This guidance was written prior to the February 27, 1997 implementation of FDA's Good Guidance Practices, GGP's. It does not create or confer rights for or on any person and does not operate to bind FDA or the public. An alternative approach may be used if such approach satisfies the requirements of the applicable statute, regulations, or both. This guidance will be updated in the next revision to include the standard elements of GGP's

Guidance Document for Testing Orthopedic Implants

With Modified Metallic Surfaces

Apposing Bone Or Bone Cement

April 28, 1994

Orthopedic Devices Branch
Division of General and Restorative Devices
Office of Device Evaluation
Center for Devices and Radiological Health
U.S. Food and Drug Administration

April 28, 1994

I. PREFACE

For a number of years there has been increasing interest in surface treating orthopedic devices in an attempt to improve implant fixation. The purpose of this document is to recommend to manufacturers of orthopedic devices and sponsors of future premarket notifications (510k), Investigational Device Exemptions (IDE) applicatons, Premarket Approval (PMA) applications, reclassification petitions, and master files, important information that should be provided to the Food and Drug Administration (FDA) in order to evaluate the substantial equivalence and/or safety and effectiveness of modified orthopedic implant surfaces that are in contact with tissue or bone cement (e.g., porous coatings).

Based on currently available data, the Orthopedic Devices Branch (ORDB) proposes to now greatly limit the scope of this document for the following three types of coatings:

a. beaded, sintered cobalt-chrome coatings on a cobalt-chrome substrate;
b. beaded, vacuum-sintered titanium coatings on a titanium substrate; and
c. vacuum-sintered titanium fiber mesh pads on a titanium substrate.

Numerous test reports describing the physical characteristics and mechanical performance of the above three coating types have been submitted to and reviewed by ORDB. These reports indicate that the integrity of these coatings can be determined with a limited description of the mechanical properties when the materials of the coating and substrate are known, and, in the case of titanium implants, when the manufacturing method is known.

For porous coated hips (the only cementless, porous coated, Class II devices), the properties of the porous coating itself (e.g., average pore size) must be determined because they are indicators of the ability of the coating to allow biologic fixation.

ORDB proposes that items 1-3 below now adequately characterize these types of porous coatings:

1. the materials used and any standards to which they conform;
2. the static shear strength of the coating to the substrate (ASTM F1044); and
3. the average bead size; average pore size; overall pore volume; number of bead layers; and thickness of the coating.

The remainder of this document pertains to modified surfaces different from the above three types of porous coatings. Note: this document does not address interfaces between prosthetic parts, articulating surfaces, calcium phosphate coatings or biodegradable materials, which are described in separate documents.

Suggestions and recommendations presented in this document are not mandatory requirements, but reflect data and methodologies which ORDB has determined to be acceptable. In this context, several points should be remembered:

- This document is primarily intended to be a scientific position paper. Therefore, it suggests some important evaluation criteria, test procedures and end points. There may be circumstances where an alternative method or additional information may be useful. If the same objectives can be accomplished by means other than, or in addition to those included in this document, do not refrain from doing so. Because the scope of the remainder of this document does not specify a particular type of modified surface, some of the following recommended test methods may have to be modified and/or additional methods may need to be included in order to address the properties of a particular product.

- As scientific knowledge changes and scientific techniques are improved, FDA will periodically update the document. Nonetheless, it should be remembered that the basic objectives will probably remain the same.
- The word "should" and "must" have been used frequently in this document to emphasize the relative merit or importance of a specific aspect of a test or protocol. However, this verbiage is not used in a regulatory sense and should not be construed as such.

In this document, the term "modified surface" includes the surface layers and excludes the unmodified substrate below the modified surface.

A device manufacturer or sponsor may include more than one model or type of prosthetic component in a single submission if the modified surfaces on all the components have exactly the same unique set of characteristics (as described later in this document) and each component is otherwise identical to one previously approved in a PMA or found to be substantially equivalent in a 510(k).

II. REQUIRED INFORMATION

Metallurgical Analysis of the Materials

The composition, trace elemental analysis and material microstructure (grain size, amounts of different phases, etc.) of the substrate and modified surfaces of the final product must be expressed quantitatively. Microphotographs of the material microstructure should be included.

The corrosion over the entire surface of the final device and interfacing components must be equal to or less than that measured in a legally marketed device if the implanted device assembly is made of material combinations with limited or no history of successful use in orthopedic implant applications.

Microstructure of the Modified Surface

The total number of different modified surface layers and the following parameters concerning each physically and/or chemically distinct layer of the modified surface must be provided:

- the surface thickness (average and range);
- either drawings or photographs of the product illustrating the position of the modified surface(s) and any variation in modified surface thickness;
- the shape and size (average, standard deviation and range) of the particles or material between the pores;
- the diameter or area of the welds (average and standard deviation) between surface coating particles and substrate; and
- microphotographs at appropriate magnifications and locations within the modified surface so all geometrical characteristics of the microstructure listed in this document will be recognizable (either the precise magnification or a magnification bar must be included with each image).

The following parameters concerning the spaces within the modified surface (i.e., pores) must be provided:

- pore diameter (average and standard deviation) at the surface;
- the minimum void intercept length or minimum pore diameter of the interconnecting porosity (average, standard deviation and range) for each physically distinct layer; and
- the mean volume percent of voids;

Physical Properties of the Untreated Substrate Surface

- Dimensioned engineering drawings of any nonrandom surface structure patterns (e.g., machined structures) must be provided.
- The roughness of all surfaces must be reported in micrometers R_a.

Mechanical Properties - Modified Surface

Either finished devices or surface treated coupon samples that are processed identically as the final device may be used in the tests below.

- The shear fatigue strength of surface coatings must be tested out to at least 10^7 cycles (provide justification for the test method used, e.g., Pilliar, 1975; Manley, 1987).
- The static shear strength of the surface/substrate interface shall exceed 20 MPa for porous surface coatings as tested by ASTM F 1044 (Levine, 1985).
- The static tensile strength of the surface/substrate interface shall exceed 20 MPa for porous surface coatings (Levine, 1985; Ducheyne, 1986). Tension may be applied to the modified surface using either a polymeric adhesive with a minimum tensile strength of 24.1 MPa (ASTM C 633: Adhesion or Cohesive Strength of Flame-Sprayed Coatings) or another substrate sintered parallel to the first (ASTM F 1147 Tension Testing of Porous Metal Coatings). If an adhesive is used, its properties must be reported.
- The abrasion of a coating due to the insertion of the implant into bone during surgery and due to micromotion after surgery must be simulated in a test which allows comparisons between different test labs. One test method involves rubbing a block of hardened material against a flat test coupon consisting of the substrate and the modified surface under study. This test method is described in detail below:

  The flat, surface treated test coupon must be at least 30 x 30 mm. The portion of the hardened block which contacts the modified surface must consist of a convex half-cylinder whose cross-sectional radius is 0.5 mm and whose axial length is 25 mm. The hardened block must have a minimum hardness of 500 Brinell C (10 mm steel ball, 3000 Kg load) or 51 Rockwell C (R diamond cone, 150 Kg load) or 64 Rockwell D (R diamond cone, 100 Kg load). The half-cylinder is cycled back and forth (in the direction normal to the axis of the half-cylinder) over the same 25 x 25 mm's of modified surface for 10 cycles. The abraded modified surface should face down so loose debris may fall away from the surface. A range of different normal loads must be tested. The minimum load is the lowest load that produces a detectable loss in the modified surface. The maximum load must be either high enough to remove at least 50% of the modified surface or the lowest load that will cause significant plastic deformation/densification of the modified surface. Plastic deformation should be verified with micrographs. If it is not possible to remove 50% of the modified surface in 10 cycles without deformation, the cyclic loading should be continued until half the modified surface is removed.

Tests must be conducted for at least 5 other loads, equally spaced between the minimum and maximum loads. At least 3 undamaged specimens (i.e., not previously tested) must be tested at each load. At the end of each test, the test coupons are thoroughly cleaned and weighed and the cumulative decrease in volume (calculated from the change in mass) of the coupon or volume of wear debris is plotted versus applied load or number of cycles. The modified surface must be photographed at high enough magnification to detect the presence of cracking or plastic deformation of the modified surface. The thickness of the modified surface before and after the test and the initial mass of the modified surface under the abraded area must also be reported.

- The amount of plastic deformation of the porosity (average, standard deviation and range) must be reported for modified surfaces with low rigidity and limited or no history of successful use for orthopedic implant application. The device must be loaded by a flat surface under the worst case loading which may occur during implantation and use by the patient.

Mechanical Properties - Substrate

Surface modified and non-modified substrates must be tested as described below. The statistical significance of any differences in the results must be reported. The yield and ultimate strength must be provided or addressed by an appropriate standard (any difference in the final product and the requirements in the referenced standard must be itemized and explained). The fatigue strength must be determined using either ASTM F 1160 (i.e., axial, bending or rotating beam specimens with a fatigue strength greater than 130 MPa) or a test method specific to the final device.

Biocompatability

Material combinations with limited or no history of successful use in orthopedic implants must be determined to exhibit an acceptable biological response equal or better than approved or substantially equivalent devices when tested by ASTM F 748, ASTM F 981, and an animal implant study in which the tissue response to the modified surface is addressed by the following: amount of tissue apposition, depth of tissue ingrowth, and the strength of the junction between the bone or bone cement and implant surface in bending, shear, tension or torsion.

Clinical Data

Any available clinical data on devices containing the modified surface characterized above should be summarized in a table. At a minimum, this data should include information regarding loosening, radiographic evidence of bone or fibrous tissue ingrowth, surface coating particulate migration, surface coating failure or other indications of success or failure. Additional clinical data may be required if any test requirements listed in this document are not met or if the modified surface or other device design features have limited or no history of successful use in orthopedic implant applications.

III. MANUFACTURING

The manufacturing process of the final product and test samples must be described in enough detail to explain any significant differences between its properties and those of currently marketed devices.

IV. REPORTING

To help FDA in its review and facilitate a determination of substantial equivalence and/or safety and effectiveness, a very brief summary (values and their units) of all information sould be organized as suggested in Section VI, MODIFIED SURFACE DATA FORMS. Any additional and important information not specifically mentioned in this document should be inserted into this organization where appropriate. All the data summarized in one set of modified surface data forms must pertain to only one modified surface design. A separate set of modified surface data forms must be submitted for every modified surface having a significant difference in any property, including those listed in this document. Detailed test reports from which the summarized data originated should be organized and included in the submission to FDA. The detailed reports should include, but are not limited to, the following:

1. The name and address of facility performing the test.
2. The name of the study director, investigators, and supervisors involved in the study.
3. The dates that testing was initiated and completed and the date the final report was completed.
4. The objectives, methods, materials, deviations from referenced protocols and standards, results and conclusions of the test. These sections must include:
    a. a description of the test system used and a schematic or photograph of the test setup;
    b. a description of the samples tested including the differences, if any, in the composition, material structure and processing methods between the test samples and the device to be marketed;
    c. the assumptions of the test, including assumed physiological loading values and environmental conditions;
    d. at least 5 identical samples for each type of test and control specimens or statistical justification for the number of each;
    e. the load directions and magnitudes;
    f. the full experimental data, complete to the extent that an independent conclusion can be made;
    g. statistical evaluation of the differences between the test results where appropriate;
    h. the clinical implications of the results; and
    i. a post-test failure analysis of the specimens for identification of cracks, plastic deformation and any other signs of failure, including the location of the point of failure initiation.
5. A bibliography of all references pertinent to the report.

Note: Corrections and additions to a final report shall be in the form of an amendment by the study director. The amendment must clearly identify the report that is being amended and the reasons for the correction or addition.

V. BIBLIOGRAPHY

- ASTM C 633: 'Adhesion or Cohesive Strength of Flame-Sprayed Coatings'. Annual Book of ASTM Standards
- ASTM Draft Standard: 'Stereological Evaluation of Porous Metal Coatings'.
- ASTM Draft Standard F04.03.XX: 'Porous-Surface Femoral Prosthesis for Cementless Implantation'.
- ASTM F 1044: 'Shear Testing of Porous Metal Coatings'. Annual Book of ASTM Standards
- ASTM F 1147: 'Tension Testing of Porous Metal Coatings'. Annual Book of ASTM Standards
- ASTM F 1160: 'Constant Stress Amplitude Fatigue Testing of Porous Metal-Coated Metallic Materials'. Annual Book of ASTM Standards
- ASTM F 748: 'Selecting Generic Biological Test Methods for Materials and Devices'. Annual Book of ASTM Standards
- ASTM F 981: 'Assessment of Compatibility of Biomaterials (Nonporous) for Surgical Implants with respect to Effect of Materials on Muscle and Bone'. Annual Book of ASTM Standards
- Ducheyne, P. and M. Martens: Orderly oriented wire meshes as porous coatings on orthopaedic implants II: The pore size, interfacial bonding and microstructure after pressure sintering of titanium OOWM. Clin Matls. 1:91-98, 1988.
- Greenwald, A.S.; et al.: A New Method of Fatigue Testing for Proximally Supported Femoral Stems. 16th Annual Meeting for the Society for Biomaterials, pp. 221, May 20-23, 1990.
- Levine, D.L., G.T. Delli Santi, and R. Crowninshield: Bond strength of porous coatings. 31st Annual ORS, 1985.
- Manley, M., et al: Effects of repetitive loading on the integrity of porous coatings. Clin Orthop. 217:293-302, 1987
- Messersmith, P.B.; Cooke, F.W.: Stress Enhancement and Fatigue Susceptibility of Porous Coated Ti-6Al-4V Implants: An Elastic Analysis'. JBMR. 24:591, 1990
- Pilliar, R.M., H.U. Cameron, and Macnab, I: Porous surface layered prosthetic devices. Biomed Eng. 10:126-131, 1975
- Wolfarth, D.; et al: Parametric Analysis of Interfacial Stress Concentrations in Porous Coated Implants. J. Appl. Biomatl. 1:183, 1990

VI. MODIFIED SURFACE DATA FORMS

The data may be presented using the following format:

Supply the following:

- The names of any implants using the modified surface described below.
- The names (if any) given to the modified Surface described below.
- The manufacturer performing the surface treatment process.

Metallurgical Analysis of Materials

	Modified Surface	Unmodified Subtrate

- Composition:
- Trace elements
- Grain size:
- Phases:
-
- Corrosion
  Method:
  Results:

Microstructure of the Modified Surface

- Number of coating layers:
- Coating thickness (average and range):
- Provide either drawings or photographs showing the location of the modified surface and values of intended variations in thickness of the modified surface.
- Description of the approximate shape of the particles or material between the pores:
- Diameter/width (average, standard deviation and range) of the particles or material between the pores
- Diameter or area of the welds (average, standard deviation) between coating particles:
- Supply microphotographs.
- Pore diameter (average and standard deviation) at the surface:
- Minimum void intercept length or minimum pore diameter (average, standard deviation and range):
- Mean volume percent of voids:

Physical Properties of the Untreated Substrate Surface

- Supply drawings of surface structures.
- Roughness of all surfaces in micrometers (Ra):

Mechanical Properties - Modified Surface

- Shear Fatigue Strength
  Method:
  Result:
- Static Shear Strength
  Method:
  Result:
- Static Tensile Strength
  Method:
  Result:
- Abrasion
  Method:
  Result
- Plastic Deformation
  Method:
  Result:

Mechanical Properties - Substrate

- Cyclic Fatigue
  Method:
  Result (both surface modified and non-modified)
  Surface Modified:
  Non-Modified:

- Yield and Ultimate Tensile Strength
  Method or differences from any referenced standards:
  Results
  Yield:
  Ultimate:

Biocompatability
Method:
Result:

Clinical Data

Provide a tabulated summary to include, at a minimum, loosening, radiographic evidence of bone or fibrous tissue ingrowth, surface coating particulate migration, surface coating failure and other indications of success or failure

Manufacturing

Provide a brief description of the manufacturing process of the final product and of all test specimens. List all differences in composition, material structure and processing methods between the test samples and the device to be marketed.

Reporting

Provide detailed test reports including methods, materials, results, raw data and conclusions.

Bibliography

The origin (e.g., published literature article or unpublished internal test report) of the data for each of the test results summarized in this form must be identified. Reference identifiers may be located next to their respective tests on this form or listed along with the name of the test in a bibliography at the end of this form.