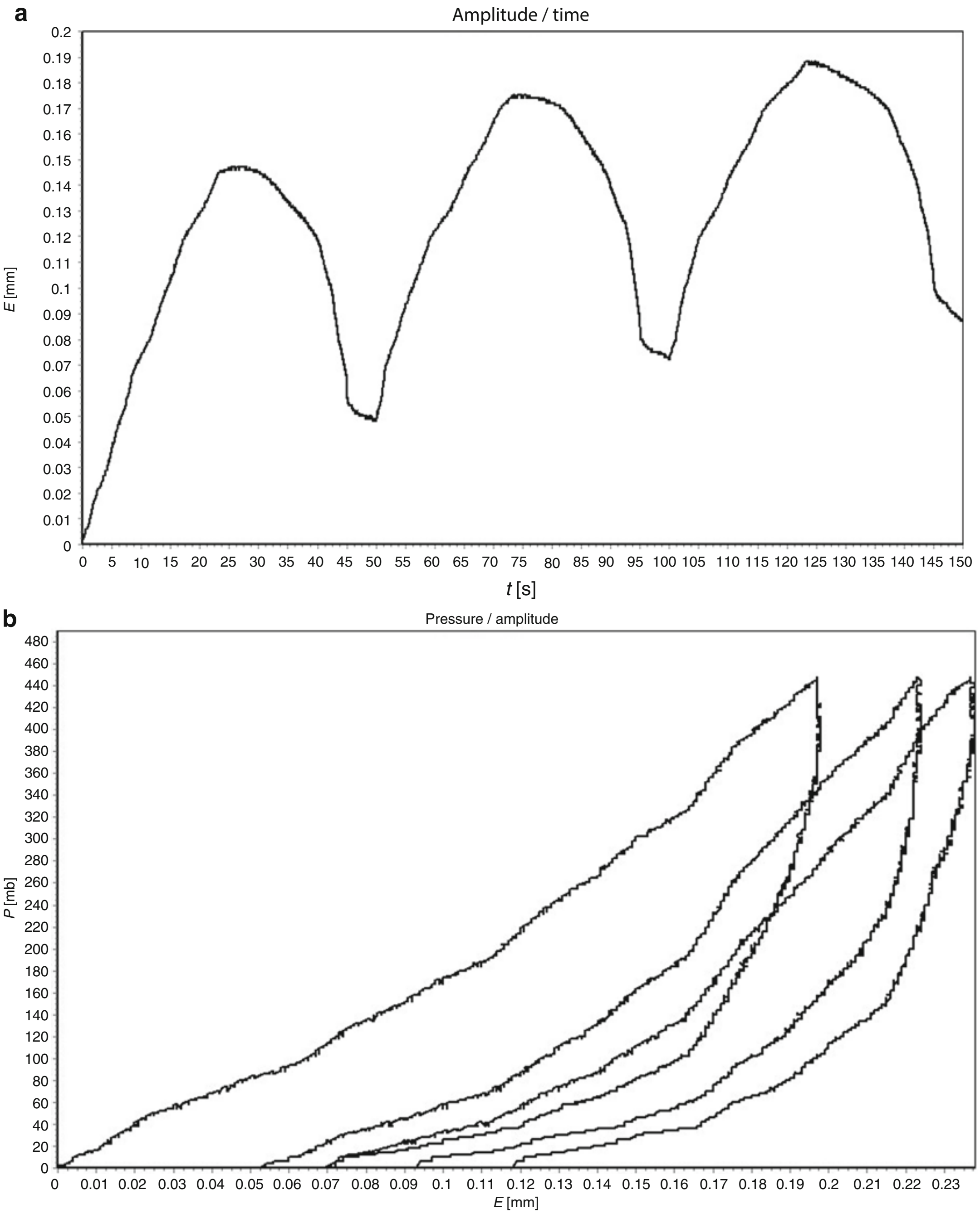


Fig. 29.6 (**a**) An example of a curve obtained in mode 2 (*E*/*T* mode; extension/time). (**b**) An example of a curve obtained in mode 2 (*P*/*E* mode; pressure/extension)

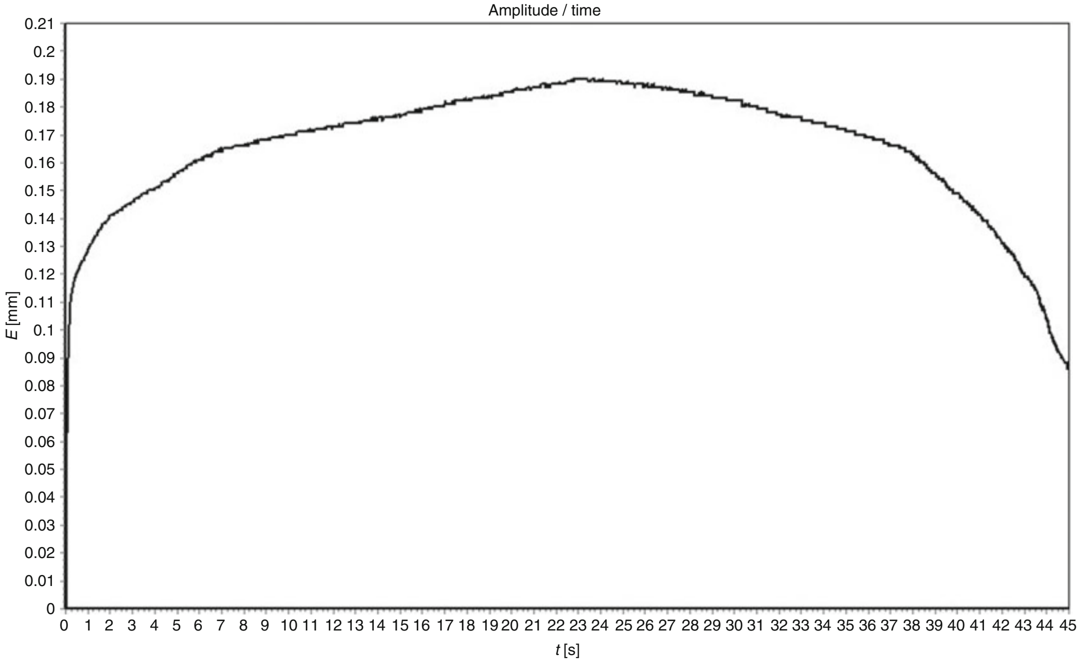


Fig. 29.7 An example of a curve obtained in mode 3 (*E*/*T* mode; extension/time)

29.3.2.3 Mode 3: Measurement with First Constant and Then Linear Decrease in Negative Pressure (–\)

The measurement consists of one measuring cycle which combines the first phase of mode 1 and the second phase of mode 2. The “On-Time” can be selected, whereas the “Off-Time” results from the selected “Pressure” and “Rate”. A relaxation time (here “Off-Time”) cannot be set as repetitions due to the combination of full pressure and slight release are impossible. The skin deformation is displayed as a function of time (Fig. 29.7).

29.3.2.4 Mode 4: Measurement with a Linear Increase in Negative Pressure and Then a Sudden Cessation of the Negative Pressure (/)

The measurement consists of one measuring cycle which combines the first phase of mode 2 and the second phase of mode 1. The “On-Time” results from the selected “Pressure” and “Rate”, whereas the “Off-Time” can be set. A repetition is impossible due to the combination of slightly increasing pressure and full release. The skin deformation is displayed as a function of time (Fig. 29.8).

In the literature measuring modes 2, 3 and 4 have no significance. There are few studies using measuring mode 2. According to Dobrev [18], the application of measuring mode 2 does not provide any advantage and only burdens the vacuum pump of the device.

29.3.3 Skin Mechanical Parameters

The new version of Cutometer® MPA 580Q software (v.1.3.6.16) allows calculating three groups of skin mechanical parameters designated as “R-parameters”, “F-parameters” and “Q-parameters”. In addition, there is a possibility for advanced users to edit the calculation formula for “R-parameters” according to their needs [56].

In this section, we describe in details the mechanical parameters derived from skin deformation curves obtained using measurement mode 1. Most detailed information concerning

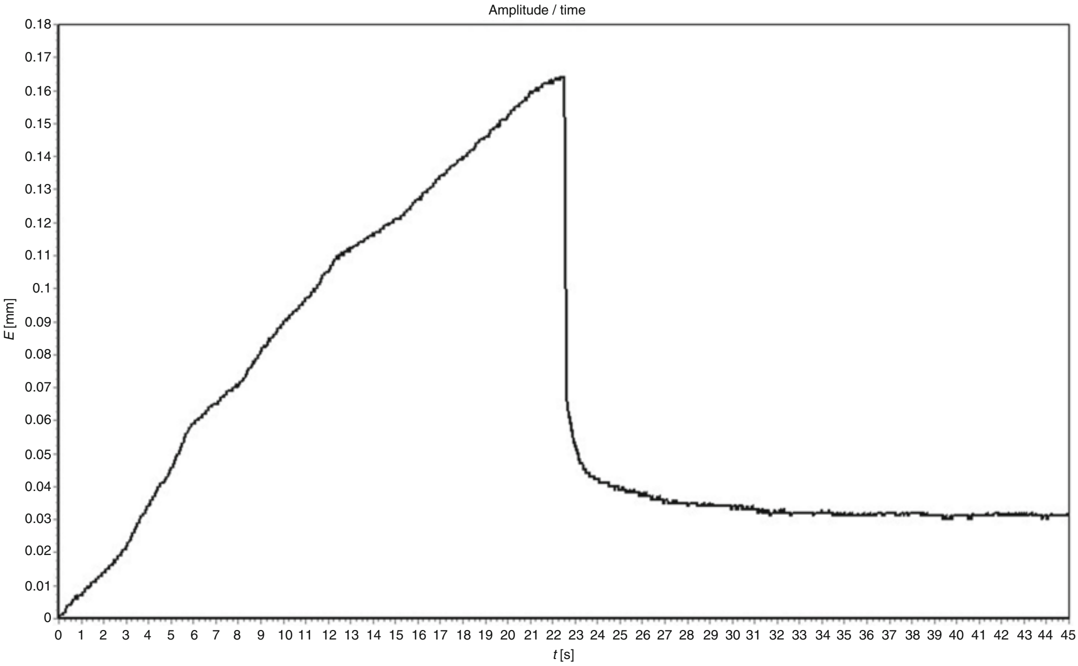


Fig. 29.8 An example of a curve obtained in mode 4 (*E*/*T* mode; extension/time)

the mechanical parameters determined by measurement modes 2, 3 and 4 can be obtained from the manufacturer's Information and Operating Instructions for the Cutometer® [56].

29.3.3.1 Mode 1 (Single Strain–Time Curve)

R-Parameters

The skin deformation curve obtained with Cutometer® includes two main parts generated during the suction phase and relaxation phase, respectively (Fig. 29.9). Each of them is composed of rapid deformation representing an elastic section, followed by a viscoelastic and finally a viscous section. These parts are designated as follows: immediate deformation (Ue), delayed deformation (Uv), immediate retraction (Ur) and delayed retraction (Ua–Ur). Values of Ue and Ur are taken at fixed intervals of time, respectively, 0.1 s after application of a suction and 0.1 s after removal of negative pressure [5, 7, 9, 56].

Based on these parts, the Cutometer® software calculates automatically the following parameters:

R0 = Uf, the final deformation (skin distensibility or skin extensibility).

R1 = Uf − Ua, the residual deformation at the end of 1st measuring cycle (resilient distension).

R2 = Ua/Uf, the ratio of total retraction to total deformation, which is called gross elasticity of the skin, including viscous deformation = gross elasticity, including viscous deformation) (overall elasticity).

R5 = Ur/Ue, the net elasticity without viscous deformation.

R6 = Uv/Ue, the ratio between delayed and immediate deformation, which indicates the relative contributions of the viscoelastic plus viscous and the elastic distension to the total deformation (viscoelastic ratio, the ratio of viscoelastic to elastic distension).

R7 = Ur/Uf, the ratio of immediate retraction to the total deformation, which is called biological elasticity (the ratio of immediate retraction to total distension).

R8 = Ua, the final retraction after removal of the vacuum (total recovery of the skin).

F-Parameters

The software calculates two surfaces ("areas") designated as F-parameters: (Fig. 29.8)

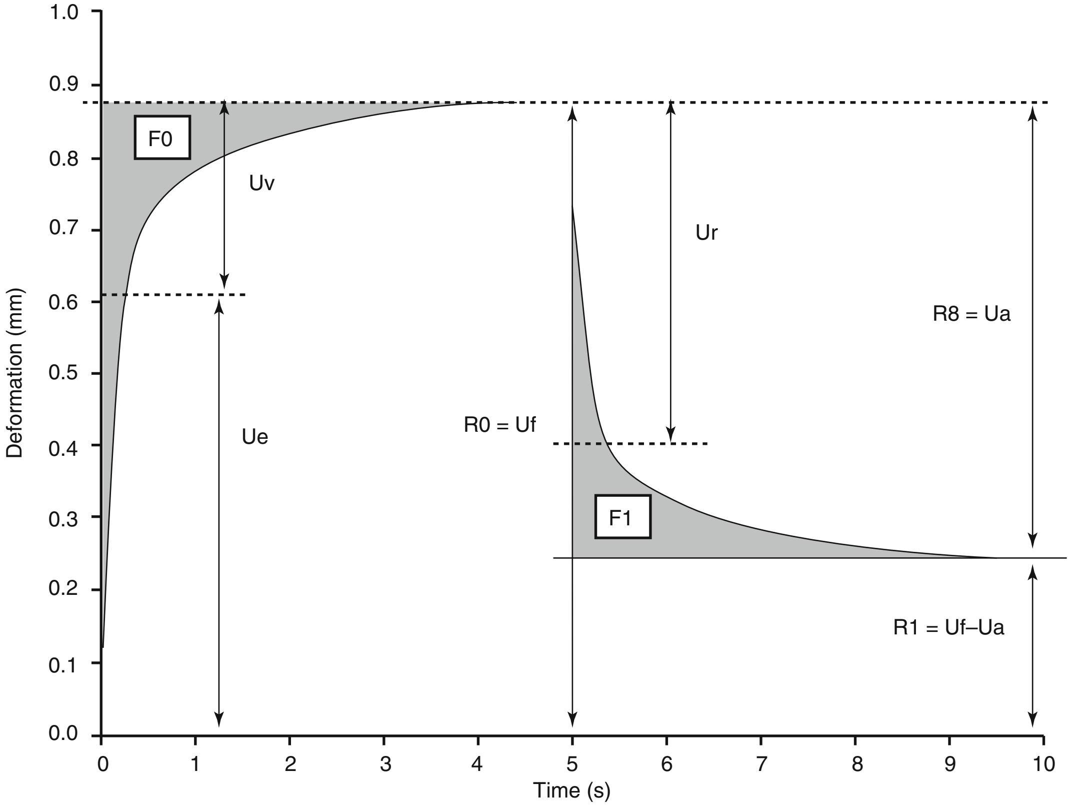


Fig. 29.9 Skin deformation curve obtained with CutoMPA 580. Aperture, 2 mm; suction time, 5 s, relaxation time, 5 s, repetition, 1

F0 = the surface between the real curve and the value corresponding to the maximal deformation Uf when going from start of suction to cease of suction.

F1 = the surface between the real recovery curve and the value corresponding to the maximal recovery going from cease of suction to cease of measurement.

Q-Parameters

The Q-parameters are developed by the scientist Di Qu et al. [56, 83] and have recently been added in the calculation formula. They could only be obtained in mode 1 for an equal suction and relaxation time. To receive these parameters, two horizontal lines have to be spread at the graph – the first one spreads through the highest point (R0), and the second one spreads through the inflexion point that is the point in time at which the recovery curve deviates from its initial linearity. At this point, the as QE and QR are divided (Fig. 29.10).

The Q-parameters include:

Q0 = the maximum recovery area, i.e. the area under the highest point (R0).

QE = the elastic recovery area of the skin.

QV = the viscous recovery area of the skin.

The parameters calculated by the Cutometer® software include:

Q0 = Q0; the maximum recovery area, i.e. the area under the highest point (R0).

Q1 = QE/Q0; the elastic recovery of the skin.

Q2 = Q2 = QV/Q0; the viscous recovery of the skin.

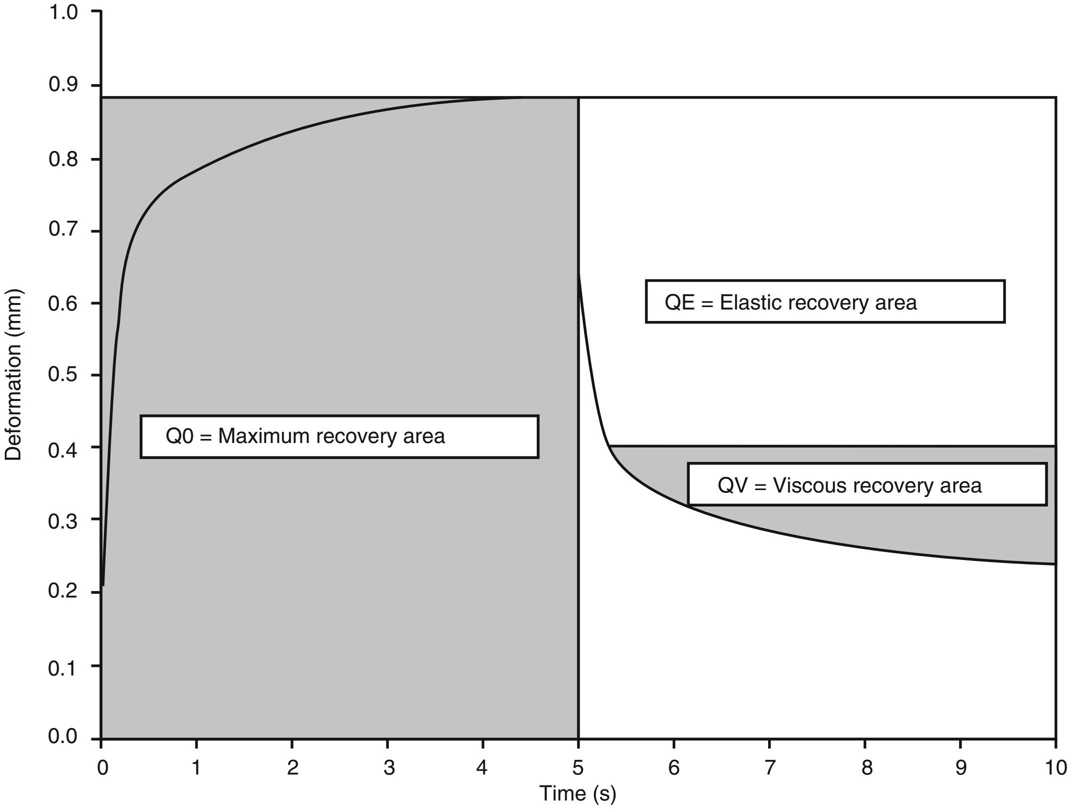


Fig. 29.10 Skin deformation curve obtained with CutoMPA 580. Aperture, 2 mm; suction time, 5 s, relaxation time, 5 s, repetition, 1

Q3 = (QE + QV)/Q0; the total viscoelastic recovery of the skin, i.e. overall skin elasticity.

29.3.3.2 Mode 1 (Repetitive Strain–Time Curve)

When repetitive suctions are applied, the subsequent curves are similar to the first one. However, they are progressively shifted vertically upward as a consequence of the slow return of the skin to the original state (Fig. 29.11) [56].

R-Parameters

The following additional parameters are calculated by the software:

R3 = last maximum amplitude (last maximal deformation).

R4 = last minimum amplitude (last residual deformation).

R9 = R3 − R0, the difference in maximal skin deformation between the last and the first suction called hysteresis (H).

F-Parameters

For curves taken in mode 1 with a minimum of 10 repetitions, the software calculates three additional surface parameters (“areas”). For this purpose, the curves are wrapped with an “envelope” function. Above and below the curves, the envelope curves appear as logarithmical average of maximum and minimum amplitudes. The F-parameters are designated as follows (Fig. 29.12):

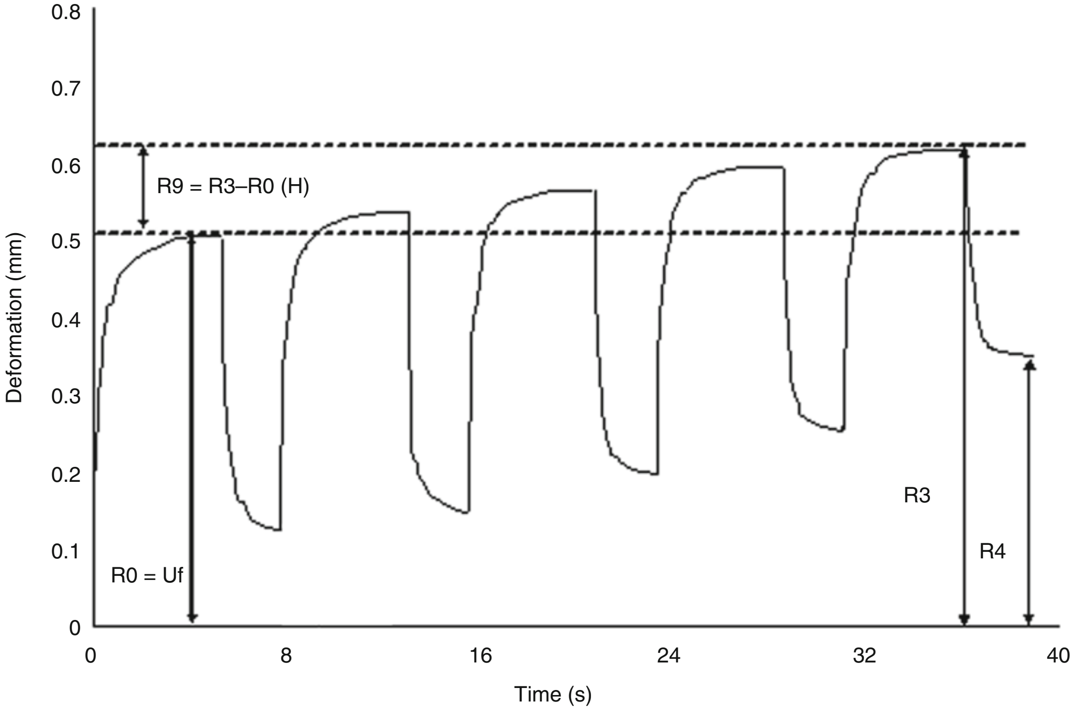


Fig. 29.11 Skin deformation curve obtained with CutoMPA 580. Aperture, 2 mm; suction time, 4 s, relaxation time, 2 s, repetition, 5

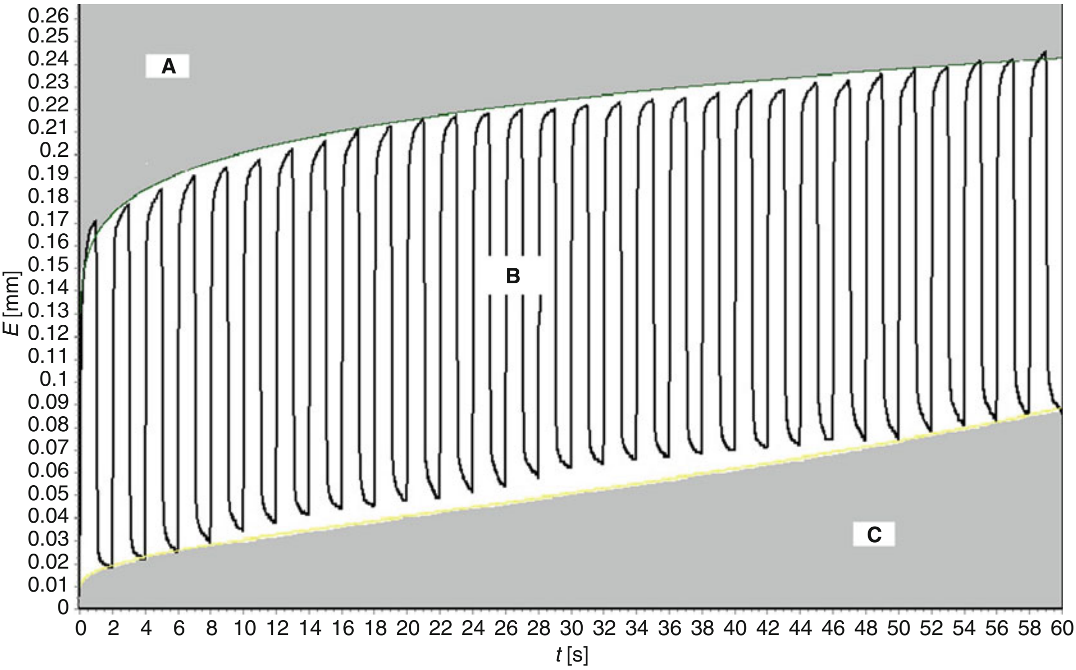


Fig. 29.12 Skin deformation curve obtained with CutoMPA 580. Aperture, 2 mm; suction time, 1 s, relaxation time, 1 s, repetition, 30 (F2 = area A; F3 = area B; F4 = area B + area C)

F2 = area above the upper envelope curve (the surface between the real curve and the value corresponding to the maximal deformation R3 after 10 cycles when going from start of suction to cease of the 10 cycles).

F3 = area within the envelope curves (the surface between the repetitive curves).

F4 = area below the upper envelope curve (the complete area, limited by the upper envelope curve).

29.4 Use of Cutometer®

29.4.1 Factors Influencing Measurements

29.4.1.1 Probe Aperture

At a constant vacuum, the degree of skin deformation (i.e. absolute parameters) directly correlates with the aperture diameter of the measuring probe and inversely correlates with the skin thickness. When using identical vacuum, the values of the absolute parameters Ue, Uv, Uf, Ur and R measured with 2-mm diameter probe are lower compared to values measured with 8-mm diameter probe. The differences in the values of relative parameters Ua/Uf, Ur/Ue, Ur/Uf and Uv/Ue measured with both probes are minimal [5, 26, 74].

The small aperture (2-mm diameter) measuring probe determines the mechanical properties of the epidermis and partly of the papillary dermis. It is applicable at any anatomical region and is most appropriate for measurement of healthy skin and studying the changes after the application of topical products.

The medium aperture (4- and 6-mm diameter) measuring probes determine the mechanical properties of the outer skin layers.

The large aperture (8-mm diameter) measuring probe determines the mechanical properties of the whole skin (derma and hypoderma). It is appropriate for evaluation of skin diseases with predominantly changes in the dermis (systemic sclerosis, scleredema of Buschke, psoriasis, keloids and erysipelas). The use of 8-mm diameter probe may be difficult for measurements at anatomic regions with thin and flabby skin (i.e. medial surfaces of the arm in elderly individuals), skin over bones or convex areas (i.e., forehead, temporal region, chest, dorsum of the hand and phalanx) as well as at the presence of residual lipid film on the skin surface shortly after the application of topical products [26, 30].

We consider that the simultaneous use of at least two probes with different apertures, i.e. both 2-mm and 8-mm probes, gives more complex information about the mechanical properties of the skin [26, 30].

29.4.1.2 Pressure (Vacuum)

For a constant opening of the probe, the absolute mechanical parameters are directly correlated with the intensity of vacuum applied, whereas the relative parameters are less independent of load for most anatomical regions [5]. Cua et al. [12] have found that Ur/Uf and Uv/Ue tended to increase with increasing loads. According to Wickett [99], the application of 200 mbar of vacuum leads to more sensitivity to moisturizing effects compared to 500 mbar of negative pressure.

29.4.1.3 Test Site

Volar forearms are considered the most appropriate test site generating reproducible measurement results using probes with different apertures. Significant differences in the skin mechanical parameters between both forearms have not been established [26, 30].

29.4.1.4 Measurement Scheme

The application of one and the same measurement scheme for study of one and the same skin condition makes the obtained results comparable. According to us, the most appropriate measurement scheme comprises the single application of constant vacuum of 400 mbar for 5 s followed by a 5-s relaxation time. This scheme produces enough meaningful results, does not overburden the device and shortens the duration of measurements [26, 30].

29.4.1.5 Preconditioning of the Skin

Barel et al. [5] have measured higher values of relative elastic parameters Ur/Ue and Ur/Uf using the pretension mode of the Cutometer®, indicating that preconditioned skin recovers more of its elastic deformation. They also consider that under pretension, the values of the skin deformation parameters are more reproducible and accurate. Dobrev [26] did not find any significant changes in the skin mechanical parameters using pretension of the skin, except for a nonsignificant tendency toward higher values.

29.4.1.6 Environmental Factors

It is recommended to perform the measurements under the same controlled room conditions. Temperature of 20–24 °C and relative humidity of 40–50 % are preferable. The tested person needs at least 15–20 min to acclimatize [56, 99].

29.4.2 Results Interpretation

The mechanical parameters determined by Cutometer® reflect the condition and the changes in skin structure and composition. They provide meaningful information about its major properties such as [5, 7, 30, 32, 70, 90]:

- Skin distension (stiffness), i.e. the ability of the skin to undergo distension or the skin resistance to change of shape under the influence of stress.
- Skin elasticity, i.e. the ability of the skin to recover the original shape after deformation.
- Skin viscoelasticity, i.e. the time-dependent deformation with a “creep” phenomenon and nonlinear stress–strain properties with “hysteresis”. The creep is characterized as a slowly increasing deformation of the skin in function of the time when a constant stress is applied. The hysteresis is related to the observation that after interrupting the stress the skin does not immediately return to its initial position and remains slightly deformed. In this way, the stress–strain curve obtained during suction time will not be superposed by the curve obtained during relaxation time.

The measurement mode 1 is most used in research studies. That is why the results obtained using mode 1 are explained in details in this section.

29.4.2.1 R-Parameters

According to their calculation, the R-parameters are divided into two groups [7, 56]:

- Absolute parameters: Ue, Uv, Uf, Ur, Ua and R1.
- Relative parameters: Ua/Uf, Ur/Uf, Ur/Ue and Uv/Ue.

The absolute parameters are measured in millimetres, while the relative parameters are presented with a number, which represents a ratio between the values of two absolute parameters – the maximal value is 1 (100 %).

It is considered that the absolute parameters are dependent on the skin thickness, which varies with age, sex and body region. That is why for comparison studies, they should firstly be standardized for skin thickness determined by ultrasound. Because this is not always possible, the ratios of absolute parameters, i.e. the relative parameters, should be compared. It is accepted that they do not depend on skin thickness and can be compared between subjects, anatomical regions and time points [5, 9].

Nevertheless, we suggest all measured skin mechanical parameters to be considered simultaneously. The reason is that relative parameters are composed of two parts – numerator and denominator, and one and the same value could be found as a result of an increase of a numerator or a decrease of a denominator and vice versa [26, 30].

According to their biological informativeness, R-parameters are divided into three groups [7, 26, 30]:

1. Elastic parameters:
   - Absolute parameters – Ue, Uf and Ur.
   - Relative parameters – Ua/Uf, Ur/Ue and Ur/Uf.
2. Viscoelastic parameters:
   - Absolute parameters – Uv and H.
   - Relative parameters – Uv/Ue.
3. Mixed parameters:
   - R1 and R4

The final skin distension Uf consists of two components – immediate distension Ue (elastic part) and delayed distension Uv (viscoelastic part).

Ue is related to the stretching of collagen and elastic fibres and reflects the skin thickness and rigidity.

Ue decreases during the skin ageing. At sun-protected areas, this is due to the decrease in elastic properties of collagen bundles as a result of fragmenting and increased number of intermolecular binds, whereas at sun-exposed areas this is due to the thickening of the skin as a result of advanced elastosis. Ue is also decreased in disorders characterized by skin thickening and induration. The enlarged volume of the skin as a result of dermal oedema (oedematous phase of scleroderma, psoriasis, erysipelas) or deposition of collagen bundles and glycosaminoglycans in the dermis (indurative phase of scleroderma, scleredema of Buschke, keloids) restricts the skin possibilities for deformation after application of vacuum [17–19, 45].

Ue is increased in some inherited diseases of connective tissue such as Ehlers–Danlos syndrome, which is due to alterations in collagen tissue and thinning of the skin [27, 32, 50]. The application of moisturizers and emollients induces an increase in Ue which is due to the softening of corneal layer and improvement of the plasticity of epidermal layer [25, 65].

Delayed distension (Uv) is attributed to the movement of the interstitial fluid throughout the fibrous network in the dermis.

Uv increases after application of moisturizing agents [6, 25], which is related to the epidermal hydration and improved plasticity of corneal layer. Uv increases in the presence of inflammatory dermal oedema (erysipelas, lymphoedema) [4, 18]. It is also increased in elderly skin because of the decrease of the viscosity due to the decrease in proteoglycans content during skin ageing [22, 26].

Uv could be decreased in scleredema of Buschke and keloids because of the increase of interstitial fluid viscosity as a result of accumulation of proteoglycans [17, 20, 45]. Lower Uv is also observed in the indurative phase of scleroderma and Ehlers–Danlos syndrome. In the first case, this is due to the increased stiffness of the skin, whereas in the second case, this is due to the thinning of the skin [19, 27, 50].

The alterations in Ue and Uv could be unidirectional (epidermal hydration, keloids) [20, 25] or heterogeneous (chronological and photoaging, UV-light irradiation, systemic sclerosis, scleredema of Buschke, erysipelas and lymphoedema, psoriasis, Ehlers–Danlos) [4, 18, 19, 24, 25, 27, 30, 50]. The changes in both elastic and viscoelastic part could influence the value of final skin distension (Fig. 29.13).

Uf could be increased at the expense of the increase in:

- Both parts Ue and Uv (epidermal hydration) [25].
- The elastic part Ue (Ehlers–Danlos syndrome) [27].
- The viscoelastic part Uv (dermal oedema in erysipelas) [18].

Uf could be decreased at the expense of the decrease in:

- Both parts Ue and Uv (keloids) [20].
- The elastic part Ue (photoaging, scleroderma, scleredema of Buschke, psoriasis) [17, 19, 22, 24, 26].

Uf could be preserved despite the changes in its parts:

- Decrease in Ue is accompanied with increase in Uv (chronological ageing, UV-light irradiation) [22, 26, 29].

Viscoelastic to elastic ratio (Uv/Ue) represents the distribution between elastic and viscoelastic parts of skin deformation. The increase of Uv/Ue indicates the prevalence of viscoelastic over elastic part of skin deformation. This can mainly be due to the increase of Uv, for example, in erysipelas [18], or decrease of Ue, in oedematous phase of scleroderma [19], scleredema of Buschke [17, 45] and lymphoedema of the lover limbs [4], for example. During skin ageing, Uv/Ue progressively increases because of the simultaneously increase of Uv and decrease of Ue [21, 22]. Identical changes are observed after UV-light irradiation [29].

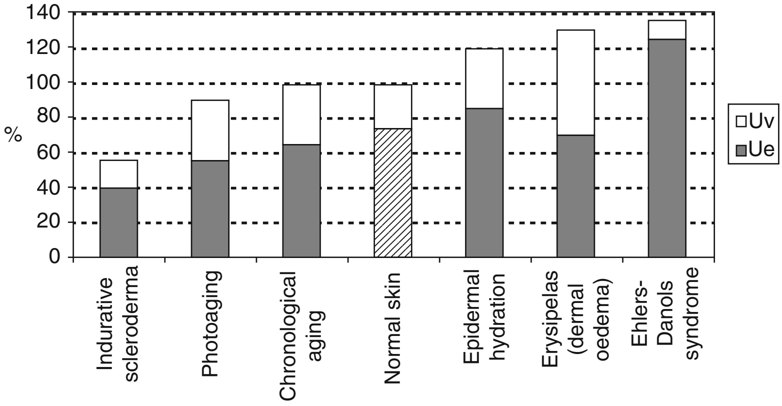


Fig. 29.13 Changes in immediate distension Ue and delayed distension Uv of the skin

A direct correlation has been established between Uv and Uv/Ue [26, 30].

Immediate retraction (Ur), gross elasticity (Ua/Uf), net elasticity (Ur/Ue) and biological elasticity (Ur/Uf) are related to the function of elastic fibres and represent the skin ability to restore its initial position after deformation. A direct correlation has been established between them [26, 30].

The elastic parameters are decreased in elderly individuals due to chronological ageing and photoaging of the skin [21, 22], after UV-light irradiation [29] and in diseases, which are characterized by increased thickness and indurations of the epidermis, dermis or whole skin such as psoriasis [24], erysipelas [18] and colloids [20].

The elastic parameters increase in varying degree after the application of moisturizers and emollients, which is due to the effects on the mechanical properties of the corneal layer rather than the effects on the elastic fibres and in inherited diseases of the connective tissue such as Ehlers–Danlos syndrome [27, 50].

In oedematous phase of scleroderma and in scleredema of Buschke, the measurements with 8-mm diameter probe explore a relative increase in the elastic parameters regardless of skin thickening. This phenomenon can be explained by the “lubricating” action of the dermal oedema and decreased friction between the fibres [17, 19].

Mechanical parameters Ua/Uf and Ur/Uf better characterize the elastic properties of the skin than Ur/Ue, because they include the viscous part of skin deformation, too [30].

Hysteresis (H) is a viscoelastic parameter. When a few consecutive suctions are applied (i.e. 3–10 suctions, 3 s/3 s), H reflects the water content of the skin. Using 8-mm diameter probe, higher values of H have been found on psoriasis and erysipelas plaques which is due to the inflammatory dermal oedema [18, 24]. H and Uv were decreased on the irradiated skin in patients undergoing telegamma therapy for breast cancer [23].

When a lot of repeated suctions are applied (i.e. 30 suctions, 1 s/1 s) at one and the same anatomic region, H characterizes skin fatigue. The age-related decline in skin elasticity results in marked fatigue of adult skin rather than of young skin [33].

Residual deformation *R* is a mixed parameter because it reflects both elastic and viscous properties of the skin. Its interpretation is somewhat difficult and it has been little reported in the literature. In healthy individuals R increases with age as well as directly correlates with the parameters Uv, Uv/Ue, R8 and H [26]. In some diseases, which are characterized by thickening of the skin such as psoriasis, scleredema of Buschke and keloids, using 8-mm diameter probe *R* is decreased, while in others such as erysipelas *R* is increased [17, 20, 24].

In general, an inverse correlation exists between the changes in elastic and viscoelastic parameters, while between the single parameters in each group, the relationship is direct [30].

We suggest the following Cutometer® R-parameters, which characterize the main mechanical properties of the skin, to be always analysed: Ue and Uf (distensibility), Ua/Uf and Ur/Uf (elasticity) and Uv and Uv/Ue (viscoelasticity) [26, 30, 32].

29.4.2.2 F-Parameters (Area-Parameters)

The surface parameters F0 and F1 reflect the viscous part of skin deformation. A completely elastic material will show the complete area (total area and F1 are the same). However, these parameters are not well-known in the scientific literature [56].

The surface parameters F2, F3 and F4 are also not familiar to scientists. We studied the age-related changes in skin fatigue applying multiple suctions at one and the same anatomic region and found that adult skin is characterized by significantly higher values of F2 and lower F3 compared to young skin [33]. F4 is considered a firmness parameter [56].

29.4.2.3 Q-Parameters

The surface Q-parameters reflect the elastic and viscous recovery of the skin. It is considered that Q0 (maximum recovery area) will go down with more firmness of the skin. Qu et al. [83] found that overall skin elasticity (Q3) and elastic recovery (Q1) decreased significantly, whereas the viscous recovery (Q2) did not show significant change with age. There was a marked decrease in Q3 and Q1, whereas Q2 was higher in the sun-exposed skin.

29.5 Practical Applications

The Cutometer® is widely used for study in the mechanical properties of healthy skin, their changes under the influence of various internal and external factors, for clinical diagnosis and monitoring, efficacy testing and claim support for medical and cosmetic topical products.

29.5.1 Study of Healthy Skin

29.5.1.1 Influence of Sex

Generally, no significant sex-dependent differences in skin mechanical parameters have been reported [5, 12, 21]. However, the menopause is associated with more expressed increase in distensibility and viscosity and decrease in elasticity of the female skin. The application of hormone replacement therapy is able to significantly reduce the climacteric-associated loss of skin elasticity [51, 75, 78, 82, 93]. Using the new introduced Q-parameters, Qu et al. [83] found that female subjects exhibited greater elastic recovery and lower viscous recovery than male subjects.

29.5.1.2 Influence of Age

Aged skin is characterized by significantly lower elastic and higher viscoelastic parameters. At all anatomic regions, the decrease in skin elasticity and the increase in skin viscoelasticity significantly correlate with the age [5, 9, 12, 21, 51, 58, 87, 94].

29.5.1.3 Influence of Body Region

The regional differences in skin mechanical properties determined by Cutometer® are mainly due to the differences in skin thickness and sun exposure. The absolute parameters are more influenced than the relative mechanical parameters [5, 12, 26, 41, 48, 53, 94, 100].

29.5.1.4 Influence of External Factors

Chronic sun exposure and UV-light irradiation produce a decrease in skin extensibility and elasticity and an increase in skin viscoelasticity. These alterations have been reported at facial and dorsal vs. volar forearm skin and are accompanied with increased skin thickness [22, 26, 94]. Similar changes in skin mechanical properties have been observed on irradiated skin in patients undergoing telegamma therapy for breast cancer [23].

Cutometer® has been used for investigation of the skin mechanical properties in astronauts before and after a long-term mission in the International Space Station [95].

29.5.2 Study of Diseased Skin

Mechanical properties of the skin are altered in many dermatological diseases. The Cutometer® allows quantifying these alterations in details, and the changes of mechanical parameters determined are valuable for diagnosis, assessment of severity, monitoring of progression and evaluation of treatment in skin diseases characterized by thickening or thinning and induration or softness of the skin (Fig. 29.14).

The Cutometer® has been used to study mechanical properties of the skin affected by systemic sclerosis [19, 42, 54, 69], Raynaud's phenomenon [36, 80], localized scleroderma [2, 14], scleredema of Buschke [17, 45], eosinophilic fasciitis [28, 86], psoriasis vulgaris [24], erysipelas [18] and lymphoedema of the lower legs [4], keloids [20] and hypertrophic scars [39, 44, 66, 67], eczema [37], striae distensae [52, 77], Ehlers–Danlos syndrome [27, 43, 50], diabetes mellitus [47, 68, 80, 96], acromegaly [10], gravitational syndrome [81], type 1 neurofibromatosis [64], spinal cord injury [73] and adult groin hernias [72].

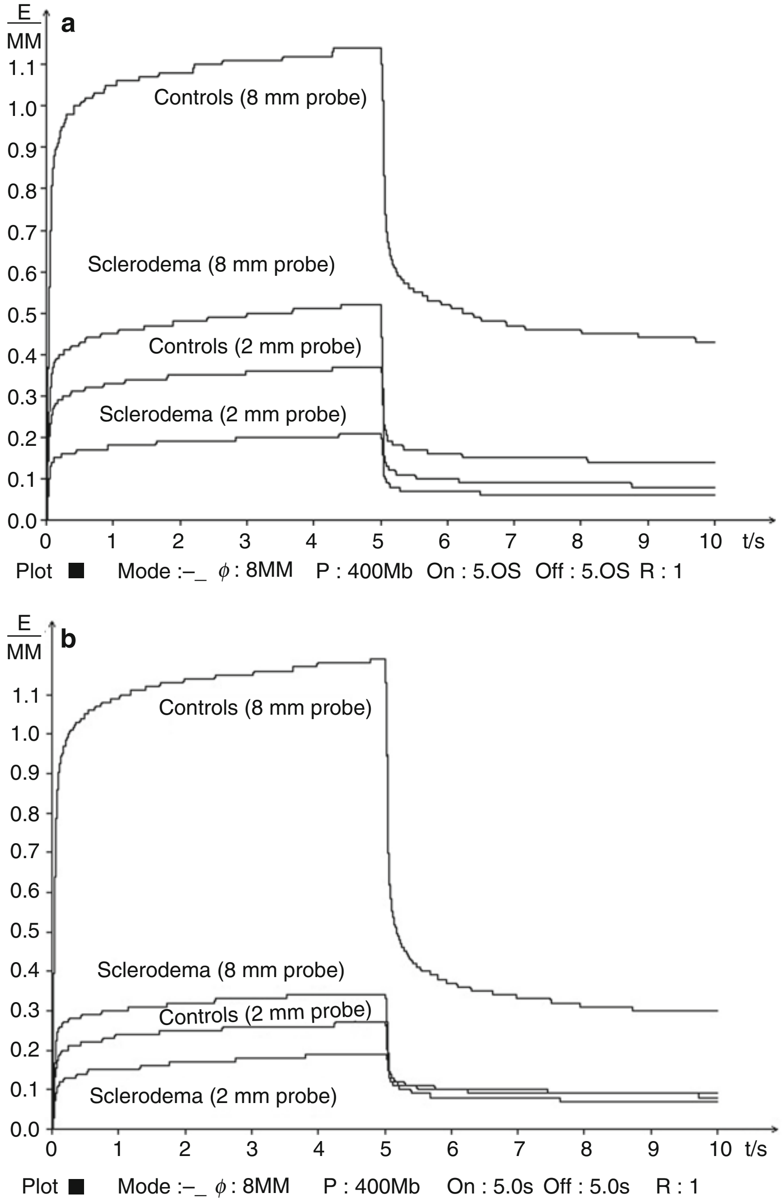
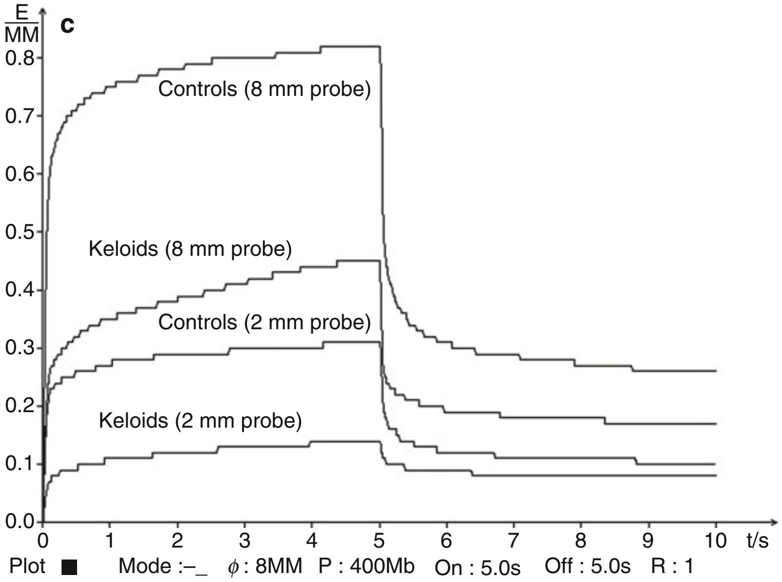


Fig. 29.14 Examples of skin deformation curves obtained with Cutometer® in some skin diseases: (**a**) Systemic sclerosis (measuring mode 1; skin deformation mode extension/time). (**b**) Scleredema of Buschke (measuring mode 1; skin deformation mode extension/time). (**c**) Keloids (measuring mode 1; skin deformation mode extension/time). (**d**) Erysipelas of the lower leg (measuring mode 1; skin deformation mode extension/time). (**e**) Erysipelas of the lower leg (measuring mode 2; skin deformation mode extension/time). (**f**) Erysipelas of the lower leg (measuring mode 2; skin deformation mode pressure/extension). (**g**) Psoriasis (measuring mode 1; skin deformation mode extension/time). (**h**) Skin fatigue (measuring mode 1; skin deformation mode extension/time)

Fig. 29.14 (continued)



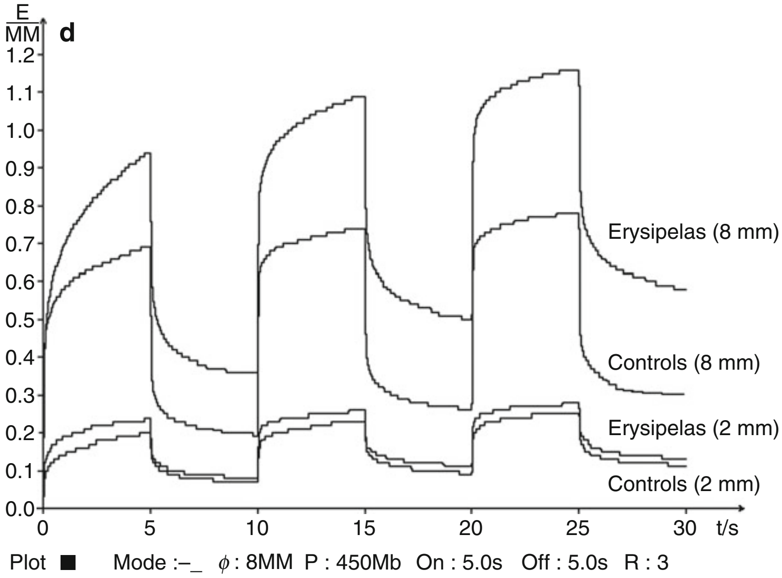


Fig. 29.14 (continued)

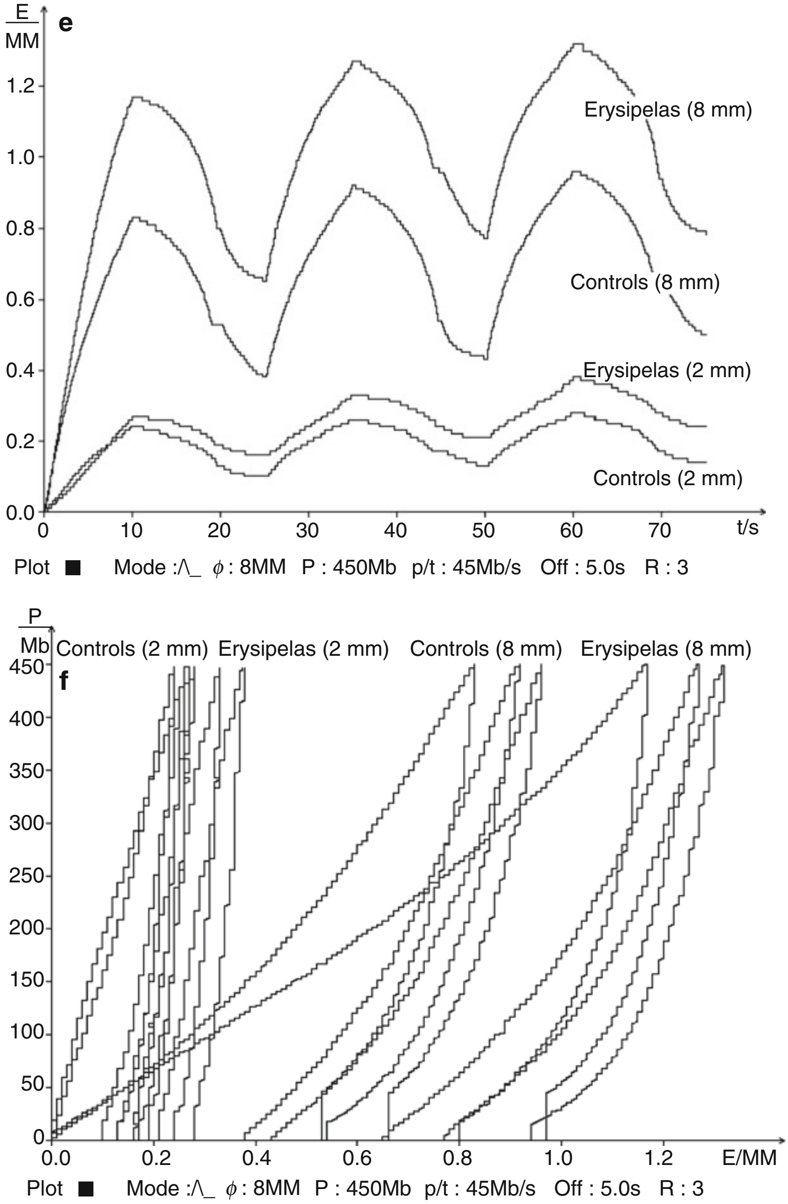
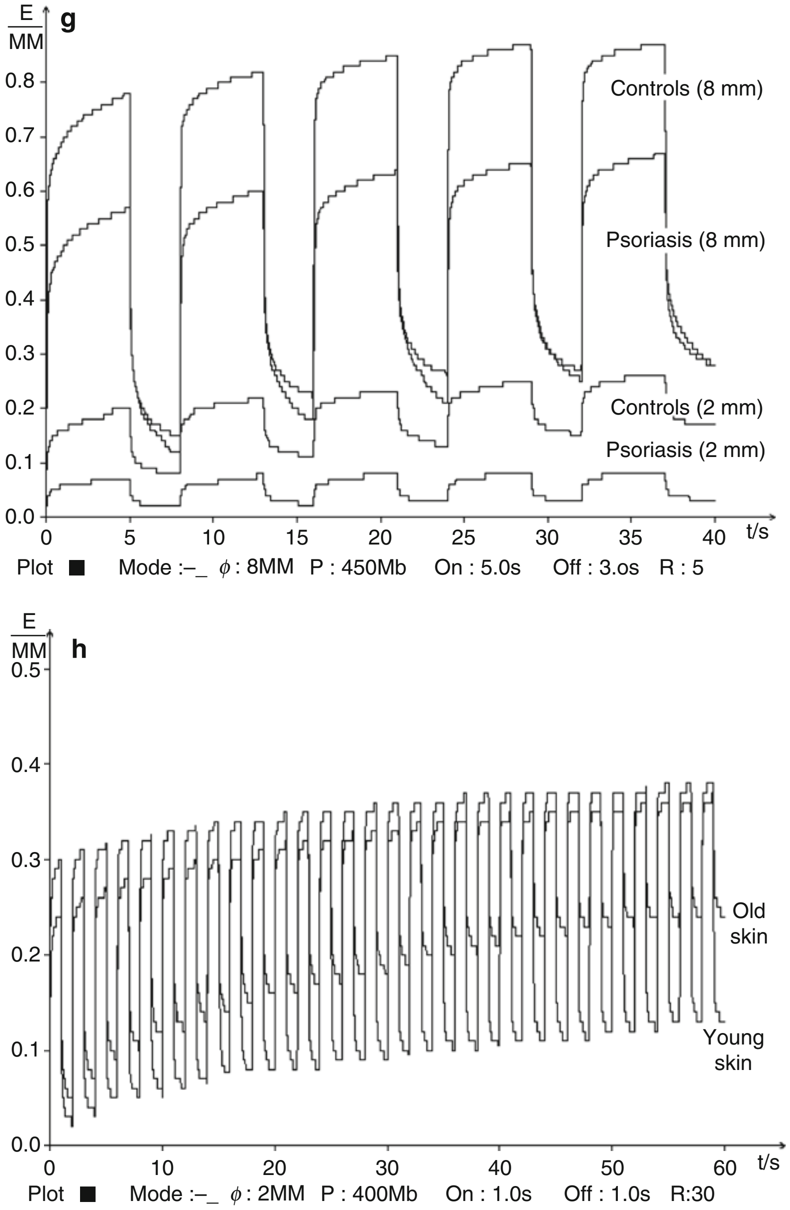


Fig. 29.14 (continued)



Results observed suggest that:

- The Cutometer® is more sensitive than the human perceptions and could detect minimal and initial changes in skin mechanical properties. The measurements could identify patients with secondary Raynaud's phenomenon at risk of developing subsequently systemic sclerosis [19, 36].
- The measurement values correlate well with clinical scoring systems and could be used for evaluation of the degree of skin involvement [17, 19, 42].
- Since the improvement in skin condition is accompanied by changes in skin mechanical parameters toward values of normal healthy skin, their measurements could be used for monitoring disease progress and treatment response, also [17, 18, 20, 28, 31, 45].
- Moreover, the Cutometer® measurements are able to differentiate the oedematous from the indurative phase of scleroderma as well as indurative phase of scleroderma from SB as well as the firm no pitting oedema in SB from the soft pitting oedema in erysipelas [17–19].

29.5.3 Study of Product Efficacy

The Cutometer® measurements could be useful for product efficacy and claim support studies. They have been used for evaluation of the effects of cosmetic products such as moisturizers and emollients [3, 6, 25, 65], anti-ageing creams containing different active ingredients [8, 34, 46, 62, 89], photoprotective creams [29], plant extracts [1, 35, 55, 88], chemical peelings [76], nutritional supplementation [60, 63], dietary bee pollen supplementation [92], intradermal [71] and oral [79] administration of growth factor and mucopolysaccharide polysulphate [98].

Measurements with Cutometer® were useful for exploring the mechanisms for improving skin mechanical properties after short-term and long-term application of cosmetic products. The single application of emulsions improves the plasticity of epidermal corneal layer by increasing its hydration (urea and other humectants; predominantly raised viscoelastic parameters) or by decreasing the intracorneal cohesion (alpha hydroxy acids; predominantly raised elastic parameters). Multiple applications of moisturizing cream containing plant extracts and oils improve the plasticity of the skin by increasing its water content (both raised elastic and viscoelastic parameters), while the cream containing pentapeptides increases skin firmness by inducing the accumulation of newly synthesized collagen (raised elastic and reduced viscoelastic parameters) [25, 34, 35, 38].

Cutometer® measurements have been used for assessment of the activity of different topical corticosteroids as ointments and creams. However, the alteration in skin mechanical properties observed was related to the effects of vehicles rather than to the effects of active substances [16].

Distante et al. [15] have conducted an interesting study using Cutometer® and other objective measurements. They aimed to evaluate if cosmetic product's packaging and strongly claimed efficacy attributes can influence the objectively measured efficacy. The results obtained suggest that the packaging characteristics cannot be a key factor for improving the biophysical skin properties related to anti-ageing and restoring effects.

29.5.4 Study of Treatment Efficacy

The Cutometer® measurements have been used for objective and quantitative evaluation of disease progress and treatment efficacy in many skin diseases such as localized scleroderma treated with phototherapy [14], scleredema of Buschke [17, 45], eosinophilic fasciitis treated with corticosteroids [28], psoriasis treated with dithranol ointment [24] and with topical corticosteroids and hydrocolloid occlusive dressings [31], erysipelas treated with regular treatment [18], eczema treated with corticosteroids [37], keloids treated with intralesional triamcinolone acetonide [59] and cryosurgery [20], anti-keloidal products [101], haemodialysis [13], burn wounds treated with composite and split-thickness skin grafts [44, 91, 97], topical dressings for wounds [84], CO2 therapy and liposuction for adipose tissue accumulation [11], skin resurfacing with pulsed carbon dioxide laser [57], skin rejuvenation treatment using hyaluronic acid-based gel of non-animal origin [85], liposuction [49] and cellulite treatment with a TriPollar radiofrequency device [61].

Conclusions

The Cutometer® is an easy to handle non-invasive suction device for evaluating the mechanical properties of the skin. It provides the users with objective, quantitative, reproducible and meaningful data on the elastic and viscoelastic properties of healthy and diseased human skin as well as their changes under the influence of various external factors, therapeutical and cosmetic products. The Cutometer® is now recognized as a standard tool in dermatological and cosmetic research.

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