



Standard Guide for Assessment of the Ultra High Molecular Weight Polyethylene (UHMWPE) Used in Orthopedic and Spinal Devices¹

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1. Scope

1.1 This guide covers general guidelines for the physical, chemical, biocompatibility, mechanical, and preclinical assessments of ultra-high molecular weight polyethylene (UHMWPE) in implantable orthopedic and spinal devices intended to replace a musculoskeletal joint. The UHMWPE components may include knee, hip, shoulder, elbow, ankle, total disc replacement, toe, finger, and wrist joint implant devices. This guide does not cover UHMWPE in fiber or tape forms.

1.2 This guide includes a description and rationale of assessments for the various UHMWPE types and processing conditions. Assessment testing based on physical, chemical, biocompatibility, mechanical, and preclinical analyses are briefly described and referenced. The user should refer to specific test methods for additional details.

1.3 This guide does not attempt to define all of the assessment methods associated with UHMWPE components in orthopedic and spinal devices.

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

1.5 *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

D256 Test Methods for Determining the Izod Pendulum

Impact Resistance of Plastics

D638 Test Method for Tensile Properties of Plastics

D695 Test Method for Compressive Properties of Rigid Plastics

D883 Terminology Relating to Plastics

D2765 Test Methods for Determination of Gel Content and Swell Ratio of Crosslinked Ethylene Plastics

D4020 Specification for Ultra-High-Molecular-Weight Polyethylene Molding and Extrusion Materials

E647 Test Method for Measurement of Fatigue Crack Growth Rates

F619 Practice for Extraction of Medical Plastics

F648 Specification for Ultra-High-Molecular-Weight Polyethylene Powder and Fabricated Form for Surgical Implants

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

F748 Practice for Selecting Generic Biological Test Methods for Materials and Devices

F749 Practice for Evaluating Material Extracts by Intracutaneous Injection in the Rabbit

F756 Practice for Assessment of Hemolytic Properties of Materials

F763 Practice for Short-Term Screening of Implant Materials

F813 Practice for Direct Contact Cell Culture Evaluation of Materials for Medical Devices

F895 Test Method for Agar Diffusion Cell Culture Screening for Cytotoxicity

F981 Practice for Assessment of Compatibility of Biomaterials for Surgical Implants with Respect to Effect of Materials on Muscle and Bone

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

¹ This guide is under the jurisdiction of ASTM Committee F04 on Medical and Surgical Materials and Devices and is the direct responsibility of Subcommittee F04.11 on Polymeric Materials.

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

- F2003** Practice for Accelerated Aging of Ultra-High Molecular Weight Polyethylene after Gamma Irradiation in Air
- F2025** Practice for Gravimetric Measurement of Polymeric Components for Wear Assessment
- F2102** Guide for Evaluating the Extent of Oxidation in Polyethylene Fabricated Forms Intended for Surgical Implants
- F2183** Test Method for Small Punch Testing of Ultra-High Molecular Weight Polyethylene Used in Surgical Implants
- F2214** Test Method for *In Situ* Determination of Network Parameters of Crosslinked Ultra High Molecular Weight Polyethylene (UHMWPE)
- F2381** Test Method for Evaluating Trans-Vinylene Yield in Irradiated Ultra-High Molecular Weight Polyethylene Fabricated Forms Intended for Surgical Implants by Infrared Spectroscopy
- F2423** Guide for Functional, Kinematic, and Wear Assessment of Total Disc Prostheses
- F2625** Test Method for Measurement of Enthalpy of Fusion, Percent Crystallinity, and Melting Point of Ultra-High-Molecular Weight Polyethylene by Means of Differential Scanning Calorimetry
- F2695** Specification for Ultra-High Molecular Weight Polyethylene Powder Blended With Alpha-Tocopherol (Vitamin E) and Fabricated Forms for Surgical Implant Applications
- 2.2 *ISO Standards*:⁴
- ISO 527** Plastics: Determination of Tensile Properties
- ISO 3451–1** Plastics: Determination of Ash Part 1: General Methods
- ISO 5834–1** Implants for Surgery—Ultra High Molecular Weight Polyethylene. Part 1: Powder Form
- ISO 5834–2** Implants for Surgery—Ultra High Molecular Weight Polyethylene. Part 2: Molded Forms
- ISO 11542–2** Plastics—Ultra-High-Molecular-Weight-Polyethylene (PE-UHMWPE) Molding and Extrusion Materials. Part 2: Preparation of Test Specimens and Determination of Properties
- ISO 10993** Biological Evaluation of Medical Devices
- ISO 14242–1** Implants for Surgery—Wear of Total Hip-Joint Prostheses. Part 1: Loading and Displacement Parameters for Wear-Testing Machines and Corresponding Environmental Conditions for Test
- ISO 14242–2** Implants for Surgery—Wear of Total Hip-Joint Prostheses. Part 2: Methods of Measurement
- ISO 14242–3** Implants for Surgery—Wear of Total Hip-Joint Prostheses. Part 3: Loading and Displacement Parameters for Orbital Bearing Type Wear Testing Machines and Corresponding Environmental Conditions for Test
- ISO 14243–1** Implants for Surgery—Wear of Total Knee-Joint Prostheses. Part 1: Load and Displacement Parameters for Wear-Testing Machines with Load Control and Corresponding Environmental Conditions for Test
- ISO 14243–2** Implants for Surgery—Wear of Total Knee-

- Joint Prostheses. Part 2: Methods of Measurement
- ISO 14243–3** Implants for Surgery—Wear of Total Knee-Joint Prostheses. Part 3: Loading and Displacement Parameters for Wear-Testing Machines with Displacement Control and Corresponding Environmental Conditions for Test
- ISO 18192–1** Implants for Surgery—Wear of Total Intervertebral Disc Prostheses. Part 1: Loading and Displacement Parameters for Wear Testing and Corresponding Environmental Conditions for Test
- 2.3 *Federal Standard*:
- 21 CFR 58** Good Laboratory Practices Regulations⁵

3. Terminology

3.1 *Definitions*—Additional terminology related to ultra high molecular weight polyethylene (UHMWPE) and plastics can be found in Terminology **D883** and Specifications **D4020** and **F648** and referenced publications (1-7).⁶

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *fabricated form, n*—any bulk shape of UHMWPE fabricated from the virgin polymer powder with or without additives or prior irradiation and used during the process of fabricating surgical implants before packaging and sterilization.

3.2.1.1 *Discussion*—This form results from the application of heat and pressure to the virgin polymer powder, and the material characteristics of this form are subject to the applicable requirements of this guide. In present practice, this includes ram-extruded bars, compression-molded sheets, and direct-molded shapes that are subsequently trimmed.

4. Significance and Use

4.1 This guide aims to provide guidance for a range of various assessments and evaluations to aid in preclinical research and device development of various UHMWPE components in orthopedic and spinal devices used for the repair of musculoskeletal disorders.

4.2 This guide includes brief descriptions of various assessments, representative data, processing conditions, and intended use or uses, as well as the qualitative and quantitative analyses of the UHMWPE powder to a finished product component.

4.3 The user is encouraged to use appropriate ASTM International and other standards to conduct the physical, chemical, mechanical, biocompatibility, and preclinical tests on UHMWPE materials, device components, or devices before assessment of an *in vivo* model.

4.4 Assessments of UHMWPE should be performed in accordance with the provisions of 21 CFR 58 where feasible.

4.5 Studies to support investigational device exemption (IDE), premarket approval (PMA), or 510K submissions

⁵ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁶ The boldface numbers in parentheses refer to the list of references at the end of this standard.

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

should conform to appropriate Food and Drug Administration (FDA) guidelines for the development of medical devices.

4.6 Assessments with physical, chemical, mechanical, biocompatibility, and preclinical tests on UHMWPE components are not necessarily predictive of human results and should be, therefore, interpreted cautiously with respect to potential applicability to human conditions. Referenced UHMWPE publications can be found in the References section at the end of this guide for further review.

5. UHMWPE Fabricated Forms and Conditions

5.1 Conventional UHMWPE is manufactured by compression molding or ram extrusion and has not been intentionally cross-linked before terminal sterilization.

5.2 Extensively radiation-cross-linked UHMWPE is manufactured by compression molding or extrusion and irradiated with a dosage higher than 40 kGy of gamma or e-beam radiation for improved wear resistance.

5.3 *Antioxidant (Alpha-Tocopherol)*—Two stabilizing methods for the antioxidant UHMWPE form (Vitamin E-stabilized or alpha-tocopherol) are blending or diffusing. The blending method has the Vitamin E mixed (blended) into the UHMWPE powder before consolidation and radiation cross-linking. The diffusing method has the Vitamin E diffusing into a consolidated UHMWPE form before or after radiation cross-linking. Also, antioxidant UHMWPE could potentially be used without any radiation cross-linking.

5.4 *Thermal Processing*—UHMWPE-fabricated forms undergo at least one or more thermal treatments during the consolidation processes of extrusion or molding, annealing, cross-linking or after cross-linking. The thermal history should be documented and its effects assessed with mechanical, physical, chemical, and preclinical testing.

5.5 UHMWPE powder is classified as Types 1, 2, or 3. These types have different molecular weights and material properties as defined in Specification F648.

6. UHMWPE Decision Chart (Table 1)

6.1 The assessment chart shown in Table 1 should be performed as indicated on the listed UHMWPE types.

6.2 UHMWPE fabricated form testing should be pursued with samples that are in the final conditions with respect to annealing, sterilization, aging, and packaging. Assessment

parameters should include and be compared to clinically successful UHMWPE materials.

7. Test Methods

7.1 *Virgin UHMWPE Powder*—The tests shown in Table 2 should be conducted on the UHMWPE types designated in Table 1. Alternative tests, such as ones found in ISO 5834–1 and ISO 5834–2), may be considered with documented analysis and rationale.

7.2 *UHMWPE Mechanical and Physical Assessments—Part 1*—The tests shown in Table 3 should be conducted on the UHMWPE types designated in Table 1. Alternative tests may be considered with documented analysis and rationale.

7.3 *Mechanical and Physical Assessment—Part 2*—The tests shown in Table 4 should be conducted on the UHMWPE types designated in Table 1. Alternative tests may be considered, such as electron spin resonance (see X1.1), with documented analysis and rationale.

7.4 *Preclinical Simulation*—Functional testing on the finished UHMWPE component that simulates clinical functions and known failure modes should be considered. Testing that should be considered include creep, accelerated aging, and/or shelf- life testing, and functional fatigue loading. Practice F2003 should be considered for determining relative oxidative stability.

7.4.1 *Wear*—See Table 5.

7.4.2 *Functional Device or Material Testing*—UHMWPE implant components have experienced known device failure modes. Examination of known clinical failure modes through functional device or material testing, such as fatigue testing of the post in a posterior-stabilized tibial insert or fatigue-impingement testing of the stem neck and polyethylene liner in a hip implant, should be considered with new UHMWPE processes, material additives, or implant designs.

7.5 *UHMWPE with Antioxidant (Alpha-Tocopherol)*—Commercially available UHMWPEs for implants containing antioxidants are blended or doped with alpha-tocopherol. Implant materials produced by blending alpha-tocopherol with polyethylene before consolidation are specified in Test Method F2695.

7.5.1 Methods for evaluating the content of alpha-tocopherol in UHMWPE have not been standardized (see X1.2 and X1.3) and shall be conducted based on agreement between the supplier and the purchaser.

TABLE 1 UHMWPE Fabricated Forms and Conditions

Test Method Group	Conventional	Extensively Cross-Linked (Irradiation)	Antioxidant
Virgin powder (7.1)	X	X	X
Mechanical and physical—Part 1 (7.2)	X	X	X
Mechanical and physical—Part 2 (7.3)	X ^A	X	X
Preclinical wear simulation (7.4)	X ^A	X	X
Antioxidant assessment (7.5)			X
Packaging and sterilization rationale (Section 8)	X	X	X
Biocompatibility (Section 9)	X	X	X

^A For materials terminally sterilized by gamma or e-beam irradiation.

TABLE 2 Requirements for UHMWPE Powders

Property	Test Method	Requirements		
		Type 1	Type 2	Type 3
Resin Type				
Viscosity number, mL/g	D4020 (0.02%)	2000-3200	>3200	>3200
Elongation stress (minimum)	D4020	0.20	0.42	0.42
Ash, mg/kg (maximum)	ISO 3451-1	125	125	300
Extraneous matter, number of particles (maximum)	F648	3	3	25
Titanium, mg/kg (maximum)	F648	40	40	150
Aluminum, mg/kg (maximum)	F648	20	20	100
Calcium, mg/kg (maximum)	F648	5	5	50
Chlorine, mg/kg (maximum)	F648	30	30	90

TABLE 3 UHMWPE Mechanical and Physical Assessments, Part 1

Test Description	Method
Tensile strength Ultimate Yield	D638 or ISO 527
Elongation, %	D638
Izod or Charpy impact strength, kJ/m ²	F648, Annex A1 or ISO 11542-2 Annex B/D256
Elastic modulus	D638
Compression modulus, MPa	D695
Thermal properties Percent crystallinity Melting temperature	F2625

TABLE 4 Mechanical and Physical Assessment, Part 2

Test Description	Method
Small punch ultimate load, N	F2183
Fatigue crack propagation	E647
Swell ratio	D2765 or F2214
Oxidation index (OI), surface oxidation index (SOI), and OI maximum	F2102
t-Vinylene content, trans-vinylene index (TVI)	F2381

TABLE 5 Wear

Test Description	Method
Hip wear	F1714, ISO 14242-1, 2, 3
Knee wear	F1715, ISO 14243-1, 2, 3
Spine wear	F2423, ISO 18192-1
Wear, polymer	F732
Wear, gravimetric	F2025

8. UHMWPE Packaging and Terminal Sterilization Rationale

8.1 The properties of UHMWPE components, including biocompatibility, can be affected by packaging and terminal sterilization. Typical sterilization methods for conventional

UHMWPE have included non-irradiation methods such as ethylene oxide gas or gas plasma and irradiation sterilization methods such as gamma or e-beam radiation dosage at 25 to 40 kGy in various inert gas or vacuum environments.

8.2 Rationale and assessment of the process methods, packaging (barrier film, inert gas, and vacuum environments), and sterilization effects, including shelf life, on UHMWPE test specimens or components should be included in any testing plan and report for UHMWPE in orthopedic and spinal devices.

9. Biocompatibility

9.1 Conventional UHMWPE has been shown to produce a well-characterized level of biological response following long-term clinical use in humans. The results of these studies and the clinical history indicate an acceptable level of biological response in the applications in which the material has been used. When new applications of the material or a modification to the material or physical form or both of the materials are being contemplated, the recommendations of Practice F748 and ISO 10993 should be considered in addition to testing, as described in Practices F619, F749, F756, F763, F813, and F981, as well as Test Method F895.

9.2 Highly cross-linked and thermally treated UHMWPE has also been shown to produce a well-characterized level of biological response following short-to-intermediate-term clinical use in humans. The clinical history for this class of materials thus far indicates an acceptable level of biological response in the applications in which the material has been used (see References section at the end of this guide). When new applications of the material or physical form or both of the material are being contemplated, the recommendations of Practice F748 and ISO 10993 should be considered in addition to testing, as described in Practices F619, F756, F763, F813, and F981, as well as Test Method F895.

9.3 The UHMWPE containing the alpha-tocopherol antioxidant has also been shown to produce a well-characterized level of biological response in published laboratory studies, as described in Specification F2695 (see also X1.4). When new applications of the material or a modification to the material or physical form or both of the materials from the formulations that have demonstrated biocompatibility are being contemplated, the recommendations of Practice F748 and ISO 10993 may be considered in addition to testing, as described in Practices F619, F749, F756, F763, F813, and F981, as well as Test Method F895.

10. Keywords

10.1 musculoskeletal joint replacement; orthopedic device; spinal device; UHMWPE; ultra-high molecular weight polyethylene

APPENDIX

(Nonmandatory Information)

X1. TITLE

X1.1 Electron spin resonance has been used to characterize the free radical content of UHMWPE Biomaterials (see Ref (7)). Standardized methods have not yet been developed to perform this testing, and these experiments are conducted based on agreement between the supplier and the purchaser.

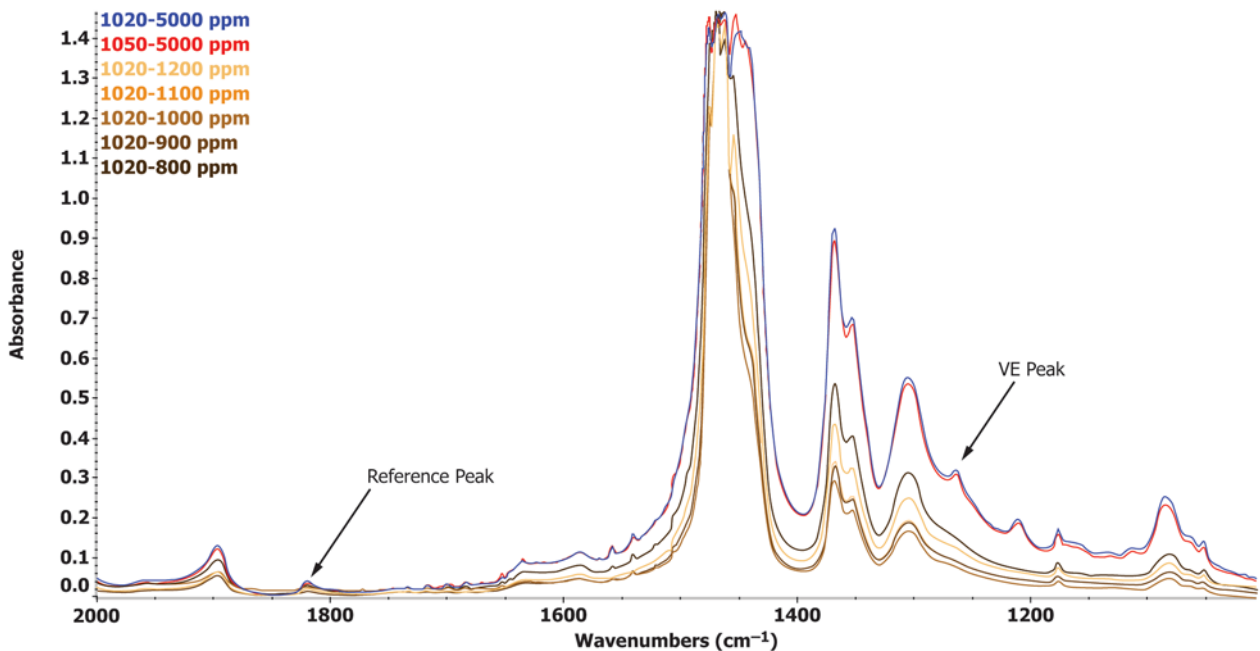
X1.2 Methods for characterizing alpha-tocopherol content in UHMWPE using an FTIR “Vitamin E Index” have been described in the literature (for example, Oral 2004, Ref (8)). According to an ASTM interlaboratory study, acceptable repeatability and reproducibility of FTIR to detect alpha-tocopherol has been demonstrated with 5000 ppm or greater concentration of antioxidant (Fig. X1.1). However, quantifying the “Vitamin E Index” in UHMWPE biomaterials containing 1200 ppm is below the detection limit of the published technique (Fig. X1.1).

X1.3 As a result, for UHMWPE biomaterials containing 1200 ppm or less Vitamin E, an indirect technique is advocated to infer the effectiveness of antioxidant in the polymer, and shall be conducted based on agreement between the supplier and the purchaser. Examples of inferring Vitamin E effective-

ness by accelerated aging are available in the scientific literature.

X1.4 There is some limited biocompatibility regarding cytotoxicity, genotoxicity, and animal studies designed to evaluate the potential transformation products of Vitamin E following consolidation and radiation of blended UHMWPE biomaterials (Refs (9-11)). These studies were performed using 8000 ppm blended UHMWPE (GUR 1020), which was irradiated with 25 kGy (Refs (9-11)), which results in the equivalent, and more voluminous, transformation products as 1000 ppm blended UHMWPE irradiated with 200 kGy. However, additional biocompatibility testing in accordance with ISO 10993 may be necessary in order to fully address the biocompatibility of degradation products of alpha-tocopherol (1) genotoxicity testing in a mammalian test system capable of detecting both gene level and chromosome level mutations; (2) irritation and sensitization testing; and (3) chronic toxicity and carcinogenicity testing. Additional testing to address the effect of degradation products of alpha-tocopherol on particulate mediated inflammatory response may also be required.

REFERENCES



NOTE 1—Also shown are spectra from vitamin E blended materials (1000 ± 200 ppm) which demonstrate too low of a vitamin E absorbance between 1245 and 1275 cm⁻¹ to calculate a Vitamin E index in accordance with Reference (8).

FIG. X1.1 Spectra of 5000 ppm GUR 1020 and GUR 1050 (blue and red, respectively) Demonstrating a Vitamin E Absorbance Between 1245 and 1275 cm⁻¹

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