Title: THE DEVELOPMENT OF A NEW NO-CONTACT METHOD TO MEASURE THE MECHANICAL PROPERTIES OF SKIN: NEW AGE-RELATED PARAMETERS

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Summary

Real-time measurements of skin movement induced by air blown on the surface was measured with time. We investigated age-related changes in displacement of the skin surface on the face or the inner upper arm caused by air on 98 Japanese women volunteers aged from 10 to 70 years old. The maximum distance (the denting state) that the skin moved reached 2-5 mm within 10-15 msec on the cheek skin. After that, the skin generally recovered to the original state within 40-50 msec. The maximum speed of movement was 0.5 m/sec and the recovery speed was about 0.25 m/sec on the cheek skin. Significant changes with age were not observed in the denting state, but a significant correlation with age was observed in the recovery state. For example, the maximum recovery speed decreased significantly with age ($\rho=-0.568$, $p<0.001$) and the time required for recovery increased significantly with age ($\rho=0.561$, $p<0.001$). Although the inner upper arm also showed similar results to a cheek, a few parameters were different. This apparatus is a more practical macroscopic system for evaluating skin mechanical properties without contact. This apparatus is effective not only for measuring the mechanical properties of facial skin but also of body skin, such as swelling or sagging of body parts.

Introduction

Over the years, a number of systems and techniques have been developed to measure the mechanical properties of the skin or other living tissue. One method uses a vacuum to pull the skin causing its deformation while another method uses a rotating disk attached to the skin [1] [2]. Other methods use an ultrasonic vibrator or a wave motion transmitted to the skin [3][4]. However, all those techniques require some form of contact with the skin and create several problems. For example, often the results depend on the skill of operators, and variations in equipment and sensor characteristics can influence the measurements. Sebum and sweat on the skin can also further add to errors.

We have now developed an apparatus to measure the mechanical properties of the skin without contact using a technique which measures the displacement of the skin induced by air blown on it [5]. We have used this NO-CONTACT apparatus to investigate age-related changes in displacement of the skin surface on various areas of the body.

Materials and Methods

Measurement System

Figure 1 shows a schematic representation of the Compressed-Air Skin Analyzer

"CASA" system which was introduced at the 14th International Congress of the International Society for Bioengineering and the Skin (ISBS)[5]. When the distance to the skin approaches within 24 mm, a shot of compressed air is automatically blown on the skin at 0.21 Mpa, at an angle of 45 degrees. The skin moves vertically in response to that shot of air, and a distance meter measures this vertical displacement. Time can be measured at a msec resolution and the displacement resolution is 0.01 mm.

Measurement

The volunteer's face or arm is fixed on a chin rest. The apparatus is moved to the measurement site along rails. When the apparatus approaches within 24 mm of the skin, a shot of compressed air is released automatically and the displacement of the skin is measured.

Study of Skin at Various Ages

Ninety-eight Japanese women living in TOKYO (aged from 10 to 70 years old) were used in this study. Measurements were taken on the forehead, below the eye, the cheek, the corner of the mouth, and the inner upper arm. All measurements were taken 3 or 4 times at each skin position for each subject.

Statistical Analysis

The level of significance of the correlation coefficient was calculated by linear regression analysis.

RESULTS

Time Course of Skin Displacement

Figure 2 shows the typical time course of skin displacement during a compressed air shot to the cheek. Starting at the time of the air shot, the maximum displacement (the denting state) that the skin moves reaches 2-5 mm within 10-15 msec. After that, the skin generally recovers to the original state within 40-50 msec ("recovery" displacement).

Set up of CASA Parameters

Figure 3 shows the CASA parameters obtained during a typical time course of skin displacement.

T1 is the time required from the air shot to the maximum displacement point, shown as the "Displacement Time".

T2 is the time required from the maximum displacement point to the recovered displacement point, shown as the "Recovery Time".

T1+T2 is the total time required from the air shot to the recovered displacement point, shown as the "Total Time".

L1 is the difference between the displacement at the original state (starting point) and the maximum displacement at T1, shown as the "Max. Displacement".

L2 is the difference between the displacement at T1 and the recovered displacement at T2, shown as the "Max. Recovery Displacement".

L3 is the difference between the "Max. Displacement" L1 and the "Max. Recovery Displacement" L2, shown as the "Max. Pass Displacement".

L1/T1 is the average displacement speed from the original state to reach the maximum displacement at T1, shown as the "Ave. Displacement Speed".

L2/T2 is the average recovery displacement speed from the maximum displacement at T1 to the recovered displacement at T2 shown as the "Ave. Recovery Displacement Speed".

dD is the maximum displacement speed from the original state to reach the maximum displacement at T1, shown as the "Max. Displacement Speed".

dR is the maximum recovery displacement speed from the maximum displacement at T1 to the recovered displacement at T2, shown as the "Max. Recovery Displacement Speed".

Analysis of Results

The CASA parameters measured on cheek skin are shown in Figure 4(a)-(c), Figure 5(a)-(c), Figure 6(a), (b), and Figure 7.

The skin movement reached 2-5 mm within 10-15 msec on the cheek skin and the skin then generally recovered to the original state within 40-50 msec, as shown in Figure 4(a), 5(a), 5(c).

There was no significant correlation between the "Max. Displacement" L1 and age

(Figure 4(a)). Also, there was no significant correlation between the "Max. Recovery Displacement" L2 and age (Figure 4(b)). However, a significant correlation was observed between the "Max. Pass Displacement" L3 and age (Figure 4(c)).

Concerning the time required to displace the skin, the "Displacement Time" T1, "Recovery Time" T2, and "Total Time" T1+T2 correlated with age significantly (Figure 5(a)-(c)). For example, T2 increased significantly correlated with the age having a correlation coefficient of $\rho=0.561$ (significance level; $p<0.001$).

The displacement and the time were also significantly correlated with age (Figure 6, 7). The "Max. Displacement Speed" dD was about 0.5 m/second, and the "Max. Recovery Displacement Speed" dR was about 0.25 m/second. The "Max. Displacement Speed" dD, the "Max. Recovery Displacement Speed" dR, the "Ave. Displacement Speed" L1/T2, and the "Ave. Recovery Displacement Speed" L2/T2 decrease significantly with age. In particular, the parameters L2/T2 and dR, which relate to recovery of the displacement process, show stronger correlations than did those of the displacement process (denting process). For example, the dR had a correlation coefficient of $\rho=-0.568$ (significance level; $p<0.001$).

The results obtained from skin at the corner of the mouth showed similar results to those of the cheek (data are summarized in Table I). At the corner of the mouth, the "Max. Displacement" L1 reached 2-5 mm, and the "Max. Displacement Speed" dD was about 0.5 m/second, while the "Max. Recovery Displacement Speed" dR was about 0.25 m/second.

Although skin on the inner upper arm showed similar results to cheek skin, a few parameters were different. In the upper inner arm, the "Max. Displacement" L1 reached 2-5 mm, and dD about 0.55 m/second, while the dR was about 0.3 m/second. The "Ave. Recovery Displacement Speed" L2/T2 showed no significant correlation with age, while the L3 of the inner upper arm skin increased with age in contrast to skin in the cheek or at the mouth corner.

In the skin below the eye, the L1 reached only 0.5-3 mm, and most of the parameters showed no significant correlation with age. In skin on the forehead, no reliable measurements could be obtained because the skin is either too tight or too thin.

The results of all measurements at various skin sites are shown in Table I.

Discussion

The CASA apparatus is capable of measuring mechanical properties of the skin using shots of compressed air. Using this apparatus, we can measure the mechanical properties of the skin without actually contacting the skin, which avoids the major problems associated with other existing methods.

We investigated several parameters based on time-displacement curves (Figure 2). A significant correlation with age was observed in most of those parameters on skin of the cheek, the corner of the mouth, and the upper inner arm (Table I). These results suggest that slower displacement causes a "Time Delay" related to aging. In other words, following the air shot to the skin, the responses of displacement and of subsequent recovery of the skin slow down with increasing age.

The correlation with age obtained on the recovery process (T2, L2, L2/T2, dR) was relatively stronger than the displacement process (T1, L1, L1/T1, dT). We suggest that the force of the air shot influences the displacement process, whereas the recovery process reflects the native mechanical properties of the skin.

Similar results were obtained on skin of the cheek and the corner of the mouth, and on the inner upper arm, but a few parameters of the latter were different. Although the exact mechanisms behind this are not clear, two potential reasons seem most likely: one being possible differences in sun-exposed or in sun-protected areas, and the other being differences in subcutaneous tissue.

For example, in skin of the cheek, the corner of the mouth and the upper arm, the "Max. Displacement" L1 reaches 2-5 mm. The skin thickness is typically 1.2-1.8 mm, indicating that this apparatus measures the mechanical properties of the skin, including the subcutaneous tissue. In other words, the measurements of this apparatus are influenced by the properties of subcutaneous tissue, such as adipose tissue or bone. The lack of correlation with age on skin below the eye and the impossibility of analyzing skin on the forehead indicates that the properties of subcutaneous tissue influence the results of this apparatus. Although we did not try to use this apparatus at lower air pressures, the decrease of "Max Displacement" L1 by lower pressure air shots may be one of the best countermeasures to minimize this problem.

Conclusion

Our research group has succeeded in developing a new NON-CONTACT technique that employs a new device using compressed air shots. This apparatus is capable of measuring mechanical properties of the skin which permits the analysis of several parameters from the time-displacement curve of the skin.

This apparatus differs from other conventional instruments that measure the mechanical properties of the skin in limited areas. More practical macroscopic evaluations, such as the skin pushed by a finger, is possible using this apparatus. Therefore, this instrument is effective not only for measuring the mechanical properties of facial or arm skin but also of body parts rich in subcutaneous tissues, providing indices of swelling or sagging of body parts.

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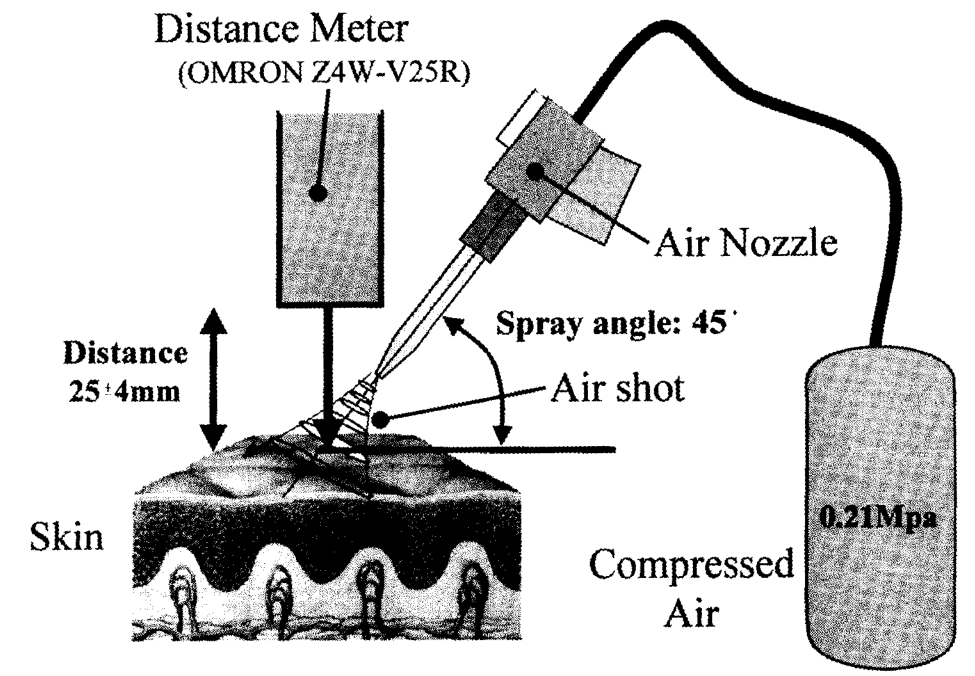

Figure 1. Measurement System of Compressed-Air Skin Analyzer (CASA)

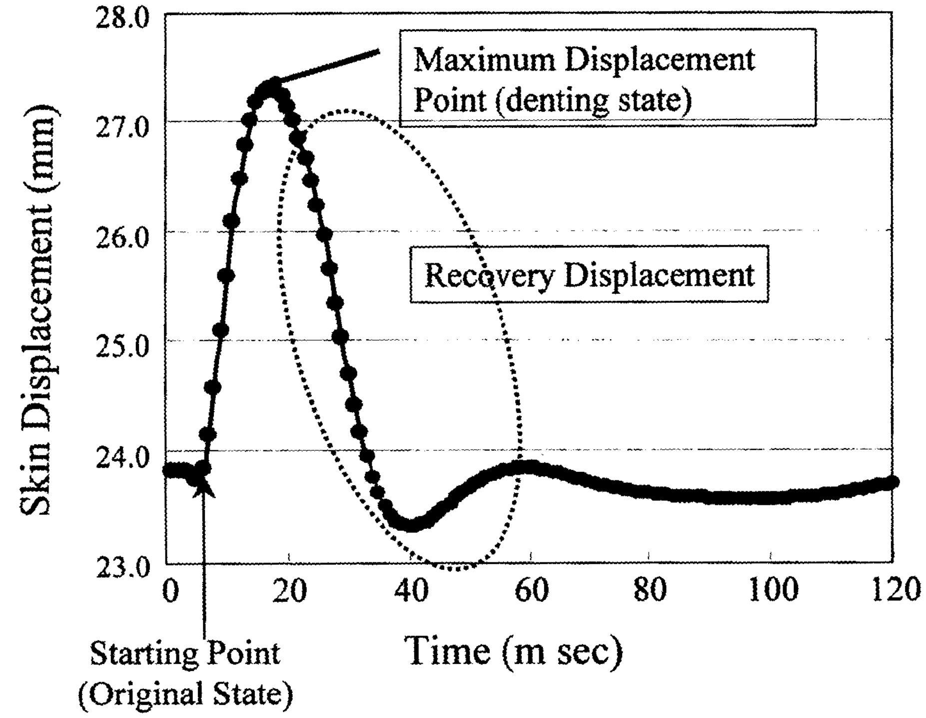

Figure 2. Time Course of Skin Displacement

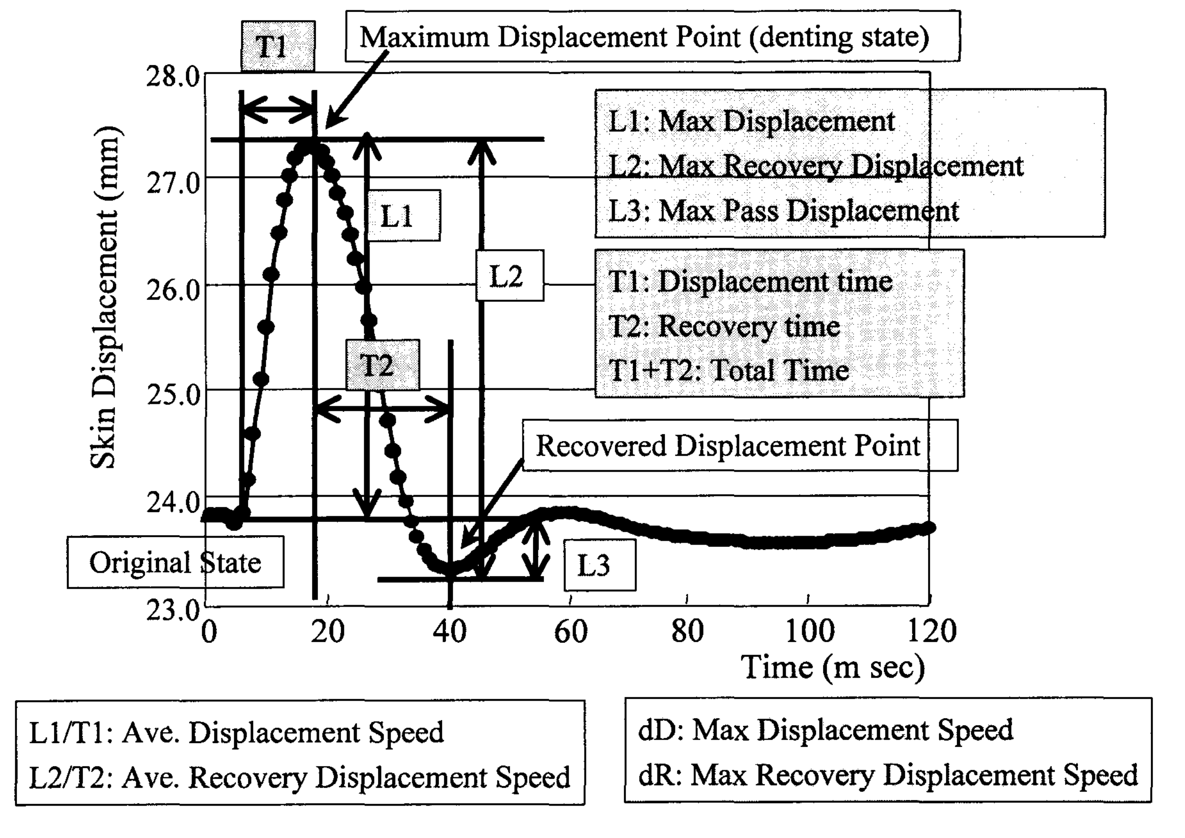

Figure 3. Setup of Parameters Obtained Typical Time Course of Skin Displacement

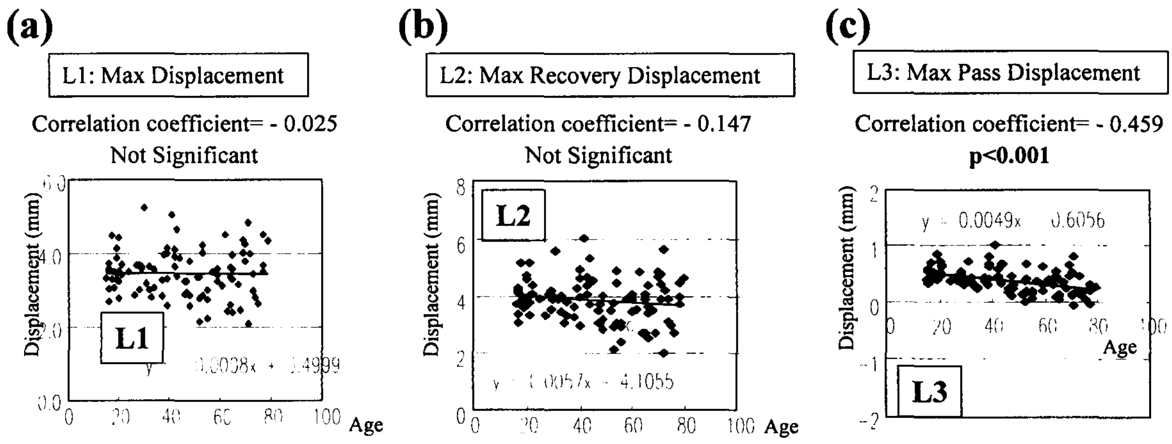

Figure 4. Relationship between Several Parameters Plotted with Age on Cheek(N=98)

(a); L1: Max Displacement (b); L2: Max Recovery Displacement (c); L3: Max Pass Displacement

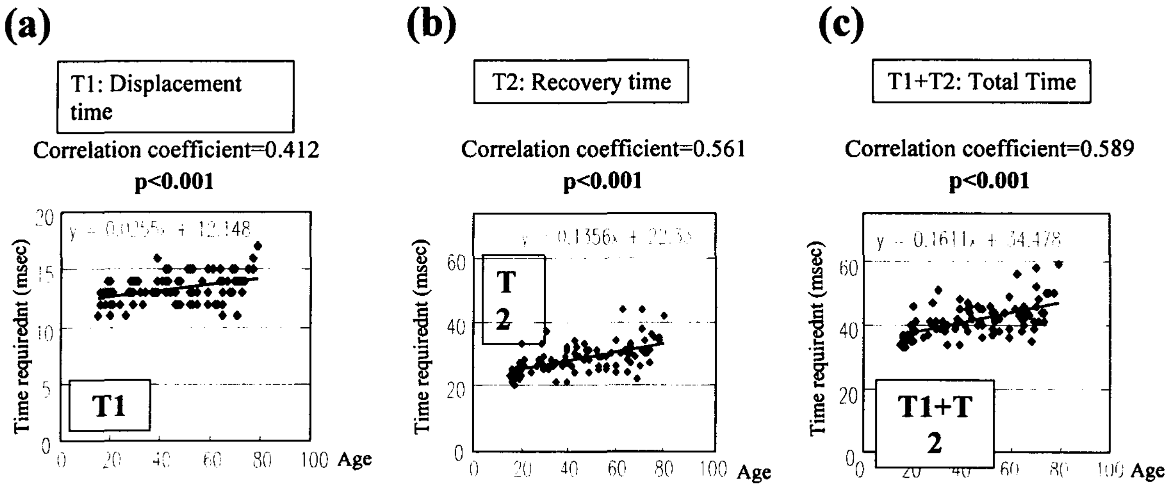

Figure 5. Relationship between Several Parameters Plotted with Age on Cheek(N=98)

(a); T1: Displacement time, (b); T2: Recovery time, (c); T1+T2: Total Time

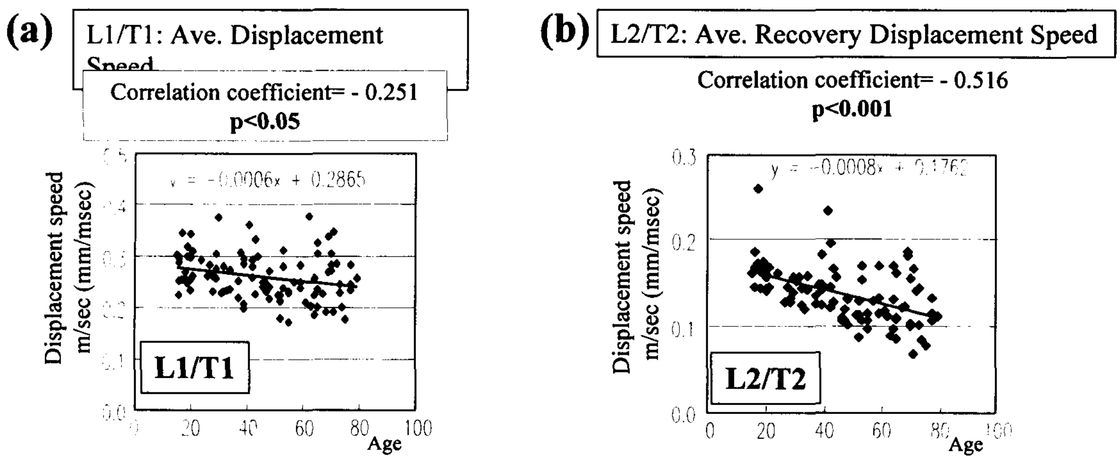

Figure 6. Relationship between Several Parameters Plotted with Age on Cheek (N=98)

(a); L1/T1: Ave. Displacement Speed, (b); L2/T2: Ave. Recovery Displacement Speed

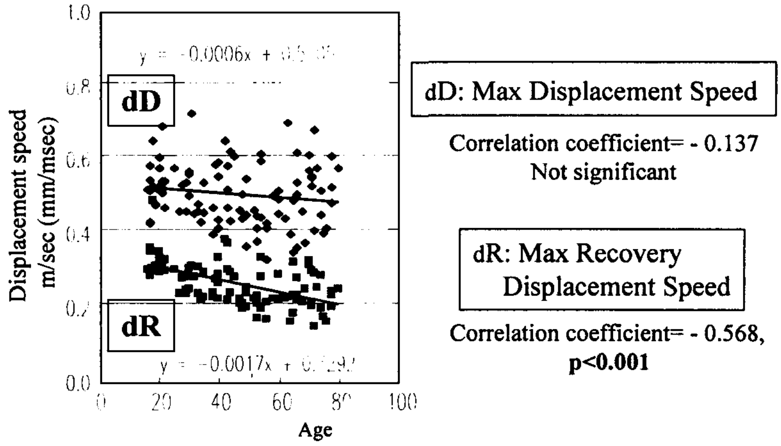

Figure 7. Relationship between Several Parameters Plotted with Age on Cheek (N=98)
dD: Max Displacement Speed, dR: Max Recovery Displacement Speed

Table I Parameters *versus* Age Correlation

		T1	T2	T1+T2	L1	L2	L1/T1	L2/T2	dD	dR
Inner Upper Arm, N=96	ρ	**0.547**	**0.333**	**0.488**	**0.043**	**0.146**	**-0.362**	**0.081**	**-0.136**	**-0.374**
	p	**<0.001**	**<0.001**	**<0.001**	**NS**	**NS**	**<0.001**	**NS**	**NS**	**<0.001**
Cheek, N=98	ρ	**0.411**	**0.561**	**0.589**	**-0.024**	**-0.146**	**-0.251**	**0.516**	**-0.136**	**-0.568**
	p	**<0.001**	**<0.001**	**<0.001**	**NS**	**NS**	**<0.05**	**<0.001**	**NS**	**<0.001**
Mouth Corner N=86	ρ	**0.436**	**0.579**	**0.621**	**-0.160**	**-0.209**	**-0.430**	**0.572**	**-0.218**	**-0.637**
	p	**<0.001**	**<0.001**	**<0.001**	**NS**	**NS**	**<0.001**	**<0.001**	**<0.05**	**<0.001**
Below Eye N=98	ρ	**0.322**	**-0.022**	**0.031**	**0.111**	**ND**	**-0.362**	**ND**	**0.052**	**-0.106**
	p	**<0.001**	**NS**	**NS**	**NS**	**-**	**NS**	**-**	**NS**	**NS**

NS; Not significant, ND; Not determined