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Mechanical properties of the skin: A comparison between two suction cup methods

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Background/aims: The objective measure of mechanical properties of the skin is relevant to the clinician as well as to the researcher concerned with skin physiology. The lack of standardization among methods used to obtain visco-elastic data from the skin is however, apparent and represents an obstacle to comparison of the results derived from the various studies concerning the subject.

Methods: The mechanical properties of the ventral forearm were studied in 35 healthy volunteers. The Dermaflex® and the DermaLab® (Both Cortex Technology, Hadsund, Denmark) were compared. The results were analyzed with descriptive statistics and correlations using non-parametric methods. Measurement accuracy was assessed using coefficient of variation. Sub analysis was made in groups according to gender and age.

Results: The overall correlations between the two methods were moderate ($r = 0.383$–0.437). A greater coefficient of variation was found in the DermaLab® machine. Significant differences were found between all values of both methods when comparing the mechanical properties of the skin in 30–39 years olds versus the group of 40–58 years olds. No differences were found between the genders.

Conclusions: The results indicate that both methods are useful in the study of the mechanical aspects of the skin, especially for detecting age-related changes. The Dermaflex® seems to produce more accurate for data. This is thought to be due to the conceptual design differences between the two methods. The methods measure related but not identical values of the mechanical properties of the skin, as reflected by the limited positive correlation between them.

Key words: mechanical properties of skin – Dermaflex® – DermaLab® – Young's modulus – distensibility – elasticity – hysteresis – recoil

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The mechanical properties of the skin are of great importance with regard to its protective functions of the underlying structures. At the same time, skin must be suitably mobile vis-avis the subcutaneous structures and allow temporary and reversible distension and compression with the general movement of the individual.

Previous *in vitro* studies have shown that the mechanical properties reside mainly in the dermis in the shape of the collagen and elastic fibres, both of which allow reversible stretch of the skin (1).

The mechanical properties of the skin are however, not only of relevance to dermatology. The skin may act as a marker of generalized collagen diseases. Elasticity and viscosity are altered in a number of diseases, e.g., Ehlers–Danlos syndrome, scleroderma or osteogenesis imperfecta (2–4). Qualitative changes of the mechanical properties of the skin in these patients may provide relevant data about changes in the mechanical properties of the connective tissue in general and may help predicting the severity and disease development.

Measurements of the mechanical properties of the skin can be carried out by relatively simple and non-invasive procedures, which inflict a minimum of discomfort upon the patient. A number of different methods are used today but in contrast to other aspects of skin physiology, there is a lack of methodological standardization among researchers. A comparison between the different methods is therefore relevant in order to evaluate and validate the results.

Material and Methods

The mechanical properties of the skin were examined in healthy controls without known disease affecting the structure or function of collagen. The mechanical properties of the skin were measured

using two different suction cup devices: the Dermaflex® and the DermaLab® (Both Cortex Technology, Hadsund, Denmark). The measurements were carried out simultaneously using the ventral side of the left and right forearm, respectively, as no difference has been shown (5). On each occasion two values from closely adjacent sites were obtained with both systems, using the mean as final result.

A total of 35 healthy volunteers, 12 men, and 23 women, age 9–58 years, were examined.

The skin of the volunteers had not been treated in any way prior to the examination.

The Dermaflex®(6). The Dermaflex® is a suction chamber device measuring three parameters: Distensibility, Elasticity and Hysteresis.

The Dermaflex® utilizes this principle by measuring the elevation of the skin resulting from a known quantity of applied stress, i.e., stress is given and deformation is measured.

A suction probe attached to the skin generates a vacuum between a cross sectional area of 10 mm^2 on the surface of the skin and an electrode placed in the top of the suction chamber. The probe is firmly attached to the skin by adhesive tape in order to avoid creep during suction.

Generation of the vacuum occurs in cycles of suction periods lasting 4 s, 6 cycles equals the completion of one test. The elevation of the skin following the stress applied at the first cycle is determined as the distensibility, expressed in millimetres.

Distensibility or strain can be defined as the elevation of the skin when applied to a particular force per cross-sectional area (= stress), and it reflects the 'stiffness' (resistance) of the skin when stretched. The stiffness is thought mainly to be due to the collagen fibres in the dermis.

Elasticity defines the ability of the skin to recover from stress/stretch. The ability to regain the original shape following exposure to stretch seems to rely mainly on the elastic fibres of the dermis. The Dermaflex® determines elasticity by measuring the remaining elevation of the skin after the first suction is terminated (the residual skin elevation). Elasticity is subsequently given as:

$$\mathrm{RER} = \frac{\text{Distensibility-residual skin elevation} \times 100\%}{\text{Distensibility}}$$

Here, RER = Relative Elastic Retraction.

In tissue reflecting an elasticity of 100% it is immediately obvious, that the residual skin elevation is 0, i.e., the tissue fully regains its shape after stress.

Hysteresis describes the irreversible alteration in maximum distensibility, resulting from continuous cycles of stress applied on a particular area of the skin.

The phenomenon is believed to be the reflection of visco-elastic changes occurring mainly in the collagen fibres in the dermis as a consequence of stretching.

In successive cycles of stress applied on the skin, each consecutive cycle will occasion an increase in the resulting maximum elevation, i.e., continually smaller amount of force will generate the same amount of distension, or strain. The same phenomenon can be observed if a given level of stress is maintained for a particular period.

Hysteresis is determined by the Dermaflex®, as the difference between the elevation during the first cycle of suction and the last, expressed in millimetres.

The DermaLab®(7). Like the Dermaflex®, the DermaLab® is a suction chamber method for measuring the visco-elastic properties of the skin. The DermaLab® calculates the mechanical parameters of the skin based on the stress necessary to achieve a given deformation, i.e., deformation is given and stress is measured.

In the DermaLab®, distensibility is a fixed value of 1.5 mm, i.e., the modulus is calculated from the applied stress (vacuum, Pa), equivalent to an elevation of the skin of 1.5 mm. The suction probe gradually exposes the skin to a growing amount of stress until the particular level of elevation is reached.

The system calculates and expresses these properties in the term of Young's modulus.

Young's modulus (E) reflects the interrelationship between the distensibility and elasticity of the skin and it can be expressed as:

$$E = \frac{\text{stress}}{\text{strain}} \text{ or } E = C \times \frac{\Delta p}{\Delta X}$$

where Δp = Pressure, ΔX = Elevation and C = Constant.

The modulus provides the researcher with a value reflecting the resultant distension of the skin when applied to a particular force. Thus, a high

modulus is equivalent to the presence of 'stiff' or sclerotic skin and conversely, a low modulus is a reflection of a highly pliable structure.

Recoil is measured as the amount of time required for the elevated area of the skin to return to its baseline value after suction has terminated. Recoil is a reflection of the elastic properties of the skin, and it is measured in seconds.

Non-parametric paired tests; Spearman Rank correlations and Bonferroni's correction were used as necessary.

Results

The results are given in Tables 1 and 2. No significant differences between the sexes were found, and previously known age-related changes were found with the Dermaflex®. A few moderate overall correlations were established (Table 3).

The results were further subdivided based on age and gender, which are known to influence the mechanical properties of the skin (8, 9). Looking at gender as a confounding factor, no significant differences were found. Age-related differences were found for the age-group 40–58 in all parameters using both methods (Distensibility and hysteresis: $P < 0.05$; elasticity: $P < 0.02$; Young's modulus: $P < 0.1$; recoil: $P < 0.005$).

Measurement accuracy is represented in Table 4 as the coefficient of variation for all groups, calculated as the standard deviation as a percentage of each sample mean.

TABLE 1. Mechanical characteristics, median, 95%CI

Parameters	Women	Men	All
N	23	12	35
Dermaflex®			
Distensibility	3.07; (2.81–3.33)	2.83; (2.46–3.20)	2.98; (2.77–3.19)
Elasticity (%)	90.17; (87.27–93.07)	90.83; (88.92–92.74)	90.40; (88.40–92.40)
Hysteresis (mm)	0.19; (0.17–0.20)	0.18; (0.16–0.20)	0.18; (0.17–0.20)
DermaLab®			
Young's modulus	5.26; (3.99–6.53)	4.80; (3.26–6.34)	5.10; (4.12–6.08)
Recoil (s)	0.11; (0.09–0.12)	0.08; (0.06–0.10)	0.10; (0.08–0.11)

TABLE 2. Age related characteristics, mean, 95%CI

Parameters	9–29 years	30–39 years	40–58 years
N	12	11	12
Dermaflex®			
Distensibility (mm)	3.07; (2.70–3.44)	3.21; (2.82–3.60)	2.69; (2.40–2.99)
Elasticity (%)	93.17; (91.23–95.08)	92.36; (88.76–95.97)	85.83; (82.61–89.06)
Hysteresis (mm)	0.17; (0.15–0.18)	0.17; (0.14–0.20)	0.21; (0.19–0.23)
DermaLab®			
Young's modulus	3.52; (2.20–4.84)	4.77; (3.49–6.05)	6.98; (5.15–8.81)
Recoil (s)	0.08; (0.07–0.1)	0.08; (0.06–0.09)	0.13; (0.10–0.16)

*TABLE 3. Overall correlations (*N = *35)*

Parameters	Distensibility	Elasticity	Hysteresis	Young's modulus	Recoil
Distensibility	×	NS	NS	−0.39942 $P < 0.05$	NS
Elasticity		×	−0.51744 $P < 0.002$	NS	−0.43662 $P < 0.01$
Hysteresis			×	NS	0.382723 $P < 0.05$
Young's modulus				×	0.363248 $P < 0.05$
Recoil					×

NS = not significant.

TABLE 4. The coefficient of variation (%)

Parameters	Men	Women	9–29 years	30–39 years	40–58 years	All
N	12	23	12	11	12	35
Dermaflex®						
Distensibility	22.9	20.47	21.58	20.46	19.32	21.36
Elasticity	3.72	7.89	3.63	6.61	6.64	6.68
Hysteresis	19.4	25.16	16.96	26.61	20.02	23.19
DermaLab®						
Young's modulus	56.67	59.13	66.21	45.48	46.30	57.80
Recoil	45.68	42.39	37.32	34.28	35.89	44.35

Discussion

Investigations concerning the mechanical properties of the skin are characterized by a lack of standardization. Because of the broad variety of methods, comparison between different studies often requires a thorough interpretation and the conclusions obtained from different studies may seem confusing, or even worse, contradicting.

In the present study, two different suction cup methods were compared.

The two methods are based on the same principle: Elevation of the skin caused by an applied vacuum in a suction chamber, with a subsequent measurement of the visco-elastic properties of the area in question. The principle is however, examined in two different ways: by either standardizing stress or standardizing deformation.

The construction of the Dermaflex® is 'based on' Young's modulus, i.e., the distension of the skin resulting from applied stress. The DermaLab® provides the researcher with the ratio between stress and distension: Young's modulus. Therefore, it would be obvious to expect a connection between the results obtained with the Dermaflex® and the DermaLab®, respectively.

Since Young's modulus reflects the stress required elevating the skin up to a given value, and distensibility describes the elevation resulting from a given amount of stress, a negative correlation between the two parameters would be expected.

Such an overall correlation, although not very strong, was obtained (Table 3: 0.399, $P < 0.05$), indicating that the two methods do measure the same quality.

Both Young's modulus and distensibility were significally altered when measuring the skin of the age group 40–58, compared to the younger age group (Distensibility: $P < 0.05$; Young's modulus: $P < 0.1$). The above results indicate that both methods are capable of detecting age-related changes in skin mechanics. These differences are detectable only after the age of 30, since no significant differences were found between the group of 9–29 and 30–39. The Dermaflex® was found to be more sensitive than the DermaLab® (Distensibility: $P < 0.05$; Young's modulus: $P < 0.1$). Young's modulus is calculated by the DermaLab® partly from the measurements, previously described, and partly from some predefined values, such as the thickness of the object measured and an elasticity constant. The standardization of a variable such as skin thickness can obscure individual differences, which may explain the large coefficients of variations. In particular in Young's modulus (Table 4), since the measured differences between the categories are not accompanied by any similar changes in the values used when calculating Young's modulus.

Hysteresis, another parameter reflecting the viscous behaviour of the skin, was also found to significantly increase when measured in the older age group ($P < 0.05$).

Weak correlations were established between elasticity and recoil (-0.437, $P < 0.01$) and between elasticity and hysteresis (-0.517, $P < 0.002$). Elasticity measured by the Dermaflex® seems more capable of reproducing data from the various groups than recoil, derived from the DermaLab® (Table 4).

Both methods failed to detect any differences in mechanical properties between men and women, indicating a limit either to the sensitivity of the methods or the existence of only negligible differences between the genders. Additional methodological comparisons are necessary to establish a higher degree of standardization in future studies of skin mechanics.

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