

In vivo determination of skin surface topography using an optical 3D device

Ute Jacobi¹, Mai Chen², Gottfried Frankowski², Ronald Sinkgraven³, Martina Hund³,
Berthold Rzany³, Wolfram Sterry¹ and Jürgen Lademann¹

¹Center of Experimental and Applied Cutaneous Physiology, Department of Dermatology, Charité – Medical Faculty, Berlin, Germany, ²GFMesstechnik GmbH, Teltow, Germany, ³Division of Evidence Based Medicine, Department of Dermatology, Charité – Medical Faculty, Berlin, Germany

Background/purpose: Topography of the skin surface is a mirror of the functional skin status. Therefore, its evaluation is of great interest for dermatological research. In the present study, a new optical measuring system was applied to evaluate human skin surface topography *in vivo* and non-invasively, in order to determine elastotic and mimic wrinkles dependent on age, body site and therapy.

Methods: The measurements were performed on the back ($n = 5$), the flexor forearm ($n = 14$) of volunteers in different age groups and on the face of women ($n = 4$) participating in an anti-wrinkle study. The evaluation of the three-dimensional-profiles was performed determining skin surface parameters (mean roughness (R_a), mean depth of roughness (R_z), maximum roughness (R_m) and waviness (W_t)) and applying Fourier analysis.

Results: Significant increases in all surface parameters were obtained on the forearms with increasing age.

Differences between the surface topographies of forearm and back were only expressed by the waviness and the Fourier analysis. The treatment with botulinum Toxin A led to a diminution of mimic wrinkles as reflected by the furrow profiles.

Conclusions: The results show a significant dependence of the skin surface topography on the age of the volunteer and the body site measured. Particularly the waviness, the Fourier analysis and the furrow profiles reflect such dependencies. The system used also fulfils the requirements for the testing of therapies, as was demonstrated by the reduction of mimic wrinkles after treatment with botulinum Toxin A.

Key words: aging – body site – botulinum toxin A – optical measurement – skin surface topography

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THE *IN VIVO* evaluation of human skin surface topography is of great interest for dermatological research because this type of topography represents the three-dimensional (3D) organization of the dermis and the subcutaneous tissue. The surface topography can be considered to be a mirror of the functional status of the skin (1). It is an expression for the possibility of the skin to respond to mechanical stimuli and threats (2).

The network of the furrows is influenced by muscle and joint movements, the environment and changes associated with aging (2–6). Various treatments exist to reverse or at least decrease these changes. In order to assess the success of a therapy or of the application of an anti-aging product, the depth, variation and distribution of the furrows and wrinkles need to be measured prior and after application of the pharmaceutical or cosmetic product.

The characterization of the skin surface topography is expressed in two-dimensional parameters used to evaluate metal surfaces (7). The maximum roughness (R_m), the mean roughness (R_a) and the mean depth of roughness (R_z) have often been used (3, 7–10). Other parameters such as waviness (W_t) (5, 11) and the depth of roughness (R_t) (3, 10) were also determined. These parameters indicate different properties of the network of the furrows (3, 11).

Usually, non-invasive methods are used to evaluate the skin surface topography. Most of these methods are based on the preparation of skin replica or reprints. The replica are measured using mechanical or optical profilometry techniques and surface image analysis (1, 7). In this way, the skin topography of skin diseases (8, 9, 11, 12) and the effect of different therapies (3, 13–15) can be determined.

A disadvantage of the replica technique is that the quality of the skin replica depends on many parameters (3, 7, 16). Besides the formation of air bubbles, the direct contact to the skin surface can change the subject of measurement. Therefore, *in vivo* methods without direct skin contact should be favored.

Recently, optical devices normally used in the technical industry (5, 10, 16) have been utilized to evaluate skin surfaces. The principle of this technique is based on the stripe projection onto the skin surface, and measuring its reflection by means of skin topography (10, 17). Until now, by the use of micro-mirrors, only one system has achieved a short measuring time of 70 ms connected with a high resolution of $1\mu\text{m}$ (17). Herein, we report on the application of this new system to evaluate human skin surface topography. This evaluation includes the influence of the body site and the age on the surface topography using surface parameters and, for the first time, Fourier analysis. The measurements were performed on the back and the flexor forearm of volunteers in different age groups. In addition, the effect of the treatment with botulinum Toxin A on mimic wrinkles was measured.

Materials and Methods

Volunteers

The experiments were carried out on 23 healthy volunteers aged between 23 and 65 years. The skin surface topography of the flexor forearm was measured on 14 volunteers, while the measurement was performed on the back of five volunteers. Mimic wrinkles were measured on the face of four women.

In vivo measurement of skin surface topography

The skin areas on the forearm or the back were carefully cleaned with a moist tissue and dried with a separate tissue. The measurements of the skin surface topography were performed using the PRIMOS optical 3D *in vivo* skin measurement device (GF Messtechnik, Teltow, Germany). This system is based on the so-called digital stripe projection technique, which is used as an optical measurement process. A parallel stripe pattern is projected onto the skin surface and depicted on the CCD chip of a shooting camera through a shooting optic (Fig. 1). The measurement system consists of a freely movable optical measurement

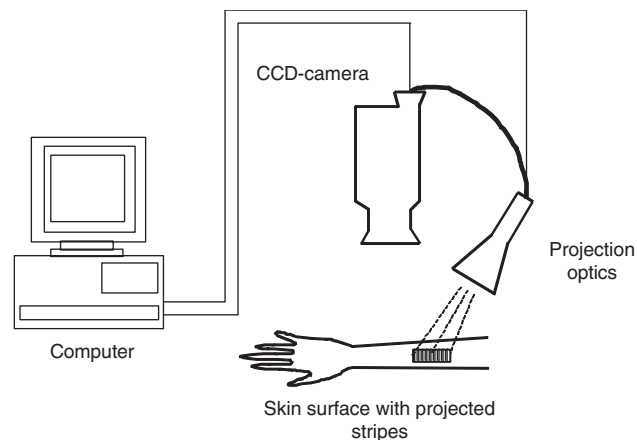


Fig. 1. Function principle of the PRIMOS optical 3D *in vivo* skin measurement device.

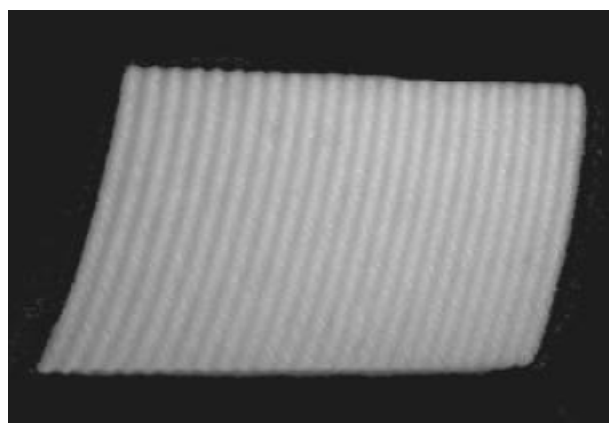


Fig. 2. Projection stripes on the forearm.

head (with an integrated micro-mirror projector, a projection optic, a shooting optic, and a CCD recording camera) together with an evaluation computer. The 3D effect is achieved by the minute elevation differences on the skin surface, which deflect the parallel projection stripes (Fig. 2). These deflections are a qualitative and quantitative measurement of the skin profile. They are digitalized and quantitatively evaluated using the software. Mathematical algorithms, originally developed and used for the highly precise optical measurement of optical and precision-mechanical parts, are employed for the evaluation providing highly precise 3D-profiles of the skin surface.

Before measurement, hairs were removed from the skin areas using scissors. The skin areas measured did not contain any visible change in the color of the skin. The area of measurement was $1.8\text{ cm} \times 1.3\text{ cm}$. Direct light from lamps or the sun was avoided. Standardized positions were used. The forearm was positioned realizing

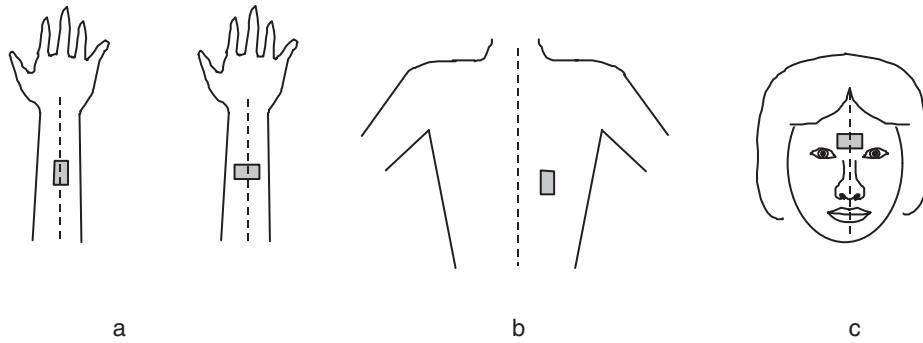


Fig. 3. Position of the measuring area (grey rectangle) to the arm, the body and the face axis (dotted line). a) On the forearm. b) On the back. c) On the face.

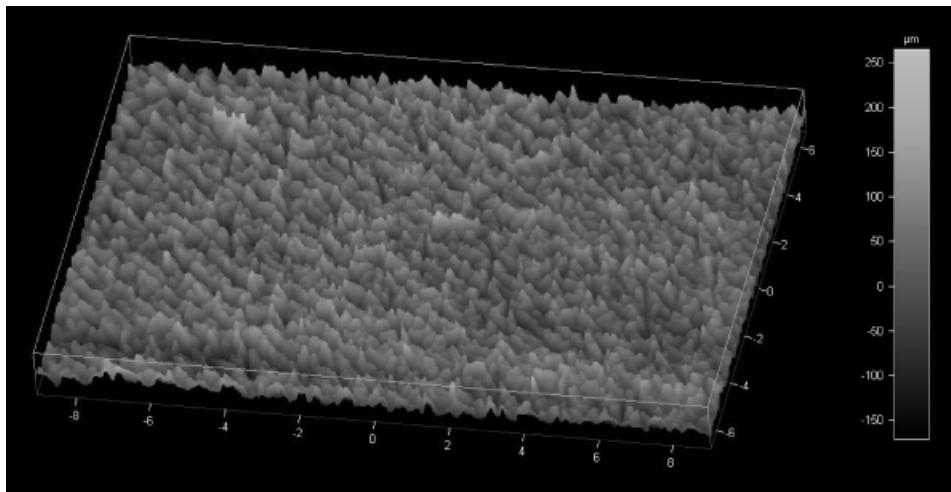


Fig. 4. 3D-profile of skin surface on the flexor forearm.

an angle of 90° between forearm and upper arm and stretched fingers. The back was measured on sitting volunteers realizing an angle of 90° between the upper part of the body and the legs. The mimic wrinkles were measured on the forehead above the nose. The chin was supported by a rest for these measurements.

For the measurements on the right flexor forearm, the rectangular measuring area was positioned parallel and longitudinal to the arm axis (Fig. 3a). On the back, the measuring area was arranged parallel to the body axis (Fig. 3b). On the forehead, the rectangular measuring area was positioned longitudinal to the face axis.

Determination of the skin surface parameters

The 3D skin profiles (Fig. 4) obtained were evaluated using the software Primos 4.0 (GFMe-stechnik, Teltow, Germany). The surface parameters, maximum roughness (R_m), the mean roughness (R_a), the mean depth of roughness (R_z) and the waviness (W_t), were determined as

mean values of the parameters measured along 16 lines arranged circularly in relation to a fixed center (Fig. 5).

R_z is the arithmetical mean of the depths of roughness of five consecutive equally spaced profile sections of the same length following the same line. R_m is the maximum depth of different segment roughnesses. R_a is calculated as the mean deviation of the actual profile from the mean profile. W_t is the height of the maximum peak to valley tangents within the profile. In addition, the Fourier analysis of the 3D-profiles was performed. When applied to dermatological terms, R_a represents the roughness of the surface structure (11). R_z reflects roughness, minor furrows and anatomically preformed lines (18). W_t indicates deeper furrows and is an expression of the skin's wave structure (19).

The Fourier analysis of the profiles transforms information regarding the number, position and periodicity of the furrows into a 3D distribution of intensity. Parallel furrows show intensities in the same direction. This linear intensity

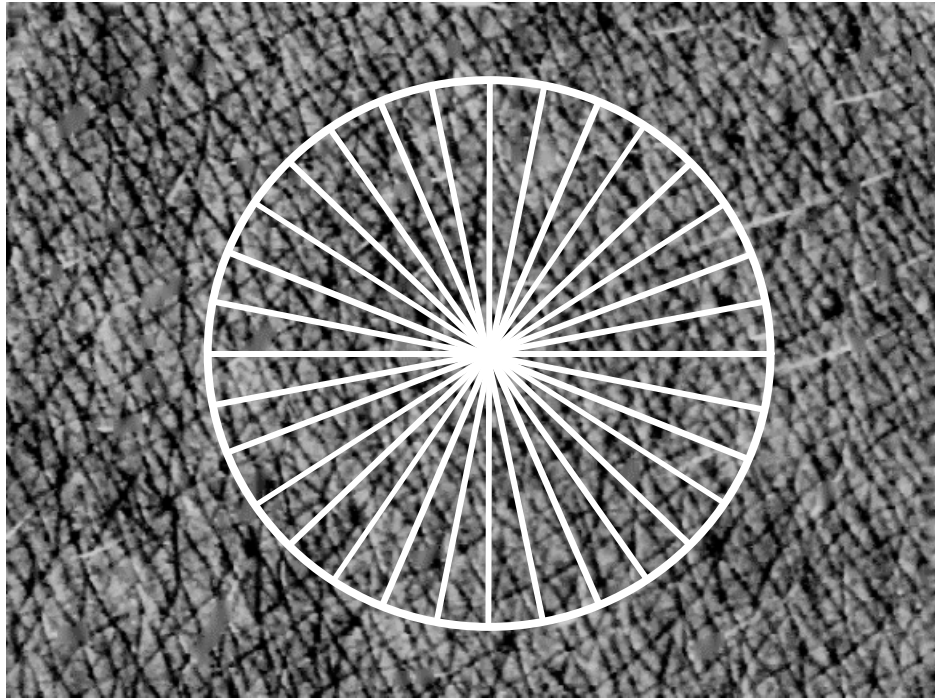


Fig. 5. Determination of the skin surface parameters.

distribution is vertically orientated to the parallel furrows on the 3D skin image. The length of the linear intensity distribution is proportional to the variance of distances between the parallel furrows.

Measurement of mimic wrinkles

In addition, the effect of injected botulinum Toxin A on mimic wrinkles was studied on four female volunteers. A total of 30–50 U botulinum Toxin A (Dysport[®], Fa. Ipsen Pharma GmbH, Ettlingen, Germany) was distributed in three to five injection points in the glabella area of each volunteer. *In vivo* measurements of the skin surface topography were performed. In addition, photographs of the forehead by a digital camera (Nikon Coolpix 990, Nikon Deutschland GmbH, Düsseldorf, Germany) were carried out as previously described in detail (20). All parameters were assessed pre- and post-treatment.

Statistics

Mean values and standard deviations were calculated using the software program Microsoft[®] Excel 97. Further statistical analysis was performed with the software program SAS[®]. Skin surface parameters R_a , R_z , R_m and W_t were analyzed between three age groups ($n = 14$, the Wilcoxon test, two-sided). In addition, the obtained skin surface parameters R_a , R_z , R_m and W_t

were compared between the forearm ($n = 6$) and the back ($n = 5$, the Wilcoxon test, two-sided). The influence of the position of the measuring area to the same body site was determined analyzing the skin surface parameters R_a , R_z , R_m and W_t ($n = 8$, the Wilcoxon test, two-sided, paired data).

Results

Measurements of skin surface topography on the forearm

3D-profiles of the skin surface topography were obtained *in vivo* (see Fig. 4). They were evaluated by determining the surface parameters R_a , R_z , R_m and W_t . The mean values for each parameter obtained on the right forearm are shown dependent on the age group (Fig. 6). The differences between these mean values are statistically significant for all parameters and all age groups ($P < 0.05$).

Additional measurements were performed by changing the position of the forearm with respect to the rectangular measuring area: from parallel to longitudinal position of the measuring area to the arm axis, as shown in Fig. 3a. A statistical analysis of the data sets (not shown) obtained for each parameter in both positions shows no significant differences ($P > 0.05$).

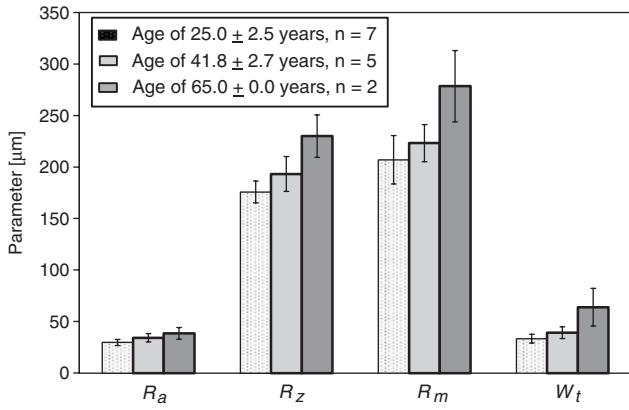


Fig. 6. Mean values and standard deviations of the skin surface parameters: mean roughness (R_a), mean depth of roughness (R_z), maximum roughness (R_m) and waviness (W_t), determined on the right flexor forearm.

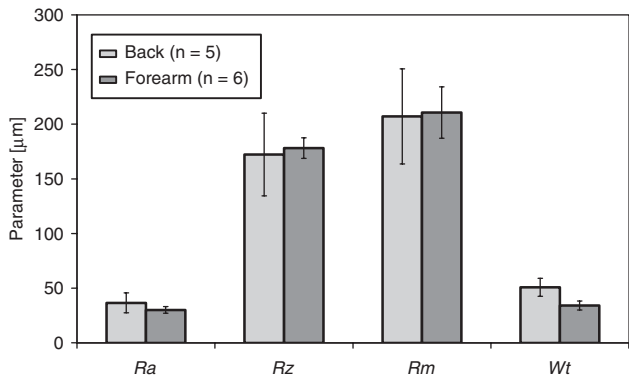


Fig. 7. Mean values and standard deviations of the surface parameters: mean roughness (R_a), mean depth of roughness (R_z), maximum roughness (R_m) and waviness (W_t), determined on the back (mean age of 27.0 ± 5.8 years) and the right flexor forearm of volunteers (mean age of 24.2 ± 1.3 years).

Measurements of skin surface topography on the back
The surface topography of the back of young volunteers was measured. The mean values of the parameters R_a , R_z , R_m and W_t obtained are shown in Fig. 7 in comparison with the mean values observed on the forearms of volunteers at a similar age. The differences between the mean values of the parameters R_a , R_z and R_m are statistically non-significant ($P > 0.05$). There were only significant differences ($P < 0.05$) in the waviness W_t measured on both skin sites.

However, there are clear differences in the 3D-profiles of the back compared with those of the forearm (Fig. 8). Therefore, the profiles obtained for both body sites were additionally evaluated using the Fourier transformation. The intensity distribution showed an X-shaped form for the forearm (Fig. 9a), whereas on the back, the intensity was mainly distributed as a line (Fig. 9b).

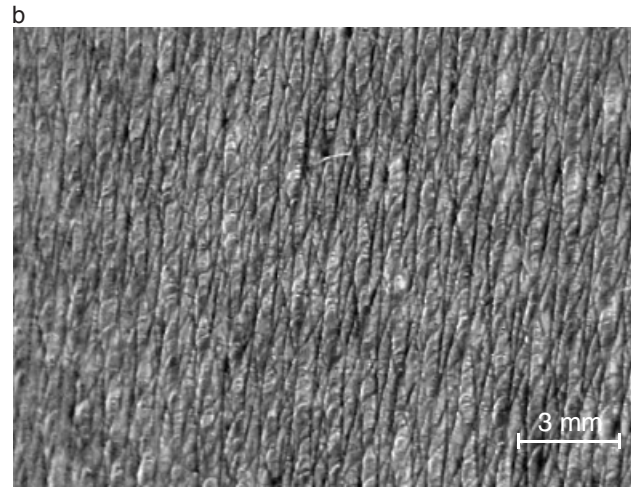
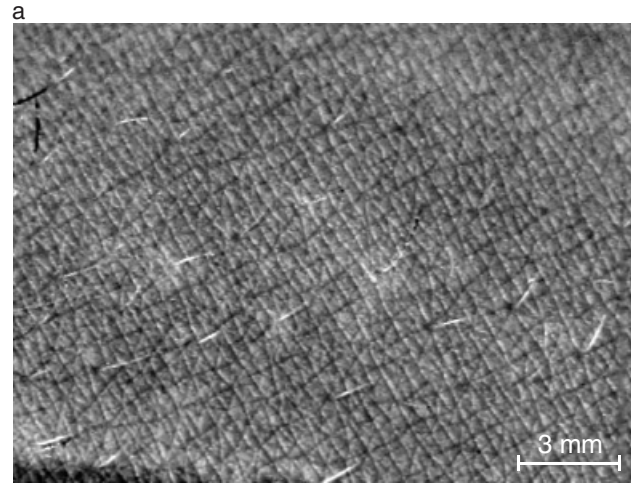


Fig. 8. 3D-profiles determined on the right flexor forearm and the back of male volunteers. (a) 3D-profile of the forearm of a male volunteer, 23 years old ($\rightarrow$ direction of the arm axis). (b) 3D-profile of the back of a male volunteer, 30 years old ($\rightarrow$ direction of the body axis).

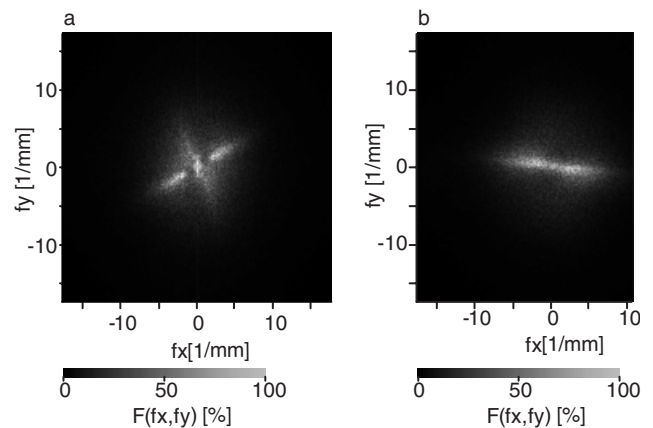


Fig. 9. Fourier analysis of the 3D-profiles determined on the right flexor forearm and the back of male volunteers. (a) Fourier analysis of the 3D-profile of the forearm of a male volunteer, 23 years old (see Fig. 8a). (b) Fourier analysis of the 3D-profile of the back of a male volunteer, 30 years old (see Fig. 8b).

Measurements of mimic wrinkles

The *in vivo* measurement of skin surface topography was used to evaluate the effect of a therapy with botulinum Toxin A against mimic wrinkles. Four female volunteers were treated with botulinum Toxin A to reduce mimic wrinkles in the face. Images were taken from the glabella area. The wrinkles were reduced or completely cleared. In Fig. 10, images of a volunteer pre- and post-treatment are shown in an exemplary manner. In Fig. 10a, two mimic wrinkles are clearly seen, which were diminished by the treatment with botulinum Toxin A (Fig. 10b).

The profiles of a wrinkle measured pre- and post-treatment with botulinum Toxin A are shown in Fig. 11. The depth of the wrinkle was



Fig. 10. Images taken from the forehead of a female volunteer. (a) Prior treatment with botulinum Toxin A. (b) Two weeks post-treatment with botulinum Toxin A.

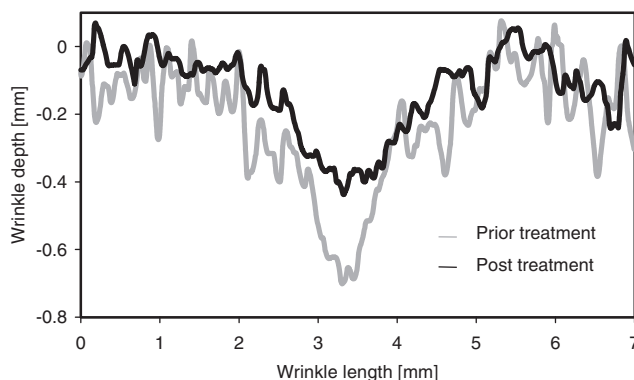


Fig. 11. Profiles of the glabella wrinkle of a female volunteer, measured prior and 4 weeks post-treatment with botulinum Toxin A.

decreased, while the width was nearly constant. This measurement could only be reproduced in one of the four volunteers, as this woman showed a small scar, which could be used as a mark for the wrinkle measurement. In the other volunteers, the treatment with botulinum Toxin A caused such a dramatic change in mimic furrows that the determination of exactly the same wrinkle profile was not possible without tattooed marks.

Discussion

The parameters R_a , R_z , R_m and W_t were determined for the 3D-profiles of the skin surface topography obtained *in vivo*. All these surface parameters determined on the forearm showed an increase with increasing age of the volunteer. A similar effect of age has also been described concerning the parameters R_a and R_m (3) and R_a , R_z and W_t (5). In contrast, no significant age-related differences in R_a (3) and in R_a , R_z and R_m (10) were observed. In these reports, for instance, the values of the parameters obtained on the forearm differ for R_z from 125 μm (3, 5) up to 240 μm (10). This variance could be caused by different factors: the posture of the body site measured influences the value of the surface parameters (3, 21), for example, by stretching the surface (5). Also, the angle between the forearm and the upper arm and the position of the fingers have influenced the results of measurements on the flexor forearm (3, 21). Therefore, standard postures should be used for the measurements and described in detail in the reports. In addition, the volunteers should be of the same age group, in order to exclude the influence of changes in the skin properties due to aging (2–5). In addition, there might be a difference between the parameters determined *in vivo* and *in vitro*. Lower values were measured at replica as performing the measurement *in vivo* using the same device (16).

Usually, the skin surface parameters were determined along parallel lines through the 3D skin surface profile. The orientation of these measuring lines to the orientation of the furrows can influence the values of the surface parameters (3). Therefore, the measurements should be performed in the same direction (3, 18). However, the preferred orientation differs depending on the volunteer and the age (22, 23). This effect can be avoided by determining the surface para-

meters following lines circularly arranged in relation to a fixed center (24). This method of evaluation has been applied in the present study. In this way, an influence on the values of the surface parameters by the orientation of these measuring lines to the orientation of the furrows could be avoided. Indeed, no significant differences between the parameters were obtained if the rectangular measuring area was positioned vertical to the arm axis, compared with the parallel orientation (see Fig. 3).

In other studies, intra-individual differences for different body sites were observed (5, 10). This can be caused by differences in the organization of the superficial dermis and the subcutaneous tissue depending on the body site (2), reflected by the surface topography (1). In the present study, the skin surface topography on the back was also evaluated. The 3D-profiles and the skin surface parameters obtained were compared with those obtained on the forearm. Particularly, the orientation of the deep furrows (primary lines classified by Hashimoto (25)) differed on both body sites. This is not reflected by the surface parameters R_a , R_z and R_m . Differences were only obtained concerning the waviness W_t .

The Fourier analysis of the profiles was performed in order to evaluate the differences. The obtained distribution of intensities (see Figs 9a, b) shows that the furrow network on the forearm is formed by two groups of primary and parallel furrows. Both groups of furrows are vertical to each other. On the back, the primary furrows are mainly located vertically to the body axis. These furrows are connected by flatter furrows that are parallel to the body axis. The variance of distances between the parallel furrows on both body areas was similar. In future, this analysis should be favored if different body sites are evaluated.

The effect of botulinum Toxin A on mimic wrinkles was additionally studied. The treatment with this substance led to a reduction in the mimic wrinkles (see Fig. 11). This result is in agreement with other studies where an improvement or diminution of facial lines could be observed after injection of botulinum Toxin A (26, 27). In the present study, this clinical wrinkle reduction was connected with a decrease in the depth of mimic wrinkles determined with the profilometric method. A change in wrinkle length, as reported by Funasaka et al. (28) was not measured due to the limited measuring area of the applied method.

Summarizing the obtained results, a simple, fast and objective *in vivo* evaluation of the skin surface topography was performed using the Primos 4.0 system. Therefore, the requirements for the evaluation of aging processes and the testing of therapies as shown for the wrinkle reduction by treatment with botulinum Toxin A are fulfilled. Besides, the normally used surface parameters and the Fourier analysis can be used satisfactorily to evaluate differences in skin surface topography.

References

1. Fischer TW, Wigger-Alberti W, Elsner P. Direct and non-direct measurement techniques for analysis of skin surface topography. *Skin Pharmacol Appl Skin Physiol* 1999; 12: 1–11.
2. Piérard GE. EEMCO guidance to the *in vivo* assessment of tensile functional properties of the skin. Part 1: relevance to the structures and ageing of the skin and subcutaneous tissues. *Skin Pharmacol Appl Skin Physiol* 1999; 12: 352–362.
3. De Paepe K, Lagarde J-M, Gall Y, Roseeuw D, Rogiers V. Microrelief of the skin using a light transmission method. *Arch Dermatol Res* 2000; 292: 500–510.
4. Leveque JL, Corcuff P, de Rigal J, Agache P. *In vivo* studies of the evolution of physical properties of the human skin with age. *Int J Dermatol* 1984; 23: 322–329.
5. Jaspers S, Hopermann H, Sauermaun G, Hoppe U, Lunderstädt R, Ennen J. Rapid *in vivo* measurement of the topography of human skin by active image triangulation using a digital micromirror device. *Skin Res Technol* 1999; 5: 195–207.
6. Fenske NA, Lober CW. Structural and functional changes of normal aging skin. *J Amer Acad Dermatol* 1986; 15 (Part 1): 571–585.
7. Lévêque JL. EEMCO guidance for the assessment of skin topography. *J Eur Acad Dermatol Venereol* 1999; 12: 103–114.
8. Eberlein-König B, Schäfer T, Huss-Marp J, Darsow U, Möhrenschlager M, Herbert O, Abeck D, Krämer U, Behrendt H, Ring J. Skin surface pH, stratum corneum hydration, trans-epidermal water loss and skin roughness related to atopic eczema and skin dryness in a population of primary school children. *Acta Derm Venerol* 2000; 80: 188–191.
9. Monti M, Bozzetti M, Motta S, Barbareschi M. Usefulness of surface topography analysis in psoriatic skin. *Acta Derm Venereol Suppl* 1989; 146: 81–83.
10. Piche E, Häfner H-M, Hoffmann J, Jünger M. Neue Ansätze zur 3-D-Rauhigkeitsanalyse menschlicher Haut. *Zeitschr f Haut* 2002; 77: 140–146.
11. Habig J, Vocks E, Kautzky F, Ring J. Biophysical characteristics of healthy skin and nonlesional skin in atopic dermatitis: short-term effects of ultraviolet A and B irradiation. *Skin Pharmacol Appl Skin Physiol* 2000; 13: 174–181.
12. Linde YW, Bengtsson A, Lodén M. Dry skin in atopic dermatitis. II. A surface profilometry study. *Acta Derm Venerol* 1989; 69: 315–319.
13. Fournier N, Dahan S, Barneon G, Diridollou S, Lagarde JM, Gall Y, Mordon S. Nonablative remodeling: clinical, histologic, ultrasound imaging, and profilometric evaluation of a 1540 nm Er:glass laser. *Dermatol Sur* 2001; 27: 799–806.

14. Creidi P, Vienne MP, Ochonisky S, Lauze C, Turlier V, Lagarde JM, Dupuy P. J Amer Acad Dermatol 1998; 39: 960–965.
15. Bourgeois JF, Gourgou S, Kramar A, Lagarde JM, Gall Y, Guillot B. Radiation-induced skin fibrosis after treatment of breast cancer: profilometric analysis. Skin Res Technol 2003; 9: 39–42.
16. Friedman PM, Skover GR, Payonk G, Kauvar ANB, Geronemus RG. 3D *in-vivo* optical skin imaging for topographical quantitative assessment of non-ablative laser technology. Dermatol Surg 2002; 28: 199–204.
17. Frankowski G, Chen M, Huth T. Real-time shape measurement with digital stripe projection by Texas Instruments Micromirror devices DMD™. San Jose, 23–28 January 2000, Electronic Imaging 2000, Three Dimensional Image Capture and Analysis III.
18. Grove GL, Grove MJ. Objective methods for assessing skin surface topography noninvasively. In: Leveque JL, ed. Cutaneous investigation in health and disease. Non-invasive methods and instrumentation. New York: Dekker, 1989: 1–32.
19. Kautzky F, Dahm M, Drosner M, Vogt HJ, Borelli S. Direct profilometry of the skin: its reproducibility and variability. J Eur Acad Dermatol Venereol 1995; 5: 15–23.
20. Honeck P, Weiss C, Sterry W, Rzany B. Gladys study group. Reproducibility of a four-point clinical severity score for glabellar frown lines. Br J Dermatol 2003; 149: 306–310.
21. Corcuff P, de Lacharrière O, Lévêque JL. Extension induced changes in the microrelief of the human volar forearm: variation with age. J Gerontol Med Sci 1991; 46: 223–227.
22. Corcuff P, Leveque JL, Grove GL. The impact of aging on the microrelief of peri-orbital and leg skin. J Soc Cosmet Chem 1987; 82: 145–152.
23. Hoppe U, Lunderstädt R, Sauermann G. Quantitative analysis of the skin's surface by digital signal processing. In: Frosch PJ, Kligman AM, eds. Noninvasive methods for the quantification of skin functions. Berlin: Springer-Verlag, 1993: 25–41.
24. Hoppe U. The topology of the skin. Cosmet Technol 1981; 2: 55–59.
25. Hashimoto K. New methods for surface ultrastructure. J Invest Dermatol 1974; 13: 357–381.
26. Goodman G. Botulinum toxin for the correction of hyperkinetic facial lines. Austral J Dermatol 1998; 39: 158–163.
27. Fagien S, Brandt FS. Primary and adjunctive use of botulinum toxin type A (Botox) in facial aesthetic surgery: beyond the glabella. Clin Plast Surg 2001; 28: 127–148.
28. Funasaka Y, Sato H, Usuki A, Ohashi A, Kotoya H, Miyamoto K, Hillebrand GG, Ichihashi M. The efficacy of glycolic acid for treating wrinkles: analysis using newly developed facial imaging systems equipped with fluorescent illumination. J Dermatol Sci 2001; 27 (Suppl. 1): S53–S59.

Address:

Jürgen Lademann
 Center of Experimental and Applied Cutaneous Physiology
 Department of Dermatology, Charité – Medical Faculty Berlin,
 10098 Berlin,
 Germany

Tel: +49 30 450 518 100
 Fax: +49 30 450 518 918
 e-mail: juergen.lademann@charite.de