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Interferometry: A New Method for No-touch Measurement of the Surface and Volume of Ulcerous Skin Lesions

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A new interferometry procedure (Holon View® measuring system) permits non-invasive and objective measurement of the surface, height/depth and volume of ulcerous lesions. The method, which uses a combination of the so-called phase-shift and gray-code technique, is new in dermatology.
The measuring system consists of a diffraction grating projection system, a video camera and a computer-aided, digital image processing and analysis system. A diffraction grating consisting of 320 lines is projected onto the skin surface or a silicone impression of the ulcerous lesion. The course of the light-intersection lines is recorded by a video camera and read into an image computer. The special feature of the method is the combination of grey-code projection and a phase-shift procedure.
For evaluation of the method in dermatology, 2,000 interferometric measurements of volume were carried out on objects of known volume, on silicone impressions and on leg ulcers. The accuracy of the method has been proven by means of the evaluation of objects of known volume. The results of interferometric measurements were compared with the values of the volume determined by water capacity and those of the surface determined by image analysis. The healing of a leg ulcer was followed over an 8-week period.
The Holon View® measuring system permits no-touch measurement of the volume and surface of ulcerous skin lesions with a high degree of accuracy and precision, in a short time. ***Key words: optical 3D-measuring systems; on-line topometry; holographic interferometry; grey code; phase shift; skin surface relief; replicas; dermatology.***

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There are to date few methods available for reproducible evaluation of the surface structures of the skin (1–3). However, such evaluation must be considered a necessity, particularly for objective and reproducible documentation of the course of a skin disease. This precludes the use of invasive methods. In longitudinal investigations it is important to ensure that the measuring procedure does not alter the surface being investigated.

Computer-aided laser profilometry can be used to quantify very small areas of skin on the basis of roughness parameters and profile heights (4–6). Laser profilometry is suitable mainly for characterisation of skin lines and fine structural pathological changes. Extensive ulcerous changes of the skin cannot be measured by laser profilometry on account of the considerable time required and the limited size of the measuring field.

In machine construction, on-line topometric measuring and testing procedures based on holographic interferometry have been used for a number of years for deformation and vibration analysis of components, aggregates and machines (7, 8). The term "on-line-topometry" as used here refers to procedures which work with structured light, which can produce a visual 3D-image and, finally, permit computer-aided processing of the recorded parameters (7, 9).

We present a new technique – derived from "on-line-topometry" – for quantification of the surface, height/depth and volume of ulcerous skin lesions. The possibilities of practical application and the validity of the procedure were examined in ulcerous skin defects and clearly defined bodies.

MATERIALS AND METHODS

Material

The volumes, surfaces and the depth of penetration of 10 chronic venous leg ulcers (5 females and 5 males) and 10 ulcerative lesions of different etiology (4 females and 6 males) of various sizes and depths were examined by interferometry.

The leg of the patient was positioned in such a way that the ulcer was lying in the plane of the image. The surface of the ulcer should be light and without any reflexion in order to guarantee optimal recording of the image. To achieve this, the ulcer was dried and covered with a thin layer of white powder, for example titan dioxide. Recording of the image takes 10 sec, during which the leg should not be moved in order to avoid faulty measurements. The largest diameter should not be greater than 10 cm. Ulcers with a depth of more than 1 cm are often unsuitable because of their sharp or lip-like protruding margins.

Interferometric evaluation of volume can also be made by measuring a silicone impression of the ulcer (replica). For this a dull white silicone mass (Silflo®, Flexico Development Limited, UK) is mixed with a catalyst and applied to the ulcer. After several minutes the mold can be removed completely.

After the examinations of a venous ulcer of the lower leg and an ulcerative lesion of the ankle by the interferometry procedure (5 independent measurements of each ulcer were made), silicone impressions of the ulcers were weighed, the indentations filled with water and, after re-weighing, the volume was calculated on the basis of the specific gravity of water. The volumes determined five-fold in this manner were compared with the volumes determined by interferometry.

For validation of the surfaces of the ulcers determined interferometrically, the values were compared with the results of planimetry determined by five-fold image analysis. The contour of the ulcer was recorded by a video camera (JVC® TK-1070 E, Hitachi, Japan). After the image analysis system (Micro Scale TM/TC®, Digithurst Ltd, UK) had been calibrated and the region of interest (ROI) had been marked by a threshold function, the base area of the ulcer was evaluated by the image processing procedure (10, 11).

*Technical principle of interferometry**

The Holon View® (Laboratory for Image Processing, Tegernsee, Ger-

* The use of interferometry in dermatology was introduced by Dr. H. Erbler (Merz + Co.) and was technically realized in cooperation with Dr. H. P. Duwe and MAN technologie AG.

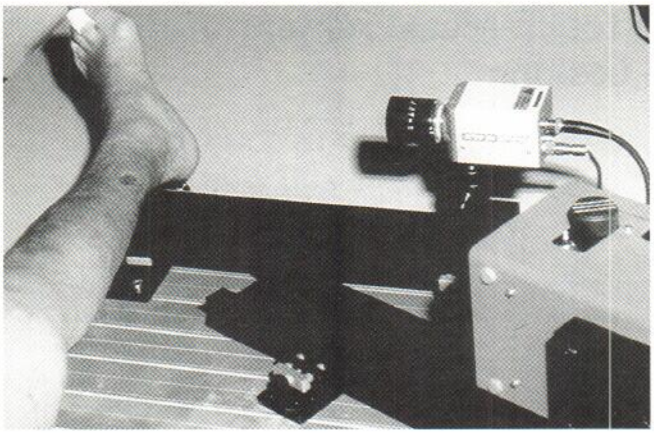


Fig. 1. In vivo measurement by interferometry of a venous leg ulcer. (Holon View system® with projection system and video camera). The camera and the projector are positioned so that the angle between the two is about 45 degrees. The object to be measured is positioned in the image plane, and the sequence of light intersection lines projected onto the object is recorded by the video camera.

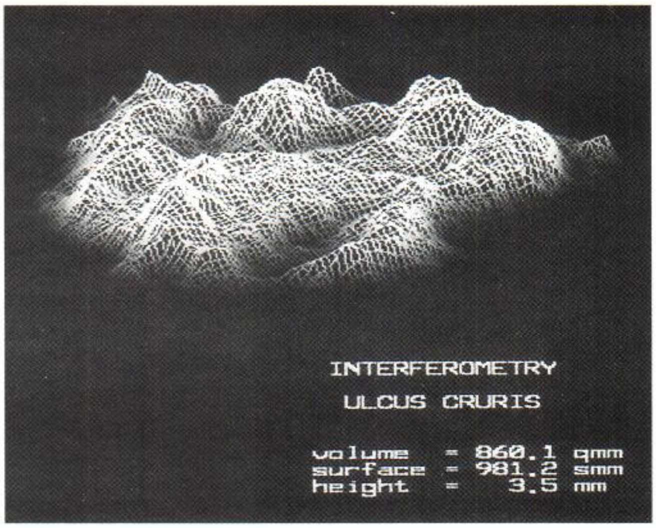


Fig. 3. Three-dimensional image of the leg ulcer (*Fig. 1*), with values of volume, surface and depth.

many) measuring system consists of an LCD-320 projection system (ABW Company, Neuhausen a.d. Fildern, Germany), a video camera (Model KP-160 CCD, Hitachi Denshi Ltd., Japan), a stable object-holding device and a computer-aided digital image processing system. After the system has been calibrated, the object to be measured is positioned in the image plane (Fig. 1). The computer-aided projection system LCD-320 permits projection of a programmable 320-line lattice onto the object. The course of the light intersection lines (Fig. 2a) is recorded by a video camera and read into and processed by the image processing computer (grey-code projection) (12, 13). This procedure is completed within 10 s. The resolution is optimised by means of the phase-shift procedure (14–16), in which lattices are used which produce a sinusoidal line pattern on slightly out-of-focus projection. The digitised measuring data are then converted into a contour map (Fig. 2b). The ROI is marked. In this contour map (Fig. 2c) the system calculates volume, surface and height/depth of the ROI. The whole measuring procedure of an object takes about 2 min.

The surface determined by interferometry includes all margins relief structures, i.e. the sum total of all surfaces. The marginal zone of the ROI is used to determine a zero plane (Fig. 2c). All elevations and troughs are calculated in relation to this zero plane. The ROI can be shown as a two-dimensional or three-dimensional computer image (Fig. 3) (5).

Depending on the size and depth of the object, the accuracy of the Holon View® measuring system is between 100 μm and 1 mm. The resolution is about 1/1000 to 5/1000 of the object size (17).

Statistics

The data processing and statistical analysis were performed on a 486 PC using Windows 3.2, the spreadsheet Excel 5.0 and the software SPSS 6.0 for Windows. Student's *t*-test for paired samples was used for the statistical analysis.

RESULTS

By interferometry we were able to determine the volume of an ulcer, its surface and its depth of penetration. The results of interferometric in vivo measurements in 10 patients with chronic ulcers of the lower leg are shown in Fig. 4a–c. The standard deviation of the mean was between 0.2 and 1.6% for determination of the volume (Fig. 4a), between 0.9 and 2.2% for determination of the surface (Fig. 4b) and between 1.4 and 2.9% for determination of the depth (Fig. 4c). The course of healing of an approximately 2-month-old venous leg ulcer was also documented by interferometry (Fig. 5a–c). The initial volume was 860 mm^3, the maximum depth of penetration 3.5 mm (Fig. 5a). Clinical regression of the ulcer was evident after 3 weeks. The volume at this time was 650 mm^3, the maximum depth of penetration 2.3 mm (Fig. 5b). After 8 weeks the ulcer was almost completely healed. This was confirmed by the interfero-

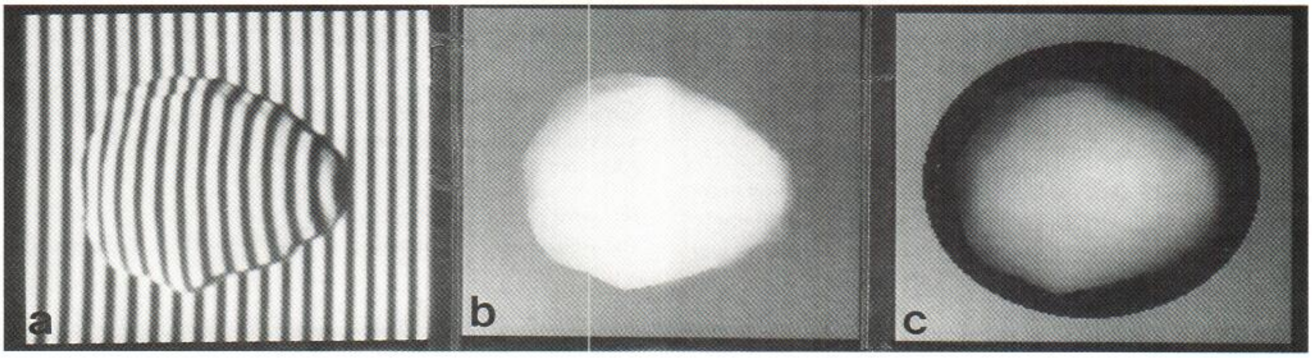


Fig. 2. (*a*) Projection of the light intersection lines onto the object. (*b*) Grey-scale image of the height intervals of the object. (*c*) Subtraction of the reference area.

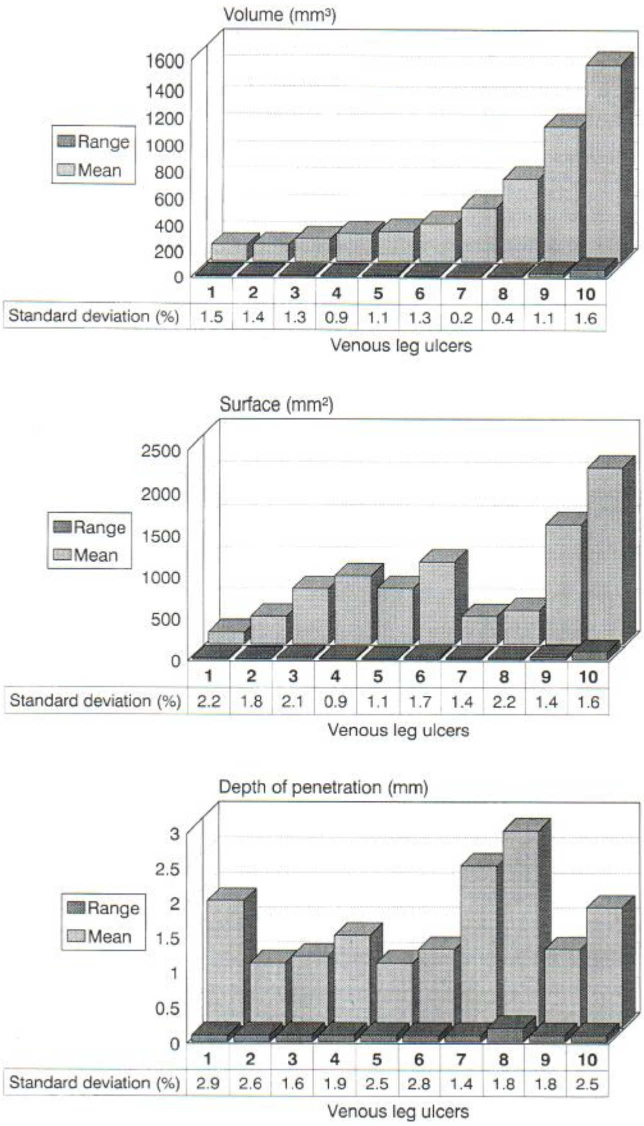


Fig. 4. Interferometric in vivo measurement of 10 venous leg ulcers (20-fold measurement) located on the lower leg. (*a*) Volume. (*b*) Surface. (*c*) Depth of penetration.

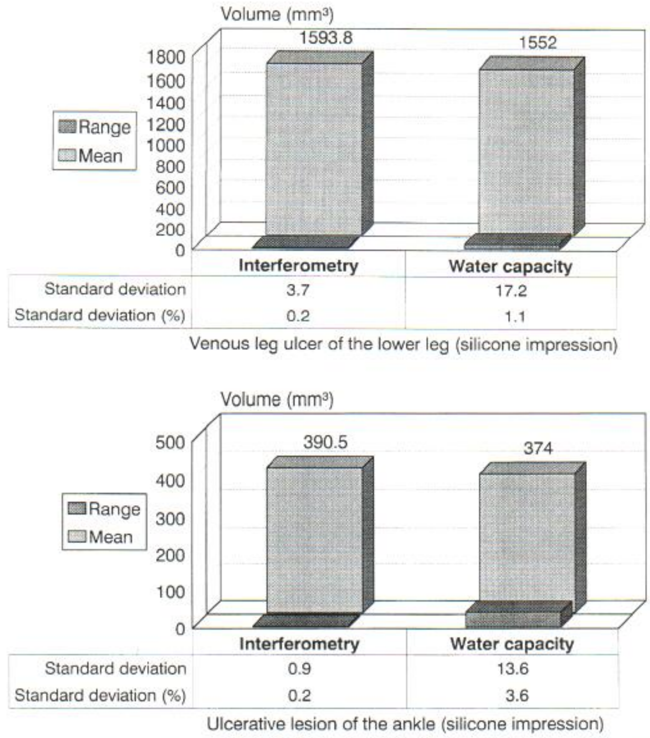


Fig. 6. Interferometric determination of the volume of a venous leg ulcer of the lower leg (*a*) and an ulcerative lesion of the ankle (*b*) (5-fold measurement), in comparison with determination of volume on the basis of water capacity.

metric analysis, which showed a residual volume of 240 mm³ and a maximum depth of penetration of 0.8 mm (Fig. 5c).

Fig. 6 shows the results of the interferometric determination of the volume of a venous ulcer of the lower leg (Fig. 6a) and an ulcerative lesion of the ankle (Fig. 6b), in comparison to the volume measured on the basis of water capacity. The standard deviation of the mean for the interferometric measurement was 0.2%, while that for the water capacity was 1.1% and 3.6%. The volume determined by interferometry correlated well with that determined by using water (102.7% and 104.4%). Parallel to the determination of the surface of ulcers by interferometry, which includes all margins and relief structures, five-fold measurements of the ulcer areas were made by computer-aided planimetry (Fig. 7a,b). The total ulcer surface measured by interferometry was considerably larger than the area determined by computer-aided planimetry.

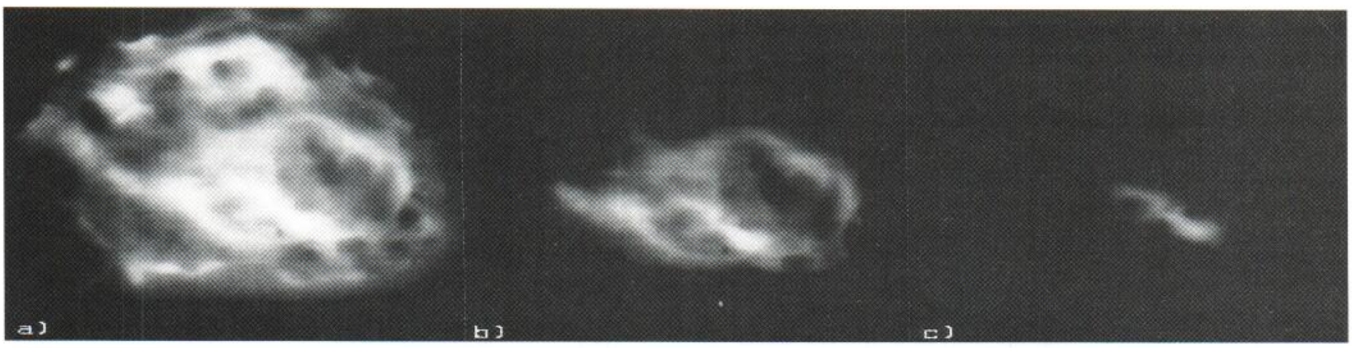
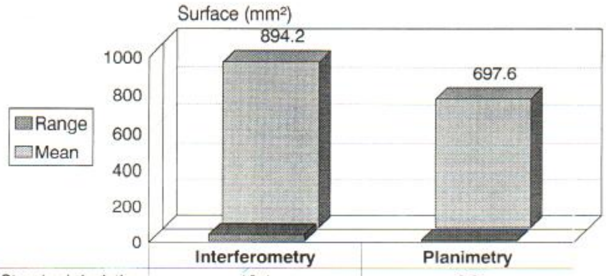
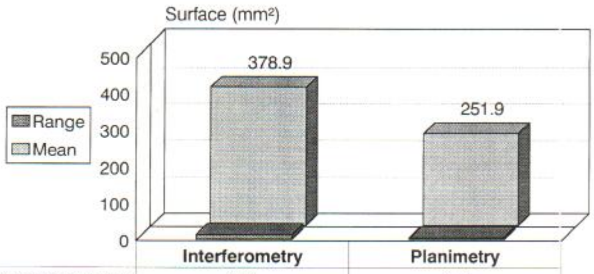


Fig. 5. Contour line image of the healing of a leg ulcer as measured by interferometry: (*a*) initial status: volume: 860 mm³, depth of penetration: 3.5 mm; (*b*) after 3 weeks: volume: 650 mm³, depth of penetration: 2.3 mm; (*c*) after 8 weeks: volume: 240 mm³, depth of penetration: 0.8 mm.



	Interferometry	Planimetry
Standard deviation	13.4	2.8
Standard deviation (%)	1.5	0.4

Venous leg ulcer of the lower leg (silicone impression)



	Interferometry	Planimetry
Standard deviation	4.7	1.7
Standard deviation (%)	1.2	0.7

Ulcerative lesion of the ankle (silicone impression)

Fig. 7. Interferometric determination of the surface of a venous leg ulcer of the lower leg (*a*) and an ulcerative lesion of the ankle (*b*) (5-fold measurement), in comparison with determination of surface on the basis of computer-aided planimetry of the base area.

DISCUSSION

To date, holographic procedures have been mainly used in machine construction for analysis of deformation and vibration (7). The special feature of the interferometry system used by us is the combination of the "phase-shift" procedure, which involves measuring an object using the projection of a line lattice onto the object and analysis of the course of the light intersection lines by the computer, and "grey-code" sequence projection, which improves the resolution by using a line lattice of sinusoidal defocussed light intersection lines. This permits exact definition and determination of contour line heights. The resolution is optimised to 100 µm. Interferometry is thus suitable for quantification of exophytic or ulcerous lesions in dermatology. The procedure can be performed either directly on the patient's skin or on skin moldings obtained by the replica technique. The use of replicas largely eliminates confounding factors such as respiratory excursions or muscle contractions (18, 19).

For standardization of the measuring procedure we used objects of known volume. The validity of the results was proved by comparing them to those of computer-aided planimetry and the water capacity method.

The ulcer has to be positioned in a 90° angle to the camera. Ulcers with sharp margins should be rotated into a position in which the margin does not lead to false measurements. The marginal zone of the ROI (e.g. the margin of the leg ulcer) is taken as the zero reference level. The computer system relates all elevations and depressions to this zero level. This is problematic in the case of lesions on particularly curved areas of the body (e.g. ankle or forearm region). The zero reference level, which is marked by a cursor, is flat so that the curved contour of normal skin could influence the measurement. We found, however, that the potential error can be minimised by tracing the skin lesion very closely with the cursor and thus reducing the base area. The form and surface of the base area can be kept constant with the help of computer-stored evaluation masks, so that the measuring error caused by the skin curvature does not negatively influence the monitoring of the progress of a skin lesion. The skin curvature and the uneven marginal zone probably constitute a general problem in the evaluation of leg ulcers in the description of the point of healing. Lip-like protruding margins lead to falsely diminished volumes.

The area determined by interferometry comprises the entire surface of the object including its margins and all relief structures, i.e. the sum total of all surfaces. The base area of an ulcer determined by computer-aided planimetry is measured as a flat area regardless of its surface relief. Interferometry measures the relief of the base of the ulcer and adds together all areas determined. The values obtained by interferometry are thus higher than those obtained by planimetry.

The reproducibility of the measurements obtained by interferometry was demonstrated by conducting serial measurements. The evaluation of objects of known volume which were measured several times showed that the mean standard deviations for the volume determination were between 0.1% and 1.4% (20). Volumes measured by interferometry were on average 103.6% of that measured on the basis of the water capacity method. The method is thus superior to all methods hitherto available for quantification of ulcerous and exophytic skin lesions. As it is non-invasive and takes place without skin contact, it is a suitable procedure for accurate documentation of the healing of leg ulcers etc. Exact quantification of treatment effects is therefore possible.

To sum up, with the introduction of interferometry to dermatology we have for the first time a procedure which enables us to measure the extent and volume of skin lesions – e.g. various types of ulcers, exophytic tumours and papulous or maculopapulous inflammatory or neoplastic lesions – below or above the skin surface without touching the skin. This procedure is of great significance for monitoring the course of and treatment effects on ulcerous and plaque-like lesions, as well as for the determination of the size of exophytic skin tumours.

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