

1 **Technical Considerations for**
2 **Additive Manufactured Devices**

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4
5 **Draft Guidance for Industry and**
6 **Food and Drug Administration Staff**

7
8 ***DRAFT GUIDANCE***

9
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11
12 **Document issued on May 10, 2016.**

13
14 You should submit comments and suggestions regarding this draft document within 90 days of
15 publication in the *Federal Register* of the notice announcing the availability of the draft
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17 comments to the Division of Dockets Management (HFA-305), Food and Drug
18 Administration, 5630 Fishers Lane, rm. 1061, Rockville, MD 20852. Identify all comments
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20 *Register*.

21
22 For questions regarding this document, contact the Division of Applied Mechanics at (301)
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24 at (301) 796-2507 or by email matthew.diprima@fda.hhs.gov. For questions about this
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U.S. Department of Health and Human Services
Food and Drug Administration
Center for Devices and Radiological Health
Center for Biologics Evaluation and Research

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Preface

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Additional copies are available from the Center for Biologics Evaluation and Research (CBER), by written request, Office of Communication, Outreach, and Development (OCOD), 10903 New Hampshire Ave., Bldg. 71, Room 3128, Silver Spring, MD 20993-0002, or by calling 1-800-835-4709 or 240-402-8010, by email, ocod@fda.hhs.gov or from the Internet at <http://www.fda.gov/BiologicsBloodVaccines/GuidanceComplianceRegulatoryInformation/Guidances/default.htm>.

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96 *This draft guidance, when finalized, will represent the current thinking of the Food and*
97 *Drug Administration (FDA or Agency) on this topic. It does not establish any rights for*
98 *any person and is not binding on FDA or the public. You can use an alternative approach*
99 *if it satisfies the requirements of the applicable statutes and regulations. To discuss an*
100 *alternative approach, contact the FDA staff or Office responsible for this guidance as*
101 *listed on the title page.*

102
103 **I. Introduction and Scope**
104

105 FDA has developed this draft guidance to provide FDA’s initial thinking on technical
106 considerations specific to devices using additive manufacturing, the broad category of
107 manufacturing encompassing 3-dimensional (3D) printing. Additive manufacturing (AM) is
108 a process that builds an object by iteratively building 2-dimensional (2D) layers and joining
109 each to the layer below, allowing device manufacturers to rapidly alter designs without the
110 need for retooling and to create complex devices built as a single piece. Rapid technological
111 advancements and increased availability of AM fabrication equipment are encouraging
112 increased investment in the technology and its increased use in medical devices. The purpose
113 of this guidance is to outline technical considerations associated with AM processes, and
114 recommendations for testing and characterization for devices that include at least one AM
115 fabrication step.
116

117 This draft guidance is broadly organized into two topic areas; Design and Manufacturing
118 Considerations (Section V) and Device Testing Considerations (Section VI). The Design and
119 Manufacturing Considerations section provides technical considerations that should be
120 addressed as part of fulfilling Quality System (QS) requirements for your device, as
121 determined by the regulatory classification of your device or regulation to which your device
122 is subject, if applicable. While this draft guidance includes manufacturing considerations, it
123 is not intended to comprehensively address all considerations or regulatory requirements to
124 establish a quality system for the manufacturing of your device. The Device Testing

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125 Considerations section describes the type of information that should be provided in premarket
126 notification submissions [510(k)], premarket approval (PMA) applications, humanitarian
127 device exemption (HDE) applications, de novo requests and investigational device exemption
128 (IDE) applications for an AM device. The type of premarket submission that is required for
129 your AM device is determined by the regulatory classification of your device.

130

131 Point-of-care device manufacturing may raise additional technical considerations. The
132 recommendations in this guidance should supplement any device-specific recommendations
133 outlined in existing guidance documents or applicable FDA-recognized consensus standards.
134 In addition, this guidance does not address the use or incorporation of biological, cellular, or
135 tissue-based products in AM. Biological, cellular or tissue-based products manufactured
136 using AM technology may necessitate additional regulatory and manufacturing process
137 considerations and/or different regulatory pathways. Therefore, all AM questions pertaining
138 to products containing biologics, cells or tissues should be directed to the Center for
139 Biologics Evaluation and Research (CBER).

140

141 This draft guidance is a leap-frog guidance; leap frog guidances are intended to serve as a
142 mechanism by which the Agency can share initial thoughts regarding emerging technologies
143 that are likely to be of public health importance early in product development. This leap-frog
144 guidance represents the Agency's initial thinking, and our recommendations may change as
145 more information becomes available. The Agency encourages manufacturers to engage with
146 the Center for Devices and Radiological Health (CDRH) and/or CBER through the Pre-
147 Submission process to obtain more detailed feedback for additively manufactured medical
148 devices. For more information on Pre-Submissions, please see "[Requests for Feedback on
149 Medical Device Submissions: The Pre-Submission Program and Meetings with FDA Staff -
150 Guidance for Industry and Food and Drug Administration Staff.](#)"

151

152 For the current edition of the FDA-recognized standards referenced in this document, see the
153 [FDA Recognized Consensus Standards Database Website](#).

154

155 FDA's guidance documents, including this guidance, do not establish legally enforceable
156 responsibilities. Instead, guidances describe the Agency's current thinking on a topic and
157 should be viewed only as recommendations, unless specific regulatory or statutory
158 requirements are cited. The use of the word *should* in Agency guidance means that
159 something is suggested or recommended, but not required.

160 **II. Background**

161

162 AM is a rapidly growing technology that is frequently used for product research and
163 development in many industries, and for commercial production in some industries (e.g.,
164 aerospace, medical devices). While different AM technologies exist, at the time of
165 publication of this draft guidance, the most commonly used technologies in the manufacture

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166 of medical devices are powder fusion, stereolithography, fused filament fabrication, and
167 liquid-based extrusion. Powder bed fusion systems rely on an energy source (laser or
168 electron beam) to selectively melt or sinter a layer of powder, either a metal or polymer,
169 which is then refreshed to create the next layer. Stereolithography systems use a vat of liquid
170 material that is selectively cured using light, either through a laser or projection system, and
171 create new layers by moving the build surface. Fused filament fabrication systems melt a
172 solid filament at the point of deposition, after which the material solidifies in place, and new
173 layers are created by moving the build surface away from the heat source. Liquid-based
174 extrusion systems eject a liquid, which then solidifies (the method of solidification could
175 include light exposure, solvent evaporation, or other chemical process), and new layers are
176 created by moving the build platform away from the deposition tip.

177

178 For medical devices, AM has the advantage of facilitating the creation of anatomically-
179 matched devices and surgical instrumentation by using a patient's own medical imaging.
180 Another advantage is the ease in fabricating complex geometric structures, allowing the
181 creation of engineered porous structures, tortuous internal channels, and internal support
182 structures that would not be easily possible using traditional (non-additive) manufacturing
183 approaches. However, the unique aspects of the AM process, such as the layer-wise
184 fabrication process, and the relative lack of medical device history of devices manufactured
185 using AM techniques, pose challenges in determining optimal characterization and
186 assessment methods for the final finished device, as well as optimal process validation and
187 acceptance methods for these devices. The FDA held a public workshop entitled "Additive
188 Manufacturing of Medical Devices: An Interactive Discussion on the Technical
189 Considerations of 3D Printing" on October 8-9, 2014 to discuss these challenges and obtain
190 initial stakeholder input.¹

191

192 The workshop provided a forum for medical device manufacturers, AM companies, and
193 academia to discuss technical considerations for AM medical devices. The workshop
194 focused on five broad themes: (1) materials; (2) design, printing, and post-printing
195 validation; (3) printing characteristics and parameters; (4) physical and mechanical
196 assessment of final devices; and (5) biological considerations of final devices, including
197 cleaning, sterility, and biocompatibility. While a variety of different types of materials can be
198 additively manufactured, workshop participants noted that material control is an important
199 aspect to ensure successful fabrication, and that final device performance is tied to the
200 machine and post-printing processes. The interaction between the material and machine was
201 also discussed in the process validation session, and the need for a robust process validation
202 and acceptance protocol appropriate to the risk profile of the final device was identified. AM
203 design procedures were also discussed, and the importance of having a good understanding of
204 the processes and limits in the design phase was identified. There was general agreement that

¹<http://www.fda.gov/MedicalDevices/NewsEvents/WorkshopsConferences/ucm397324.htm>

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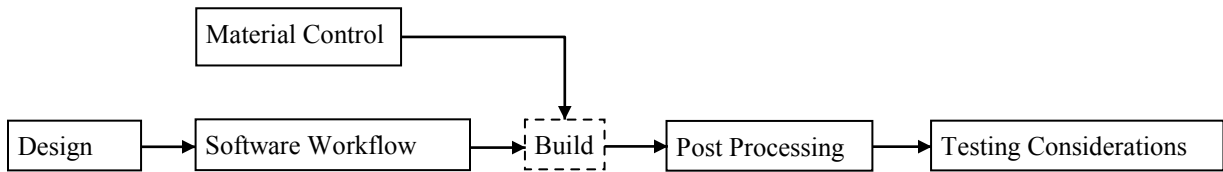
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205 printing parameters should be captured and validated for each machine/material combination.
206 The discussion on the physical and mechanical assessment focused heavily on validation of
207 the process and acceptance of devices and components after post-processing. The discussion
208 on the biological considerations revealed that there is a concern across the community
209 regarding how to achieve adequate cleaning, sterility, and biocompatibility of an AM device.
210 Specifically, the challenge of assessing and verifying these issues in porous or internally
211 complex devices was discussed. The feedback obtained at the workshop served as the basis
212 for this draft guidance.
213

214 **III. Overview**

215
216 The information, characterization, and testing necessary for a device made through AM may
217 depend on a variety of factors including, but not limited to, whether it is an implant, load
218 bearing, and/or available in pre-specified standard sizes or is patient-matched. This draft
219 guidance outlines technical aspects of an AM device that should be considered through the
220 phases of development, production process, process validation, and final finished device
221 testing. Not all considerations described will be applicable to a single device, given the
222 variety of AM technologies available. Similarly, not all considerations are expected to be
223 addressed in premarket submissions of AM devices. It is anticipated that AM devices will
224 generally follow the same regulatory requirements as the classification and/or regulation to
225 which a non-AM device of the same type is subject to. In rare cases, AM may raise different
226 questions of safety and/or effectiveness. In addition, this draft guidance only addresses
227 manufacturing considerations specific to the AM process. If it is unclear what technical
228 information should be provided in a premarket submission for an AM device, we strongly
229 encourage manufacturers to engage with FDA through the Pre-Submission process to obtain
230 more detailed feedback. For more information on Pre-Submissions, please see [“Requests for
231 Feedback on Medical Device Submissions: The Pre-Submission Program and Meetings with
232 FDA Staff - Guidance for Industry and Food and Drug Administration Staff.”](#)
233

234 The overall AM process and the related sections in this draft guidance are shown in the flow
235 chart below. The first step is the design process, which can include a standard design with
236 discrete pre-specified sizes and models, or a patient-matched device designed from a patient’s
237 own medical images. Once the device design has been created, the software workflow phase
238 begins, where the device design is further processed to prepare it for printing, printing
239 parameters are optimized, and the build file is converted into a machine-ready format.
240 Concurrently with this step, material controls are established for materials used in the
241 printing of the device. After printing is complete, post-processing of the built device or
242 component (e.g., cleaning, annealing, post-printing machining, sterilization) takes place.
243 After post-processing, the final finished device is ready for testing and characterization.
244 Your quality system should be applied across all of these processes.



254 **Figure 1:** Flow chart of the additive manufacturing process
255

256 IV Definitions

257
258 The following terms are defined for the purpose of this draft guidance and may not be
259 applicable to any other documents issued by the FDA.

260
261 **Build Cycle** – a single cycle in which one or more devices or components are built up in
262 layers in the process chamber of the machine.²

263
264 **Build Preparation Software** – the software used to convert the digital design to a format
265 that can be used to build a device or component through an AM process. This may include
266 multiple software components.

267
268 **Design Manipulation Software** – the computer program that allows a medical device design
269 to be modified for specific circumstances (e.g., patient-matching).

270
271 **Lot or Batch** – one or more components or finished devices that consist of a single type,
272 model, class, size, composition, or software version that are manufactured under essentially
273 the same conditions and that are intended to have uniform characteristics and quality within
274 specified limits.³

275
276 **Machine** – a system including the hardware, machine control software, required set-up
277 software, and peripheral accessories necessary to complete a build cycle.⁴

278
279 **Quality** – the totality of features and characteristics that bear on the ability of a device to
280 satisfy fitness for use, including safety and performance.⁵

²ASTM F2924 *Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion*

³21 CFR 820.3(m)

⁴ASTM F2924 *Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion*

281

282 **V Design and Manufacturing Process Considerations**

283

284 This section highlights technical considerations that should be addressed as part of fulfilling
285 Quality System (QS) requirements for your device. However, this draft guidance is not
286 intended to comprehensively address all regulatory requirements for a quality system. For
287 class II and class III devices and select class I devices, manufacturers must establish and
288 maintain procedures to control the design of the device in order to ensure that specified
289 design requirements are met per 21 CFR 820.30 Design Controls. Manufacturers must also
290 establish and maintain procedures for monitoring and control of process parameters for
291 validated processes to ensure that the specified requirements continue to be met.⁶

292 Alternatively, where the results of a process cannot be fully verified by subsequent inspection
293 and test, the process must be validated with a high degree of assurance and approved
294 according to established procedures.⁷ FDA interprets these regulations to require
295 manufacturers to establish procedures, including validation of the manufacturing process of
296 AM devices, to ensure that the device can perform as intended. Please note that exemption
297 from the requirement to submit a premarket notification (510(k)) does not mean a device is
298 exempt from compliance with QS requirements. Some devices are specifically exempted by
299 regulation from most QS requirements. Manufacturers should refer to applicable regulations
300 for their specific device type to determine what QS requirements apply. In this section, the
301 use of the terms “document,” “describe,” and “identify” refers to documentation requirements
302 according to the QS regulations and premarket submission requirements for manufacturing
303 information determined by the regulation of a specific device type or classification, regardless
304 of the method of manufacture.

305

306 There are several AM technologies and different combinations of processing steps which can
307 be used with each technology to build a device. Therefore, it is important to clearly identify
308 each step in the printing process. A production flow diagram that identifies all critical steps
309 involved in the manufacturing of the device, from the initial device design to the post-
310 processing of the final device, can help ensure product quality. In addition, a high-level
311 summary of each critical manufacturing process step may be helpful in documenting the AM
312 process used. The characterization of each process step should include, but need not be
313 limited to, a description of the process and identification of the process parameters and output
314 specifications. Since processes that optimize one design parameter may influence another,
315 information on processing steps should demonstrate your understanding of these trade-offs.
316 Additionally, the cumulative effects of prior processes on the final finished device or

⁵ 21 CFR 820.3(s)

⁶ 21 CFR 820.75(b)

⁷ 21 CFR 820.75(a)

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317 component should be incorporated into the development of each process step and
318 documented. The effects of the different steps in the AM processes can be seen in final
319 device testing; however, determining the root cause of failures from manufacturing defects
320 can be very difficult without a clear understanding of each step. For example, the ratio of
321 recycled to virgin powder can affect melting properties, which affects the energy needed to
322 create consistent bonding between layers, which in turn affects final mechanical properties.
323 Similarly, risks identified for each step of the manufacturing process, as well as mitigations
324 of these risks, should be documented. It is important to use all reasonably obtainable
325 knowledge about your specific machine’s capabilities to ensure the manufacturing process
326 outputs meet defined requirements.⁸ Quantitative knowledge of the machine’s capabilities
327 and limitations can be gained through test builds, worst-case builds, or process validation
328 (See section V.E Process Validation and Acceptance Activities and section VI.B Mechanical
329 Testing for more information).

330

331 As with traditional manufacturing methods, design requirements drive the processes that can
332 be used to reliably produce the device. It is therefore important to clearly identify key design
333 parameters for your device, including, but not limited to, size range and available design or
334 configuration options (e.g., range of angles between the trunnion and stem of the femoral
335 component of a hip arthroplasty device).

336

337 While this section includes manufacturing considerations, it is not intended to
338 comprehensively address all considerations or regulatory requirements for establishing a
339 quality system for the manufacturing of your device. Aspects of the “[Global Harmonization
340 Task Force Process Validation Guidance](#)” may be helpful in developing process validation
341 procedures. Additional information on design controls can be found in the “[Design Control
342 Guidance For Medical Device Manufacturers](#).” For general questions regarding quality
343 system regulations, contact the Division of Industry and Consumer Education (DICE), Office
344 of Communication and Education, at 1-800-638-2041 or 301-796-7100 or
345 DICE@fda.hhs.gov.

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A. Device Design

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(1) Standard-Sized Device Design

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Standard-sized devices, or devices offered in pre-established discrete sizes, are often made by AM if they include features that are too complex to be made using other techniques. The innovative potential of AM introduces variability into the design process that may not be present when using other manufacturing

⁸ISO 14971 *Medical devices - Applications of risk management to medical devices*

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356 techniques. Specifically, we recommend that you compare the minimum possible
357 feature size of your AM technique, in addition to the manufacturing tolerances of
358 the machine, to the desired feature sizes of your final finished device. This is to
359 ensure that devices and components of the desired dimensional specifications can
360 be reliably built using the chosen additive technology. Dimensional specifications
361 for the final device or component, as well as manufacturing tolerances of the
362 machine, should be documented. Pixelation of features, where smooth edges
363 become stepped, can lead to inaccuracies in final finished device dimensions.
364 Any pixelation of features caused by mismatch of machine resolution and model
365 resolution should be identified.
366

(2) Patient-Matched Device Design

367
368
369 Patient-matched devices can be based on a standard-sized template model that is
370 matched to a patient’s anatomy. Patient-matching can be accomplished by
371 techniques such as scaling of the device using one or more anatomic references, or
372 by using the full anatomic features from patient imaging. Note that while patient-
373 matched or patient-specific devices are sometimes colloquially referred to as
374 “customized” devices, they are not custom devices meeting the FD&C Act custom
375 device exemption requirements unless they comply with all of the criteria of
376 section 520(b). For further information on custom device exemptions, please
377 refer to the [Custom Device Exemptions guidance](#).
378

379 Patient-matched device designs may be modified either directly by clinical staff,
380 the device manufacturer, or a third party in response to clinical inputs. These
381 inputs may be acquired from individual measurements, clinical assessments,
382 patient imaging, or a combination thereof. Alterations to the final device, and the
383 methods used to make the alterations, may have direct consequences to the
384 patient. Therefore, you should clearly identify clinically-relevant design
385 parameters, the range (min/max) for these parameters, and which of these
386 parameters can be modified for patient-matching.
387

388 Considerations for standard-sized devices are applicable for patient-matched
389 devices. In addition, for patient-matched AM devices, we recommend that you
390 address the following, if applicable:

i. Effects of imaging

391
392
393
394 Many AM devices and components are derived from medical imaging data.
395 Not every medical device will need the same level of anatomic matching or
396 imaging accuracy for optimal device performance. Several factors may affect
397 the fit of AM devices that use patient imaging to precisely control their size or
398 shape, including, but not limited to:

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- the minimum image feature quality and resolution used for matching,
- any smoothing or image-processing algorithms that may alter the dimensions of the final device when compared to the reference anatomy,
- the rigidity of the anatomic structures being imaged, and
- the clarity of anatomic landmarks used to match the device to the patient's anatomy.

If the device relies on anatomic features that are not accurately imaged or are not consistent over time, then the final device may not fit the patient. However, small changes in size or geometry may be difficult to identify during visual inspection of the device or through evaluation of patient imaging, and the mismatch may only be identified during device use. Process validation (see section V.E.1) is especially important to prevent these situations. In addition, for devices intended to be fitted to or matched to soft tissues and non-rigid structures, deformation of the tissue is likely to impact the worst-case size and placement. Therefore, it is important to note the range of deformation experienced by the target location or tissue compared to the reference image.

You should also consider the potential time constraints associated with producing an AM device based on the intended use of your device. Specifically, when the device is intended to match a patient's anatomy, and that anatomy can change over time (e.g., with disease progression), the time that can elapse between when the patient is imaged and when the final device is used should be reflected in the expiration date of the device (see section VI.G Additional Labeling Considerations). Many implantable devices and their patient-matched accessories depend on the patient's anatomy being identical to the recorded images in order for the device to function as intended. Therefore, the labeled shelf life of the device should account for the potential for time-dependent changes to the patient anatomy before the device is used.

ii. Interacting with design models

Patient-matched devices are often made by altering the features of a standard-sized device for each patient within a pre-determined range of device designs and size limits. This is typically accomplished through the use of anatomic-matching or design manipulation software that may be developed specifically for the AM device or through the use of other third party software. Patient-matching may also be accomplished by manual methods using specific measurements on radiographs or key anatomic landmark measurements. Any software or procedure used to make modifications to the device design based on clinical input should include internal checks that prevent the user from

442 exceeding the pre-established device specifications documented in the device
443 master record. We recommend that the design manipulation software identify
444 the iteration of the design the user is making changes to. You should also
445 identify all medical devices and accessories that the design manipulation
446 software is validated to work with.

447
448

449 **B. Software Workflow**

450

451 **(1) File Format Conversions**

452

453 AM involves interaction between several software packages, often from different
454 manufacturers, which requires files to be compatible across the different software
455 applications used. Patient images (e.g., computed tomography (CT) or magnetic
456 resonance (MR) imaging), design manipulation software for patient-matching,
457 digital point clouds and meshes (e.g., Additive Manufacturing (AMF),
458 STereoLithography (STL), 3D Graphic (STP) file formats), and machine-readable
459 files (e.g., sliced files, build files, g-code) each have their own standards,
460 coordinate systems, and default parameters. Errors in file conversion can
461 negatively impact final finished device and component properties, such as
462 dimensions and geometry. Patient-matched devices that follow the patient
463 anatomy precisely are especially vulnerable to these errors because anatomic
464 curves are typically geometrically or mathematically complex and can create
465 difficulties when calculating conversions. Additionally, for patient-matched
466 devices, all of the file conversion steps are typically performed for every device,
467 whereas for a standard-sized device, most of the file conversion steps would be
468 performed once during the design phase. Therefore, we recommend that you test
469 all file conversion steps with simulated worst-case scenarios to ensure expected
470 performance, especially for patient-matched devices. Factors that may cause
471 unexpected conversion failures, such as changes to the software used, may trigger
472 the need for revalidation (see section V.E.2 Revalidation).

473

474 When possible, final device files for printing should be maintained and archived
475 in robust, standardized formats that are able to store AM-specific information,
476 such as the Additive Manufacturing File format (AMF) described in the
477 ISO/ASTM 52915 *Standard specification for additive manufacturing file format*
478 *(AMF)*. This file format should include material information and the location of
479 objects in a build volume and have high geometric fidelity (e.g., curved patches).

480

481 **(2) Digital Device Design to Physical Device**

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483 When a digital device design is finalized, additional preparatory processes are
484 needed before the device can be additively manufactured. This is commonly
485 accomplished using build preparation software. These processes can generally be
486 divided into four steps: 1) build volume placement, 2) addition of support
487 material, 3) slicing, and 4) creating build paths.
488

i. Build Volume Placement

489
490
491 Placement and orientation of devices or components within the build volume
492 is integral to individual device or component quality. The distance between
493 each device or component can affect the material properties (e.g., poor
494 consolidation or curing), surface finish, and ease of post-processing.
495 Orientation of each device or component can also impact its functional
496 performance by affecting the anisotropic properties of the device or
497 component. Similarly, all machines have areas of the build volume where
498 they function optimally and areas where they do not function optimally. For
499 example, printing may be sub-optimal in the regions near the outer edge of the
500 build volume and optimal at the center. The affected region may be different
501 for every machine, even between machines of the same model.
502

ii. Addition of Support Material

503
504
505 Some types of AM require temporary support structures for certain design
506 features during printing due to the layer-by-layer printing process. The
507 location, type, and number of supports can affect the geometric accuracy and
508 mechanical properties of the final finished device or component. Each AM
509 technology has different needs for support material that must be met for the
510 successful printing of a device. For example, the critical overhang angle may
511 be different for a stereolithography machine, extrusion-based machine, and a
512 metal powder bed fusion machine. Automated algorithms are often used to
513 choose the location and number of supports. However, geometric
514 complexities or printing limits often necessitate further manual intervention.
515 Therefore, if your AM process requires support material, we recommend that
516 you analyze the geometry and other requirements that could be affected by
517 adding supports. Some common structures that may need support are:
518

- 519 • overhangs,
- 520 • high aspect ratio features that protrude from the main body of the
521 device or component,
- 522 • internal features (e.g., voids, channels), and
- 523 • thin features prone to warping.
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525 Support material can be removed physically (e.g., abrasion, melting) or by
526 chemical means. Support material that is physically removed may leave
527 surface defects that should be addressed in the post-processing phase of
528 production. Support material that is chemically removed may leave residue on
529 or within the built device or component. Cleaning processes should ensure
530 that residues are removed (see section VI.E Cleaning and Sterilization).
531 Information about how support material will be used and processed should be
532 included in the Device Master Record (DMR), including documents such as
533 work flow diagrams and work instructions.

534

535

iii. Slicing

536

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Your choice of layer thickness should be documented, and reflect a balance among the above-mentioned effects, accuracy, quality, and printing speed.

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iv. Build Paths

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The build path, the path traced by the energy or material delivery system (e.g., laser or extruder), can impact the quality of the final finished device or component. For example, if the delivery system sweeps from left to right on the build volume, then makes the next pass from right to left, one side of the device or component has more time to cool or harden. Similarly, the space between each line of the build path and the path speed will change the amount of melting and re-melting that the boundaries of each line of material will experience. In addition, the build path will result in an orientation or anisotropy in the device or component. Therefore, it is important to maintain consistency of the build path between identical devices and components. If more than one build path is used, each build path should be documented. We

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568 also recommend that you assess whether differences in the build path
569 significantly affect the performance of each component or device.

570

571 When the path of the delivery system is generated by the build preparation
572 software, the fill density of a component can be specified separately from
573 patterns in the component's geometry. For example, if the geometry shows a
574 solid wall, it is possible to fill that solid space with a sparse honeycomb
575 instead. These voids are easily formed with an extrusion-based machine. The
576 fill density of parts that are not fully dense (i.e., not a solid) should be
577 documented. If a non-solid fill density is used, we recommend that you
578 identify whether internal voids are externally accessible or sealed. If the voids
579 are sealed, you should identify the fluid or gas that fills the voids. The risk
580 associated with patient exposure to the materials in the voids should also be
581 assessed.

582

v. Machine Parameters and Environmental Conditions

583

584
585 Each AM technology and machine model has a unique set of parameters and
586 settings that can be modified by the device manufacturer and a unique set of
587 those that are configured at the time of calibration (typically by the machine
588 manufacturer). Maintaining proper calibration and performing preventative
589 maintenance have been identified as key factors to achieve low rejection rates
590 of devices and components from an individual machine.

591

592 Environmental conditions within the build volume can also affect the part
593 quality. For machines without a self-contained build volume, the ambient
594 temperature, atmospheric composition and flow patterns can impact
595 solidification/polymerization rate, layer bonding, and the final mechanical
596 properties of the component. Therefore, it is critical to establish and maintain
597 procedures to adequately control environmental conditions within the build
598 volume.

599

600 Optimal settings and parameters for a single model of a machine can vary
601 greatly when printing different devices or components. They can likewise
602 vary greatly between one machine of the same model and another when
603 printing the same devices or components. Some parameters that can be
604 modified by the device manufacturer and may have a significant impact on the
605 device or component quality include, but are not limited to:

606

- 607 • instantaneous power of the energy delivery system (e.g., temperature
608 gradients of deposition nozzle for fused filament systems, energy
609 density of laser or electron beam for powder bed fusion or
610 stereolithography),

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- 611 • build speed or beam speed,
- 612 • build path,
- 613 • total energy density, and
- 614 • focal point or nozzle diameter.

615
616 Machine parameters should be documented, and the machine should be
617 qualified for use in its installation location. Aspects of the “[Global](#)
618 [Harmonization Task Force Process Validation Guidance](#)” also address
619 Installation Qualification.
620
621

C. Material Controls

(1) Starting Material

622
623
624 In the AM process, the starting material may undergo significant physical and/or
625 chemical changes. As such, the starting material can have a significant effect on
626 the success of the build cycle, as well as on the properties of the final finished
627 device. It is therefore, important to document the following information regarding
628 each starting material used, as well as any processing aids, additives, and cross-
629 linkers used:
630
631

- 632 • identity of the material or chemical by common name, chemical name,
633 trade names, and Chemical Abstracts Service (CAS) number,
- 634 • material supplier, and
- 635 • incoming material specifications and material certificates of analysis
636 (COAs), with the test methods used for the COAs.
637
638

639 The specifications for incoming materials and test methods should be based on the
640 AM technology used (i.e., material specifications will be different for powder-
641 based vs. stereolithography machines). Examples of specifications for commonly
642 used material types and machine technologies may include, but are not limited to:
643

- 644 • if the material is a solid: particle size and size distribution for powders or
645 filament diameter and diametric tolerances for filaments,
- 646 • if the material is a fluid: viscosity or viscoelasticity, pH, ionic strength,
647 and pot life,
- 648 • if the material is a polymer or monomer mixture: composition, purity,
649 water content, molecular formula, chemical structure, molecular weight,
650 molecular weight distribution, glass transition temperatures, and melting
651 and crystallization point temperatures,

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- 652 • if the material is a metal, metal alloy, or ceramic: chemical composition
653 and purity,
- 654 • if the material is of animal origin, refer to: “[Medical Devices Containing](#)
655 [Materials Derived from Animal Sources \(Except for In Vitro Diagnostic](#)
656 [Devices\)](#).”

657

658 In addition, when any material specification is changed, the effect on the build
659 process and the final device should be well understood and documented.

660

661 **(2) Material Recycling**

662

663 Some additive manufacturing approaches (e.g., powder bed fusion,
664 stereolithography) allow efficient use of raw material by recycling the material
665 that is not incorporated into the device (e.g., unsintered powder or uncured resin).
666 However, the reused material could be exposed to conditions (e.g., heat, oxygen,
667 humidity, ultraviolet energy) that may alter it from the virgin state. Therefore, we
668 recommend that you describe the material recycling process, which may include,
669 but is not limited to, a description of recycling processes such as filtering recycled
670 material, or monitoring for changes in chemistry, oxygen, or water content. We
671 also recommend that you document evidence that material recycling does not
672 adversely affect the final device. This may include an assessment of the recycling
673 protocol by conducting studies on the effect of material recycling on the properties
674 of the final finished device (see section V.E.1 Process Validation).

675

676

677 **D. Post-Processing**

678

679 Final device performance and material properties can be affected by post-processing
680 steps of AM (i.e., manufacturing steps occurring after the printing process). These
681 steps could range from cleaning excess starting material from the device, through
682 annealing the device to relieve residual stress, to final machining. All post-processing
683 steps should be documented and include a discussion of the effects of post-processing
684 on the materials used and the final device. We recommend that you identify any
685 potentially detrimental effects of post-processing and describe mitigations
686 implemented. For example, while annealing will remove residual stress to prevent
687 warping, it may lower the strength of the device, which could be mitigated by a
688 subsequent surface hardening process or by altering the design to accommodate a
689 lower material strength.

690

691 Devices that are intended for applications where fatigue is a factor may require
692 minimum surface finish or roughness to reduce the chance of failure. The desired
693 surface roughness can often be achieved through various post-processing steps (e.g.,

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694 mechanical polishing); however, hard-to-reach spaces may remain in the as-built
695 state. These spaces should be assessed for their effects on mechanical performance
696 (including fatigue) of the device or component.

697
698

E. Process Validation and Acceptance Activities

700

(1) Process Validation

701

702
703 Device quality, such as feature geometry, overall dimensions, material
704 characteristics, and mechanical properties, are impacted by AM process
705 parameters, process steps, and raw material properties, as described in the sections
706 above. In addition, quality may vary when identical devices or components are
707 built using different machines, even when the same machine model, parameters,
708 process steps, and raw materials are used. Therefore, knowledge of how the
709 variability of each input parameter and processing step affects the final finished
710 device or component is critical to ensuring part quality. Process validation must
711 be performed to ensure and maintain quality for all devices and components built
712 in a single build cycle, between build cycles, and between machines, where the
713 results of a process (i.e., output specifications) cannot be fully verified by
714 subsequent inspection and test.⁹ Software also must be validated for its intended
715 use according to an established protocol¹⁰ (i.e., software workflow).

716

717 For validated processes, the monitoring and control methods and data must be
718 documented.¹¹ Methods for ensuring the consistency of quality could include:

719

- 720 • in-process monitoring¹² of parameters such as:
 - 721 ○ temperature at the beam focus,
 - 722 ○ melt pool size,
 - 723 ○ build-space environmental conditions (e.g., temperature, pressure,
724 humidity),
 - 725 ○ power of the energy delivery system (e.g., laser, electron beam,
726 extruder), or
 - 727 ○ status of mechanical elements of the printing system (e.g., recoater,
728 gantry);

⁹ See 21 CFR 820.75(a)

¹⁰ See 21 CFR 820.70(i), and [“General Principles of Software Validation: Final Guidance for Industry and Staff.”](#)

¹¹ See 21 CFR 820.75(b)(2)

¹² In-process monitoring may also be helpful for processes that are not validated, but is not required.

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- 729
- manual or automated visual inspection with defined acceptance criteria;
 - 730 • non-destructive evaluation (see section V.E.3 Acceptance Activities); and
 - 731 • test coupon evaluation (see section V.E.4 Test Coupons).
- 732

733 Test methods used for process monitoring and control must be validated.¹³ For
734 example, analysis should be conducted to confirm that test coupons used are
735 representative of the final finished device or component and representative of a
736 certain area within the build volume.

737

738 A single failed component or device in a build cycle may not necessitate all
739 devices or components within that build cycle to also be rejected. The criteria for
740 determining whether to reject a single device or component, or the entire build,
741 should be established before testing.

742

(2) Revalidation

743

744 Changes to the manufacturing process or process deviations can trigger the need
745 for revalidation, and these changes or deviations should be identified for each
746 process. Some examples of triggers for revalidation specific to AM may include:

747

- 748 • certain software changes (e.g., change or update of build preparation
749 software),
 - 750 • changes in material (e.g., supplier, incoming material specification, ratio
751 of recycled powder) or material handling,
 - 752 • change in the spacing or orientation of devices or components in the build
753 volume,
 - 754 • changes to the software workflow (see section V.B.2 Digital Device
755 Design to Physical Device),
 - 756 • physically moving the machine to a new location, and
 - 757 • changes to post-processing steps or parameters.
- 758

(3) Acceptance Activities

759

760 Acceptance activities are integral to process control. Many AM technologies can
761 produce more than one device or component simultaneously on different locations
762 in the build volume. These devices or components can be copies of a single
763 design or different designs. This poses a unique challenge in ensuring
764 repeatability and consistency within a build cycle and across lots.

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¹³See 820.72(a) and 820.250(a)

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Some acceptance activities for individual devices or components can be performed through non-destructive evaluation (NDE). Specifically, NDE techniques can be used for the verification of geometry, microstructure, and some performance characteristics. Techniques include, but are not limited to:

- ultrasound,
- computed tomography (CT) or micro-CT,
- X-ray (in cases where the geometry is simple),
- confocal microscopy, and
- hyperspectral imaging.

Some techniques are not suitable for some materials or designs. The ASTM Committee on Nondestructive Testing has published general NDE testing protocols and the ASTM Committee on Additive Manufacturing Technologies has developed protocols specific to AM¹⁴. If an NDE technique is used in your process validation or acceptance activities, the choice of technique should be discussed and documented.

(4) Test Coupons

A test coupon is a representative test sample of the device or component. The design of test coupons and placement within the build volume is especially important for AM. Coupons can be simple shapes suitable for destructive mechanical testing, or they may contain one or more structural features (e.g., surface porosity, internal channels) representative of the component or device that can be assessed using destructive techniques. We recommend that coupons be used for your process validation, and to identify worst-case conditions in your manufacturing process (e.g., worst-case orientation and location in build volume). Test coupons can also be used for in-process monitoring by placing them in build volume locations that are known to have the worst-case outputs. These test coupons can confirm that the components or devices built in the same build cycle will meet specifications if the test coupons also meet these specifications. For example, test coupons may be placed at the edges of the build volume if edges are known to have less optimal build quality. They may also be placed randomly in between components or devices to produce a sampling of the build quality. Data

¹⁴ <http://www.astm.org/COMMIT/SUBCOMMIT/F42.htm>

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803 to demonstrate that test coupons are representative of the components, in-process
804 devices, or finished devices should be documented.

805

806

807 **F. Quality Data**

808

809 The analysis of sources of quality data to identify existing and potential causes of
810 nonconforming product, or other quality problems is an essential part of any quality
811 system. For devices produced by AM, it is important to consider whether it is
812 necessary to keep track of the location in the build volume where a device or
813 component was built. This will depend on information obtained during process
814 validation activities and design specifications. For example, if process validation
815 demonstrated that quality is not affected by location in the build volume, it may not be
816 necessary to be able to keep track of the build volume location for each device. This
817 level of specificity is important in identifying possible causes of failure when multiple
818 different components or devices are made in the same build volume at the same time.
819 Therefore, you should ensure that quality data such as build volume location can be
820 analyzed to enable proper identification of quality problems and investigation of the
821 cause of nonconformities.

822

823

824 **VI Device Testing Considerations**

825

826 The following section contains a description of the type of information that we recommend
827 that you include in a premarket submission of a device made using AM. The type and
828 amount of data to support a substantial equivalence determination or approval will vary
829 depending on the intended use, risk profile, and classification and/or regulation for the device
830 type. In addition, the type of information needed for a device made through AM may also
831 depend on a variety of factors, including, but not limited to, whether it is an implant, load
832 bearing, and/or available in pre-specified standard sizes or is patient-matched. Not all
833 considerations described will be applicable to a single device, given the variety of devices
834 that can be made by AM and the AM technologies available. In general, if the type of
835 characterization or performance testing outlined in each of the sub-sections below is needed
836 for a device made using non-AM techniques, the information should also be provided for an
837 AM device of the same device type. If you have specific questions regarding the information
838 to support a premarket application for an AM device, please contact the relevant review
839 division in CDRH or contact CBER for products containing biologics, cells or tissues.

840

841

842 **A. Device Description**

843

844 AM facilitates the creation of intermediate and customized device sizes. Patient-
845 matched devices are a good example of this application. Since these devices may not

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846 have discrete sizes, such as small, medium, and large, we recommend that you
847 identify the range of dimensions for your device. In addition, you should describe any
848 design variations, for example the amount of anatomical coverage for a cranioplasty
849 plate. Any critical dimensions or features that are intended to be altered to match a
850 patient should be clearly identified, and the range of allowable values for these
851 parameters should also be identified. Since each type of AM technology has different
852 technical considerations, you should describe the type of AM technology used to build
853 your device. In addition, because AM use for medical devices is relatively new, we
854 recommend that you include a flow chart describing your AM process, including post-
855 processing, in order to help determine if additional assessments are needed.

856
857 Due to the generally complex geometry of AM devices, we recommend that critical
858 features of the device be clearly described in the device description and identified in
859 technical drawings. For example, the location and thickness of porous scaffolding
860 should be described, as these features may have reduced mechanical properties in
861 comparison to a solid material. In the technical drawings of your device we
862 recommend that you identify components made using AM.

863
864

B. Mechanical Testing

865

866
867 The type of performance testing that should be conducted on a device made using AM
868 is generally the same as that for a device manufactured using a traditional
869 manufacturing method. Depending on the device type, these may include material
870 property testing such as, but not limited to, modulus, yield strength, ultimate strength,
871 creep/viscoelasticity, fatigue, and abrasive wear. Performance testing should be
872 conducted on final finished devices subjected to all post-processing, cleaning, and
873 sterilization steps or on coupons, if the coupon undergoes identical processing as the
874 final finished device. In addition, the worst-case combinations of dimensions and
875 features (e.g., holes, supports, porous regions) should be considered when
876 determining the worst-case devices for performance testing. You should also provide
877 a discussion of how the worst-case devices were selected for each performance test
878 conducted.

879

880 Due to the nature of AM, devices will have an orientation (i.e., anisotropy) relative to
881 the build direction and location within the build space. The orientation and build
882 location can affect the final properties and should be considered when conducting
883 device mechanical testing. Specifically, the build orientation (including worst-case
884 orientation) of devices or components should be identified for each performance test.
885 If the orientation changes with device size or design, the worst-case orientation should
886 be identified for each configuration. Since the effect of orientation can vary based on
887 the manufacturing technology used, a baseline study of the machine/material
888 combination used may be helpful in determining the degree to which the build

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889 orientation will affect mechanical properties. Coupons may be used for material
890 property assessments if the coupon undergoes identical processing (including post-
891 printing processes, cleaning, and sterilization) to that of the final finished device.
892 This information can be used to aid in the selection of worst-case samples with
893 respect to orientation.

894
895 In addition, for some AM machines, the location within the build space can have an
896 effect on mechanical properties.¹⁵ For example, for a powder bed system, the
897 difference in distance from the energy source to different locations in the build space
898 (e.g., center vs. corner) could lead to variability in the mechanical properties of
899 devices built in those locations. To determine whether build location has a significant
900 effect on device characteristics or performance (including fatigue strength), we
901 recommend that you perform a baseline study of your machine/material combination
902 (see section V.E.1 Process Validation). The use of coupons for your baseline study is
903 recommended. If there is a significant effect, build location should be considered in
904 the identification of worst-case samples for mechanical testing.

905
906 Since mechanical properties of the device may be impacted by orientation and
907 location, it is important to ensure that production processes are properly developed,
908 conducted, controlled, and monitored to ensure devices or components are not
909 adversely affected by fabrication orientation. The information on the impact of
910 orientation and location may be leveraged from process validation described in
911 section V.E. Process Validation and Acceptance Activities.

912
913

C. Dimensional Measurements

914

915
916 Similar to mechanical properties, device dimensions may be affected by orientation
917 and location within the build space. Therefore, we recommend that you specify the
918 dimensional tolerances and perform dimensional measurements for each additively
919 manufactured component. Samples selected for dimensional measurements should
920 address variability due to orientation and build location if baseline studies show a
921 dependence on these parameters. To demonstrate consistency and reproducibility
922 between build cycles, dimensional measurements should be made on samples from
923 multiple build cycles, and a justification should be provided on the sampling scheme
924 used. Alternatively, you may use process validation information to demonstrate that
925 there is negligible variability between build cycles.

926

¹⁵ASTM F3122 “*Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes*”

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927 While we are aware of the potential effects of orientation and build location on
928 mechanical properties and dimensional tolerances, there may be other properties that
929 could be affected based on the intended use and technological characteristics of the
930 device.

931

932 **D. Material Characterization**

933

934 **(1) Material Chemistry**

935

936 Since the AM process creates the final material or alters the starting material
937 during the process, all materials involved in the manufacturing of the device
938 should be identified. As noted in section V.C Material Controls, this information
939 should include the source and purity of each material used. Certificates of
940 Analysis and/or Materials Safety Data Sheets (MSDS) can facilitate the review of
941 each material. The Chemical Abstract Service (CAS) number, if available, of
942 each chemical component should be provided. If material chemistry information
943 in a device master file (MAF) will be referenced, you should include a right to
944 reference letter from the MAF holder in your premarket submission.¹⁶ You
945 should also document the chemical composition of the final finished device.

946

947 Given the iterative nature of AM, the starting material can be exposed to partial
948 re-melting and solidification processes multiple times, which may result in
949 unexpected or undesired material chemistries for some polymer systems.
950 Therefore, if biocompatibility is not evaluated as described in the guidance [“Use
951 of International Standard ISO-10993, ‘Biological Evaluation of Medical Devices
952 Part 1: Evaluation and Testing.’”](#) or if biocompatibility testing identifies a
953 concern, additional material chemistry information may be needed, such as a
954 description of all material chemistry changes expected during the manufacturing
955 of your device. In addition, based on this description and the material/machine
956 type used, it may also be necessary to provide additional information or testing for
957 polymers to ensure that there are no unintentionally formed chemical entities that
958 could pose a risk to patient health.

959

960 **(2) Material Physical Properties**

961

962 Inter-layer bonding (adhesion/cohesion) is unique to AM and determines the
963 ultimate structural integrity of the final finished device. As such, material

¹⁶<http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/HowtoMarketYourDevice/PremarketSubmissions/PremarketApprovalPMA/ucm142714.htm>

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964 properties known to affect interlayer bonding should be characterized. This
965 information should be representative of the final finished device (subjected to all
966 post-processing, cleaning, and sterilization steps). Material properties can be
967 determined from the final device or by using coupons. If coupons are used, a
968 description of the coupon and a justification for why coupon testing is
969 representative of the final device should be provided.

970

971 If your device is additively manufactured using metal or ceramic, we recommend
972 that you characterize the grain size and orientation, as well as phase composition
973 and microstructure. If the AM process results in structural inhomogeneity,
974 microstructural voids, incomplete consolidation, or other microstructural issues,
975 additional mechanical testing may be needed to show that these issues do not
976 affect device performance.

977

978 If your device is additively manufactured using a polymer, we recommend that
979 you characterize the shore hardness and presence of voids or evidence of
980 incomplete consolidation to ensure that the AM process is creating a device or
981 component with uniform properties. For AM processes that utilize polymer
982 crosslinking, the percent crosslinking and degree of curing should be evaluated to
983 ensure that the AM process results in a material that is fully cured and has uniform
984 properties. For systems using a crystalline or semi-crystalline material,
985 crystallinity and crystalline morphology should be characterized to ensure that the
986 AM process is not adversely altering the polymer structure and subsequently
987 altering the performance (e.g., creep, material transparency) of the final device.
988 For hydrogel materials, the percent water swelling or water content of the material
989 should be reported to ensure that that the AM process has not adversely affected
990 the materials' ability to uptake water.

991

992 If your device is additively manufactured using an absorbable material, we
993 recommend that you perform *in vitro* degradation testing using final finished
994 devices or coupons. If coupons are used, they should be representative of your
995 final finished device in terms of both processing and properties (e.g., surface-to-
996 volume ratio, crystallinity). This will establish whether AM has an adverse effect
997 on the degradation profile of the material.

998

999

1000

E. Cleaning and Sterilization

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AM facilitates the creation of devices with complex geometries, such as engineered porosity, honeycomb structures, channels, and internal voids or cavities that cannot be produced by traditional manufacturing methods. Such complex geometries in additively manufactured devices are expected to increase the difficulty for cleaning and sterilization due to the likelihood of increased surface area, generation of

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1007 extensive tortuous pathways, and creation of internal voids with limited or no access.
1008 Additionally, AM allows porous structures to be produced earlier in the
1009 manufacturing process than traditional methods, which could result in greater soiling
1010 of those porous structures. Therefore, cleaning process validation and sterilization
1011 process validation should account for the complex geometry of your device under
1012 worst-case conditions (e.g., greatest amount of residual manufacturing materials for
1013 cleaning validation, and a combination of largest surface area, greatest porosity, and
1014 most internal voids for sterilization validation). Manufacturing material means any
1015 material or substance used in or used to facilitate the manufacturing process, a
1016 concomitant constituent, or a byproduct constituent produced during the
1017 manufacturing process that is present in or on the final finished device as a residue or
1018 impurity and not by design or intent of the manufacturer.¹⁷ There is also an increased
1019 risk of residual manufacturing material, such as excess starting material or support
1020 material, remaining on the final finished device. Since residual manufacturing
1021 material may negatively impact the performance of the device, you should describe
1022 how the cleaning process used ensures adequate removal of residual manufacturing
1023 materials as part of the cleaning validation process. Note that for complex geometries
1024 and trapped volumes, destructive testing may be needed to properly validate the
1025 cleaning method. In addition, we recommend using final finished devices for
1026 validation of the cleaning process, and final finished devices after they have
1027 undergone the cleaning process for validation of the sterilization process. For
1028 additional information on sterilization, see “[Submission and Review of Sterility
1029 Information in Premarket Notification \(510\(k\)\) Submissions for Devices Labeled as
1030 Sterile - Guidance for Industry and FDA Staff.](#)”

1031
1032 It is important to note that many end user facilities may not have routine access to the
1033 equipment or materials needed to implement cleaning procedures that are designed to
1034 remove residual manufacturing materials and are likely not to have personnel who are
1035 adequately trained to perform cleaning procedures to remove residual manufacturing
1036 materials. In addition, where a manufacturing material could reasonably be expected
1037 to have an adverse effect on device quality, the manufacturer must establish and
1038 maintain procedures for the use and removal of such manufacturing material to ensure
1039 that it is removed or limited to an amount that does not adversely affect the device's
1040 quality. 21 CFR 820.70(h). Therefore, for devices manufactured using AM, only
1041 devices that are cleaned of manufacturing materials should be provided to the end
1042 user. We recommend that you include information in your premarket submission to
1043 indicate that your device is cleaned of manufacturing materials before being provided
1044 to the end user. In addition, due to the challenges posed by the complex geometry of

¹⁷ See 21 CFR 820.3(p)

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1045 some AM devices, you should consider sterilizing your device prior to providing the
1046 device to the end user.

1047

1048 If additively manufacturing a reusable medical device involves reprocessing in health
1049 care facilities, we recommend the inclusion of reprocessing instructions in your
1050 device labeling. Please refer to the guidance, [“Reprocessing Medical Devices in
1051 Health Care Settings: Validation Methods and Labeling - Guidance for Industry and
1052 Food and Drug Administration Staff.”](#)

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F. Biocompatibility

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We recommend that you evaluate the biocompatibility of the final finished device as described in the guidance [“Use of International Standard ISO-10993, ‘Biological Evaluation of Medical Devices Part 1: Evaluation and Testing.’”](#) If chemical additives with known toxicities are used (e.g., certain additives, catalysts, binding and curing agents, uncured monomers, plasticizers), additional information may be necessary.

G. Additional Labeling Considerations

Device labeling should be developed in accordance with applicable regulations, device-specific guidance documents, and consensus standards. Since clinical staff, device manufacturers, or a designated 3rd party might modify the design of each patient-matched device, additional labeling information is recommended for AM devices that are patient-matched. Each patient-matched device should be marked or have accompanying physician labeling included in the packaging to identify the:

- patient identifier,
- details identifying use, such as anatomical location (e.g., left distal femoral surgical guide), and
- final design iteration or version used to produce the device.

The expiration date for a patient-matched device may be driven by the patient imaging date or the design finalization date rather than the standard methods of determining device shelf life (see section V.A.2 Patient-Matched Device Design). In addition, it is possible that the patient may have experienced events between the time of imaging and surgery (e.g. additional trauma) that could impact performance of the device. Therefore, we recommend that you include a precaution in your labeling that the patient should be surveyed for potential anatomical changes prior to the procedure.