Class II Special Controls Guidance Document: Polymethylmethacrylate (PMMA) Bone Cement; Guidance for Industry and FDA

Document issued on: July 17, 2002

This document supersedes “Class II Special Controls Guidance Document: Polymethylmethacrylate (PMMA) Bone Cement 510(k)s; Final Guidance for Industry” dated August 2, 2001.

U.S. Department of Health and Human Services
Food and Drug Administration
Center for Devices and Radiological Health
Orthopedic Devices Branch
Division of General, Restorative, and Neurological Devices
Office of Device Evaluation
Preface

Public Comment

Comments and suggestions may be submitted at any time for Agency consideration to Dockets Management Branch, Division of Management Systems and Policy, Office of Human Resources and Management Services, Food and Drug Administration, 5630 Fishers Lane, Room 1061, (HFA-305), Rockville, MD, 20852. When submitting comments, please refer to the exact title of this guidance document. Comments may not be acted upon by the Agency until the document is next revised or updated.

For questions regarding the use or interpretation of this guidance contact Hany W. Demian at (240) 276-3676 or by electronic mail at hany.demian@fda.hhs.gov.

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# TABLE OF CONTENTS

1. **INTRODUCTION** ................................................................................................................. 4  
2. **BACKGROUND** .................................................................................................................. 4  
3. **THE CONTENT AND FORMAT OF AN ABBREVIATED 510(K) SUBMISSION** .... 5  
4. **SCOPE** ................................................................................................................................ 7  
5. **RISKS TO HEALTH** ........................................................................................................... 8  
6. **BIOCOMPATIBILITY** .......................................................................................................... 8  
7. **MATERIAL AND PERFORMANCE CHARACTERIZATION** ......................................... 9  
8. **STERILITY** ....................................................................................................................... 11  
9. **LABELING** ...................................................................................................................... 12  
10. **CLINICAL STUDIES** ......................................................................................................... 14  

**APPENDIX 1** ..................................................................................................................... 15  
**APPENDIX 2** ..................................................................................................................... 17
1. Introduction

On October 14, 1999, FDA issued an order reclassifying the polymethylmethacrylate (PMMA) bone cement from class III (premarket approval) into class II (special controls). This guidance document was developed as a special control guidance to support the reclassification of PMMA bone cement into class II. The device, as classified, is intended for use in arthroplastic procedures of the hip, knee, and other joints for the fixation of polymer or metallic prosthetic implants to living bone. This guidance will be issued in conjunction with a Federal Register notice announcing reclassification of this device type.

As stated on the coversheet, this guidance supersedes “Class II Special Controls Guidance Document: Polymethylmethacrylate (PMMA) Bone Cement 510(k)s; Final Guidance for Industry,” dated August 2, 2001. This August 2001 document served to update the information presented in “Guidance Document for Testing Orthopedic Bone Cement” dated November 1, 1993. We have since updated the August 2001 guidance to more clearly reflect that a person may submit an abbreviated 510(k) when relying on a Class II Special Control Guidance Document. While we have reformatted some of the sections, we have not substantially changed any of the recommendations about the performance characteristics or labeling for the device.

Following the effective date of the final rule classifying the device, any firm submitting a 510(k) premarket notification for a PMMA bone cement will need to address the issues covered in the special control guidance. However, the firm need only show that its device meets the recommendations of the guidance or in some other way provides equivalent assurances of safety and effectiveness.

2. Background

FDA believes that special controls, when combined with the general controls, will be sufficient to provide reasonable assurance of the safety and effectiveness of PMMA bone cement. Thus, a manufacturer who intends to market a device of this generic type should (1) conform to the general controls of the Federal Food, Drug & Cosmetic Act (the Act), including the 510(k) requirements described in 21 CFR 807 Subpart E, (2) address the specific risks to health associated with PMMA bone cement identified in this
guidance and, (3) obtain a substantial equivalence determination from FDA prior to marketing the device, unless exempt from the premarket notification requirements of the Act (refer to 21 CFR 807.85).

This special control guidance document identifies the classification regulations and product codes for the PMMA bone cement to which it applies (refer to Section 4 – Scope). In addition, other sections of this special control guidance document list the risks to health identified by FDA and describe measures that, if followed by manufacturers and combined with the general controls, will generally address the risks associated with these PMMA bone cement and lead to a timely 510(k) review and clearance. This document supplements other agency documents regarding the specific content requirements of a 510(k) submission. You should also refer to 21 CFR 807.87 and other agency documents on this topic, such as the 510(k) Manual - Premarket Notification: 510(k) - Regulatory Requirements for Medical Devices, http://www.fda.gov/cdrh/manual/510kprt1.html.

Under “The New 510(k) Paradigm - Alternate Approaches to Demonstrating Substantial Equivalence in Premarket Notifications; Final Guidance,” a manufacturer may submit a traditional 510(k) or has the option of submitting either an Abbreviated 510(k) or a Special 510(k). FDA believes an Abbreviated 510(k) provides the least burdensome means of demonstrating substantial equivalence for a new device, particularly once a Class II Special Controls Guidance Document has been issued. Manufacturers considering modifications to their own cleared devices may lessen the regulatory burden by submitting a Special 510(k).

**The Least Burdensome Approach**

The issues identified in this guidance document represent those that we believe need to be addressed before your device can be marketed. In developing the guidance, we carefully considered the relevant statutory criteria for Agency decision-making. We also considered the burden that may be incurred in your attempt to comply with the statutory and regulatory criteria in the manner suggested by the guidance and in your attempt to address the issues we have identified. We believe that we have considered the least burdensome approach to resolving the issues presented in the guidance document. If, however, you believe that there is a less burdensome way to address the issues, you should follow the procedures outlined in the “A Suggested Approach to Resolving Least Burdensome Issues” document. It is available on our Center web page at: http://www.fda.gov/cdrh/modact/leastburdensome.html.

**3. The Content and Format of an Abbreviated 510(k) Submission**

An Abbreviated 510(k) submission must include the required elements identified in 21 CFR 807.87, including the proposed labeling for the device sufficient to describe the device, its intended use, and the directions for its use. In an Abbreviated 510(k), FDA may consider the contents of a summary report to be appropriate supporting data within the meaning of 21 CFR 807.87(f) or (g); therefore, we recommend that you include a summary report. The report should describe how this special control guidance document was used during the device development and testing and should briefly describe the methods or tests used and a summary of the test data or description of the acceptance criteria applied.

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1 http://www.fda.gov/cdrh/ode/parad510.html
to address the risks identified in this guidance document, as well as any additional risks specific to your device. This section suggests information to fulfill some of the requirements of 807.87 as well as some other items that we recommend you include in an Abbreviated 510(k).

Coversheet

The coversheet should prominently identify the submission as an Abbreviated 510(k) and cite the title of this Class II Special Controls Guidance Document.

Proposed labeling

Proposed labeling should be sufficient to describe the device, its intended use, and the directions for its use. (Refer to Section 9 for specific information that should be included in the labeling for devices of the types covered by this guidance document.)

Summary report

The summary report should contain:

- Description of the device and its intended use. We recommend that the description include a complete discussion of the performance specifications and, when appropriate, detailed, labeled drawings of the device. You should also submit an "indications for use" enclosure.²

- Description of device design requirements.

- Identification of the Risk Analysis method(s) used to assess the risk profile in general as well as the specific device’s design and the results of this analysis. (Refer to Section 5 for the risks to health generally associated with the use of this device that FDA has identified.)

- Discussion of the device characteristics that address the risks identified in this Class II Special Controls Guidance Document, as well as any additional risks identified in your risk analysis.

- A brief description of the test method(s) you have used or intend to use to address each performance aspect identified in Sections 6-8 of this Class II Special Controls Guidance document. If you follow a suggested test method, you may cite the method rather than describing it. If you modify a suggested test method, you may cite the method but should provide sufficient information to explain the nature of and reason for the modification. For each test, you may either (1) briefly present the data resulting from the test in clear and concise form, such as a table, or (2) describe the acceptance criteria that you will apply to

² Refer to http://www.fda.gov/cdrh/ode/indicate.html for the recommended format.
your test results.\(^3\) (See also 21 CFR 820.30, Subpart C - Design Controls for the Quality System Regulation.)

- If any part of the device design or testing relies on a recognized standard, (1) a statement that testing will be conducted and meet specified acceptance criteria before the product is marketed, or (2) a declaration of conformity to the standard.\(^4\) Please note that testing must be completed before submitting a declaration of conformity to a recognized standard. (21 USC 514(c)(2)(B)). For more information, see FDA guidance, Use of Standards in Substantial Equivalence Determinations; Final Guidance for Industry and FDA, http://www.fda.gov/cdrh/ode/guidance/1131.html.

If it is not clear how you have addressed the risks identified by FDA or through your risk analysis, we may request additional information about aspects of the device’s performance characteristics. We may also request additional information if we need it to assess the adequacy of your acceptance criteria. (Under 21 CFR 807.87(l), we may request any additional information that is necessary to reach a determination regarding substantial equivalence.)

As an alternative to submitting an Abbreviated 510(k), you can submit a traditional 510(k) that provides all of the information and data required under 21 CFR 807.87 and described in this guidance. A traditional 510(k) should include all of your methods, data, acceptance criteria, and conclusions. Manufacturers considering modifications to their own cleared devices should consider submitting Special 510(k)s.

The general discussion above applies to any device subject to a special controls guidance document. The following is a specific discussion of how you should apply this special controls guidance document to a premarket notification for a PMMA bone cement.

### 4. Scope

The scope of this document is currently limited to bone cement as described in 21 CFR 888.3027 (product code: LOD).

§ 888.3027 Polymethylmethacrylate (PMMA) Bone Cement.

\(^3\) If FDA makes a substantial equivalence determination based on acceptance criteria, the subject device should be tested and shown to meet these acceptance criteria before being introduced into interstate commerce. If the finished device does not meet the acceptance criteria, and thus differs from the device described in the cleared 510(k), FDA recommends that submitters apply the same criteria used to assess modifications to legally marketed devices (21 CFR 807.81(a)(3)) to determine whether marketing of the finished device requires clearance of a new 510(k).

\(^4\) See Required Elements for a Declaration of Conformity to a Recognized Standard (Screening Checklist For All Premarket Notification [510(K)] Submissions), http://www.fda.gov/cdrh/ode/reqrecstand.html.
(a) **Identification.** Polymethylmethacrylate (PMMA) bone cement is a device, intended to be implanted that is made from methylmethacrylate, polymethylmethacrylate, esters of methacrylic acid, or copolymers containing polymethylmethacrylate and polystyrene. The device is intended for use in arthroplastic procedures of the hip, knee, and other joints for the fixation of polymer or metallic prosthetic implants to living bone.

(b) **Classification.** Class II (special controls). The special control for this device is the FDA document "Class II Special Controls Guidance Document: Polymethylmethacrylate (PMMA) Bone Cement; Guidance for Industry and FDA."

Alternate materials may be demonstrated to be substantially equivalent to PMMA used in bone cement. FDA will assign new product codes for bone cements formulated from alternate materials that are determined to be substantially equivalent under section 510(k) of the Act.

### 5. Risks to Health

In the table below, FDA has identified the risks to health generally associated with the use of the PMMA bone cement addressed in this document. The measures recommended to mitigate these identified risks are given in this guidance document, as shown in the table below. You should also conduct a risk analysis, prior to submitting your 510(k), to identify any other risks specific to your device. The premarket notification should describe the risk analysis method. If you elect to use an alternative approach to address a particular risk identified in this guidance document, or have identified risks additional to those in the guidance, you should provide sufficient detail to support the approach you have used to address that risk.

<table>
<thead>
<tr>
<th>Identified risk</th>
<th>Recommended mitigation measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone cement implantation syndrome</td>
<td>Sections 7, 9</td>
</tr>
<tr>
<td>Polymerization setting problems</td>
<td>Section 7</td>
</tr>
<tr>
<td>Loosening or migration of the device</td>
<td>Sections 7, 9</td>
</tr>
<tr>
<td>Infection and fever</td>
<td>Section 8</td>
</tr>
<tr>
<td>Adverse tissue reaction</td>
<td>Section 6, 9</td>
</tr>
<tr>
<td>Pain and/or loss of function</td>
<td>Sections 7, 9</td>
</tr>
<tr>
<td>Revision</td>
<td>Sections 7, 8, 9</td>
</tr>
</tbody>
</table>

### 6. Biocompatibility

The biocompatibility of your device should be evaluated. We recommend conducting an evaluation as described in the FDA-modified Use of International Standard ISO-10993, Biological Evaluation of Medical Devices Part-1: Evaluation and Testing, [http://www.fda.gov/cdrh/g951.html](http://www.fda.gov/cdrh/g951.html) for blood-contacting, long-term implanted devices. Your summary report should contain either a statement that testing will be conducted as described in the standard (the statement should also include the acceptance criteria to be applied) or declaration of conformity to Parts 5 and 10 of ISO-10993.
7. Material and Performance Characterization

PMMA bone cement is a self-curing, two component system consisting of liquid and powder components. Typically, the liquid component contains the monomer, accelerator, and the inhibitor. The powder contains the polymer, radio-opacifier, and initiator.

We recommend that you provide the following to evaluate the material and performance characteristics of your final sterilized PMMA bone cement.

A. Physical and Chemical Characterization

Physical and chemical analyses are used to characterize the liquid, powder, and cured bone cement. Appendix 1 lists important information, including mixing and application of the cement in which the dough, working, and set times are characterized (ASTM 451 and ISO 5833). You should identify the main ingredients, additives, and trace elements found in a bone cement composition, along with their respective amounts. You should evaluate the residual monomer levels and elution of monomer during initial mixing and after polymerization by gas chromatography or another applicable method (testing performed at 1 hour, 24 hours, and 72 hours after polymerization). You should establish the molecular weight of the powder and cured cement by gel permeation chromatography or solution viscosity measurements. If the polymerization process is other than the free radical polymerization, then you should evaluate the degree of polymerization.

You should provide the final product release specifications for each chemical, along with other specifications for the dough, working, set time, and residual monomer limit and elution of monomer limits for cured bone cement.

You should characterize other physical properties, such as the powder’s morphology, size distribution, and dispersion of the polymer and additives. This is typically achieved by light microscopy or scanning electron microscopy (SEM).

You should present a table comparing the similarities and differences in these parameters, including component ratios, between the proposed product and a predicate bone cement.

B. Mechanical Testing

You should evaluate the material’s integrity with several in vitro mechanical test methods. Appendix 2 includes mechanical characterization testing (i.e., modulus, fatigue, fracture toughness, fatigue crack propagation (optional), flexural strength, compressive strength, shear strength, tensile strength, and creep). FDA recommends using a predicate bone cement as a control when performing these tests. See below for what should be provided as part of a complete test report.

You should consider the morphology of the fracture surface after mechanical testing. Analyses of the fracture surface include:

- porosity measurements of the fracture surface and the bulk material
• additive dispersion measurements on the fractured surface
• failure analysis of the fracture surface

You should use the applicable American Society for Testing and Materials (ASTM) and International Organization for Standardization (ISO) consensus standards listed below to establish the material and performance characterization of your device:

• ASTM D 2990-95, “Standard Tensile, Compressive, and Flexural Creep and Creep Rupture of Plastics”
• ASTM E 647-00, “Standard Test Method for Measurement of Fatigue Crack Growth Rates”

You should include the following PMMA cement-specific information as part of your test report:

• Description of the following preparation variables that may affect the reported in vitro mechanical properties:
  ➔ mixing – temperature of the environment and mixing surfaces throughout the procedure
  ➔ centrifugation - amounts of ingredients, monomer temperature, rate (revolutions per minute), and time
  ➔ method of mixing, i.e., hand mixing, mechanical (machine) mixing, or vacuum mixing - amounts of ingredients, order of mixing, pressure, rate (beats per minute), duration, and geometry of mixer (rotor, container)
  ➔ molding – design, material, and temperature
  ➔ machining- number of specimens broken during machining
  ➔ finishing effects - number of specimens rejected due to surface defects
  ➔ aging (curing) - sequence stages chronology of events, duration, environment, and temperature
• Summary of results

• Discussion of all specimens prepared but not tested, including the number of rejected specimens, the reasons for rejection, the evaluation methods, and the rejection pass/fail criteria

C. Shelf-life, Product Expiration Dating, and Storage Conditions

You should establish the shelf-life by either real time storage or by using a validated accelerated stability testing protocol (Appendix 2). The appropriateness of conducting accelerated stability studies is related to device composition and the relationship between accelerated study conditions and real-time aging. The value of accelerated stability is dependent on identical decomposition mechanisms at both standard and elevated temperatures. Regardless of the type of study conducted, you should collect data from at least three production lots. Stability studies should monitor the critical physical and mechanical properties of a device that are required to ensure it will perform consistently during its entire shelf-life. Your summary report should disclose the device shelf-life and recommend storage conditions and identify the method used to support the values. Detailed study protocol and underlying data should be maintained at the manufacturing facility in accordance with the Quality System Regulation.

8. Sterility

You should evaluate the sterility of your device. We recommend providing information according to the Updated 510(k) Sterility Review Guidance K90-1; Final Guidance for Industry and FDA, [link](http://www.fda.gov/cdrh/ode/guidance/361.html).

We recommend your summary report contain the following information for devices sold as sterile:

- the sterilization method that will be used in the sterilization cycle (e.g., dry heat, ethylene oxide (EtO), steam, radiation)
- the maximum levels of EtO and ethylene chlorhydrin residues, if sterilized by EtO
- the radiation dose, if sterilized by radiation
- a description of the method that will be used to validate the sterilization cycle
- a description of the packaging to maintain the device's sterility
- the sterility assurance level specification (SAL)\(^5\)
- a description of the method used to determine non-pyrogenicity (e.g., the limulus amebocyte lysate (LAL) method), if the device is labeled pyrogen free.

\(^5\) FDA recommends a SAL of \(10^{-6}\) for PMMA bone cement.
9. Labeling

The premarket notification should include labeling in sufficient detail to satisfy the requirements of 21 CFR 807.87(e). The following suggestions are aimed at assisting you in preparing labeling that satisfies the requirements of 21 CFR 807.87(e).6

**Outer Box Label**

The outside box label should clearly identify the storage conditions for the bone cement and, if necessary, the equilibration time (i.e., the time to reach optimal temperature) of the bone cement.

**Package Insert and Surgical Technique**

The package insert and surgical technique should include the following:

**Intended Use**

PMMA bone cement is intended for use in arthroplastic procedures of the hip, knee, and other joints for the fixation of polymer or metallic prosthetic implants to living bone.

**Contraindications**

PMMA bone cement is contraindicated in the presence of active or incompletely treated infection, at the site where the bone cement is to be applied.

**Warnings**

Monitor patients carefully for any change in blood pressure during and immediately following the application of bone cement. Adverse patient reactions affecting the cardiovascular system have been associated with the use of bone cements. Hypotensive reactions have occurred between 10 and 165 seconds following application of bone cement; they have lasted from 30 seconds to 5 or more minutes. Some have progressed to cardiac arrest. Patients should be monitored carefully for any change in blood pressure during and immediately following the application of bone cement.

Follow the handling, mixing and canal preparation instructions carefully.

- Caution should be exercised during the mixing of the two components to prevent excessive exposure to the concentrated monomer vapors, which may produce irritation of the respiratory tract, eyes, and possibly the liver. Personnel wearing contact lenses should not be near or involved in mixing this bone cement.

- Polymerization of the bone cement is an exothermic reaction, which occurs while the cement is hardening in situ. The released heat may damage bone or other tissues surrounding the implant.

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6 Although final labeling is not required for 510(k) clearance, final labeling must also comply with the requirements of 21 CFR 801 before a medical device is introduced into interstate commerce. In addition, final labeling for prescription medical devices must comply with 21 CFR 801.109. Labeling recommendations in this guidance are consistent with the requirements of part 801.
- Inadequate fixation or unanticipated postoperative events may affect the cement-bone interface and lead to micromotion of cement against bone surface. A fibrous tissue layer may develop between the cement and the bone, and loosening of the prosthesis may occur leading to implant failure. Long-term follow-up is advised for all patients on a regularly scheduled basis.

- Do not allow the liquid component to contact rubber or latex gloves. The liquid component is a powerful lipid solvent. Should contact occur, the gloves may dissolve and tissue damage may occur. Wearing a second pair of gloves and strict adherence to the mixing instructions may diminish the possibility of hypersensitivity reactions. The mixed bone cement should not make contact with the gloved hand until the cement has acquired the consistency of dough. This usually occurs between one and two minutes after the liquid and powder components are mixed.

Avoid over pressurization of the bone cement because this may lead to extrusion of the bone cement beyond the site of its intended application and damage to the surrounding tissues.

The safety of the bone cement in pregnant women or in children has not been established. Bone cement may adversely affect bone growth and fetal health.

**Precautions**

Do not use this product after the expiration date printed on the package. This device may not be safe or effective beyond its expiration date.

Follow the handling and mixing instructions to avoid contact dermatitis. Strict adherence to the instructions for mixing the powder and liquid components may reduce the incidence of this complication.

Adequately ventilate the operating room to eliminate as much monomer vapor as possible. The liquid monomer is highly volatile and flammable. Ignition of monomer fumes caused by use of electrocautery devices in surgical sites near freshly implanted bone cements has been reported.

Dispose of the polymer component in an authorized waste facility. The liquid component should be evaporated under a well-ventilated hood or absorbed by an inert material and transferred in a suitable container for disposal.

**Adverse Events**

Serious adverse events, some with fatal outcome, associated with the use of acrylic bone cements include myocardial infarction, cardiac arrest, cerebrovascular accident, and pulmonary embolism.

The most frequent adverse reactions reported with acrylic bone cements are a transitory fall in blood pressure, thrombophlebitis, hemorrhage and hematoma, loosening or displacement of the prosthesis, superficial or deep wound infection, trochanteric bursitis, and short-term cardiac
conduction irregularities. Other reported adverse reactions include heterotopic new bone formation and trochanteric separation.

Other reported adverse events for acrylic bone cements include pyrexia due to an allergy to the bone cement, hematuria, dysuria, bladder fistula, delayed sciatic nerve entrapment due to extrusion of the bone cement beyond the region of its intended application, and adhesions and stricture of the ileum due to the heat released during polymerization.

**Instructions and Training**

The instructions for use should include a handling time versus temperature chart to give the user information regarding how fast the bone cement will polymerize at a given temperature and humidity.

The surgeon should, by specific training and experience, be thoroughly familiar with the properties, handling characteristics, and application of bone cements. Because the handling and curing characteristics of this bone cement vary with temperature, humidity, and mixing technique, they are best determined by the surgeon's actual experience.

### 10. Clinical Studies

The agency does not intend to request clinical studies for new devices unless there is a specific reason to require such information to support a substantially equivalent determination. There may be situations in which FDA believes clinical studies are necessary to support submissions for these devices, e.g., a new intended use or certain changes to the bone cement’s chemical formulation, including the addition of certain new chemicals.

If a clinical study is needed to demonstrate substantial equivalence, i.e., conducted prior to obtaining 510(k) clearance of the device, the study must be conducted under the Investigational Device Exemptions (IDE) regulation, 21 CFR 812. FDA has determined that PMMA bone cement addressed by this guidance document is a significant risk device as defined in 21 CFR 812.3(m)(4). In addition to the requirement of having an FDA-approved IDE, sponsors of such trials must comply with Parts 50 and 56.

After FDA determines that the device is substantially equivalent, clinical studies conducted in accordance with the indications reviewed in the 510(k), including clinical design validation studies conducted in accordance with the quality systems regulation, are exempt from the investigational device exemptions (IDE) requirements. However, such studies must be performed in conformance with the regulations governing institutional review boards (21 CFR 56) and informed consent (21 CFR 50).

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## Appendix 1

### PHYSICAL AND CHEMICAL METHODS OF ANALYSES

<table>
<thead>
<tr>
<th>Suggested Testing</th>
<th>Examples of Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mixing and Application</strong></td>
<td></td>
</tr>
<tr>
<td>Mix liquid &amp; powder components</td>
<td>ASTM F451-95, ISO 5833-92</td>
</tr>
<tr>
<td>Dough time</td>
<td>ASTM F451-95, ISO 5833-92</td>
</tr>
<tr>
<td>Setting time</td>
<td>ASTM F451-95, ISO 5833-92</td>
</tr>
<tr>
<td>Viscosity: Pre-dough stage extrusion</td>
<td>ASTM F451-95, ISO 5833-92</td>
</tr>
<tr>
<td>Dough stage intrusion</td>
<td>ASTM F451-95, ISO 5833-92</td>
</tr>
<tr>
<td><strong>Chemical Composition</strong></td>
<td></td>
</tr>
<tr>
<td>Ingredients: chemical formula, structure, additives, etc.</td>
<td>Liquid-NMR, FTIR, HPLC/MS</td>
</tr>
<tr>
<td>Type of radio-opacifier</td>
<td>TGA/gross pyrolysis</td>
</tr>
<tr>
<td>Purity or trace elements</td>
<td>ICP/MS, GC/FTIR/MS, titration</td>
</tr>
<tr>
<td>Residual low MW molecules</td>
<td>GC, HPLC/GPC, liquid-NMR</td>
</tr>
<tr>
<td>Leachables (e.g., low MW molecules)</td>
<td>GC, HPLC/GPC</td>
</tr>
<tr>
<td><strong>Molecular Weight and Polymer Structure</strong></td>
<td></td>
</tr>
<tr>
<td>MW by viscous flow</td>
<td>Viscosity measurements (e.g., solution)</td>
</tr>
<tr>
<td>MW: Polydispersity, $M_n$, $M_w$</td>
<td>GPC with refractive index detector using polystyrene as standard material</td>
</tr>
<tr>
<td>Branched, linear, or crosslinked</td>
<td>Solubility, swelling, liquid-NMR</td>
</tr>
<tr>
<td>% Crystallinity, if applicable</td>
<td>X-ray diffraction, DSC</td>
</tr>
<tr>
<td>Crystallization temperature, if applicable</td>
<td>DSC, DMA</td>
</tr>
<tr>
<td>Glass transition temperature (Tg), if applicable</td>
<td>DSC, DMA</td>
</tr>
<tr>
<td><strong>Physical Properties</strong></td>
<td></td>
</tr>
<tr>
<td>Powder’s morphology, size characterization and dispersion of polymer and additives</td>
<td>Light microscopy, SEM of powder and cured cement</td>
</tr>
<tr>
<td>Porosity characterization</td>
<td>Scanning Acoustical Microscopy of bulk cement (e.g., SLAM, C-SAM) and serial sectioning of the cured cement</td>
</tr>
<tr>
<td>Dimensional changes during curing (shrinkage)</td>
<td>Volume measurement</td>
</tr>
<tr>
<td>% Water absorption (swelling)</td>
<td>Saturation testing</td>
</tr>
<tr>
<td>Aging due to fluid absorption and polymerization</td>
<td>Mechanical testing (Appendix 2)</td>
</tr>
<tr>
<td><strong>Stability of Components</strong></td>
<td></td>
</tr>
<tr>
<td>Change in monomer viscosity due to artificial aging</td>
<td>ASTM 451 - 95</td>
</tr>
<tr>
<td>Change in benzoyl peroxide levels</td>
<td>Titration method, FTIR, GC</td>
</tr>
<tr>
<td><strong>Thermal Properties</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum polymerization temperature</td>
<td>ASTM F451 - 95, ISO 5833 - 92</td>
</tr>
</tbody>
</table>

C-SAM=C-mode scanning acoustical microscopy  
DMA=Dynamic mechanical analysis  
DSC=Differential scanning calorimetry  
FTIR=Fourier transform infrared  
GC=Gas chromatography  
GPC=Gel permeation chromatography  
HPLC=High-performance liquid chromatography  
ICP=Inductively coupled plasma  
MS=Mass spectroscopy  
MW=Molecular weight  
NMR=Nuclear magnetic resonance  
SEM=Scanning electron microscopy  
SLAM=Scanning laser acoustical microscopy  
TGA=Thermogravimetric analysis
## Appendix 2

### MECHANICAL PROPERTIES AND SHELF-LIFE

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Suggested Testing</th>
<th>Examples of Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus</td>
<td>Flexural 4-Point bending</td>
<td>ISO 5833-92</td>
</tr>
<tr>
<td></td>
<td>Compressive Uniaxial compression</td>
<td>ISO 5833-92, ASTM F451-95</td>
</tr>
<tr>
<td></td>
<td>Tension Uniaxial tension</td>
<td>ASTM D638–91 - rectangular or cylindrical specimen</td>
</tr>
<tr>
<td>Cyclic Fatigue Properties</td>
<td>Uniaxial tension/compression or tension/tension</td>
<td>ASTM D638–91 - rectangular or cylindrical specimen, frequency – physiologically relevant or justified level, sinusoidal wave form, load control, stress levels which are similar to expected in vivo stresses</td>
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<tr>
<td></td>
<td>3 or 4-Point bending</td>
<td>Use rectangular specimens</td>
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<tr>
<td>Fracture Toughness, K&lt;sub&gt;IC&lt;/sub&gt;</td>
<td>Compact tension</td>
<td>ASTM E399–90</td>
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<tr>
<td></td>
<td>Notched bending</td>
<td>Compact tension or single-edge notched</td>
</tr>
<tr>
<td>Fatigue Crack Propagation (optional)</td>
<td>Compact tension</td>
<td>ASTM E647–95</td>
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<tr>
<td>Static Strength</td>
<td>Flexural 4-Point bending</td>
<td>ISO 5833-92</td>
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<td></td>
<td>Compressive Uniaxial compression</td>
<td>ISO 5833-92, ASTM F451-95</td>
</tr>
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<td></td>
<td>Tensile Uniaxial tension</td>
<td>ASTM D638–91 – rectangular/cylindrical specimens</td>
</tr>
<tr>
<td></td>
<td>Shear Single shear (cement-cement)</td>
<td>ASTM D732-93</td>
</tr>
<tr>
<td>Viscoelasticity</td>
<td>Uniaxial compressive creep</td>
<td>ASTM D2990-95 or compressive creep of cylindrical specimens</td>
</tr>
<tr>
<td></td>
<td>Dynamic mechanical analysis</td>
<td>DMA</td>
</tr>
<tr>
<td></td>
<td>(optional mechanical testing should be considered if further evaluation is needed)</td>
<td></td>
</tr>
<tr>
<td>Shelf-Life</td>
<td>Measurement of mechanical properties of hardened cement after components have been aged over time.</td>
<td>Real-time storage or a validated accelerated aging condition of sterilized liquid and powder components. Perform testing on cured bone cement.</td>
</tr>
</tbody>
</table>