Designation: F1877 – 16

Standard Practice for Characterization of Particles[1]

This standard is issued under the fixed designation F1877; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers a series of procedures for characterization of the morphology, number, size, and size distribution of particles. The methods utilized include sieves, optical, scanning electron microscopy (SEM), transmission electron microscopy (TEM), and electrooptical.

1.2 These methods are appropriate for particles produced by a number of different methods. These include wear test machines (Test Method F732), total joint simulation systems (Guides F1714 and F1715), abrasion testing, methods for producing particulates, such as shatter boxes or pulverizers, commercially available particles, and particles harvested from tissues in animal or clinical studies.

1.3 The debris may include metallic, polymeric, ceramic, or any combination of these.

1.4 The digestion procedures to be used and issues of sterilization of retrieved particles are not the subject of this practice.

1.5 A classification scheme for description of particle morphology is included in Appendix X3.

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

1.7 As a precautionary measure, removed debris from implant tissues should be sterilized or minimally disinfected by an appropriate means that does not adversely affect the particulate material.

1.8 *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]

C242 Terminology of Ceramic Whitewares and Related Products

C678 Test Method for Determination of Particle Size Distribution of Alumina or Quartz Using Centrifugal Sedimentation (Withdrawn 1995)[3]

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E161 Specification for Precision Electroformed Sieves

E766 Practice for Calibrating the Magnification of a Scanning Electron Microscope

E1617 Practice for Reporting Particle Size Characterization Data

F561 Practice for Retrieval and Analysis of Medical Devices, and Associated Tissues and Fluids

F660 Practice for Comparing Particle Size in the Use of Alternative Types of Particle Counters

F661 Practice for Particle Count and Size Distribution Measurement in Batch Samples for Filter Evaluation Using an Optical Particle Counter (Discontinued 2000) (Withdrawn 2000)[3]

F662 Test Method for Measurement of Particle Count and Size Distribution in Batch Samples for Filter Evaluation Using an Electrical Resistance Particle Counter (Discontinued 2002) (Withdrawn 2002)[3]

F732 Test Method for Wear Testing of Polymeric Materials Used in Total Joint Prostheses

F1714 Guide for Gravimetric Wear Assessment of Prosthetic Hip Designs in Simulator Devices

F1715 Guide for Wear Assessment of Prosthetic Knee Designs in Simulator Devices (Withdrawn 2006)[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *agglomerate, n*—a jumbled mass or collection of two or more particles or aggregates, or a combination thereof, held

---

[1] This practice is under the jurisdiction of ASTM Committee F04 on Medical and Surgical Materials and Devices and is the direct responsibility of Subcommittee F04.16 on Biocompatibility Test Methods.

Current edition approved Oct. 1, 2016. Published October 2016. Originally approved in 1998. Last previous edition approved in 2010 as F1877 – 05 (2010). DOI: 10.1520/F1877-16.

[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] The last approved version of this historical standard is referenced on www.astm.org.

together by relatively weak cohesive forces caused by weak chemical bonding or an electrostatic surface charge generated by handling or processing.

3.1.2 *aggregate, n*—a dense mass of particles held together by strong intermolecular or atomic cohesive forces that is stable with normal mixing techniques, including high-speed stirring and ultrasonics.

3.1.3 *flocculate, n*—a group of two or more attached particles held together by physical forces, such as surface tension, adsorption, or similar forces.

3.1.4 *aspect ratio (AR), n*—a ratio of the major to the minor diameter of a particle, which can be used when the major axis does not cross a particle outline (see 11.3.3).

3.1.5 *elongation (E), n*—ratio of the particle length to the average particle width (see 11.3.4).

3.1.6 *equivalent circle diameter (ECD), n*—a measure of the size of a particle (see 11.3.2 and Appendix X1).

3.1.7 *Feret diameter, n*—the mean value of the distance between pairs of parallel tangents to a projected outline of a particle.

3.1.8 *form factor (FF), n*—a dimensionless number relating area and perimeter of a particle, as determined in 11.3.6.

3.1.9 *irregular, adj*—referring to a particle that cannot be described as round or spherical. A set of standard nomenclature and reference figures are given in Appendix X2.

3.1.10 *particle, n*—the smallest discrete unit detectable as determined in test methods. A nanoparticle has at least one dimension less than 100 nm.

3.1.11 *particle breadth, n*—distance between touch points of the shortest Feret pair, orthogonal to length.

3.1.12 *particle length, n*—distance between the touch points of maximum Feret pair. This value will be greater than or equal to the maximum Feret diameter.

3.1.13 *rectangular, adj*—referring to a particle that approximates a square or rectangle in shape.

3.1.14 *roundness (R), n*—a measure of how closely an object represents a circle as determined in 11.3.5.

3.1.15 *spherical, adj*—referring to a particle with a generally spherical shape that appears round in a photograph.

4. Summary of Practice

4.1 Particles produced by implant wear *in vivo* in animal or clinical studies are harvested from tissues after digestion utilizing methods, such as those in Practice F561. Particles generated *in vitro*, or obtained from commercial sources, are used as received, or after digestion, if they were generated in protein solutions, and further separation if there are signs of aggregation. A two level analysis is provided. For routine analysis, the particles are characterized by the terms of morphology and by size using Feret diameters. For more detailed studies, several methods that may be utilized for numerically characterizing their dimensions, size distribution, and number are described.

5. Significance and Use

5.1 The biological response to materials in the form of small particles, as from wear debris, often is significantly different from that to the same materials as larger implant components. The size and shape (morphology) of the particles may have a major effect on the biological response; therefore, this practice provides a standardized nomenclature for describing particles. Such a unified nomenclature will be of value in interpretation of biological tests of responses to particles, in that it will facilitate separation of biological responses associated with shape from those associated with the chemical composition of debris.

5.2 The quantity, size, and morphology of particles released as wear debris from implants *in vivo* may produce an adverse biological response which will affect the long term survival of the device. Characterization of such debris will provide valuable information regarding the effectiveness of device designs or methods of processing components and the mechanisms of wear.

5.3 The morphology of particles produced in laboratory tests of wear and abrasion often is affected by the test conditions, such as the magnitude and rate of load application, device configuration, and test environment. Comparison of the morphology and size of particles produced *in vitro* with those produced *in vivo* will provide valuable information regarding the degree to which the method simulates the *in vivo* condition being modeled.

6. Interferences

6.1 Particles may form aggregates or agglomerates during preparation and storage. These could result in an increase in measured particle size and decrease in particle number. It is essential that care be taken to resuspend particles prior to analysis and to note any effects of the dispersant used.

6.2 Debris from wear tests or harvested from tissues may contain a mixture of materials. Care should be taken to separate the particles and methods utilized to determine the chemical composition of the particles.

6.3 Many automated particle counters operate on the assumption that the particles are spherical. These methods may not be appropriate for nonspherical debris. Additional methods should be used to verify size using methods that take aspect ratio into consideration, for example, SEM or TEM image analysis.

7. Apparatus

7.1 *Scanning Electron Microscope (SEM) (see Practice E766):*

7.1.1 Standard SEM equipment can be utilized for many studies. In special instances, such as with polymeric particles, a low acceleration voltage (1-2 kV) machine with a high brightness electron source, such as a field emission tip, may be utilized.

7.1.2 Elemental analysis may be accomplished with an energy dispersive spectrometer (EDS) for energy dispersive X-ray analysis (EDXA).

7.2 *Transmission Electron Microscopy (TEM):*

7.2.1 TEM equipment can be used for the analysis of nanoparticles, although SEM with a field emission tip has also been successfully used to characterize particles as small as 50 to 100 nm.

7.2.2 Elemental analysis may be accomplished with an energy dispersive spectrometer (EDS) for energy dispersive X-ray analysis (EDXA).

7.3 *Optical Microscope*—An optical microscope operating in the transmission mode may be utilized. Dark field illumination may enhance visualization of some particles. Polarized light will facilitate identification of semicrystalline polymeric materials.

7.4 *Automatic Particle Counters (see Practice F660):*

7.4.1 *Image Analyzer*—This instrument counts particles by size as those particles lie on a microscope slide.

7.4.2 *Optical Counter*—This instrument measures the area of a shadow cast by a particle as it passes a window. From this area the instrument reports the diameter of a circle of equal area.

7.4.3 *Electrical Resistance Counter*—This instrument measures the volume of an individual particle. From that volume the instrument reports the diameter of a sphere of equal volume (see Test Methods C678).

8. Reagents

8.1 *Particle-Free (0.2 µm Filtered) Deionized Water,* for nonpolymeric particles.

8.2 *Particle-Free (0.2 µm Filtered) Methanol or Ethanol,* for polymeric or mixed debris.

8.3 *Ultra-Cleaning Reagent,* for apparatus or labware cleaning.

9. Specimen Preparation

9.1 Specimens from explanted tissues from animal or clinical studies may need to be harvested and digested using methods, such as those described in Practice F561.

9.2 Particles from *in vitro* cell culture tests also may need to be digested and harvested.

9.3 Centrifugation of particles from wear may be considered, if necessary, at 400 g for 10 min, or at 16,000 g for 15 min. for nanoparticles, and resuspended in water, ethanol, or methanol. Resuspended particles may be filtered in accordance with Practice F561 prior to examination by SEM or TEM, although it should be recognized that filtration can lead to a loss of nanoparticles and/or the agglomeration of particles.

10. Particle Imaging by Light, Scanning, or Transmission Electron Microscopy

10.1 Images may either be captured electronically or photographically for subsequent analysis.

10.2 For the characterization and measurements to be accurate, it is essential that the particles be imaged at the largest magnification possible. The magnifications in Table 1 are recommended.

10.3 For particle size distribution measurements, divide each of the size ranges specified in Table 1, into 10 bins.

TABLE 1 Recommended Magnifications for Particle Imaging

Magnification	Particle Size Range (µm)
25,000	0.02 to 0.2
10000	0.2 to 1.0
1000	1 to 10
100	10 to 100

11. Particle Characterization

11.1 *Particle Shape (Morphology)*—Refer to the photographs and classify the morphology of the particles using the nomenclature in Appendix X2.

11.2 *Routine Particle Size Determination Using Feret Diameters:*

11.2.1 The use of multiple Feret diameters is especially useful for spherical and rectangular particles.

11.2.2 Determine the particle size and aspect ratio as the mean of two Feret diameters.

11.2.3 Calculate the particle size distribution based on the volume of solution used and the size of the filters.

11.3 *Detailed Particle Shape Analysis for Irregular Shaped Particles:*

11.3.1 Five particle dimensional measurements are provided using examples shown in Appendix X1. One is a measure of particle size while the other four are shape descriptors.

11.3.2 *The Equivalent Circle Diameter (ECD) as a Measure of Particle Size:*

11.3.2.1 The ECD is defined as the diameter of a circle with an area equivalent to the area (A) of the particle and has the units of length:

$$ECD = (4*A/\pi)^{\frac{1}{2}} \quad (1)$$

11.3.3 *The Aspect Ratio (AR) is a Common Measure of Shape:*

11.3.3.1 The *AR* is the ratio of the major diameter (d_{max}) to the minor diameter (d_{min}). The major diameter is the longest straight line that can be drawn between any two points on the outline. The minor diameter is the longest line perpendicular to the major diameter:

$$AR = d_{max}/d_{min} \quad (2)$$

11.3.4 The elongation (E), is similar to the *AR* except it is more suited for the measurement of much longer particles, especially fibrilar particles, where the major axis line does not stay within the particle boundaries. Refer to particle types *A* and *C* in Appendix X1.

11.3.4.1 The E is the ratio of the length (FL) to the breadth (FW):

$$E = FL/FW \quad (3)$$

11.3.5 The roundness (R) is a measure of how closely a particle resembles a circle. The R varies from zero to one in magnitude with a perfect circle having a value of one.

$$R = (4A)/(\pi\, d_{max}^{2}) \quad (4)$$

where:

A = area, and
d_{max} = the maximum diameter.

11.3.6 The form factor (*FF*) is similar to *R* but is based on the perimeter (*p*) of the particle outline rather than the major diameter. The *FF* is more sensitive to the variations in roughness of the particle outline.

$$FF = 4\pi A/p^2 \quad (5)$$

where:

p = perimeter of the particle outline.

11.4 *Other Particles Size Determination Methods:*

11.4.1 Particles larger than 20 µm may be determined by sieves described in Specifications E11 and E161.

11.4.2 Particles in liquid suspension may be sized as directed in Practice F661 or Test Method F662.

12. Elemental Analysis

12.1 SEM-EDS and TEM-EDS analysis should be conducted at a magnification suggested in 10.2.

12.2 Elemental analysis should be conducted for at least 10 s for each particle. Since detailed compositional analysis is of questionable reliability for micron and submicron sized particles, it is recommended that composition be determined based on identification of key elemental peaks for the major elements likely to be present in the sample.

13. Report

13.1 Report the following information (see Practice E1617):

13.1.1 The source of the particles and materials and methods for generation.

13.1.2 Methods utilized to digest and separate the particles.

13.1.3 Morphological description of the particles.

13.1.4 Results of particle size and shape analysis.

14. Precision and Bias

14.1 The precision and bias of this practice has not been determined.

15. Keywords

15.1 biocompatibility; morphology; particles; SEM; wear debris

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE FIGURES FOR CALCULATION OF PARTICLE SIZE AND SHAPE

X1.1 See Fig. X1.1.[4]

[4] The examples provided were analyzed with the NIH Image Program by Landry and Agarwal. A set of macros is available from the Department of Orthopaedics, University of Texas Health Science Center at San Antonio.

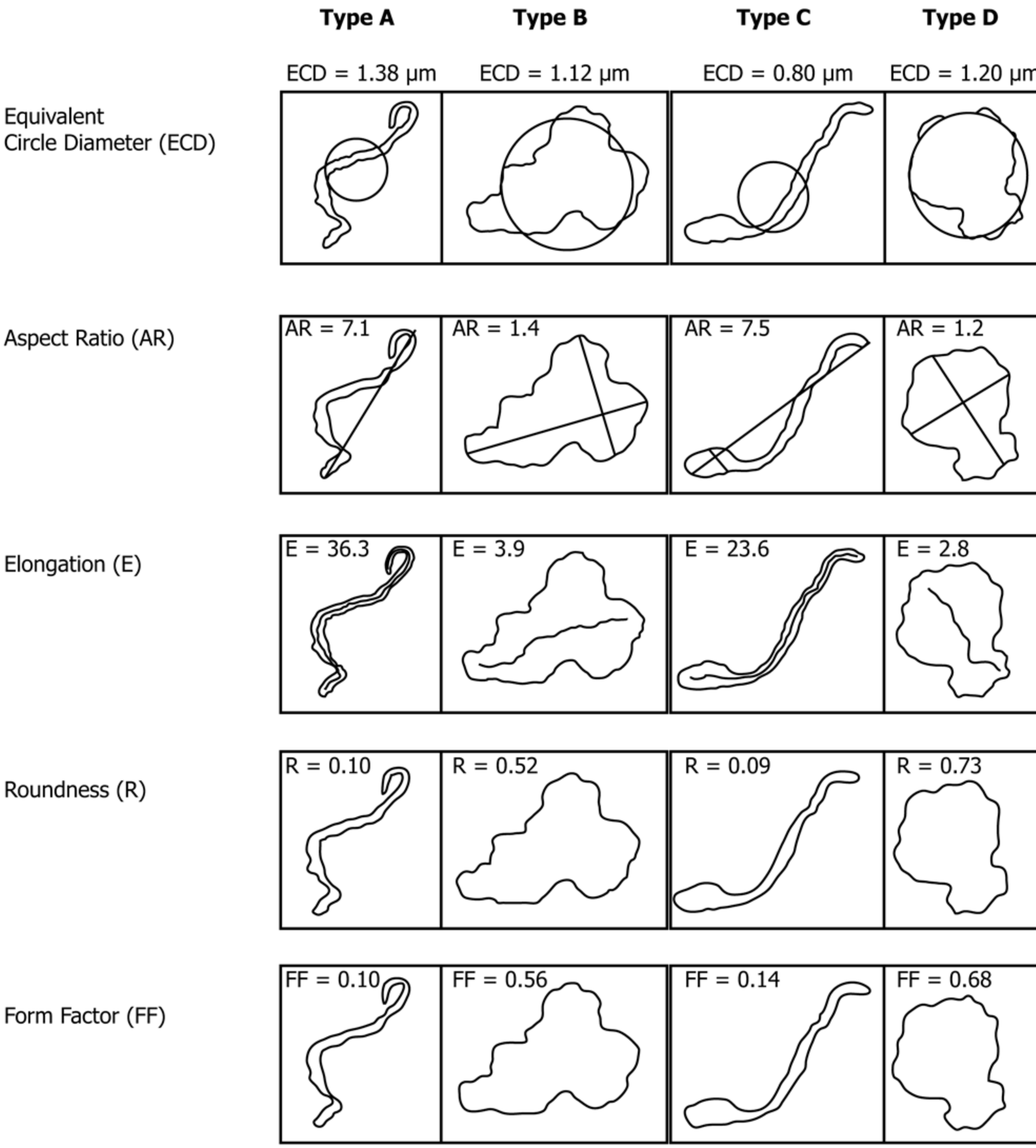

FIG. X1.1 Sample Figures for Calculation of Particle Size and Shape

X2. NOMENCLATURE FOR PARTICLE MORPHOLOGY DESCRIPTION

X2.1 This collection is not intended to be all inclusive, but rather to provide a frame work for describing the morphology of particles.

NOTE X2.1—These figures are used as illustrative examples. Sources are indicated in parentheses (used with permission).

X2.1.1 *Spherical or Spheroidal:*

X2.1.1.1 Smooth, round (Fig. X2.1).[5]

X2.1.1.2 Smooth, oblong (Fig. X2.1).[5]

X2.1.1.3 Agglomerated, red blood cell - like (Fig. X2.2).[6]

X2.1.1.4 Rough (Fig. X2.3).[5]

X2.1.1.5 Spongy, porous (Fig. X2.4).[7]

X2.1.2 *Granular, Irregular:*

X2.1.2.1 Smooth (Fig. X2.5).[8]

X2.1.2.2 Rough (Fig. X2.6).[9]

X2.1.2.3 Porous (Fig. X2.7).[9]

X2.1.2.4 Angulated (Fig. X2.8).[10]

X2.1.2.5 Fines, too small to characterize accurately (Fig. X2.9).[5]

X2.1.3 *Globular:*

X2.1.3.1 Clumped, florets, cauliflower (Fig. X2.10).[11]

X2.1.3.2 Agglomerated, diffuse (Fig. X2.11).[12]

X2.1.4 *Flakes:*

X2.1.4.1 Smooth (Fig. X2.12).[11]

X2.1.4.2 Roughened (Fig. X2.13).[11]

X2.1.4.3 Irregular (Fig. X2.14).[12]

X2.1.4.4 Shards (probably thin cross sections of flakes) (Fig. X2.15).[5]

X2.1.5 *Fibrillar:*

X2.1.5.1 Straight (Fig. X2.16).[6]

X2.1.5.2 Twisted (Fig. X2.17 and Fig. X2.18).[6]

X2.1.5.3 Hammerhead (Fig. X2.19 and Fig. X2.18).[12]

X2.1.5.4 Tadpole (Fig. X2.19).[12]

X2.1.5.5 Seahorse (Fig. X2.18).[12]

X2.1.6 *Sharps or Shards:*

X2.1.6.1 Flakes, stacked sheets (Fig. X2.20).[13]

X2.1.6.2 Rectangular, fibers (Fig. X2.21).[14]

X2.1.6.3 Lathe-like (Fig. X2.22).[9]

X2.1.6.4 Cuttlefish (Fig. X2.23).[11]

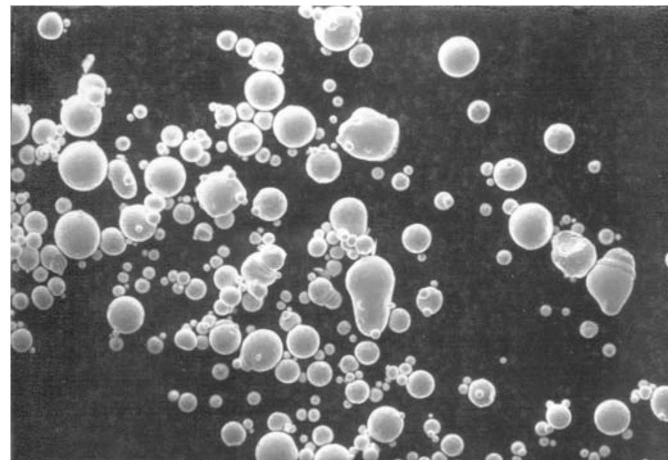

FIG. X2.1 Spherical or Spheroidal—Smooth, Round or Oblong

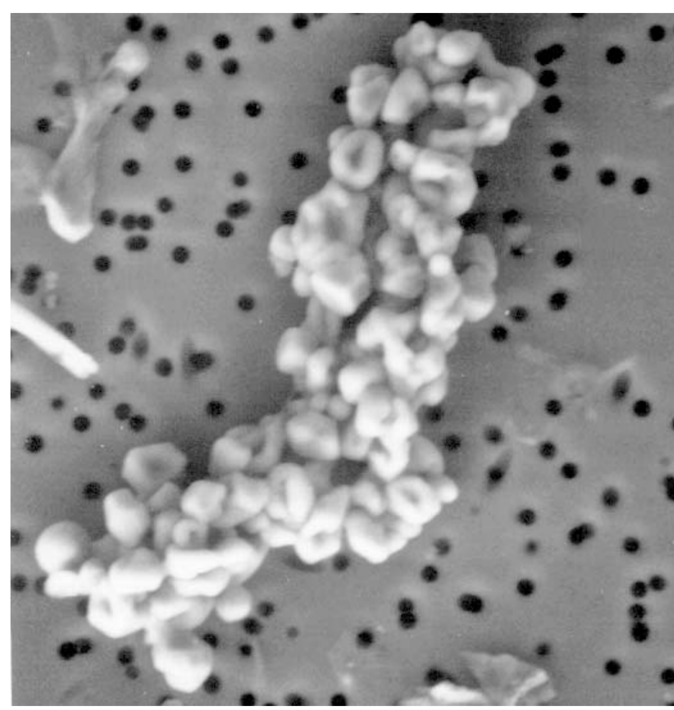

FIG. X2.2 Spherical or Spheroidal—Agglomerated Red Blood Cell-Like

---

[5] Lalor, P., donated photographs from Howmedica R and D laboratories.

[6] Szivek, J. A., donated sample set.

[7] Jacobs, J. J., and Urban, R. M., donated photograph.

[8] Margevicius, K. J., Bauer, T. W., McMahon, J. T., Brown, S. A., Merritt, K., "Isolation and Characterization of Debris in Membranes Around Total Joint Prostheses," *J Bone Joint Surg*, 76A, 1994, pp. 1664–1675.

[9] Kieswetter, K., Bauer, T. W., Brown, S. A., Van Lente, F., Merritt, K, "Characterization of Calcium Phosphate Powders by ESCA and EDXA," *Biomaterials*, 15, 1994, pp. 183–188.

[10] Lerouge, S., Huk, O., Yahia, L H., Sedel L., "Characterization of *In Vivo* Wear Debris from Ceramic-Ceramic Total Hip Arhroplasties ," *J Biomed Mater Res*, 32, 1996, pp. 627–633.

[11] Hailey, J. L., Ingham, E., Stone, M., Wroblewski, B. M., Fisher, J., "Ultra-High Molecular Weight Polyethylene Wear Debris Generated *In Vivo* and in Laboratory Tests: the Influence of Counterface Roughness," *Proc Inst Mech Eng*, 210, 1996, pp. 8–10.

[12] Campbell, P., donated photographs.

[13] Shanbhag, A. S., donated photograph.

[14] Bauer, T. W., donated photograph.

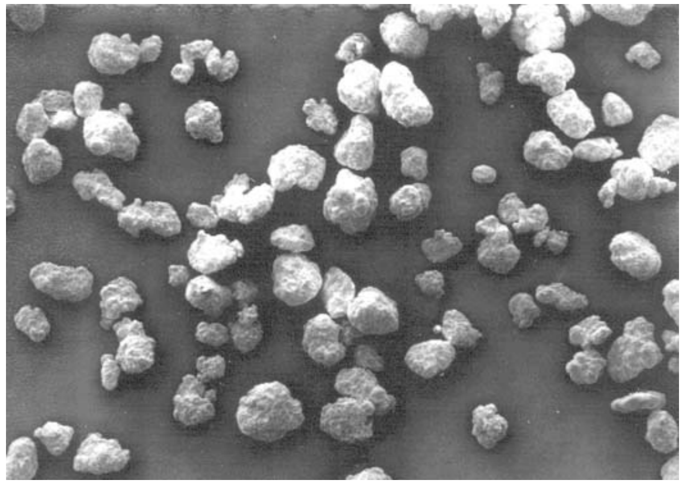

FIG. X2.3 Spherical or Spheroidal—Rough

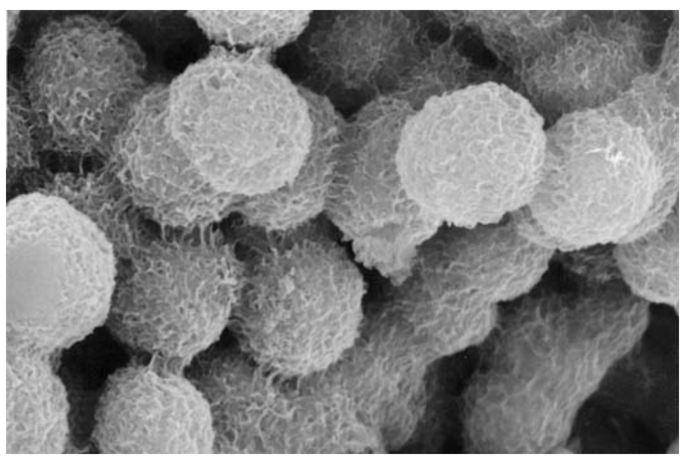

FIG. X2.4 Spherical or Spheroidal—Spongy, Porous

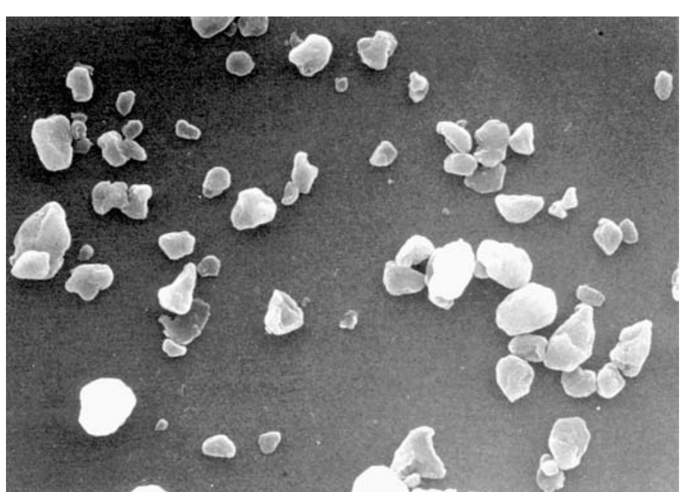

FIG. X2.5 Granular, Irregular—Smooth

FIG. X2.6 Granular, Irregular—Rough

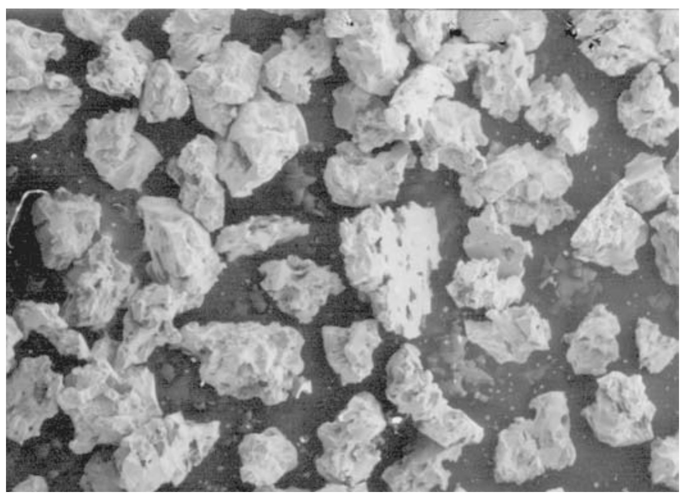

FIG. X2.7 Granular, Irregular—Porous

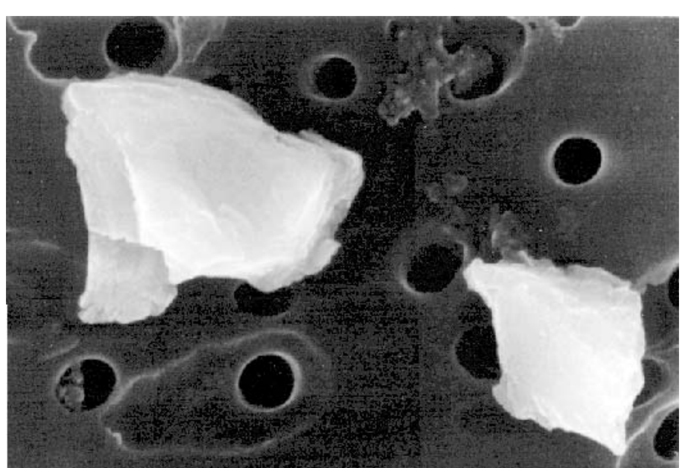

FIG. X2.8 Granular, Irregular—Angulated

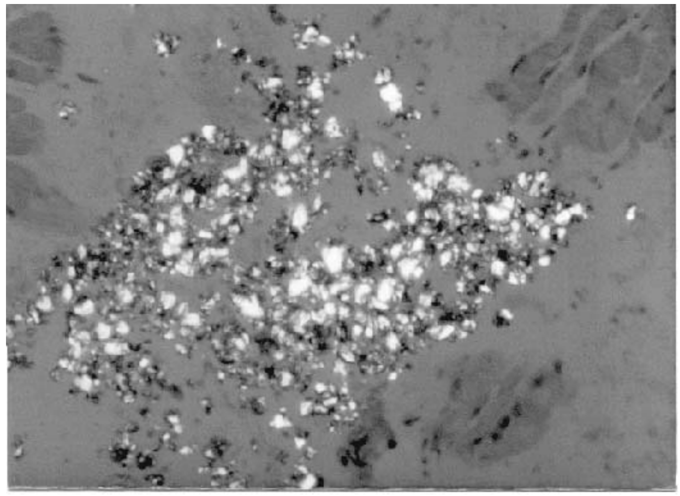

FIG. X2.9 Granular, Irregular—Fines Too Small to Characterize Accurately

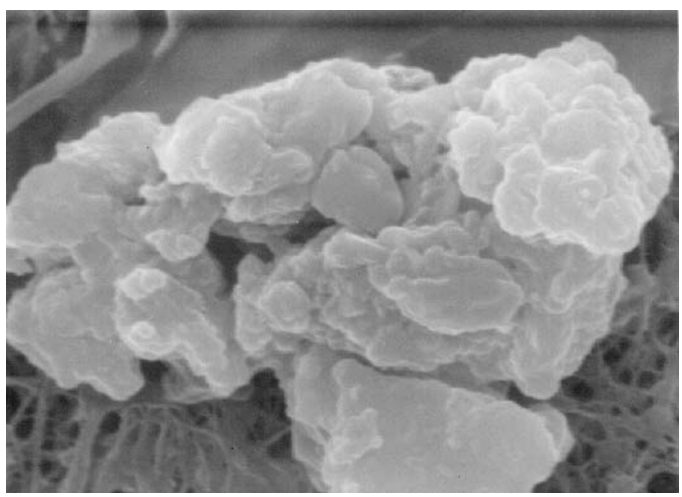

FIG. X2.10 Globular—Clumped, Florets, Cauliflower

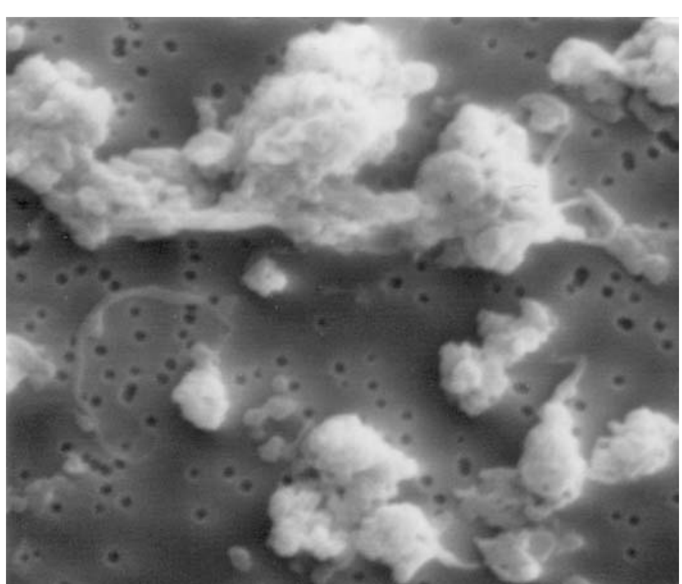

FIG. X2.11 Globular—Agglomerated, Diffuse

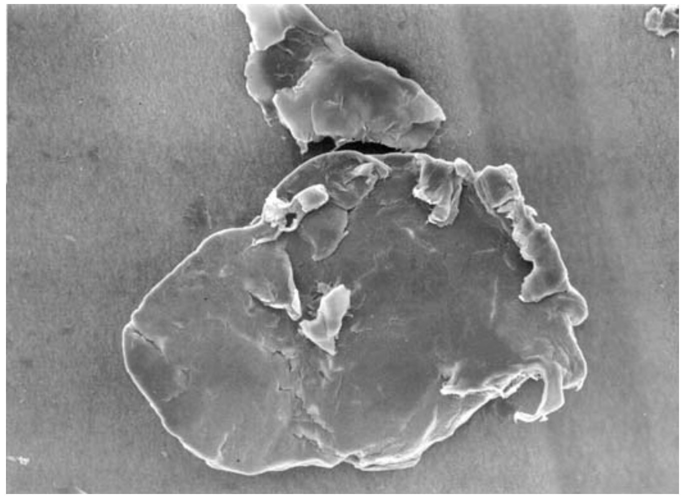

FIG. X2.12 Flakes—Smooth

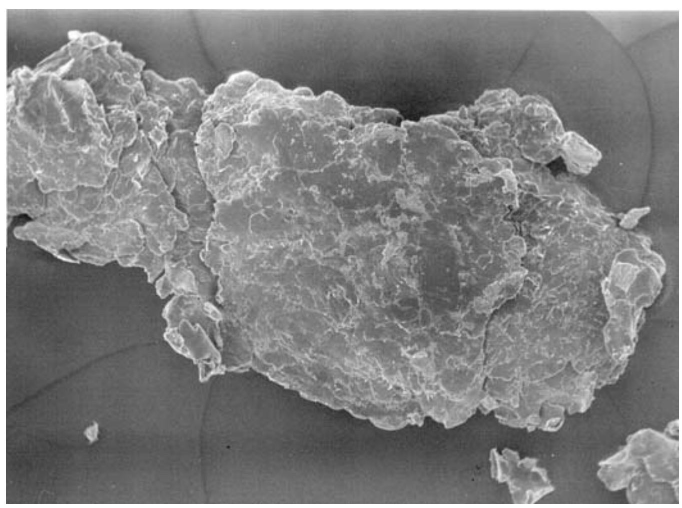

FIG. X2.13 Flakes—Roughened

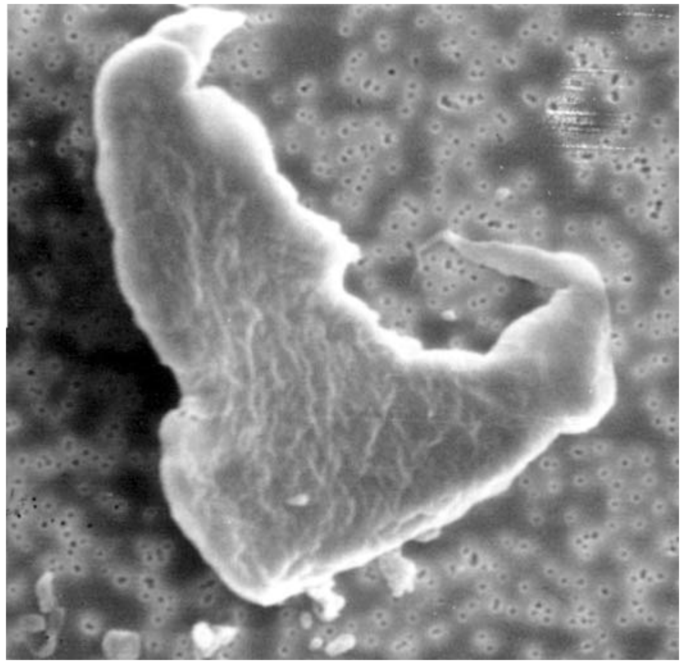

FIG. X2.14 Flakes—Irregular

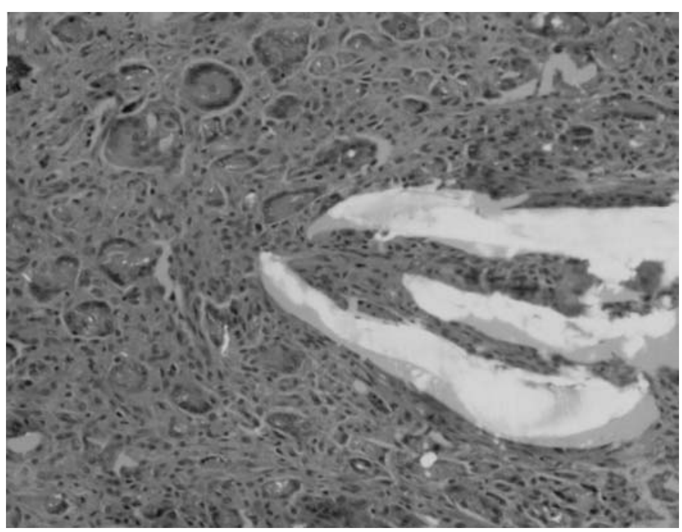

FIG. X2.15 Flakes—Shards

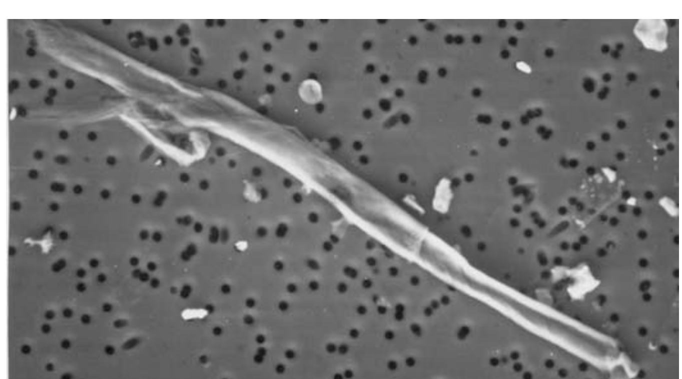

FIG. X2.16 Fibrillar—Straight

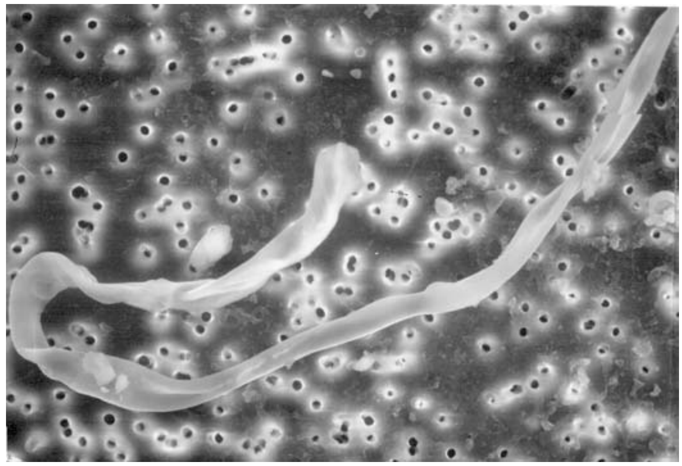

FIG. X2.17 Fibrillar—Twisted

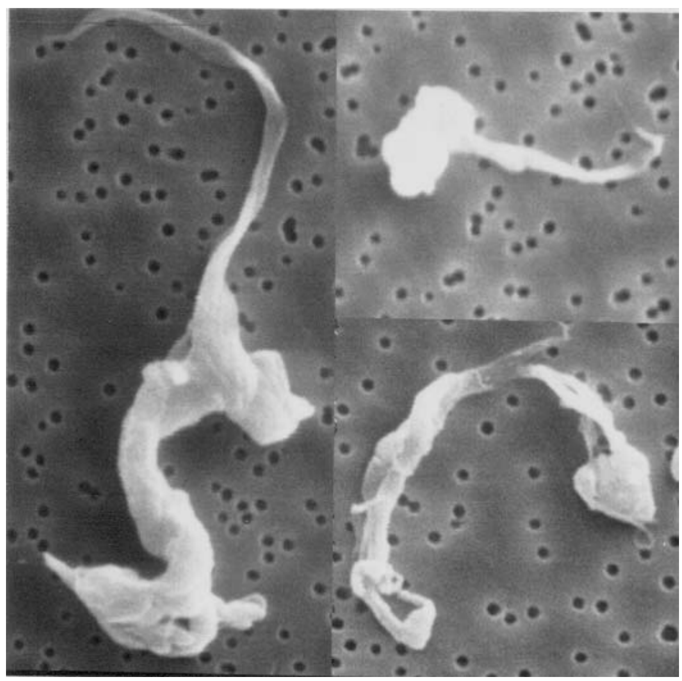

FIG. X2.18 Fibrillar—Seahorse / Hammerhead / Twisted

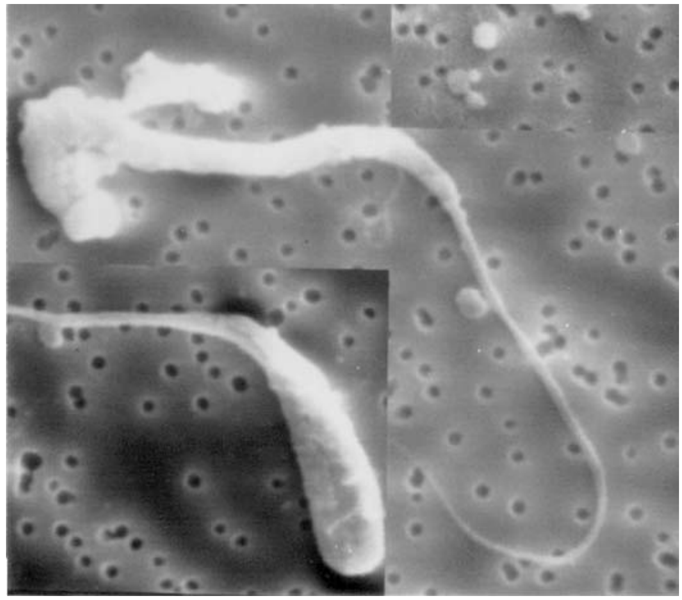

FIG. X2.19 Fibrillar—Hammerhead / Tadpole

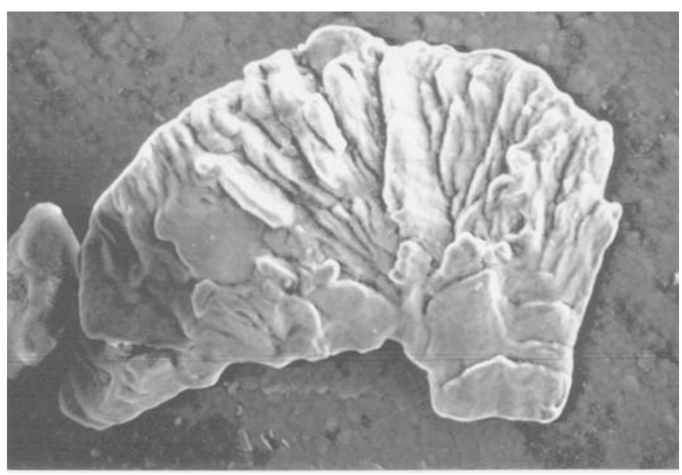

FIG. X2.20 Sharps or Shards—Flakes, Stacked Sheets

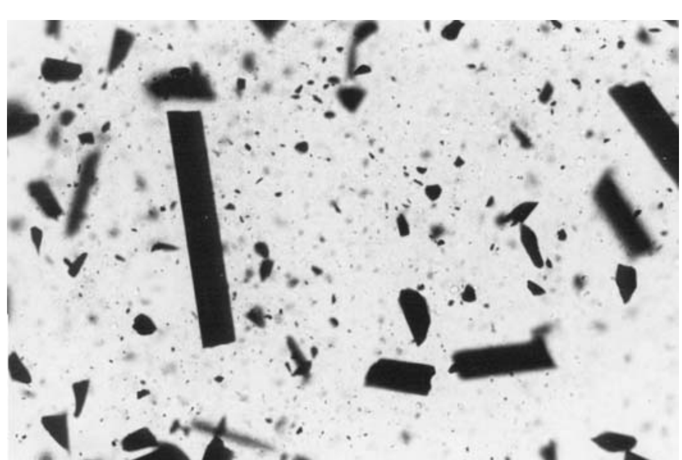

FIG. X2.21 Sharps or Shards—Rectangular Fibers

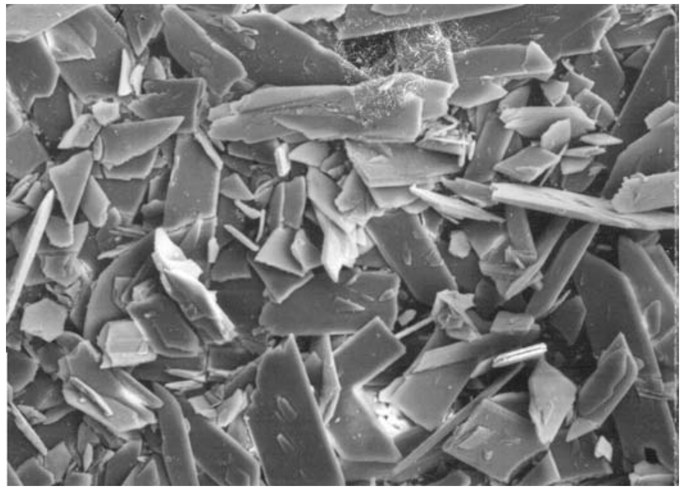

FIG. X2.22 Sharps or Shards—Lathe-Like

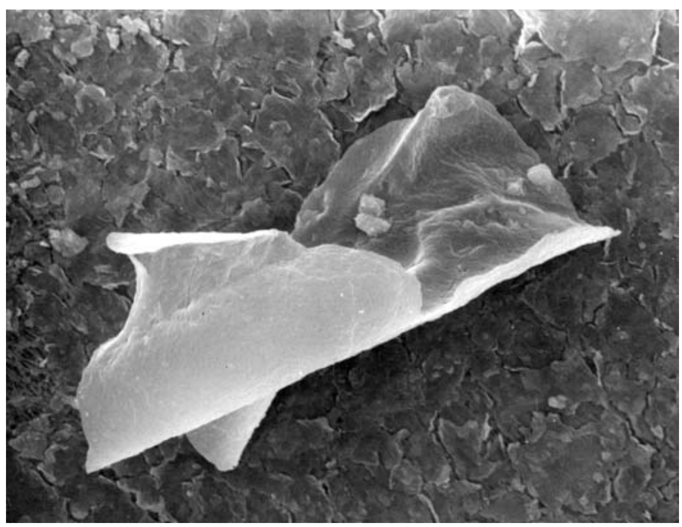

FIG. X2.23 Sharps or Shards—Cuttlefish

X3. RATIONALE

X3.1 Establishment and use of a standardized nomenclature for describing particulate debris is critical for a wide range of studies regarding implants and devices. By using a common vocabulary for particle description, biological responses to different shapes of debris can separated from other factors such as chemistry. Matching morphology of debris produced in the laboratory with that produced *in vivo* will better refine the accuracy of laboratory test methods. Characterization of debris produced *in vivo* will help in assessment of device performance.

X3.2 The characterization methods and sample morphologies provided are not intended to be all inclusive of those published in the literature. The intent is to provide illustrative examples of methods as well as morphologies and to assign names to each type. Thus, communication between investigators should be more precise.

X3.3 The detailed methods of calculating particle shape have been developed by M. E. Landry and C. M. Agrawal at the University of Texas Health Science Center at San Antonio and were the basis for a Masters of Science in Engineering thesis by M. E. Landry at the University of Texas at Austin. These methods are provided as a way to numerically describe complicated particle shapes. While not all measurements need to be made, standardization of these methods should provide an additional data set for description of the wide variety of particle morphologies generated *in vivo* and *in vitro*.