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Scale sensitive fractal analysis using the patchwork method for the assessment of skin roughness

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Abstract

A new method for the three dimensional assessment of skin topology is presented. The method, which is based on principles from fractal geometry analyzes the change in apparent area of the skin surface as a function of scale. This is done by virtual tiling of 3D topograpic data sets which record the height as a function of position. These data sets were acquired with the SkinVisiometer (Courage & Khzaka, Cologne, Germay). The virtual tiling analysis is performed using Surfrax (Burlington Computer Systems, Waterbury Center, VT, USA). Our results show that the apparent area of skin is independent of scale above a smooth-rough crossover that can be measured in square micrometers. Below this smooth-rough crossover scale, the log of the apparent area of the skin increases linearly with a decrease in the log of the scale of measurement. Over this linear range the roughness of the skin can be described using the fractal dimension or a complexity parameter. The complexity and the smooth-rough crossover scale can be used to differentiate skin conditions.

Introduction

Natural surfaces are often complex and detailed in structure and often selfsimilarities are found: that is, a magnified view of the surface will look very similar to the original surface. These types of surfaces cannot be expressed by euclidean geometry, because they do not consist of perfectly shaped pyramids or straight lines.
A new appraoch to this kind of surfaces was introduced by Benoit B. Mandelbrot with his definition of fractal geometry in the 1970s (1). Mandelbrot used a different definition of dimension, than that used in Euclidean geometry. Instead of being limited to integers to describe the dimensions of a given object, his mathematics contained fractions of dimensions. The fractions or fractal dimensions express the complexity of the object and how it fills the dimension.
Skin is one of the natural surfaces that is difficult to describe in euclidean geometry. With the naked eye, one sees well defined squares and triangles, but with increasing magnification one finds, that each structure consists of another more complex structure. Besides, skin is an anisotropic surface: unlike machined surfaces, it has no regular shapes in either one direction of analysis (2).
We will here present the application of fractal mathematics on skin and show, that skin has fractal properties and that skin surfaces can be differentiated by fractal mathematics.

Methods

Hardware

To assess the roughness of the skin, the topography has to be quantified. We used the SkinVisiometer (Courage & Khazaka, Cologne)(3). This instrument reads silicon replicas of the skin. The replicas consist of transparent silicon. By using a mold when making the replica, it is achieved, that the thickness of the replica is constant, refrained from small deviations, that are caused by the furrows and peaks in the replicated skin. By shining light through the replica and recording the light that passes through the replica by means of a CCD camera, the thickness can be measured: the thicker the replica at a specific point, the less light passes through. The result is a three-dimensional image of the surface of the skin area.

Software

Conventional roughness analysis was done by the software of the SkinVisiometer. 12 parallel profile lines (length 5.8 mm) were choosen accross the replicas, perpendicular to the north-south axis (elbow to wrist) after high-pass filtering of the data (cut off 0.8 mm). The following parameters were calculated: Rz: mean peak-to-valley height, Ra: arithmetic average

The fractal roughness analysis was done with the program Surfrax (www.surfract.com), which was developed by C.A. Brown at the Worcester Polytechnical Institute (4,5). Surfrax determines the area of a given surface by rebuilding the surface with equally sized isosceles triangles. By using ever decreasing sizes of triangles (=scale of measurement), the surface is more and more precisely replicated (figure 1). The area of the surface is set into relation to the size of the triangle by means of a log-log-plot (figure 2). In fractal surfaces, the log of the apparent area of the skin increases linearly with a decrease in the log of the scale of measurement, resulting in a nearly straight descending line over a specific range of triangle sizes, whereas in euclidean surfaces the apparent area of skin is independent of scale and the plot shows a nearly horizontal line. When the triangle has reached a certain size, every surface will produce a nearly horizontal line.

Surfrax calculates the slope of the descending line and determines the crossover between the descending and the horizontal line. The slope depends on the complexity of the surface. Absolute(slope)/1000+2 gives the fractal dimension [D] of the surface. The crossover region determines the scale at which the surface appearance changes from euclidean (rough) to fractal (smooth).

Trial

An area of the flexor side of the forearm skin of 8 volunteers was treated with 15 % glycerol solution. A first replica of the skin was taken before treatrment, a second replica one hour, a third two hours after treatment.

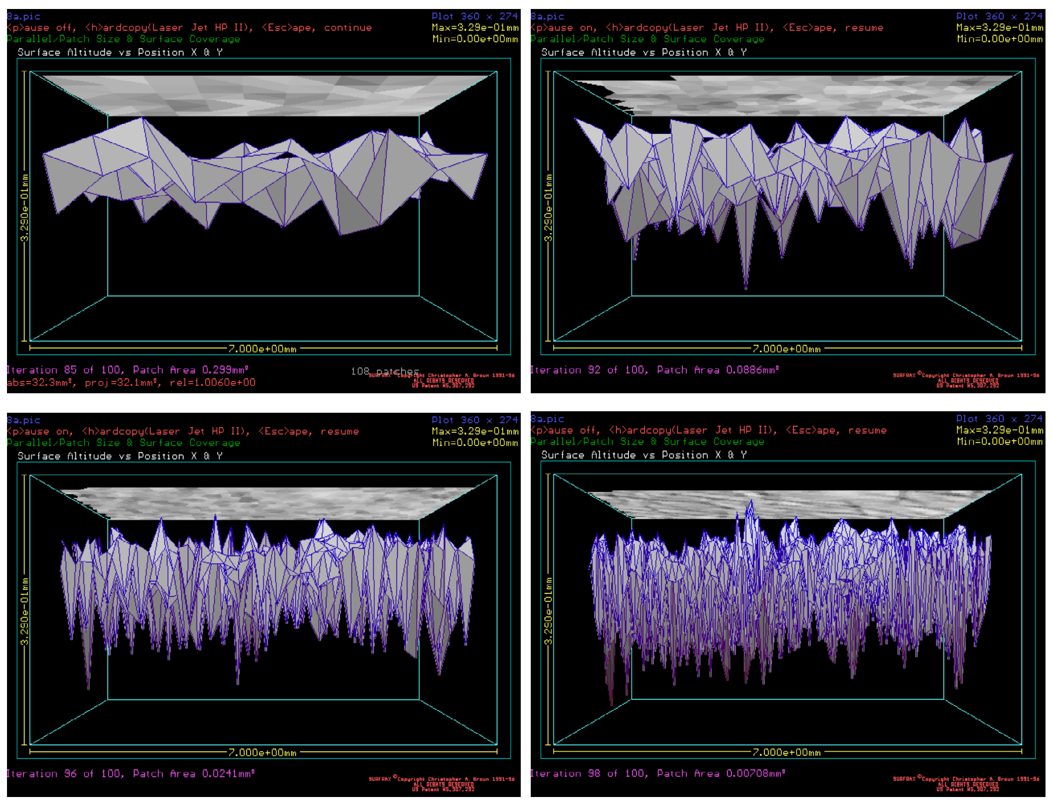

Figure 1

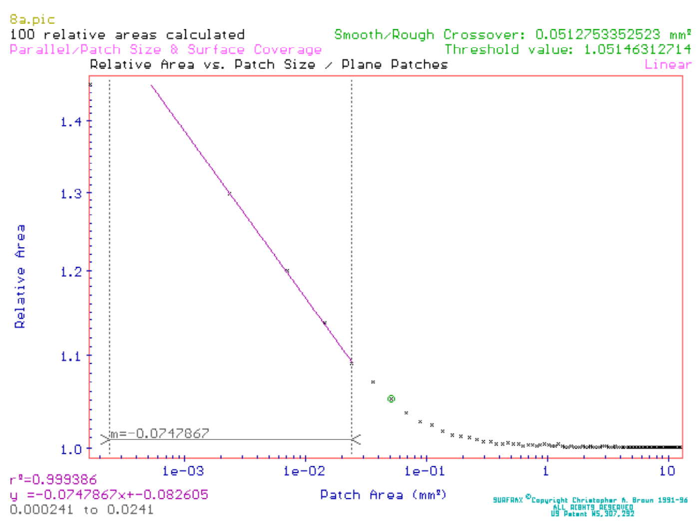

Figure 2

Results

The data of the conventionel and the fractal roughness analysis are shown in table 1 (Slope values (e.g. complexity) are multiplied with -1000, crossover values with 1000).

The fractal and the conventional roughness parameters point in the same direction: the skin is smoother one hour after treatment with glycerol. Two hours after treatment, the surface of the skin tends to return to pre-treatment values.

	Rz	Ra	Complexity	Crossover
before treatment	185.00	42.00	72.57	598.15
1 hour after treatment	152.00	34.00	54.16	249.03
2 hours after treatment	171.00	37.00	64.57	300.84

Table 1

Conclusion

During our calculations we found that below a certain smooth-rough crossover scale, the log of the apparent area of the skin increases linearly with a decrease in the log of the scale of measurement. Over this linear range the roughness of the skin can be described using the fractal dimension or a complexity parameter.

Fractal skin analysis with Surfrax is indepent of the anisometry of the surface of the skin and delivers one scale insensitive parameter to describe it.

References

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