Designation: F2791 – 15

Standard Guide for
Assessment of Surface Texture of Non-Porous Biomaterials in Two Dimensions[1]

1. Scope

1.1 This guide describes some of the more common methods that are available for measuring the topographical features of a surface and provides an overview of the parameters that are used to quantify them. Being able to reliably derive a set of parameters that describe the texture of biomaterial surfaces is a key aspect in the manufacture of safe and effective implantable medical devices that have the potential to trigger an adverse biological reaction in situ.

1.2 This guide is not intended to apply to porous structures with average pore dimensions in excess of approximately 50 nm (0.05 µm).

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C813 Test Method for Hydrophobic Contamination on Glass by Contact Angle Measurement

F2312 Terminology Relating to Tissue Engineered Medical Products

F2450 Guide for Assessing Microstructure of Polymeric Scaffolds for Use in Tissue-Engineered Medical Products

F2664 Guide for Assessing the Attachment of Cells to Biomaterial Surfaces by Physical Methods

2.2 *Other Standards:*[3]

ISO 3274 Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Nominal Characteristics of Contact (Stylus) Instruments

ISO 4287 Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Terms, Definitions and Surface Texture Parameters

ISO 4288 Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Rules and Procedures for the Assessment of Surface Texture

ISO 13565–1 Geometrical Product Specifications (GPS)—Surface Texture: Profile Method—Surfaces Having Stratified Functional Properties; Filtering and General Measurement Conditions

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *biomaterial, n*—any substance (other than a drug), synthetic or natural, that can be used as a system or part of a system that treats, augments, or replaces any tissue, organ, or function of the body. **F2664**

3.1.2 *evaluation length, ln, n*—length in the direction of the *x*-axis used to assess the profile under evaluation.

3.1.2.1 *Discussion*—The evaluation length may contain one or more sampling lengths. **ISO 4287**

3.1.3 *hydrophilic, adj*—having a strong affinity for water; wettable.

3.1.3.1 *Discussion*—Hydrophilic surfaces exhibit zero contact angles. **C813**

3.1.4 *hydrophobic, adj*—having little affinity for water; nonwettable.

3.1.4.1 *Discussion*—Hydrophobic surfaces exhibit contact angles appreciably greater than zero: generally greater than 45° for the advancing angle. **C813**

3.1.5 *implant, n*—a substance or object that is put in the body as a prosthesis, or for treatment or diagnosis. **F2664**

3.1.6 *lay, n*—the direction of the predominant surface pattern. **ISO 13565–1**

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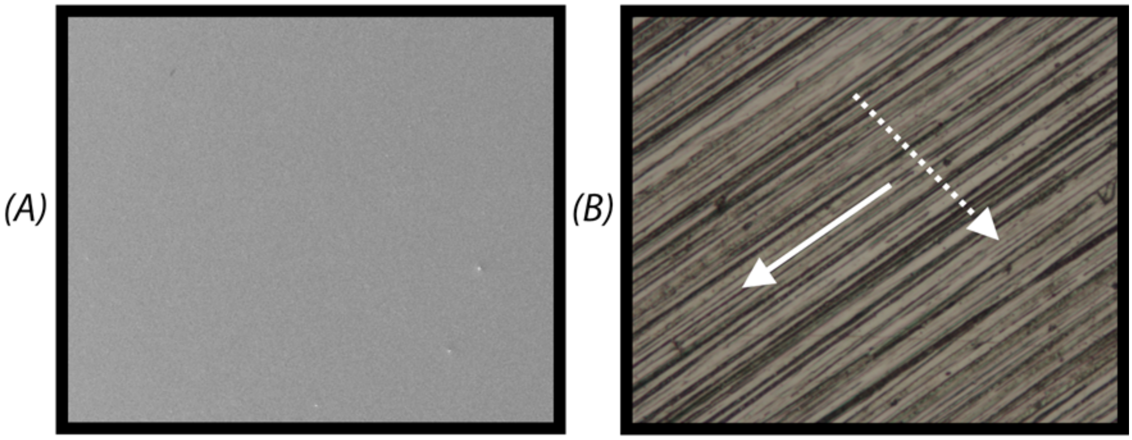
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.



NOTE 1—The surface shown in (*A*) has no directionality or lay, therefore profiles can be oriented at any angle. Profiles (dashed line arrow) are drawn perpendicular to the lay (solid line arrow) in surfaces that have directionality (*B*).

FIG. 1 Profile Orientation and Surface Features

3.1.7 *primary profile, n*—the profile after application of the short wavelength filters. **ISO 3274**

3.1.8 *profile peak, n*—an outwardly directed (from the material to the surrounding medium) portion of the assessed profile connecting two adjacent points of the intersection of the profile with the *x*-axis. **ISO 4287**

3.1.9 *profile valley, n*—an inwardly directed (from surrounding medium to material) portion of the assessed profile connecting two adjacent points of the intersection of the assessed profile with the *x*-axis. **ISO 4287**

3.1.10 *real surface, n*—surface limiting the body and separating it from the surrounding medium. **ISO 4287**

3.1.11 *sampling length, lr, n*— length in the direction of the *x*-axis used for identifying the irregularities characterizing the profile under evaluation. **ISO 4287**

3.1.12 *scaffold, n*—a support, delivery vehicle or metric for facilitating the migration, binding, or transport of cells or bioactive molecules used to replace, repair, or regenerate tissues. **F2450**

3.1.13 *surface profile, n*—profile that results from the intersection of the real surface by a specified plane.

3.1.13.1 *Discussion*—In practice, it is usual to choose a plane with a normal that nominally lies parallel to the real surface and in a suitable direction. **ISO 4287**

3.1.14 *surface texture, n*—irregularities on a surface (peaks and valleys) produced by the forming process.

4. Significance and Use

4.1 The term "surface texture" is used to describe the local deviations of a surface from an ideal shape. Surface texture usually consists of long wavelength repetitive features that occur as results of chatter, vibration, or heat treatments during the manufacture of implants. Short wavelength features superimposed on the long wavelength features of the surface, which arise from polishing or etching of the implant, are referred to as roughness.

4.2 This guide provides an overview of techniques that are available for measuring the surface in terms of Cartesian coordinates and the parameters used to describe surface texture. It is important to appreciate that it is not possible to measure surface texture per se, but to derive values for parameters that can be used to describe it.

5. The Relationship Between Surface Texture, Surface Chemistry, Surface Energy, and Biocompatibility

5.1 The biocompatibility of materials is influenced by many factors such as size, shape, material bulk, and surface chemical composition, surface energy, and surface topography. Changing any one of these related characteristics of a biocompatible material can have a significant effect on cell behavior. The response of a cell to a biomaterial can be assessed by measuring the adhesive strength between it and the underlying surface, monitoring changes in its shape or in the expression of biomarkers.

5.2 The chemical species present on a surface can be mapped in detail using surface sensitive analysis techniques (for example, X-ray photoelectron spectroscopy where the penetration depth is 10 nm or below (**1**)).[4] The chemical species present on the surface together with the surface topography determine how hydrophilic the surface is. Measuring the contact angle between the surface and a fluid, usually water, can assess the degree of hydrophilicity of a surface. Care should be taken when comparing contact angle measurements made on different surfaces, as the relative contributions from the surface chemistry and texture are unlikely to be the same.

6. Surfaces and Surface Profiles

6.1 Conventionally surfaces are described in Cartesian coordinates where the *x*-axis is defined as being perpendicular to the lay direction. The *y*-axis is in-plane and is perpendicular to the *x*-axis direction. The *z*-axis is out of plane. The profile of a surface that has a uniform, non-directional texture can be measured at any in-plane orientation (see Fig. 1(*A*)); however, several profiles at different orientations should be measured to

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[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

find the maximum amplitude (see Fig. 1(*A*)). For patterned surfaces that have periodic features, a lay, the orientation of the profile is at right angles to it (see Fig. 1(*B*)).

6.2 The measured surface is composed of three components: form, waviness and roughness. The form corresponds to the underlying shape and tilt of the surface with respect to the measuring platform. The software packages used for surface texture analysis all have a methodology for removing the form from the surface. The "corrected" surface can then be used to obtain a 2-D profile that describes the surface texture. This profile after removal of form is defined according to ISO 3274 as the primary profile. The stages involved in the analysis of the measured profile through primary profile to the roughness profile are shown in Fig. 2.

7. Filtering and the Cut-Off Wavelength

7.1 Surface data can be filtered to remove unwanted noise or to remove texture information at unwanted wavelengths. Filters are classified according to the spatial periodicity that they allow to pass through; low-pass filters admit long wavelengths and reject short ones; high-pass filters do the opposite. Band-pass filters, as the name implies, allow a limited range of wavelengths to pass. In practice, using filters can create problems in deciding how much of the noise in the measurements is "real" and how much can be attributed to the surface. It should be noted that some aspects of the surface are not faithfully reproduced due to limitations of the measurement method, for example, an inability to track the sides of steep valleys that is in essence a form of filtering. This topic is further discussed in Section 11.

7.2 Filters used in surface texture measurements do not have a sharp cut-off in spatial frequency above or below which information is rejected. This gradual attenuation of high or low spatial frequency data helps avoid distortion of the measurements that can occur when strong features are close to the filtration limits. The point on the transmission curve at which the transmitted signal is reduced to 50 % is referred to as the cut-off wavelength, λc, of the filter (Fig. 3). For measurements made using a stylus instrument (Section 11), the choice of λc depends on the sampling frequency and the speed at which the stylus moves over the surface. For example, measurements made at intervals of 0.01 mm from a device moving at 1 mms^{-1} will generate data at a frequency of 100 Hz. Increasing the sampling interval to 0.1 mm will reduce the frequency at which data are obtained to 10 Hz. A high-pass filter that suppresses all frequencies below 10 Hz effectively removes any surface irregularities larger than 0.1 mm spacing from the data. Hence, filters can be used to bias the experimental data towards detecting profile (surface texture after applying a low-pass to filter the data), waviness (after applying a band-pass filter), and roughness (after applying a high-pass filter). Measurement conditions are set for filters according to the respective values of the sampling interval, measurement speed, and filtration limits, according to ISO 3274.

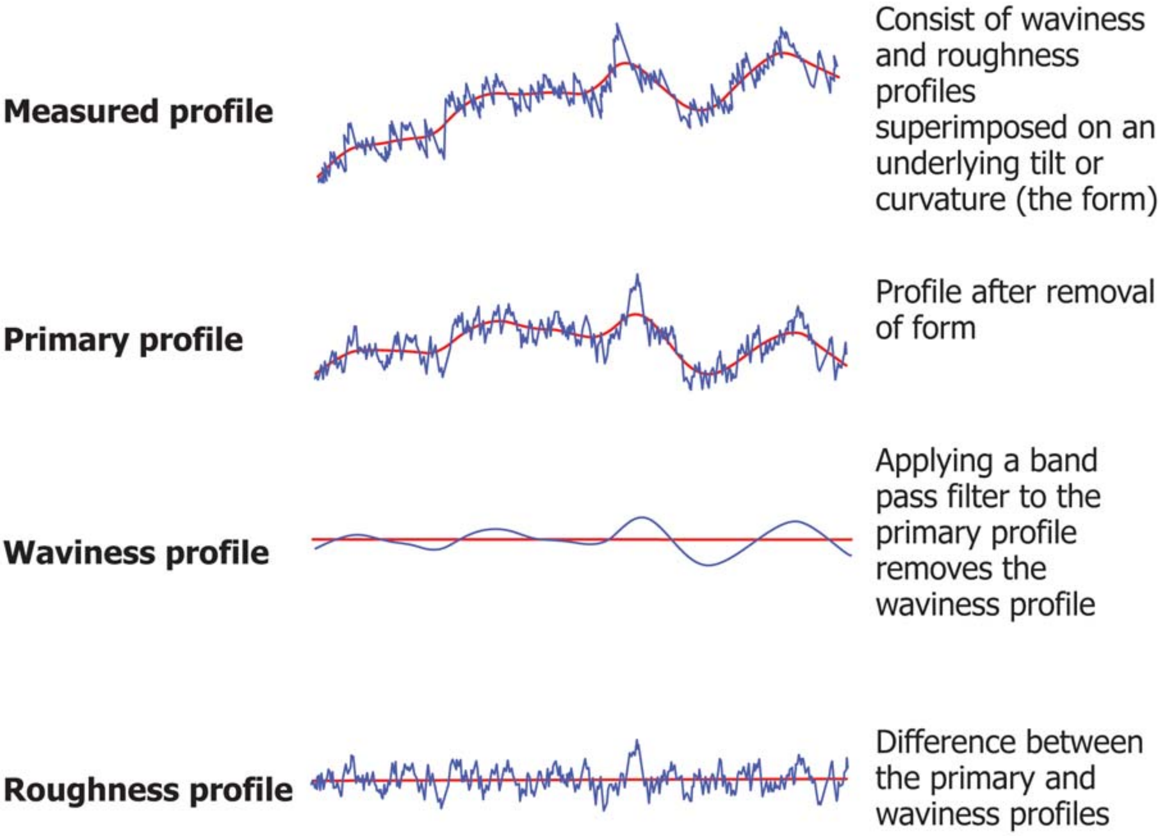


FIG. 2 Summary of Stages Involved in Analysis of Measured Profile to Obtain a Roughness Profile

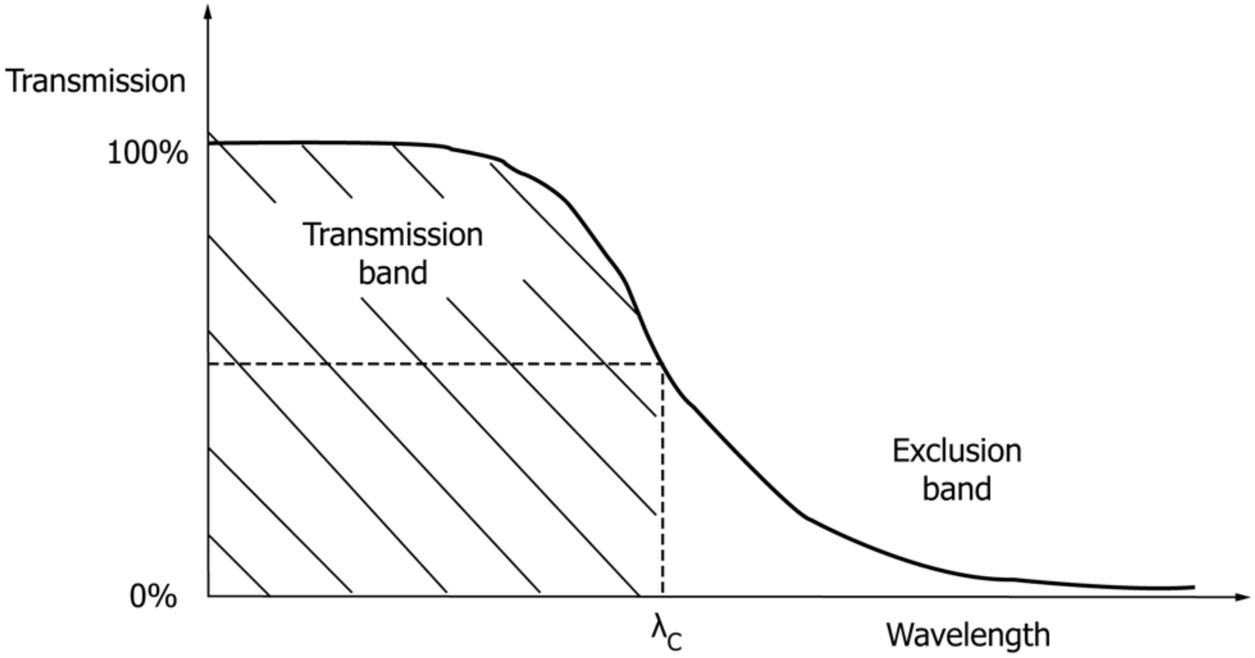


FIG. 3 50 % Reduction in Transmission Curve

7.3 ISO 4287 specifies that 2-D roughness parameters need to be determined over five sequential sampling lengths, *lr*, unless otherwise specified. This grouping of five serial sampling lengths is referred to as the evaluation length, *ln*. The sampling length varies according to the length scale of the texture being assessed; larger features require a long sampling length. Guidance as to which sampling length to use for a given range of feature sizes is shown in Table 1. It may be necessary to perform one or more iterations to identify the best value for *lr*. This can be achieved by calculating the mean width of a profile element, *RSm* (see Fig. 4), from a measured profile where the value for *lr* is based on a best guess. This initial iteration will enable a new value for *RSm* to be determined and that leads to a potential revision of *lr* according to Table 1.

8. Quantification of Surface Profiles

8.1 Parameters that are used to characterize 2-D surface profiles are grouped as:

8.1.1 Amplitude parameters, which are measures of variations in profile height. These parameters are split into two subclasses: averaging parameters, and peak and valley parameters;

8.1.2 Spatial parameters, which describe in-plane variations of surface texture; and

8.1.3 Hybrid parameters, which combine both amplitude and spatial information (for example, mean slope).

8.2 *Ra*—The most widely used parameter to quantify surface texture is the arithmetical mean deviation of the absolute ordinate values, *Z(x)*, of the profile from a center line (see Table 2 and Fig. 5). Despite its common usage, *Ra* does not provide a truly accurate representation of a surface profile since any information regarding peak heights or valley depths can be lost in its derivation. This insensitivity to surface texture is apparent in Fig. 6, which shows that quite different profiles can have the same *Ra* value. The statistical significance of *Ra* is improved by averaging the values obtained for each of the five sampling lengths.

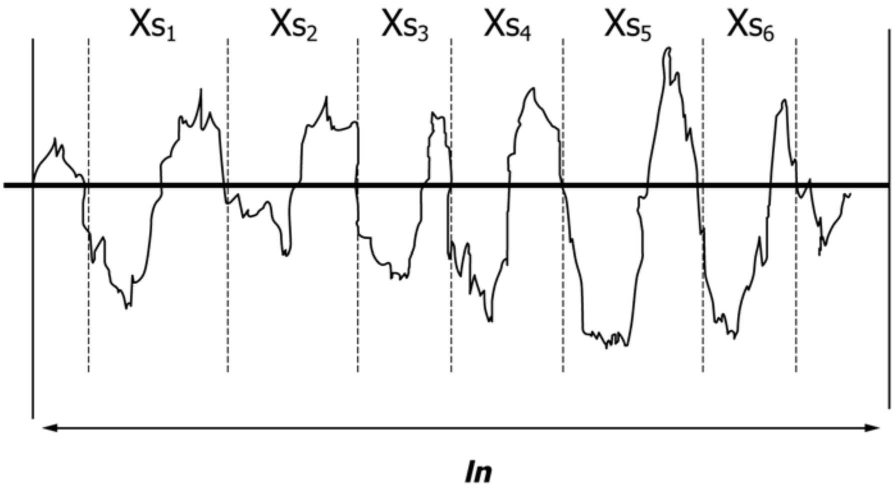
8.3 *Rq*—The root-mean-square value of all distances of the measured profile away from the center line, *Rq*, although similar in terms of its derivation to *Ra*, has a subtle but significant difference. The deviations of the peak heights and valley depths from the midline appear as a squared term in *Rq*. That increases its sensitivity to high peaks or deep valleys. This sensitivity can be useful, but it should be noted that the presence of a foreign body, for example, hair or a scratch in the surface can have a significant influence on the value of *Rq*.

8.4 *Rsk*—Skewness, the distribution of peak heights and valley depths provides valuable information about surface texture. A surface that has a range of peak heights and valley depths will have a bell-shaped probability distribution centered on the mean. The dimensionless skewness parameter, *Rsk*, is used to quantify bias in the shape of this distribution. The skewness of a perfectly random surface with a wide range of peak heights and valley depths is zero. If the surface has more valleys than peaks then the distribution will skew away from

TABLE 1 Guide to Choosing Sampling Lengths for the Measurement of Periodic Profiles[A]

Mean profile element width, *RSm* (µm)	Sampling length, *lr* (µm)
13 < *RSm* ≤ 40	80
40 < *RSm* ≤ 130	250
130 < *RSm* ≤ 400	800
400 < *RSm* ≤ 1300	2500
1300 < *RSm* ≤ 4000	8000

[A] Based on ISO 4288. The evaluation length is usually taken to be five times the sampling length.

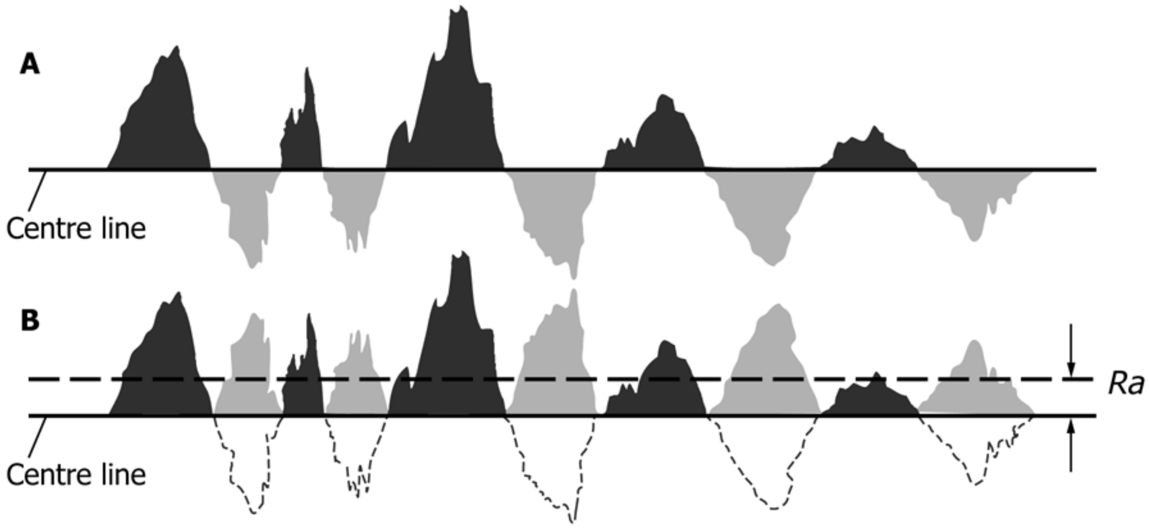


NOTE 1—The sum of each peak and adjacent valley, Xs_i is *RSm*.

FIG. 4 Mean Width of Profile Elements Over the Evaluation Length

TABLE 2 A Summary of Commonly Used Parameters for Quantifying 2-D Roughness Profiles

Type of Parameter	Parameter	Definition
Amplitude (Average of cordinates)	*Ra*	Arithmetic mean deviation of the absolute ordinate value from a mean line.
	Rq	Root-mean-squared value of the deviation of ordinate values from a midline.
	Rsk	A measure of the skewness in the distribution of peaks and valleys across a surface.
	Rku	A measure of the similarity of the distribution of measured peaks and valleys to a Gaussian distribution (kurtosis).
Amplitude (Peak and valley)	*Rp*	Maximum profile height above a mean line.
	Rv	Maximum profile depth below a mean line.
	Rz	Difference between *Rp* and *Rv*.
	Rc	The mean value of the profile element widths within a sampling length.
	Rt	The total height of profile.
Spatial	*RSm*	The mean value of the profile element widths within a sampling length.
Hybrid	*RΔq*	The root mean square slope, *dz/dx*, over the length of the profile at a location *y* on the surface.



NOTE 1—(*A*) Averaging the peaks and valleys in measured profile data over each sampling length is used to identify a midline. (*B*) The “valleys” are inverted to form “peaks” and averaged with existing peaks to obtain *Ra*, the arithmetic mean deviation from the midline.

FIG. 5 Derivation of *Ra*

the ideal distribution producing negative values of skewness. The converse will be true for a surface that has more peaks than valleys.

8.5 *Rku*—Kurtosis is a statistical measure of the sharpness of a distribution of peak heights and valley depths. Specifically, kurtosis is a means of quantifying the similarity of the

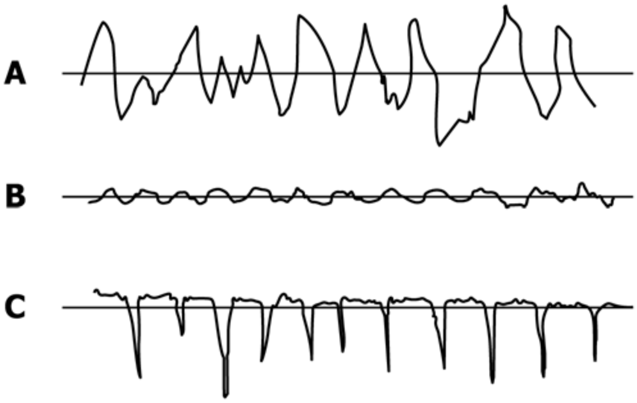


FIG. 6 Quite Different Surface Textures (*A*, *B*, and *C*) Can Have the Same *Ra* Value

measured profile with a Gaussian distribution characteristic of a perfectly random distribution of peak heights and valley depths.

8.6 *Rp*—The largest profile peak height above the mean line within the sampling length. This is not an averaging parameter.

8.7 *Rv*—This parameter is defined as the largest profile valley depth of the lowest point on the profile from the mean line within the sampling length. This is not an averaging parameter. *Rp* and *Rv* may or may not be useful in characterizing a biomaterial surface other than potentially highlighting the presence of contaminants or damage that will have an impact on the averaging parameters.

8.8 *Rz*—The maximum height of a profile. It is the sum of the height of the largest profile peak height, *Rp*, and the largest profile valley depth, *Rv*, within a sampling length.

8.9 *Rc*—The mean height of profile elements heights within a sampling length. The *Rc* parameter requires height and spacing discrimination.

8.10 *Rt*—The total height of profile is a sum of the height of the greatest profile peak and the largest profile valley depth within the evaluation length. This parameter has no averaging effect and may be strongly affected by scratches on the surface or by material contaminants on the surface.

8.11 *RSm*—Some spatial information can be obtained through the mean width of the profile elements. *RSm* is the mean value of the profile element widths (that is, the average width of a peak and valley combined).

8.12 $R\Delta q$—The root mean square slope, dz/dx, over the length of the profile at a location y on the surface. It is defined as a hybrid parameter since it contains both amplitude and spacing information. The hybrid parameter, $R\Delta q$, can be used to find the actual length of a profile and hence to compare the actual length of surface available for molecular adsorption.

9. Resolution, Range and Curvature

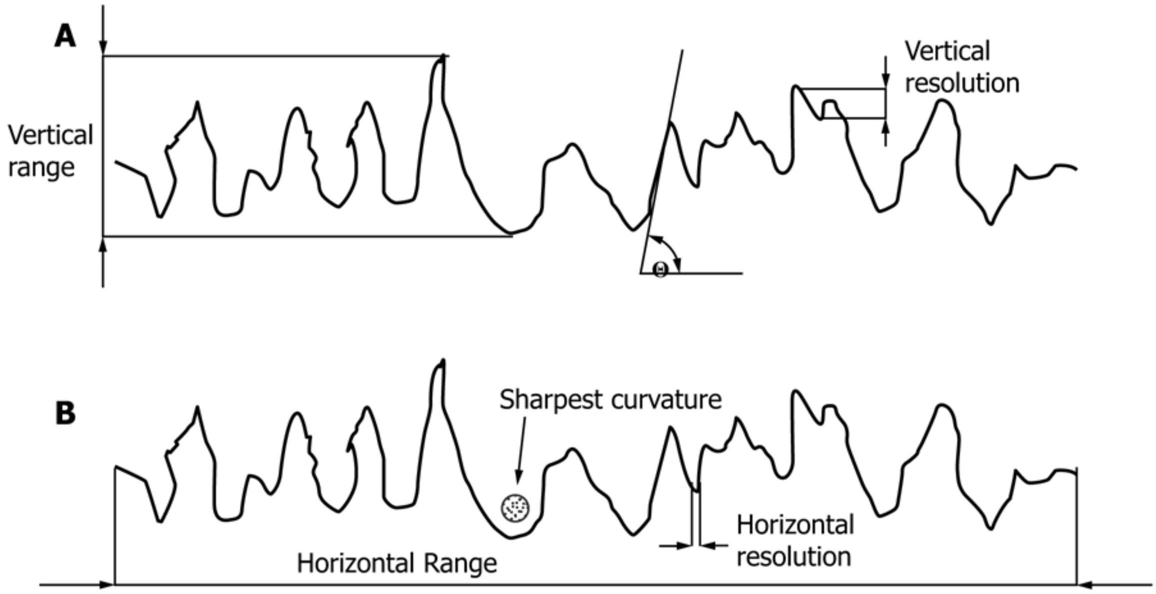
9.1 The technique (or preferably techniques) that are chosen to measure surface data is usually selected on the basis of the size of the features that need to be measured as well as the characteristics of the material. These include the degree of hardness, the degree of reflectivity, and the geometry of the specimen. Large peaks or valleys may be beyond the vertical range of the instrument (that is, the largest amplitude that can be measured in the vertical direction, Fig. 7(*A*)). For many instruments, there is an inverse relationship between the measurable range and the vertical resolution (that is, the smallest change in amplitude that can be measured, with resolution decreasing as the amplitude increases). The steepness of peaks or valleys should also be considered as all the measurement methods used to capture surface data will be limited in terms of the steepness of the slope that they can measure. Similar considerations need to be made for the horizontal axis in terms of resolution, range, and steepest curvature (see Fig. 7(*B*)).

9.2 It is important to preserve as much detail as possible in the measured data when storing images for further analysis. Ideally images should be stored as at least 16-bit, non-compressed, full color red, green, and blue (RGB) .tif files. Storing files as compressed 8-bit .jpeg files will result in loss of information such as tonal detail, particularly if the .jpeg is re-saved as a .jpeg file as re-compression further degrades the data.

9.3 All measurement techniques used to measure surface data have some form of limitation in terms of what they can and cannot detect. A measured surface is, therefore, never identical to the real surface. The impact of this disparity on the value of the parameters used to describe surface roughness may not be significant but should be considered when selecting measurement methods or interpreting profiles. Poor quality or poorly resolved data will have an influence on the accuracy of texture profiles.

10. Techniques for Surface Texture Measurement

10.1 Surface profiles can be measured using both contact and non-contact methods. The former approach involves tracing the surface profile with a stylus that is in contact with the surface, a method unsuitable for materials that are soft or easily damaged. Non-contact methods are better suited to these materials. Non-contact methods include vertical scanning white light interferometers and confocal microscopes (**2**, **3**, **4**). Scanning probe microscopes such as atomic force microscopy and scanning tunneling microscopy can also be used in the non-contact mode. Both contact and non-contact methods have



NOTE 1—The resolution and range of measurement required in both vertical (*A*) and horizontal (*B*) directions need to be considered as well as the sharpest curvature/steepness of slopes.

FIG. 7 Issues of Measurement and Range

TABLE 3 Suggested Techniques for Measuring the Surface Texture of Commonly Encountered Biomaterials and Coatings[A]

Material/ Coating	Stylus instruments	Scanning probe microscopes	White light interferometers	Confocal microscopes
Gels	N	N	Y[B]	Y[B]
Metals (including metallic coatings)	Y	Y	Y	Y
Plastic (including coatings)	Y[C]	Y	Y[B]	Y
Ceramics	Y	Y	Y	Y

[A] The exact choice of the technique also depends on factors such as contrast and how soft the surface of the material is.

[B] Lack of reflectivity and diffuse scattering of light can limit the signal-to-noise ratio to an unacceptably low level in low opacity materials.

[C] Care should be taken to ensure that stylus instruments do not tear or scratch plastics.

their limitations in terms of what can and cannot be measured. For example, optical instruments are unable to detect steep slopes; stylus instruments are unable to accurately trace sharp peaks or to penetrate steep sided valleys.

10.2 Instrumentation issues, such as the geometry of the tip used in stylus instruments and the wavelength of light used in optical profilers, also contribute to the uncertainty of surface texture measurements. Therefore, a number of factors including the resolution required, the measurement time, the measurement area, and the hardness of the material should be considered in selecting appropriate measurement methods.

10.3 Suggestions as to which technique or techniques are suitable for measuring the surface texture of commonly encountered surfaces on implantable materials are listed in Table 3. A lack of signal from materials of low reflectivity and/or that scatter light weakly can result in a low signal-to-noise ratio. Artifact peaks or spikes in the image and/or holes where data have not been captured in optical images are indicative of poor surface reflectivity or features that are beyond the accessible Δz range of the instrument. Table 4 provides a list of the accessible length scales and typical sample sizes for commonly used measurement methods (**5**).

11. Techniques for Surface Texture Measurements: Contact Methods

11.1 Contact or stylus instruments record the movement of a stylus as it traces the profile of a surface. Currently this approach to surface texture measurement is the only one covered by international standards as described in ISO 3274. The coordinates of the stylus in the *x* direction are obtained from sensors located within the device. Typically, cone-shaped diamond styli with spherical tips are used for measuring surface features. The cone angle is usually 60° or 90° with the tip radius ranging from 1 to 10 µm. Both the cone angle and tip radius affect the sensitivity of the stylus, effectively filtering out some of the detail that is present on the surface.

11.2 Stylus instruments are relatively low-cost instruments that are easy to use and that can sample hundreds of millimetres in length. The resolution of these instruments can, when coupled with a laser interferometer, have an out-of-plane resolution of around 10 nm or better over a sampling length of around 6 mm. These instruments do have limitations, one of the most severe being that they tend to damage soft materials by effectively ploughing the surface to leave a pattern of furrows. On more resilient samples, this measurement method tends to smooth out surface features by rounding off peaks and valleys; the latter effect leads to an underestimate of the depth of valleys within the surface (see Fig. 8). Stylus instruments also suffer from other limitations. For example, they are unable

TABLE 4 Accessible Length Scales and Typical Sample Sizes for Commonly Used Techniques^A

Technique	Vertical Range	Lateral Resolution	Vertical Resolution
Stylus instruments (Mechanical Stylus Profilometer)	0.5–1.0 mm	≈5 µm	≈50 nm
Scanning probe microscopy (Atomic Force Microscopy)	Up to 25 µm	Atomic resolution possible under appropriate conditions	<0.1 nm
Light Interferometry (Interference Microscopy)	Up to 100 µm	≈0.2 µm	≈1 nm
Confocal microscopy (Confocal Laser Scanning Microscopy)	Up to 100 µm	≈0.25 µm	≈500 nm

^{A}Vertical range and lateral and vertical resolution refers to the techniques in the brackets.

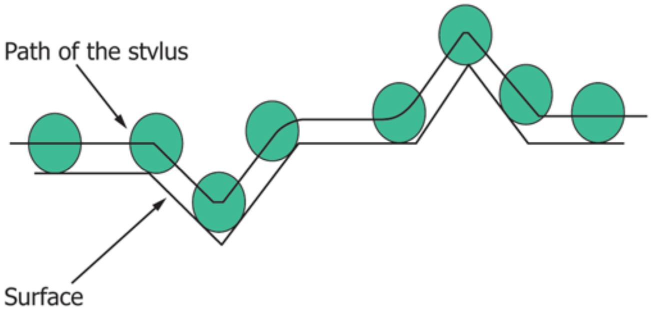


FIG. 8 Stylus Instruments Tend to Smooth Out Valleys and Round Off Peaks

to accurately follow overhangs (Fig. 9) or penetrate steep sided valleys, issues that increase in importance with increasing tip radius. This limitation also applies to optical instruments.

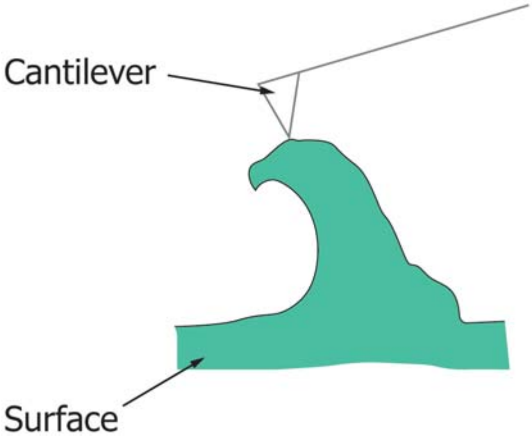


FIG. 9 Stylus Instruments are Unable to Detect Overhangs

12. Techniques for Surface Texture Measurements: Non-Contacting Techniques

12.1 Non-contacting optical techniques can be grouped into two classes depending on the spatial coherence of the light source. Monochromatic sources (that is, lasers) are typically used in confocal microscopy, phase shifting interferometry, holography, fringe projection and speckle techniques. Polychromatic light sources are used in vertical scanning white light interferometers and interference microscopy.

12.2 Optical methods, besides offering the obvious advantage for softer materials of not being in contact with the sample, are usually also able to capture data over much shorter times than mechanical devices, especially in three dimensions. Of course, there are some practical limitations that need to be considered when using optical methods, which are dominated by the sample's reflectivity. This can be as low as about 4 %, but at this level weak signals can cause "holes" to appear in optical data.

12.3 Surface reflectivity can be improved by applying a fine coat of paint, lycopodium powder, or by sputter coating a thin layer of gold. Obviously such coatings need to be carefully applied to avoid altering the surface profile; a problem that becomes increasingly significant with increasing sensitivity of the measurement and with materials with high water content, such as gels.

12.4 The surface profile and the composition of the surface may have an adverse effect on the suitability of optical methods as a metrology tool. Slopes that are steeper than around 50° are difficult to measure by optical methods and may cause artifact spikes or non-measured points to appear in optical data or loss of orientation of profilometers. Both artifacts and non-measured points can usually be overcome, as most software packages provided with the measuring instrument will allow the user to interpolate data to "clean" artifacts or "patch" non-measured points. The success of this process depends on both the software and the user. This variability is a limitation since the success of the interpolation procedures are difficult to gauge on a day-to-day basis without invoking a time-consuming, expensive validation process. Materials with more than one component can also be difficult to measure using optical techniques, especially if there are significant differences in the optical constants.

13. Summary

13.1 Quantification of surface texture can be carried out using a variety of techniques including mechanical stylus measurements, confocal microscopes, or white light interferometers. The advantage of these techniques over the scanning electron microscopy relies on quantification of the data, which can be extracted from the recorded images. Scanning electron microscopy is a good tool for qualitative imaging of the surfaces. In its conventional usage it does not provide out-of-plane data that can easily be quantified; however, software packages are under development to obtain such data.

13.2 The reflectivity and transparency of the sample is a major consideration when using optical techniques. Poor reflectivity and diffuse scattering within the sample can lead to poor signal-to-noise ratios or complete loss of signal that leads to loss of data of the measurement probe. Coating the samples with a fine powder or paint offers a potential solution, but for high-resolution techniques this option leads to an examination of the surface coating and not the underlying texture. Atomic force microscopy as a contact technique or other means of non-contacting microscopy may be used to examine surfaces.

13.3 Care should also be taken to ensure that the measurement method and instrument chosen is commensurate with the mechanical properties of the material (stylus instruments will damage soft surfaces) and that the measurable range of the instrument can cover the range of sample features, that is, *x*, *y*, and *z* dimensions.

14. Keywords

14.1 biomaterial; characterization; optical instrument; non-porous; profile; roughness; stylus instrument; surface texture; waviness

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