On the measuring of roughness

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For the present study some roughness parameters often used in dental research were defined and some of their properties discussed. The technique of filtration or cut-off as a means of distinguishing between roughness and curvature was explained and demonstrated in some specimens of dental amalgam.

Key-words: Dental materials; physical properties

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Roughness is an important property for surface phenomena. It has the effect of increasing the surface area, it affects the friction, and it provides mechanical attachment for foreign material, e.g. dental plaque, on the surface. In the dental literature articles have appeared in which surface roghness has been measured and related to phenomena such as the adaptability of dental amalgam (10), the accumulation of plaque on teeth and on dental restorative materials (7), the efficacy of clinical finishing procedures (3, 4, 9), the polishability of restorative materials (8, 11), the surface smoothness of gold castings (5, 6), and the retentive ability of prepared tooth surfaces (18). Both *in vivo* and *in vitro* studies of biocompatibility of materials have shown that minimum cellular response is obtained using polished specimens instead of rough ones (15, 16).

Several methods have been employed in order to characterize a surface with respect to its roughness. In some of these the so-called roughness factor is determined as the ratio of absolute to nominal surface area. The measurement of absolute area has been based on surface phenomena such as adsorption of gases and polarization capacity (12). Measurement of roughness has also been based on light reflection from the surface (17).

The most common approach, however, is to determine the profile along a line on the surface by the use of a mechanical tracing device and to express the roughness by the undulations of the profile relative to some base line. In this case roughness can be expressed in different ways. In the dental literature papers on roughness measurements have often been presented in which a certain roughness quantity or parame-

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ter has been used without any discussion of its properties or any explanation of why it was preferred. Roughness can also be conceived in various ways. In general a surface is considered rough if it is characterized by protrusions and recesses of high amplitudes and short wavelengths. If the wavelengths are long, the surface may be thought of as being smooth, but wavy. The roughness of dental enamel surfaces can be measured in such a way that the perikymata, appearing in numbers of 10–30 per millimeter, contribute to the roughness value. However, this undulation of the enamel surface can also be considered as a base line and the roughness measured as the deviations from this base. When calculating roughness in this case the roughness meter must be adjusted to exclude long-waved oscillations and to use only the short-waved deviations, superimposed on the curved base line. In studying surface roughness, therefore, a distinction must often be made between roughness and curvature. In modern roughness meters this can usually be done since the equipment offers a possibility of filtering away some of the long-waved oscillations. In the dental literature filtration as a means of distinguishing between shape and roughness has only been very briefly mentioned in a few papers (4, 11). The technical literature, on the other hand, contains papers which discuss filtration and the separating of roughness from curvature (13, 14).

The results obtained in the measuring of roughness depend on several factors. Some of these pertain to the material itself, its softness, the presence of voids etc. Others refer to equipment design, in particular to the design of the surface tracer (1, 2, 14).

The purpose of the present paper was to examine the phenomenon of filtration and its effects on the numerical expression of roughness.

DEFINITIONS

In Fig. 1A a rough surface is schematically indicated. When determining the corresponding roughness value a stylus is moved along the surface, recording all the peaks and recesses which characterize the surface. While the stylus is tracing the surface all the deviations from a base line are measured (Fig. 1B). The so-called R_a-value is calculated as the shaded area divided by the scanned length, in accordance with the mathematical definition in Fig. 1. If the deviations from the base line are squared, the R_s-value is obtained. The R_a and R_s parameters are often designated CLA and RMS, respectively. These parameters give an average roughness value for the part of the surface which has been traced by the stylus. The R_t-value, on the other hand, gives only the maximum peak-to-valley distance throughout the sampling length. (Fig. 1C). Definitions of other roughness parameters are found in the literature (1, 14).

FILTRATION

In the presentation below the effects of filtration are demonstrated by the use of a Perthometer W5A/ppk (Perthen, Mahr, Germany) roughness meter and a Perthograph R 100 T5 (Perthen, Mahr, Germany) profile recorder.

In Fig. 2A a rough profile is shown. The protrusions and recesses occur in two different frequencies, in long-waved and short-waved periods. The R_a – and R_s-values can be obtained from a direct calculation of all positive and negative deviations from a straight base line. In such a case no filtration

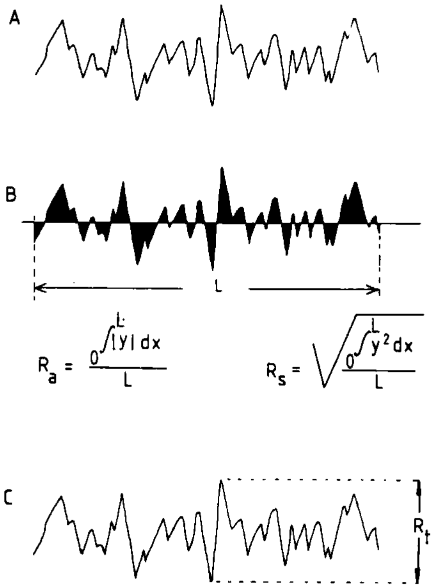

Fig. 1. Definitions of R_a, R_s, and R_t

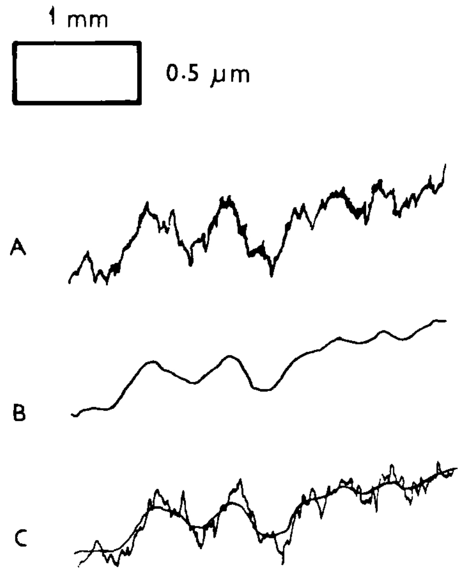

Fig. 2. A: a roughness profile as recorded by the stylus of the tracing device. B: the curved baseline resulting from a certain filtration or cut-off. C: the base line superimposed on the unfiltered roughness profile.

has been done, and the average roughness values R_a and R_s will be the largest possible. If, on the other hand, some long-waved oscillations are filtered away, the base line will appear as shown in Fig. 2B. This profile is then considered as curvature, and the roughness is calculated on the basis of all measurements departing from this new base line. The R_a and R_s parameters will have smaller values, which is indicated in Fig. 2C, where the curved base line has been superimposed on the unfiltered profile.

For the calculation of R_a and R_s the filtration implies a gradual reduction in the weight of the vertical deviations when the rate of change or the derivative of the function representing the profile decreases. The phenomenon is explained in Fig. 3, assuming a profile in the shape of a sine function. The wavelength on the X-axis is in a logarithmic scale. The percentage of the vertical amplitude which enters into the calculation of R_a and R_s is given on the Y-axis. For the curve in the middle (Fig. 3) it is seen that the vertical deviations which appear with a wavelength of approximately 20 mm or more are not used at all in the calculation of roughness. Furthermore, if the wavelength is approximately 0.1 mm or less, the entire vertical deviations will be used in the calculation of R_a and R_s. Between these extreme wavelengths a gradual decrease in the effective part of the waves' amplitude takes place as the wavelength increases. For this graph 75 % of the wave's amplitude is effective in the calculation of roughness when the wavelength is 0.8 mm. This value is called the cut-off value. The higher the cut-off value, the more is recorded as roughness. No filtration corresponds to an infinite cut-off value; in other words the base line will be a straight one.

The effect of a variation in the degree of filtration in the recording of an amalgam surface is shown in Fig. 4.

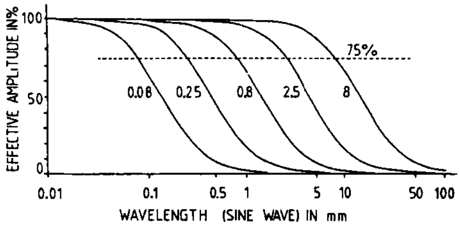

Fig. 3. Cut-off curves demonstrating the portion of the amplitude which is effective in the calculation of R_a and R_s for various cut-off values and wave-lengths. Adapted from original illustration in Perthen's Perthometer instruction manual.

The two graphs on top (A_1 and A_2) are identical and give the unfiltered profile. The graphs in the middle (B_1 and B_2) show the base lines obtained as a result of using cut-off values of 0.25 mm (B_1) and 0.8 mm (B_2). The lower graphs (C_1 and C_2) present the roughness profiles from which the roughness values are calculated. In C_1 the R_s-value is 0.54 µm, and the R_a-value 0.34 µm. In C_2 the R_s-value is 0.73 µm, the R_a-value 0.54 µm. It is seen that a higher cut-off value implies an increase in the roughness values. This was also demonstrated in a series of 25 measurements on polished amalgam using a scan length of 5 mm. The R_a-values increased 32 % and the R_s-values 21 % as a result of changing the cut-off value from 0.25 to 0.8 mm.

The R_a and R_s parameters are so defined that quite different roughness patterns can give similar or equal values. In Fig. 5 three schematic surface profiles are shown. Based on the definitions (Fig. 1) it can be calculated that R_a has the same value in all three cases, in other words, the value depends on the amplitude and not on the horizontal extensions of peaks and recesses. It can be shown that this also applies in the case of R_s Only by using an appropriate cut-off value is it possible to dis-

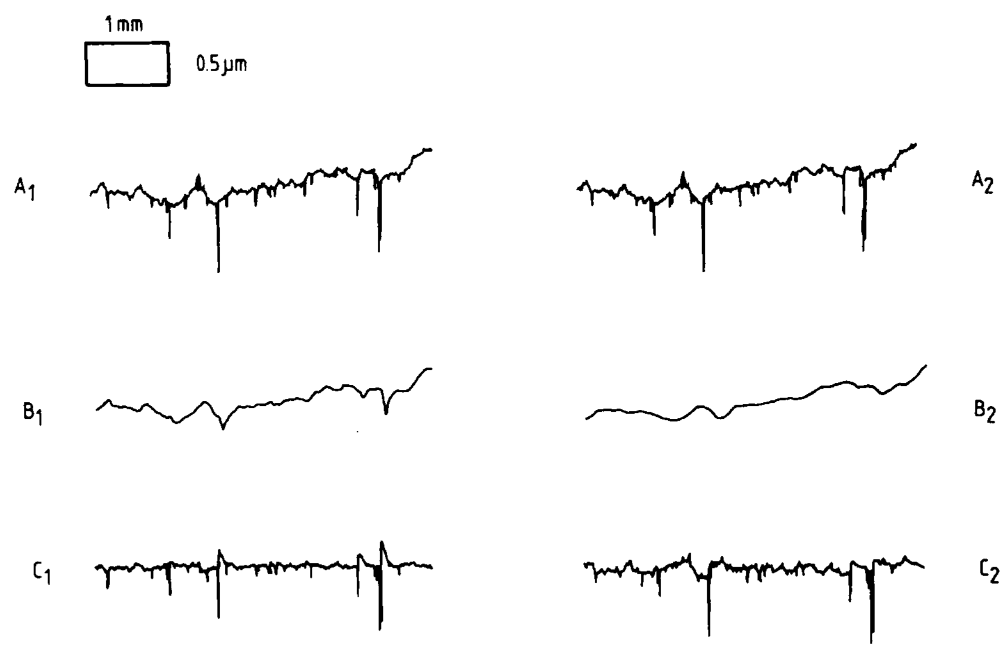

Fig. 4. Graphic roughness presentation of the same polished amalgam surface using different cut-off values. A_1 and A_2: surface profiles as recorded by the tracing equipment. B_1 and B_2: base lines not considered as roughness, but curvatures as a result of using a cut-off value of 0.25 mm (B_1) and 0.80 mm (B_2). C_1 and C_2: remaining roughness used in the calculation of the R_a and R_s values.

tinguish numerically between these different profiles.

DISCUSSION

The results of roughness measurements depend on several factors. It is obvious that a numerical characterization of surface roughness to a large extent depends on the roughness parameter chosen. The R_t-value, e.g. gives only a very limited information about the whole surface, and it does not allow any discrimination to be made between curvature and roughness. The R_t-values are generally much higher than those describing average situations. The meaning of the information contained in the R_a and R_s numbers, on the other hand, is affected by the fact that several roughness patterns can be represented by the same number, although the patterns may have quite different geometry and properties. In such a case only filtration will provide a means of discriminating between them. If a surface is characterized by a high number of void sections which are impossible to record properly for mere physical reasons, the R_a-value underestimates the roughness. In such a case the use of the R_s parameter may give a better description of the surface because the deviations are squared so that added weight is given to the large deviations from the base line.

When the roughness parameter is chosen carefully and when the cut-off value is selected with a view to discriminating between roughness and curvature, the most correct information can be obtained about the surface along the scan line. It is, of course, a statistical problem to arrive at a good characterization of the whole surface from such scans. It was demonstrated in the present paper that the values of

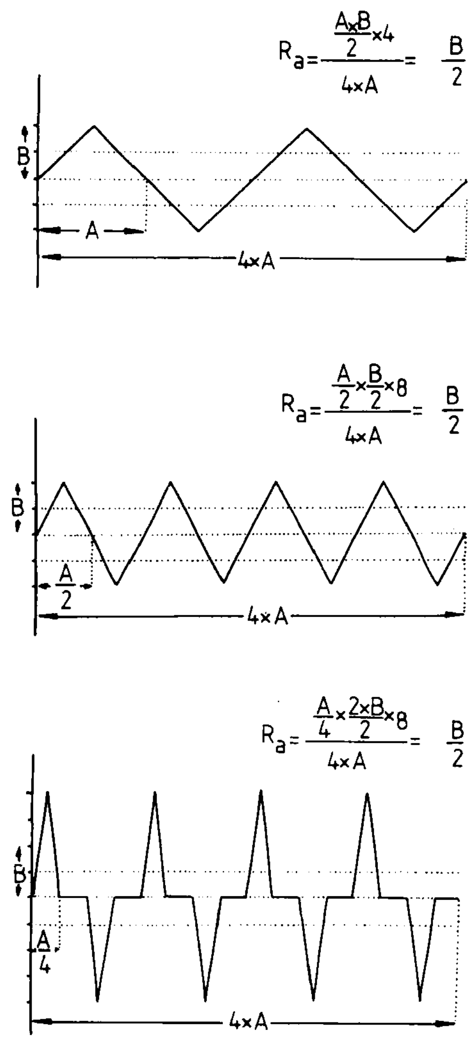

Fig. 5. Three theoretical surface profiles recorded without any filtration, which are expressed by the same R_a value.

R_a and R_s are greatly influenced by the degree of filtration. When presenting roughness values, therefore, the cut-off value, if any, should always be indicated. Unfortunately, some types of roughness meters do not have any facility for filtration so that the cut-off value is infinite and the base line straight. Modern commercial roughness meters usually provide a possibility of filtration, but the cut-off values in some instruments cannot be chosen freely because they are linked with the scan length. The most useful instruments are those which allow the filtration to be continuously adjusted in accordance with the need in each case.

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