



**International
Standard**

ISO 25539-3

**Cardiovascular implants —
Endovascular devices —**

**Part 3:
Vena cava filters**

*Implants cardiovasculaires — Dispositifs endovasculaires —
Partie 3: Filtres de veine cave*

**Second edition
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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Contents

Page

Foreword	v
Introduction	vi
1 Scope	1
2 Normative references	1
3 Terms and definitions	2
4 General requirements	5
4.1 Classification	5
4.2 Materials of construction for filter system	5
4.3 Configuration and size designation for filters	6
4.4 Intended clinical use designation	6
5 Intended performance	6
6 Design attributes	6
6.1 General	6
6.2 Filter system	6
6.3 Vena cava filter	6
6.4 Optional filter	7
6.5 Convertible filter	7
6.6 Retrieval system	7
6.7 Conversion system	7
6.8 Filter system, retrieval system and conversion system	7
6.9 Coating on delivery system or filter	8
6.10 Absorbable filter or coating	8
7 Materials	8
8 Design evaluation	8
8.1 General	8
8.2 Sampling	9
8.3 Conditioning of test samples	10
8.4 Reporting	10
8.5 Bench and analytical tests	11
8.5.1 General	11
8.5.2 Filter system	11
8.5.3 Vena cava filter	13
8.5.4 Optional filter	15
8.5.5 Convertible filter	16
8.5.6 Retrieval system	16
8.5.7 Conversion system	17
8.5.8 Filter system, retrieval system and conversion system	18
8.5.9 Coating on the delivery system, the retrieval system, the conversion system or the filter	19
8.5.10 Absorbable filter or coating	19
8.6 Preclinical in vivo evaluation	20
8.6.1 Purpose	20
8.6.2 Specific aims	20
8.6.3 Protocol considerations	21
8.6.4 Data acquisition	21
8.6.5 Test report and additional information	23
8.7 Clinical evaluation	24
8.7.1 Purpose	24
8.7.2 Specific aims	25
8.7.3 Protocol considerations	25
8.7.4 Data acquisition	26
8.7.5 Final report	29

9	Post-market experience	30
10	Manufacturing	30
11	Sterilization	30
11.1	Products supplied sterile	30
11.2	Sterilization residuals	30
12	Packaging	31
12.1	General	31
12.1.1	General	31
12.1.2	Unit container	31
12.1.3	Outer container	31
12.1.4	Shipping container	31
12.1.5	Maintenance of sterility in transit	31
12.2	Labelling	31
12.2.1	Container label	31
12.2.2	Filter systems	31
12.2.3	Retrieval systems	32
12.2.4	Conversion systems	32
12.2.5	Record label	32
12.3	Information supplied by the manufacturer	33
12.3.1	General	33
12.3.2	Information and instructions for use	33
Annex A	(informative) Relationship between testing requirements, device attributes and potential failure modes, and guidance for the creation of a device evaluation strategy	35
Annex B	(informative) Description of clinical effects of failure	53
Annex C	(informative) Description of device effects of failure	55
Annex D	(informative) Test methods	56
Annex E	(informative) Examples of general issues related to the clinical use of vena cava filters	92
Bibliography		94

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 150, *Implants for surgery*, Subcommittee SC2, *Cardiovascular implants and extracorporeal systems*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 285, *Non-active surgical implants*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

The second edition cancels and replaces the first edition (ISO 25539-3:2011), which has been technically revised.

The main changes are as follows:

- the testing and clinical use related to vena cava filters has been updated;
- the consistency in nomenclature and reporting requirements has been improved.

A list of all parts in the ISO 25539 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document was prepared to provide guidance on the minimum requirements for vena cava filter systems. The rationale for the requirements for bench tests and analyses to assess device performance and safety, guidance on the identification of appropriate testing to evaluate a specific device design, and guidance for developing test methods are provided in informative annexes. Further clarification of terminology is provided in [Annexes B, C and E](#).

This document has been updated to reflect current knowledge regarding the testing and clinical use related to vena cava filters, reflected in modifications to the requirements in the main body and in the guidance for developing test methods in [Annex D](#). In addition, revisions have been made to improve consistency in nomenclature and reporting and to enhance the utility of this document.

This revised document introduces methodology to identify appropriate testing and analyses applicable to intended clinical use, design and potential failure modes for a specific vena cava filter system, designated as the device evaluation strategy. The requirement regarding the device evaluation strategy is in the main body. [Annex A](#) provides guidance for developing a focused device evaluation strategy table that is specific to the unique characteristics of a device, device design modifications or changes in intended use. [Annex A](#) also provides guidance for the development of a comprehensive device evaluation strategy table that may be used when it is not sufficient to focus only on the unique characteristics or changes.

The guidance on the development of methods to address the requirement for evaluating fatigue and durability through computational analyses has been modified to include recommendations regarding verification of the solution and validation of the computational model, as well as reporting. The guidance on the model development for simulated use has also been significantly revised to improve the clinical relevance of this testing.

In addition to modifications to specific design evaluation requirements, guidance has been provided regarding the assessment of the acceptability of test results. When the requirement is to quantitatively appraise or analyse a parameter, test results generally may be compared to a quantitative value (i.e. acceptance criteria). For characterization tests, it is appropriate to provide an explanation of the relevance of the results. Additionally, some testing can include a comparison to test data or existing data from a previously evaluated device.

For design evaluation, requirements regarding sampling, conditioning of test samples and reporting have been incorporated in the main body. Guidance on these elements of testing and documentation were previously only included in [Annex D](#).

The revisions to the annexes to this document are given in [Table 1](#).

Table 1 — Revisions to the annexes in this document

Annex of ISO 25539-3:2011	Changes in ISO 25539-3:2024
Annex A – Attributes of endovascular devices – Vena cava filters – Technical and clinical considerations	Annex A now includes the relationship between testing requirements, device attributes, and potential failure modes and guidance for the creation of a device evaluation strategy.
Annex B – Descriptions of potential device effects of failure and failure modes and descriptions of detrimental clinical effects	Annex B now includes a description of potential clinical effects of failure.
Annex C – Bench and analytical tests	The list of tests is included in Table D.1 . Annex C now includes a description of potential device effects of failure.
Annex D – Test methods	Annex D – Test methods

Many filter systems have been shown to be safe and effective in clinical use – this update is not intended to require additional evaluations of these devices to remain in compliance with this document as the testing would not provide useful information regarding the expected clinical performance of the device. Manufacturers may rely on historical data gathered under the guidance of the previous edition of this document (i.e. ISO 25539-3:2011). Similarly, for device modifications or changes in intended clinical use, this

edition of this document is not intended to require additional evaluation of aspects of the device that are not expected to change clinical performance.

NOTE The relationship between testing requirements, device attributes and potential failure modes is provided in [Clause A.1](#). [Clause A.1](#) also provides general information regarding device evaluation strategies. [Tables A.3](#) to [A.9](#) provide the rationale for the requirements specified in this document for bench tests and analyses to assess device performance and safety. An explanation of the table headings for [Tables A.3](#) to [A.9](#) is given in [Table A.1](#).

Guidance for the creation of a device-specific evaluation strategy is provided in [Clause A.2](#). Two approaches to create a device-specific evaluation strategy are provided:

- a) focused device evaluation strategy in [A.2.1](#);
- b) comprehensive device evaluation strategy in [A.2.2](#).

[Annex B](#) provides a description of the potential clinical effects of failure identified in [Annex A](#).

[Annex C](#) provides a description of the potential device effects of failure identified in [Annex A](#).

Additional descriptions of clinical and device effects of failure are included in [Annexes B](#) and [C](#), respectively.

[Annex D](#) provides information to consider in developing appropriate bench test and analytical methods.

[Annex E](#) provides examples of terms for clinical use related to vena cava filters.

Cardiovascular implants — Endovascular devices —

Part 3: Vena cava filters

1 Scope

This document specifies the requirements for the evaluation of vena cava filter systems (filters and delivery systems) and the requirements with respect to nomenclature, design attributes and information supplied by the manufacturer. Guidance for the development of in vitro test methods is included in [Annex D](#). This document is intended to be used in conjunction with ISO 14630, which specifies general requirements for the performance of non-active surgical implants.

NOTE 1 Due to the variations in the design of implants covered by this document, and in some cases due to the emergence of novel types of such implants, acceptable standardized in vitro tests and clinical results are not always available. As further scientific and clinical data become available, a revision of this document will be necessary.

This document is applicable to vena cava filters intended to prevent symptomatic pulmonary embolism by capturing blood clots in the inferior vena cava (IVC). While this document can be useful with respect to filters implanted in other venous locations (e.g. superior vena cava, iliac veins), it does not specifically address the use of filters in other implantation sites.

This document is also applicable to permanent filters together with their associated delivery systems, optional filters that can be retrieved and their associated retrieval systems, and convertible filters and their associated conversion systems. While this document can be useful with respect to the evaluation of repositioning filters after chronic implantation, it does not specifically address filter repositioning.

This document is not applicable to

- temporary filters (e.g. tethered) that need to be removed after a defined period of time,
- issues associated with viable tissues and non-viable biological materials, and
- procedures and devices (e.g. venous entry needle) used prior to the vena cava filter procedure.

Although absorbable filters and filters with absorbable coatings are within the scope of this document, this document is not comprehensive with respect to the absorbable properties of these devices.

NOTE 2 Absorbable implants are covered in ISO/TS 17137.

Although coated filters and coated filter systems are within the scope of this document, this document is not comprehensive with respect to coatings.

NOTE 3 Vascular device-drug combination products are covered in ISO 12417-1 and some coating properties are covered in ISO 25539-4.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10993 (all parts), *Biological evaluation of medical devices*

ISO 11135, *Sterilization of health-care products — Ethylene oxide — Requirements for the development, validation and routine control of a sterilization process for medical devices*

ISO 11137 (all parts), *Sterilization of health care products — Radiation*

ISO 11607-1, *Packaging for terminally sterilized medical devices — Part 1: Requirements for materials, sterile barrier systems and packaging systems*

ISO 13485, *Medical devices — Quality management systems — Requirements for regulatory purposes*

ISO 14630:2012, *Non-active surgical implants — General requirements*

ISO 14937, *Sterilization of health care products — General requirements for characterization of a sterilizing agent and the development, validation and routine control of a sterilization process for medical devices*

ISO 14971, *Medical devices — Application of risk management to medical devices*

ISO 17665-1, *Sterilization of health care products — Moist heat — Part 1: Requirements for the development, validation and routine control of a sterilization process for medical devices*

ASTM F2503, *Standard Practice for Marking Medical Devices and Other Items for Safety in the Magnetic Resonance Environment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14630 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

absorption

<biomaterial> action of a non-endogenous (foreign) material or substance or its degradation products passing through or being assimilated by cells and/or tissue over time

3.2

absorbable coating

implant coating (3.20) that is intended to be absorbed

Note 1 to entry: Drugs are excluded from this definition of absorbable coatings.

3.3

access site

vein that is used for accessing the vena cava

EXAMPLE Jugular vein, femoral vein, subclavian vein, antecubital vein.

3.4

adverse event

unfavourable change in health that occurs in a subject who participates in a study while receiving the treatment or within a specified time after receiving treatment

Note 1 to entry: For the purpose of this document, clinical effects of failure are a subset of adverse events and are described separately.

Note 2 to entry: Adverse events are categorized by the system affected (e.g. cardiac, vascular, respiratory, neurological, renal, gastro-intestinal) and the severity of the event.

3.5

caval perforation/penetration

imaging [e.g. venography, computed tomography (CT)] showing filter components (e.g. struts, anchors) extending more than 5 mm outside the wall of the vena cava

3.6

clinical effect of failure

specific detrimental clinical observations potentially associated with device failures

Note 1 to entry: The clinical effects of failure are described in [Annex B](#).

3.7

clinical perforation/penetration

protrusion of filter components (e.g. struts, anchors) through the vena cava wall causing haemorrhage or hematoma, or interacting with another organ (e.g. liver, bowel, aorta, psoas muscle, vertebral body, lymph nodes), and resulting in adverse clinical symptoms (e.g. abdominal or back pain) or autopsy findings

3.8

conversion system

components that are intended to structurally alter a *convertible filter* ([3.23.2](#)) after implantation so that it no longer functions as a filter

Note 1 to entry: A conversion system may also be used to inject contrast media (e.g. to obtain a cavagram) if indicated in the instructions for use (IFU).

3.9

delivery system

components of the *filter system* ([3.18](#)) used to deliver the filter to the target position and to deploy the filter

Note 1 to entry: The delivery system may also be used to inject contrast media (e.g. to obtain a cavagram) if indicated in the instructions for use (IFU).

3.10

determine

appraise or analyse quantitatively

Note 1 to entry: Also see *evaluate* ([3.15](#)).

3.11

device effect of failure

consequence to the device potentially associated with device failure

Note 1 to entry: The device effects of failure are described in [Annex C](#).

3.12

device evaluation strategy

rationale for testing selected for a specific vena cava *filter system* ([3.18](#)), based on requirements of the device design and potential *failure modes* ([3.16](#))

3.13

comprehensive device evaluation strategy table

optional communication tool to present the *device evaluation strategy* ([3.12](#)) for a specific vena cava *filter system* ([3.18](#)) that addresses attributes of *failure modes* ([3.16](#))

3.14

focused device evaluation strategy table

optional communication tool to present the *device evaluation strategy* ([3.12](#)) for a specific vena cava *filter system* ([3.18](#)) that focuses on the unique characteristics of the device design or procedure and unique aspects of the intended use

3.15

evaluate

qualitatively appraise or analyse

Note 1 to entry: Also see *determine* ([3.10](#)).

3.16

failure mode

type of difficulty or failure of the *filter system* ([3.18](#)) that can be encountered (hazards) in preclinical in vivo or clinical use and can result in consequences (harm) to the subject

3.17

filter formation

manufacturer's specified final expanded geometric configuration of the filter in the vena cava

3.18

filter system

component consisting of the *vena cava filter* ([3.23](#)) and the *delivery system* ([3.9](#))

3.19

filter system orientation

orientation (e.g. jugular, femoral) of the loaded filter within the *delivery system* ([3.9](#)), based on the designated *access site* ([3.3](#)) (e.g. jugular, femoral, subclavian, antecubital)

3.20

implant coating

surface coating ([3.24](#)) or *surface modification* ([3.25](#))

Note 1 to entry: Implant coating is considered a constituent of an implant.

Note 2 to entry: A laminate, i.e. a composite material made of multiple layers of the same or different materials with the same or different internal structures assembled sandwich-like and bonded by heat, pressure, welding, soldering or adhesives, is not in itself considered an implant coating but the exposed surface of the laminate can be an implant coating.

Note 3 to entry: A covering, for example additional material (e.g. a graft) added to a structure (e.g. a stent) specifically to bridge elements of the structure for the sole purpose of reducing the permeability of the structure, is not considered an implant coating.

[SOURCE: ISO 17327-1:2018, 3.1]

3.21

implantation site

location of *vena cava filter* ([3.23](#)) placement within the body

3.22

retrieval system

components that are intended to remove a specific filter

Note 1 to entry: A retrieval system may also be used to inject contrast media (e.g. to obtain a cavagram) if indicated in the instructions for use (IFU).

3.23

vena cava filter

filter implant

transluminally placed implant, which is used to prevent pulmonary embolism by capturing blood clots traveling in the inferior vena cava (IVC)

3.23.1

absorbable filter

filter, or filter with a component, that is designed to be *absorbed* (3.1)

Note 1 to entry: A filter with a component designed to be absorbed can function as a *convertible filter* (3.23.2) without intervention.

3.23.2

convertible filter

filter that can be altered structurally after implantation such that some permanent implant remains that no longer functions as a filter (e.g. functions as a stent)

3.23.3

optional filter

filter that can be removed (retrievable filter) or can be left as an implant that permanently functions as a filter

3.23.4

permanent filter

filter that is designed as an implant which permanently functions as a filter

Note 1 to entry: All *optional filters* (3.23.3) are also permanent filters. Permanent filters can incorporate design characteristics that allow for retrieval or conversion and can be labelled for use of these optional features, if applicable.

3.24

surface coating

layer of material with any different property than the natural surface of the substrate that is intentionally added to the substrate

Note 1 to entry: The coating can partially or fully cover the substrate surface.

Note 2 to entry: The term includes surface coatings created as a result of additive manufacturing.

[SOURCE: ISO 17327-1:2018, 3.2]

3.25

surface modification

intentional conversion or reconstruction of the surface of the original substrate to form a new surface material consisting of components of the substrate's own material and possibly foreign material and forming a surface layer with different properties

[SOURCE: ISO 17327-1:2018, 3.3]

3.26

unacceptable filter tilting

clinically significant rotation of the filter relative to the longitudinal axis of the vena cava and resulting in performance failure (e.g. inadequate filtration, excessive filtration, filter migration, filter embolization, *caval perforation/penetration* (3.5), *clinical perforation/penetration* (3.7), inability to retrieve the filter as applicable, inability to convert the filter as applicable)

4 General requirements

4.1 Classification

A filter system shall be designated by its access site (see 3.3), orientation (see 3.17), implantation site (see 3.19), type (see 3.22), materials of construction, as well as surface modifications, coatings and/or drugs.

4.2 Materials of construction for filter system

Materials of the filter system (e.g. wire, imaging markers, coatings) shall be described by their generic or chemical names.

4.3 Configuration and size designation for filters

The configuration of a filter shall be designated by its geometry (e.g. conical) and whether it is permanent, optional or convertible. The size of a filter shall be designated by the minimum and maximum intended caval lumen diameters.

4.4 Intended clinical use designation

Vena cava filters are intended to prevent symptomatic pulmonary embolism by capturing blood clots in the IVC.

5 Intended performance

The requirements of ISO 14630:2012, Clause 4 shall apply.

6 Design attributes

6.1 General

The requirements for design attributes in 6.2 to 6.10 and of ISO 14630:2012, Clause 5 apply. General design attributes for the filter system, the filter, the filter retrieval system and the filter conversion system are listed in [Tables A.3](#) and [A.9](#) with reference to the nonclinical testing necessary for the evaluation of the design. It is recognized that not all tests identified in a category are necessary or practical for any given filter and/or system. The tests considered and the rationale for selection and/or waiving of tests shall be documented.

6.2 Filter system

In addition to the general requirements, the design attributes of the filter system shall at least take into account the following:

- a) the ability to permit safe and consistent deliverability of the filter to the intended deployment location;
- b) the ability to permit accurate and safe deployment of the filter;
- c) the ability to inject contrast via the delivery system if indicated in the IFU;
- d) the ability to permit safe withdrawal of the delivery system following deployment;
- e) the ability to maintain adequate structural integrity.

6.3 Vena cava filter

The design attributes of the vena cava filter shall at least take into account the following:

- a) the ability to ensure effective fixation in the intended location within the inferior vena cava;
- b) the ability to maintain adequate integrity;
- c) the ability to capture clots in the blood, while allowing acceptable blood flow;
- d) the ability to prevent clinical perforation/penetration;
- e) the compatibility of the filter dimensions for use with the specified caval diameters;
- f) the compatibility with exposure to magnetic resonance imaging (MRI) fields.

6.4 Optional filter

In addition to the attributes listed in [6.3](#), the design attributes of the optional filter shall at least take into account the following:

- a) the ability to be engaged;
- b) the ability to be retrieved;
- c) the ability to maintain adequate structural integrity through retrieval.

6.5 Convertible filter

In addition to the attributes listed in [6.3](#), the design attributes of the convertible filter shall at least take into account the following:

- a) the ability to be engaged;
- b) the ability to be converted (e.g. into a stent);
- c) the ability to maintain adequate structural integrity through and after conversion.

6.6 Retrieval system

The design attributes of the retrieval system shall at least take into account the following:

- a) the ability to safely reach the filter location;
- b) the ability to safely engage the filter;
- c) the ability to safely retrieve the filter;
- d) the ability to inject contrast via the retrieval system if indicated in the IFU;
- e) the ability to be safely withdrawn.

6.7 Conversion system

The design attributes of the conversion system shall at least take into account the following:

- a) the ability to safely reach the filter location;
- b) the ability to safely engage the conversion component of the filter;
- c) the ability to safely convert the filter;
- d) the ability to inject contrast via the conversion system if indicated in the IFU;
- e) the ability to be safely withdrawn.

6.8 Filter system, retrieval system and conversion system

In addition to the general requirements, the design attributes of the filter system, the retrieval system and the conversion system, as applicable, shall at least take into account the following:

- a) visibility under fluoroscopy or other applicable imaging modalities;
- b) compliance with the requirements of ISO 10993-1 and other appropriate parts of the ISO 10993 series;
- c) the sterility of the systems;
- d) the ability to minimize blood loss (haemostasis);

- e) the ability to maintain adequate resistance to unintended particulate generation;
- f) the ability to meet specifications under conditions of transit and storage.

6.9 Coating on delivery system or filter

The design attributes of a coating on a delivery system or filter shall at least take into account the following:

- a) the ability of the coating to maintain adequate integrity in accordance with design specifications (e.g. freedom from significant delamination, flaps and bare spots);
- b) the ability of the coating to maintain adequate resistance to unintended particulate generation;
- c) conformance of the coating dimensions, functional requirements (e.g. lubricity) and other coating parameters (e.g. porosity, density, distribution) to the design requirements.

6.10 Absorbable filter or coating

The design attributes of an absorbable filter, and a filter containing an absorbable component or an absorbable coating, shall at least take into account the following:

- a) the ability to degrade or absorb as designed over time;
- b) appropriate mechanical properties over time;
- c) the ability of the absorbable filter, absorbable component or absorbable coating to maintain adequate resistance to unintended particulate generation over time;
- d) the potential biological effects of degradants;
- e) the ability to safely use MRI on a patient with an absorbable filter or filter with absorbable coating without negatively affecting the absorbable properties (e.g. due to heating).

7 Materials

The requirements for materials of ISO 14630:2012, Clause 6 apply. Additional testing specific to certain materials should be performed to determine the appropriateness of the materials for use in the design. For example, nitinol materials dependent on shape memory properties should be subjected to testing in order to assess transformation properties.

NOTE Additional information regarding nitinol materials can be found in ASTM F2063 and ASTM F2082.

8 Design evaluation

8.1 General

The requirements of ISO 14630:2012, Clause 7, apply. A risk analysis shall be carried out in accordance with the requirements of ISO 14971.

Because optional filters can be used as permanent filters, testing appropriate for a permanent filter shall be conducted for optional filters. Additional testing is appropriate for optional filters.

If the convertible filter can be used as a permanent filter, testing appropriate for a permanent filter system shall be conducted. If part of the convertible filter is retrieved, testing appropriate for an optional filter system shall be conducted. If the convertible filter is intended to function as a stent after conversion, the requirements of ISO 25539-2 are applicable after conversion. If the convertible filter is not intended to function as a stent after conversion, additional testing addressing the risks associated with the remaining implant can be appropriate.

The requirements and testing described in ISO 10555-1 and ISO 10555-3 can apply to the design evaluation of a delivery system, retrieval system or conversion system.

The device design concept shall be considered in the selection of appropriate tests and associated test methods. The device design concept includes the:

- device description (e.g. physical description, materials of construction), what the device key design features are intended to do and how the key design features accomplish the intended objective;
- intended clinical use (see [4.4](#));
- device implantation procedures;
- conditions of use/intended in vivo environment;
- minimum design life of the device.

A device evaluation strategy shall be created. A device evaluation strategy provides the rationale for the testing selected to evaluate the filter system, retrieval system or conversion system, based on the requirements of the device design and potential failure modes. The device evaluation strategy may be communicated in a table (device evaluation strategy table) as described in [Annex A](#). Alternative methods for presenting the device evaluation strategy may be used (e.g. a non-tabular presentation of the rationale for the testing based on the potential risks and benefits of the various systems for the intended clinical use).

Emerging-technologies associated with the intended clinical use should be evaluated following the requirements of this document, where appropriate. The device evaluation strategy should identify testing needed beyond the scope of this document to characterize these systems.

NOTE 1 All testing in this document are not necessarily appropriate for all within scope systems or intended clinical uses.

Whenever changes are made in materials, construction, configuration, intended clinical use or processing methods, an appropriate analysis of the potential impact of the change on the potential failure modes and performance of the system shall be performed. This evaluation may be communicated using appropriate tables as described in [Clause A.2](#). Appropriate testing shall be conducted as deemed necessary, considering the potential impact on device performance of the change.

The use of a comparator device may be considered in the evaluation of certain design attributes, particularly for design iterations.

The device design evaluation should be appropriate for the conditions of use described in the design concept and in the IFU. Though not required for the design evaluation, testing beyond these limits may be considered to characterize the changes in device performance (e.g. durability, proper positioning, orientation) as a function of use outside of the recommended conditions (e.g. sizing). Information obtained from such testing can be useful in establishing acceptance criteria and in identifying appropriate warnings or precautions in the IFU for physician users.

Testing to establish the labelled shelf-life shall be conducted by repeating appropriate tests after aged conditions, where applicable. Justification for the selection of tests shall be provided. Generally, this will not include long-term durability testing, unless the materials of construction are susceptible to degradation that cannot be evaluated through shorter-term testing, or other tests that measure parameters that are not expected to be affected by aging (e.g. MRI safety testing, corrosion testing).

NOTE 2 Additional information regarding shelf-life can be found in ASTM F2914.

8.2 Sampling

A sampling plan shall be utilized which ensures adequate representation of the design has been obtained for each characteristic measured. It should be verified that the design attributes of the filter system, retrieval system or conversion system are representative of the devices to be released for distribution including all sizes, configurations and components.

The sampling shall fully represent the range of device sizes and does not necessarily require testing of each size. It can be necessary to conduct an analysis to identify the size(s) of the device with the greatest potential for failure.

Multiple approaches to sample selection should be considered, depending on whether there are differences in relevant attributes of different device sizes (e.g. strut thickness, length, diameter) and the parameter under test (e.g. radial force).

The samples selected for each test shall represent adequately challenging case(s). Consideration shall be given to filter size and orientation, delivery system sizes (diameter and length) and implant conditions (e.g. intended vena cava size and shape). It can be necessary to conduct an analysis to identify the samples with the greatest potential for failure under specified implant conditions.

A rationale should be provided for sample selection. For all tests, the number of samples should be justified.

8.3 Conditioning of test samples

All samples shall be subjected to sterilization, including multiple sterilizations, if appropriate, unless justification is provided for use of non-sterilized products.

Samples should be subjected to conditions that are normally encountered that can affect the performance of the device and test results. Examples of conditioning are preparation of the filter system, loading of the filter inside the delivery system, tracking of the filter system through relevant simulated tortuous vasculature and deployment of the filter.

8.4 Reporting

For the purposes of this document, reporting refers to submission to a national regulatory authority.

The design evaluation report should include an appropriate table of contents and four main sections: a background, an executive summary, individual test summaries and appendices that include the device evaluation strategy and the detailed reports. Pages should be numbered sequentially throughout the document (including appendices).

- a) The background section should describe the device design concept.
- b) The executive summary should include:
 - a description of the bench testing and analyses that have been performed;
 - a summary of the device evaluation strategy, including justification for the omission of tests identified in this document;
 - a table to summarize the testing completed, with the following columns: name of test, test purpose, test sample description, number of samples, acceptance criteria, summary of results and conclusions, and cross references to the test summary and full test report;
 - a summary conclusion statement.
- c) Individual test summaries should include:
 - a brief summary of the purpose, methods and results;
 - the significance of the test results:
 - for tests with acceptance criteria, justification for the criteria; or
 - for characterization tests, an explanation of the relevance of the results.
- d) Individual test reports should include the following information:
 - purpose: state the purpose of the test as it corresponds to this document;

- materials: list significant materials (e.g. test articles with lot/serial numbers or other appropriate means of traceability, critical equipment) used in performing the test, using figures and diagrams as appropriate;
- sampling: state the sampling plan, including the basis for and the number of samples tested; selection of test articles shall be justified (e.g. sizes, conditioning);
- acceptance criteria, if applicable: state the criteria for the test results, including justification and/or clinical relevance; clinical applicability of the acceptance criteria shall take into consideration the anatomical and physiological conditions of the intended use;
- test method: describe in detail the method used to perform the test, including any prospectively defined inspection procedures, and provide a justification for relevant test parameters;
- protocol deviations: describe any deviations and their potential significance on the interpretation of the results;
- expression of results: report testing results expressed in units as indicated in the test method;
- discussion, if applicable: include a discussion on the potential clinical significance of the results;
- conclusions: state conclusions, based on comparing results to acceptance criteria or provide an explanation of the relevance of the results for characterization tests.

8.5 Bench and analytical tests

8.5.1 General

Testing of the filter system, the filter, the filter retrieval system and the filter conversion system shall be conducted to evaluate the design attributes in [Clause 6](#), as applicable. The appropriate tests to evaluate each design attribute are based on the potential associated failure modes, device effects of failure and clinical effects of failure. The rationale for the requirements specified in this document for the bench tests and analytical analyses to assess device performance is described in [Annex A](#).

8.5.2 Filter system

8.5.2.1 General

The ability of the filter system to permit safe and consistent delivery, deployment and withdrawal shall be assessed.

The associated device/procedure related functions, potential failure modes and potential device effects of failure and clinical effects of failure to be considered are listed in [Table A.3](#).

Testing shall include the items listed in [8.5.2.2](#) to [8.5.2.6](#), as appropriate to the design of the filter system.

8.5.2.2 Dimensional verification and component dimensional compatibility

Determine the filter system dimensions, including the usable or working length, profile, and all other appropriate dimensions, for conformance with design specifications, and determine the dimensions for compatibility with the dimensions of recommended accessories.

8.5.2.3 Force to deploy

Determine the force to deploy the filter under simulated anatomical conditions. All applicable steps of the deployment process (e.g. filter release, delivery system retraction) as specified in the IFU should be evaluated.

NOTE The force to deploy can be used to help establish relevant tensile strength acceptance criteria.

8.5.2.4 Simulated use

8.5.2.4.1 General

Evaluate the performance of the filter system with accessory devices specified in the IFU and using a model(s) that simulate(s) the intended use conditions.

8.5.2.4.2 Ability to deliver

Evaluate the ability of the filter system to be advanced through the introducer sheath. Torquability shall be assessed for designs that require significant rotational control.

8.5.2.4.3 Ability to deploy

8.5.2.4.3.1 General

Evaluate the ability of the filter system to deploy the filter.

8.5.2.4.3.2 Deployment accuracy

Evaluate the accuracy of the filter deployment in relation to the intended target site.

8.5.2.4.3.3 Deployed configuration

Evaluate the ability of the filter to take the proper configuration and orientation (e.g. without unacceptable tilting) following deployment from the filter system.

8.5.2.4.4 Ability to withdraw

Evaluate the ability of the filter system to be withdrawn from the anatomical model(s), post filter deployment.

8.5.2.4.5 Compatibility

Evaluate the compatibility of the filter system with accessory devices.

8.5.2.4.6 Contrast injection

Evaluate the ability to perform a contrast injection via the delivery system, as applicable.

8.5.2.5 Tensile bond strength

Determine the tensile bond strength of the joints and/or fixed connections of the filter system. Evaluate the strength of the segments adjacent to the bonds of the filter system separately or concurrently with the bond strength determination.

The acceptance criteria for the bond strength(s) should take into consideration the expected forces applied to the filter system during clinical use [e.g. tracking (access and withdrawal) and deployment].

NOTE The force to deploy can be used to help establish relevant bond strength acceptance criteria.

8.5.2.6 Torsional bond strength

Evaluate the torsional strength of the joints and/or fixed connections in the segments of the filter system that are subjected to torsion during clinical use, or provide justification if torsion is not applicable based on the intended clinical use. Evaluate the torsional strength of the segments adjacent to the bonds of the filter system separately or concurrently with the torsional bond strength evaluation. The results shall be evaluated in relation to the torque necessary to access, deploy and withdraw the system, if applicable based on the intended clinical use.

8.5.3 Vena cava filter

8.5.3.1 General

The ability of the implant to filter blood for clots without causing caval occlusion shall be assessed.

The associated device/procedure related functions, potential failure modes and potential device and clinical effects of failure to be considered are listed in [Table A.4](#).

Testing shall include the items listed in [8.5.3](#) to [8.5.5](#), as appropriate to the design of the filter. The tests are grouped based on similarities in the objectives of the testing; however, tests are not repeated within multiple categories. Refer to [Annex A](#) for a complete listing of the test applicable to each design attribute.

8.5.3.2 Clot trapping

Determine the ability of the filter to capture clots, demonstrating that the device can capture clinically significant emboli, yet still permit sufficient blood flow around trapped emboli without caval occlusion. Clinically significant emboli, usually described as the numbers of clots at various sizes (e.g. diameters and lengths), shall be determined and justified by the manufacturer. The clot-trapping ability of the filter shall also be challenged in non-optimal positions (e.g. tilted) to determine the sensitivity of the design. Refer to References [\[48\]](#), [\[52\]](#), [\[73\]](#), [\[75\]](#), [\[80\]](#), [\[82\]](#) to [\[86\]](#) and [\[104\]](#) to [\[106\]](#) for more information on clot trapping.

8.5.3.3 Corrosion

Evaluate the susceptibility of a filter with metallic materials to corrosion.

The corrosion mechanisms can include pitting, fretting, crevice and galvanic corrosion. Each corrosion mechanism should be evaluated for specific filter designs, as appropriate.

In cases where different metals can be in contact by virtue of the device design or IFU, galvanic corrosion shall be assessed (e.g. radiopaque markers). Corrosion assessment includes, but is not limited to, the evaluation of test results, the review of literature and the consideration of the historical clinical performance of the material(s) under assessment. Guidance on corrosion assessment is given in a variety of sources (e.g. literature, textbooks, standards, regulatory guidance documents).

NOTE 1 Additional guidance is given in ISO 17475, ASTM F746, ASTM F2129, ASTM G5, ASTM G71, ASTM G102 and ASTM F3044.

Depending on the surface finish and the corrosion testing results, the potential detrimental clinical effect of ion release should also be considered. Guidance on ion release is given in a variety of sources (e.g. literature, textbooks, standards, regulatory guidance documents).

NOTE 2 Additional guidance is given ASTM F3306.

8.5.3.4 Fatigue and durability — Computational analyses

Calculate the magnitude and location of the maximum stresses and/or strains for each appropriate loading scenario based upon the intended clinical application and device design. Appropriate computational analysis tools, such as finite element analysis (FEA), can be used to calculate the stresses and/or strains. The stresses and/or strains can be compared to material characteristics to calculate the fatigue safety factor.

Computational analyses may also be used to establish appropriate test conditions and to select test articles for fatigue and durability testing.

8.5.3.5 Fatigue and durability — In vitro testing

8.5.3.5.1 General

Evaluate the long-term structural integrity of the filter under cyclic loading conditions that represent the in vivo environment (this can require several different test configurations).

Potential integrity failures to be assessed can include fracture and component separation. Relevant in vivo loads (e.g. compression resulting from respiration and Valsalva manoeuvre) shall be considered when evaluating fatigue and durability.

In vitro fatigue testing of the filter or the appropriately justified test article shall be performed to demonstrate durability for an appropriate and justified duration. For example, in vitro testing representing a minimum of 10 years should be conducted for permanent implants. If the intended implant duration is less than 10 years, then shorter duration fatigue testing is more appropriate, with justification.

If fatigue testing is performed to compare the durability of one filter to another filter that has clinically demonstrated durability or clinically known problems with durability, the duration of the test shall be justified.

Consideration shall be given specifically to convertible filters in both filtering and converted states.

8.5.3.5.2 General considerations

In identifying the appropriate durability tests, developing test methods and establishing acceptance criteria, consideration of the device design (e.g. geometry, material selection) and intended clinical use (e.g. implant location, disease state) is necessary. Compressive loading associated with normal respiration, Valsalva or an interaction with other native anatomy in the vicinity of the vena cava should be considered. The loading modes, magnitudes and numbers of cycles should be justified.

8.5.3.5.3 Compression fatigue and durability

Evaluated the long-term structural integrity of the filter when subjected to cyclic compressive loading conditions perpendicular to the filter axis (e.g. compression along the entire length, local compression), if applicable.

8.5.3.6 Dimensional verification of the filter

Determine the appropriate dimensions of the deployed filter for verification to design specifications.

8.5.3.7 Filter tensile strength

Determine the tensile strength of relevant components, including bond joints and/or fixed connections of the filter.

8.5.3.8 Migration resistance

Determine the pressure gradient necessary to cause a clot-loaded filter or the force necessary to cause a non-loaded filter to migrate in the cephalad direction. Also, consider determining migration resistance in the caudal direction depending upon the device design.

8.5.3.9 Magnetic resonance imaging

Using clinically relevant magnetic resonance (MR) environments (e.g. appropriate static magnetic field and spatial magnetic gradient field), evaluate the potential for

- a) magnetically induced displacement force and torque, and
- b) radiofrequency-induced (RF) heating of the filter.

Determine the appropriate MR safety term (i.e. MR safe, MR conditional or MR unsafe) as defined in ASTM F2503.

Characterize the MR image artefact produced by the filter. Describe the location and extent of the image artefact effect on the ability to visualize the device and adjacent anatomy.

NOTE 1 No acceptance criterion is needed for image artefact as the effect of the MR artefact on the usefulness of the image depends on the MR environment and the anatomical region being imaged with respect to the location of the filter. For example, although image artefact associated with an abdominal filter can affect the ability to image the lumbar spine, it would not affect the ability to image the head and neck.

NOTE 2 The MRI artefact caused by some filters can compromise the effectiveness and limit the use of MRI in patients with the implants.

Test methods for evaluating magnetically induced displacement, torque, RF heating and imaging artefact can be found in:

- ASTM F2052;
- ASTM F2213;
- ASTM F2182;
- ASTM F2119.

8.5.3.10 Radial force

Determine the force exerted on the surrounding tissue by a vena cava filter as a function of the filter diameter.

8.5.4 Optional filter

8.5.4.1 General

In addition to the attributes listed in [8.5.3.1](#), the ability of the optional filter to be safely, consistently and accurately retrieved shall be assessed.

The associated device/procedure related functions, potential failure modes and potential device and clinical effects of failure to be considered are listed in [Table A.5](#).

Testing shall include the items listed in [8.5.4.2](#) to [8.5.4.4](#), as appropriate to the design of the optional filter.

8.5.4.2 Filter tensile strength

Determine the tensile strength of relevant components, including bond joints and/or fixed connections of the filter.

8.5.4.3 Force to retrieve

Determine the force to retrieve the vena cava filter in an anatomical model, using the retrieval system as specified in the IFU, if applicable.

8.5.4.4 Simulated use

Evaluate the performance of the optional filter using a model(s) that simulate(s) the intended use conditions.

Evaluate the ability to be engaged during retrieval and the ability to be retrieved using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population.

8.5.5 Convertible filter

8.5.5.1 General

In addition to the attributes listed in [8.5.2.1](#), the ability of the convertible filter to be safely, consistently and accurately converted shall be assessed, including the use of the conversion system as specified in the IFU, as applicable. The associated device/procedure related functions, potential failure modes and potential device and clinical effects of failure to be considered are listed in [Table A.6](#).

Testing shall include the items listed in [8.5.4.2](#) to [8.5.4.4](#), as appropriate to the design of the convertible filter.

8.5.5.2 Filter tensile strength

Determine the tensile strength of relevant components, including bond joints and/or fixed connections of the filter.

8.5.5.3 Force to convert

Determine the force to convert the vena cava filter in an anatomical model, using the conversion system as specified in the IFU, as applicable.

8.5.5.4 Simulated use

Evaluate performance of the convertible filter using a model(s) that simulate(s) the intended use conditions.

Evaluate the ability to be engaged during conversion and the ability to be converted to the proper configuration, using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population.

8.5.6 Retrieval system

8.5.6.1 General

The ability of the retrieval system to permit safe and consistent retrieval of the filter shall be assessed.

The associated device/procedure related functions, potential failure modes and potential device effects of failure and clinical effects of failure to be considered are listed in [Table A.7](#).

Testing shall include the items listed in [8.5.6.2](#) to [8.5.6.6](#), as appropriate to the design of the retrieval system.

8.5.6.2 Dimensional verification and component dimensional compatibility

Determine the retrieval system dimensions, including the usable or working length, profile and all other appropriate dimensions, for conformance with design specifications and determine the dimensions for compatibility with the dimensions of recommended accessories.

8.5.6.3 Force to retrieve

Determine the force to retrieve the filter in an anatomical model using the retrieval system as specified in the IFU.

8.5.6.4 Simulated use

8.5.6.4.1 General

Evaluate the performance of the retrieval system using a model(s) that simulate(s) the intended conditions.

Evaluate the ability to be advanced through the introducer sheath, engage the filter, retrieve the filter and withdraw the retrieval system (including filter, if applicable) using an anatomical model(s) that is (are)

representative of the anatomical variation in the intended patient population. Evaluate the compatibility of the retrieval system with accessory devices.

8.5.6.4.2 Contrast injection

Evaluate the ability to perform a contrast injection via the retrieval system, as applicable.

8.5.6.5 Torsional bond strength

Evaluate the torsional strength of the joints and/or fixed connections in the segments of the retrieval system that are subjected to torsion during clinical use. Evaluate the torsional strength of the segments adjacent to the bonds of the retrieval system separately or concurrently with the torsional bond strength evaluation. The results shall be evaluated in relation to the torque necessary to access, retrieve and withdraw the system. Alternatively, provide justification if torsion is not applicable based on the intended clinical use.

8.5.6.6 Tensile bond strength

Determine the tensile bond strength of the joints and/or fixed connections of the retrieval system. Evaluate the strength of the segments adjacent to the bonds of the retrieval system separately or concurrently with the bond strength determination.

The acceptance criteria for the bond strength(s) should take into consideration the expected forces applied to the retrieval system during clinical use [e.g. tracking (access and withdrawal) and retrieval].

NOTE The force to retrieve can be used to help establish relevant bond strength acceptance criteria.

8.5.7 Conversion system

8.5.7.1 General

The ability of the conversion system to permit safe and consistent conversion of the filter shall be assessed.

The associated device/procedure related functions, potential failure modes and potential device effects of failure and clinical effects of failure to be considered are listed in [Table A.8](#).

Testing shall include the items listed in [8.5.6.2](#) to [8.5.6.6](#), as appropriate to the design of the conversion system.

8.5.7.2 Dimensional verification and component dimensional compatibility

Determine the conversion system dimensions, including the usable or working length, profile and all other appropriate dimensions, for conformance with design specifications and determine the dimensions for compatibility with the dimensions of recommended accessories.

8.5.7.3 Force to convert

Determine the force to convert the filter in an anatomical model using the conversion system as specified in the IFU, if applicable.

8.5.7.4 Simulated use

8.5.7.4.1 General

Evaluate conversion using a model(s) that simulate(s) the intended conditions.

As applicable, evaluate the ability of the conversion system to be advanced, to engage the filter, to convert the filter and to be withdrawn using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population. Evaluate the ability to perform a contrast injection with the filter system in place, as applicable. Evaluate the compatibility of the conversion system with accessory devices.

8.5.7.4.2 Contrast injection

Evaluate the ability to perform a contrast injection via the conversion system, as applicable.

8.5.7.5 Torsional bond strength

Evaluate the torsional strength of the joints and/or fixed connections in the segments of the conversion system that are subjected to torsion during clinical use. Evaluate the torsional strength of the segments adjacent to the bonds of the conversion system separately or concurrently with the torsional bond strength evaluation. The results shall be evaluated in relation to the torque necessary to access, convert and withdraw the system. Alternatively, provide justification if torsion is not applicable based on the intended clinical use.

8.5.7.6 Tensile bond strength

Determine the tensile bond strength of the joints and/or fixed connections of the conversion system. Evaluate the strength of the segments adjacent to the bonds of the conversion system separately or concurrently with the bond strength determination.

The acceptance criteria for the bond strength(s) should take into consideration the expected forces applied to the conversion system during clinical use [e.g. tracking (access and withdrawal) and conversion].

NOTE The force to convert can be used to help establish relevant bond strength acceptance criteria.

8.5.8 Filter system, retrieval system and conversion system

8.5.8.1 General

The associated device/procedure related functions, potential failure modes and potential device effects of failure and clinical effects of failure to be considered are listed in [Table A.9](#).

Testing shall include the items listed in [8.5.7.1](#) and [8.5.7.5](#), as appropriate to the design of all device components.

8.5.8.2 Visibility

Evaluate the ability to visualize filter and/or system radiopaque components (e.g. markers) using the imaging techniques specified in the IFU.

8.5.8.3 Biocompatibility

The biocompatibility of the filter system, the retrieval system and the conversion systems shall be evaluated in accordance with ISO 10993-1 and appropriate other parts of the ISO 10993 series. The filter should generally be tested separately from the delivery system. However, there can be some tests (e.g. thrombogenicity, implantation) where the filter and delivery system are used or tested together for at least part of the test, and these should be appropriately justified.

8.5.8.4 Sterilization assurance

Sterilization shall be ensured in accordance with appropriate international standards.

8.5.8.5 Haemostasis

Evaluate the ability of haemostatic seals or valves in the filter system, the retrieval system and the conversion system to minimize leakage of blood. This requirement is not applicable to systems that do not contain haemostatic seals or valves.

8.5.8.6 Particulate generation

8.5.8.6.1 General

Consider the potential for particulate generation and likely clinical significance that can be associated with the filter system through a risk assessment. The risk assessment should consider the potential for occurrence of adverse clinical events associated with particulate generation (e.g. stroke, pulmonary embolism) based on several factors, including the tolerance for ischemia of the end organ. The risk assessment should consider whether there are device design features that are susceptible to particulate generation (e.g. presence of an absorbable coating, hydrophilic coating) or if there is an observation during testing to indicate that there can be a higher risk of having significant particulates generated in either size or quantity (e.g. generation of visible particles during simulated use, observation of particulates or particle effects in downstream tissue beds during in vivo studies).

Document the risk assessment. If the risk assessment indicates that either acute and/or chronic particulate generation does not require further evaluation based on the level of risk, the risk assessment documentation is sufficient to address the particulate generation requirement. If the risk assessment indicates that the potential for acute and/or chronic particulate generation and likely clinical significance exists, acute and/or chronic testing shall be conducted, as applicable. It is not expected that particulates will always need to be characterized beyond size and quantity. Depending on the quantified particulate test results and associated clinical risk, additional particulate characterization (e.g. chemical identification, crystallinity, morphology) and identification of the particulate source can be appropriate.

8.5.8.6.2 Acute particulate generation

Characterize the particles generated acutely from the filter system, the retrieval system and the conversion system that can be associated with advancement, deployment, retrieval, conversion and withdrawal.

8.5.8.6.3 Chronic particulate generation

Characterize the particles generated over time from the filter that can be associated with designs that are susceptible to particulate generation over time (e.g. absorbable, coated).

8.5.9 Coating on the delivery system, the retrieval system, the conversion system or the filter

Based on the potential associated failure modes, device effects of failure and clinical effects of failure, identify the appropriate testing to evaluate the specific design attributes associated with a coating on a delivery system or filter and conduct testing to address the risks identified in the assessment. Testing shall be identified as part of the device evaluation strategy and shall include an assessment of shelf-life.

Selection of the appropriate tests for a filter coating (i.e. an implant coating such as a surface coating or surface modification) should take into account the overall requirements described herein as well as the potentially relevant evaluations described in ISO 25539-4, which describes numerous coating varieties and methods of characterization that should be selected based on their relevance to both the utilized coating process and this intended filter application. Although ISO 25539-4 considers an oxide layer to be a coating, it is expected that the testing described in this document would be adequate to fulfil the requirements described in ISO 25539-4 for a filter with an oxide layer.

8.5.10 Absorbable filter or coating

Based on the potential associated failure modes, the device effects of failure and the clinical effects of failure, identify the appropriate testing to evaluate the specific design attributes associated with an absorbable filter or a filter containing an absorbable coating and conduct testing to address the risks identified in the assessment. Testing shall be identified as part of the device evaluation strategy and shall include an assessment of shelf-life.

Not all testing parameters described in this document are applicable to absorbable filters. Selection of the appropriate tests should take into account this document and ISO/TS 17137 which includes requirements and testing applicable to absorbable implants.

8.6 Preclinical in vivo evaluation

8.6.1 Purpose

The purpose of preclinical in vivo testing is to evaluate the deployment of the filter, the biological response of the host to the filter, the effect of the implant environment on the filter, and the retrieval or conversion of the filter. Preclinical in vivo testing should provide data pertaining to safety. If the objective of an animal study can be met through alternative means (e.g. through reference to previously conducted animal and/or clinical studies), the use of previously obtained data or other supportive information shall be justified. The justification should include comment on the relevance of any differences between the subject device and the device used in the previous study and the relevance of any differences in the intended uses. Multiple studies may be conducted to address all the relevant specific aims for a particular filter system, a retrieval system and/or a conversion system.

8.6.2 Specific aims

Specific aims of the study shall be stated in the protocol. More than one study may be used to address these aims which can include the following:

- a) to evaluate the ability to access the target location with the filter system;
- b) to evaluate the handling, the ease of use, the visualization of the filter system, the visualization of the filter and the visualization of caval perforation/penetration;
- c) to evaluate the deliverability of the filter to the intended implant location;
- d) to evaluate the accuracy of deployment including adequate fixation;
- e) to evaluate the ability to withdraw the delivery system;
- f) to evaluate the position, patency and structural integrity of the filter acutely and at explant;
- g) to evaluate the ability to access the intended retrieval or conversion location with the retrieval system or the conversion system (if applicable);
- h) to evaluate the handling, the ease of use and the visualization of the retrieval system or the conversion system (if applicable);
- i) to evaluate the ability and ease of retrieving or converting the filter (if applicable);
- j) to evaluate the ability to withdraw the retrieval system or conversion system, with any removed previously implanted components following retrieval or conversion (if applicable);
- k) to evaluate the functional haemostasis of the delivery system, the retrieval system or the conversion system, as applicable;
- l) to conduct gross and histopathological evaluation of explants and pertinent tissues/organs including the following:
 - evaluate local effects after implantation (e.g. caval wall response, thrombogenicity, haemorrhage, filter extending outside cava wall);
 - evaluate regional effects after implantation (e.g. clinical perforation/penetration, potential downstream effects in lungs);
 - evaluate systemic effects after implantation (e.g. necropsy);
- m) to consider the end points that can be used to help address the requirements of the ISO 10993 series;
- n) to record failure modes, device and clinical effects of failure (see [Annexes A, B and C](#) for potential failure modes and effects of failure) and adverse events.

Although the evaluation of failure modes such as structural failure of the filter is not always a specific aim of an animal study, recording and addressing the associated observations is appropriate.

8.6.3 Protocol considerations

Each filter system, retrieval system and/or conversion system shall be tested by implantation of the filter at the intended, or an analogous, vena cava site in a reasonable number of animals for an adequate duration of time (e.g. 12 weeks) to accomplish the specific aims of the study. A control can be appropriate for comparison purposes. For retrievability, an appropriate duration prior to filter retrieval shall be justified. Similarly, for conversion studies, an appropriate duration prior to conversion shall be justified. The type and intervals of interim assessments shall be specified and justified. For novel technologies, interim sacrifices and longer implant durations may be indicated. As far as permitted by the limitations of the animal model, all devices used should be of clinical quality and size and of the design intended for clinical use.

Interpretation of animal study results can be enhanced by the use of at least a small number of control animals or control devices for comparison purposes. A rationale should be provided if a control is not used in the study.

All animals in the study shall be regularly examined. Histological and pathological assessment of explants and appropriate tissues/organs shall be completed. If an animal either dies or must be sacrificed prior to scheduled termination, it shall be subjected to immediate post-mortem examination. The cause of death or illness, and the extent to which the implant was implicated shall be documented. Information for all animals implanted with either test or control filter, including those excluded from the final analyses, shall be recorded and included in the test report.

The design of the preclinical in vivo testing, including the experimental protocol, measurement methods and data analysis, shall be documented. In addition, the choice of animal model, such as species, gender, age, weight, shall be justified and shall be consistent with the study objectives. Implantation, and as applicable retrieval or conversion, shall be consistent with the instructions for use, as far as permitted by the limitations of the animal model. In particular, the filter sizing with respect to the IVC should be as close to the indicated sizing as possible in order to realistically simulate implantation conditions.

Follow appropriate quality management practices and animal welfare protection measures should be followed in the execution of an animal study.

8.6.4 Data acquisition

The following minimum data shall be recorded for each animal receiving a filter:

- a) identification data:
 - 1) species;
 - 2) source of animal;
 - 3) animal identification;
 - 4) sex;
 - 5) approximate age;
 - 6) mass;
- b) pre-operative data:
 - 1) the verification of satisfactory health status;
 - 2) medication (e.g. prophylactic antibodies);
- c) operative data:
 - 1) the date of procedure;

- 2) the name of person(s) performing procedure;
- 3) the implant and procedure information including:
 - i) the identification of filter system, retrieval system and/or conversion system;
 - ii) the identification of accessory devices;
 - iii) the filter identification number;
 - iv) the diameter(s) of recipient vessel(s), including major and minor axes before and after implant;
 - v) the use of any medications;
 - vi) the implant location;
 - vii) the access site;
 - viii) the use of systemic antiplatelet/anticoagulant therapy;
- 4) the assessment of parameters specified in the protocol, such as:
 - i) the ability to access the target site with the filter system (e.g. pushability, flexibility, torquability, trackability as applicable);
 - ii) the ease and ability to accurately deploy the filter, including adequate fixation;
 - iii) the ability to visualize the delivery system, the filter and the retrieval or conversion system as applicable;
 - iv) the ability to withdraw the delivery system;
 - v) the compatibility with accessory devices;
 - vi) blood loss (e.g. amount and location);
 - vii) functional haemostasis of the delivery system and the retrieval or conversion system as applicable;
 - viii) position (e.g. location, tilt), patency, integrity and absence of abnormalities (e.g. filter damage) at pre-specified intervals;
 - ix) the ability to access the intended retrieval and conversion location with the retrieval system and conversion system (if applicable);
 - x) handling and visualization of the retrieval system and conversion system (if applicable);
 - xi) the ability to retrieve or convert filter (if applicable);
 - xii) the ability to withdraw the retrieval system and conversion system, with any removed previously implanted components following retrieval or conversion (if applicable);
 - xiii) the observed device and clinical effects of failure and adverse perioperative events, including severity, management and outcome;
 - xiv) any significant deviation from the proposed deployment instructions or protocol;
- 5) description of the explant procedure including:
 - i) the identification of retrieval system, conversion system and accessory devices (if applicable);
 - ii) the filter identification number;
 - iii) the diameter(s) of the recipient vessel(s);

- iv) the description of filter formation;
- v) the location of filter prior to explant;
- vi) the access site for retrieval or conversion (if applicable);
- d) post-operative and follow-up data:
 - 1) post-operative duration at the time of follow-up;
 - 2) medications, including those that affect coagulation;
 - 3) the assessments of structural integrity, the position of the filter (e.g. location, tilt, caval perforation/penetration), including the method and date of visualization;
 - 4) the observed device and clinical effects of failure and adverse events (e.g. clinical perforation/penetration, including date of occurrence, severity, management and outcome);
 - 5) the assessment of other parameters specified in the protocol;
 - 6) any significant deviation from protocol;
- e) termination data:
 - 1) the date of sacrifice;
 - 2) the reason for early termination or death (if applicable);
 - 3) the name of person(s) performing procedures and assessments;
 - 4) the assessments of structural integrity, patency and position of filter, including the method of visualization;
 - 5) the assessment of other parameters specified in the protocol;
 - 6) the gross alteration in the dimensional and physical properties of the filter;
 - 7) the gross and histopathological assessment of explants and appropriate surrounding and distal tissues/organs.

8.6.5 Test report and additional information

Results of all animals enrolled in the protocol shall be recorded and reported, even if excluded from the final analysis.

The test report shall include the following:

- a) the study protocol;
- b) the rationale for selection of the following:
 - 1) animal model, including species, gender, age and weight;
 - 2) implantation site;
 - 3) the control for comparison or rationale for not using a control group (if applicable);
 - 4) implantation periods;
 - 5) methods of assessment;
 - 6) intervals of observation;

- 7) sample size (i.e. number of animals and implants);
- c) results:
 - 1) animal accountability, including rationale for exclusion of data from the primary analysis;
 - 2) the number of filters successfully implanted and the number of filters unsuccessfully implanted;
 - 3) the number of filters successfully retrieved or converted, and the number of filters not successfully retrieved or converted, as applicable;
 - 4) the operator's assessment of ease of deployment, visualization and handling;
 - 5) the discussion of sizing and potential impact on study results;
 - 6) a summary of any changes in position, structural and material integrity and patency of the filter;
 - 7) a summary of device and clinical effects of failure and adverse events;
 - 8) a summary of unexpected deaths or early terminations, with discussion of post-mortem pathological evaluation, suspected aetiology and the potential for the death to be related to the device;
 - 9) a summary of animal health including scheduled examinations, clinical observations, clinical pathology values and weight gain or loss;
 - 10) a summary of gross pathology evaluation and histopathology of explants and appropriate tissues/organs, including gross photographs, radiographs of explants and representative photomicrographs;
 - 11) a summary of other information required by the protocol;
 - 12) significant and/or relevant deviations from protocol;
 - 13) a comparison of outcomes for test and control groups (if applicable);
 - 14) conclusions from the study;
 - 15) a summary of quality assurance and data auditing procedures.

8.7 Clinical evaluation

8.7.1 Purpose

The purpose of clinical evaluation is to assess the safety and effectiveness of the filter system, the retrieval system and/or the conversion system. An investigation shall be carried out for each new filter or new clinical application of a filter using the principles given in ISO 14155 or an equivalent reference. Significant design changes that can impact safety and performance shall require clinical evaluation if determined to be necessary based on an appropriate risk assessment. This evaluation may follow the requirements described in this document or the abbreviated requirements as appropriate to address the identified risks. Additional filter sizes outside the previously evaluated range can require clinical evaluation but does not always require assessment consistent with all requirements (e.g. multicenter study, statistically powered sample size).

If an objective of a clinical study can be met through alternative means (e.g. through reference to previously conducted clinical studies), the use of previously obtained data or other supportive information shall be justified. The justification should include comment on the relevance of any differences between the subject device and the device used in the previous study and the relevance of any differences in the intended uses.

The principles of [8.7](#) may be applied for the clinical evaluation of filters for uses other than in the inferior vena cava. Additional specific aims, end points and reporting requirements can be needed to define an appropriate study.

8.7.2 Specific aims

Specific aims of the study shall be based on an appropriate risk assessment for the filter system, the retrieval system and/or the conversion system stated in the protocol. The specific aims may include the following:

- a) to evaluate the performance of the filter system, the retrieval system or the conversion system, such as:
 - 1) the ability to access the target location with the filter system;
 - 2) the handling and visualization of the filter system and visualization of the filter and caval perforation/penetration;
 - 3) the accuracy of deployment, including adequate fixation;
 - 4) the ability to withdraw the delivery system;
 - 5) the position, patency and structural integrity of the filter acutely and over time;
 - 6) the appropriateness of filter sizing;
 - 7) the ability to access the intended retrieval or conversion location with the retrieval system or conversion system (if applicable);
 - 8) the handling and visualization of the retrieval system or conversion system (if applicable);
 - 9) the ability to retrieve or convert the filter (if applicable);
 - 10) the ability to withdraw the retrieval system or conversion system, with any removed previously implanted components following retrieval or conversion (if applicable);
 - 11) the device effects of failure (see [Annex C](#) for potential effects of failure);
- b) to evaluate the safety of the filter system, the retrieval system or the conversion system, such as:
 - 1) the clinical effects of failure (see [Annex B](#) for potential clinical effects of failure);
 - 2) adverse events.

8.7.3 Protocol considerations

A multicenter study shall be performed at a minimum of three investigational sites. A justification for the number of investigational sites shall be provided.

A specific question or set of questions (i.e. hypotheses) shall be defined prospectively. These questions shall delineate the appropriate safety (e.g. freedom from major adverse events), effectiveness (e.g. technical success in absence of serious device related events) or combined safety and effectiveness end points to be measured. Definitions of success and failure for each end point and the duration of follow-up needed to assess each end point shall be specified. A definition for the study success shall also be specified (e.g. meeting both the safety and effectiveness primary end points).

A statistical justification for the number of patients studied shall be provided based upon the primary hypotheses. Preferably no investigational site should enroll more than 35 % of the total number of study subjects.

The duration of the patient follow-up shall be determined in relation to the objectives of the clinical investigation. Patient follow-up intervals shall include a minimum of an assessment at discharge and at the specified study duration. A justification will be required for follow-up intervals. All patients enrolled in the study, including those excluded from the primary end point analyses, shall be recorded and reported. The final report may be completed when the required number of patients to test the hypotheses have reached the specified study duration. The report shall include current follow-up data on all patients. Longer-term patient follow-up (e.g. 2 years to 5 years after the filter has been implanted) can be appropriate for the post-market clinical assessment of device designs with a limited history of clinical use.

A method for evaluating the clinical outcomes shall be prospectively defined and justified (e.g. performance goals or a justifiable control group).

NOTE 1 Patients receiving filters are not always candidates for anticoagulation and a control group that involves no treatment can be difficult to justify.

The study design shall be designated by appropriate terms [e.g. number of study arms, type of control (randomized, literature, performance goal), blinding, prospective versus retrospective]. The assessments can differ between the control group and the treatment group. If so, the assessments for both the control and treatment subjects shall be included in the protocol.

Patient inclusion and exclusion criteria shall be clearly identified. The criteria shall specify the target population (i.e. those for whom the filter is intended) and the accessible population (i.e. those you agree and are able to participate fully in the study). An appropriate epidemiological approach shall be utilized for recruiting subjects to minimize bias (e.g. encourage sequential enrolment).

Definitions, primary and secondary clinical end points, measurement methods and data analysis shall be specified in the clinical protocol. Secondary end points can include the following:

- individual components that make up any composite primary end points;
- change in quality of life status or other relevant patient reported outcomes;
- measure of therapeutic success;
- technical success (e.g. successful deployment of filter at intended implantation site);
- procedural success (e.g. technical success in absence of serious device-related adverse events at 30 days);
- retrieval or conversion success;
- device and clinical effects of failure;
- longer-term outcomes (e.g. 12-month safety data if the primary safety end point is at 30 days).

NOTE 2 Additional guidance can be found in clinical society and consensus publications [\[37\]](#)–[\[41\]](#).

Consideration should be given to the use of independent core laboratories and event adjudication committees, as appropriate. The sources of the data to be included in reporting (e.g. site, core lab, adjudication committee) should be specified in the protocol.

8.7.4 Data acquisition

Data similar to those for patients in the treatment group shall be recorded for each patient in the control group, as appropriate.

At a minimum, the following data shall be recorded for each patient in the treatment group:

- a) identification and demographic data:
 - 1) patient identification;
 - 2) indication for treatment (e.g. evidence of PE or DVT in the IVC or lower extremity veins and either an absolute or relative contraindication to anticoagulation, a failure of anticoagulation, or high risk from complication to anticoagulation) and associated medical diagnosis (e.g. lower extremity DVT);
 - 3) demographics:
 - i) age;
 - ii) sex;
 - iii) weight or body mass index;

- iv) height;
- v) race, as appropriate (i.e. when this information can be legally obtained);
- 4) name of investigator;
- 5) name of institution;
- b) pre-procedural data:
 - 1) risk factors, such as deep vein thrombosis (DVT), trauma, malignancy, anticoagulation therapy, pelvic and orthopaedic procedures, female contraceptive pill and female hormone replacement therapy, hypercoagulable states including post-splenectomy, post-operative cessation of anticoagulant therapy, severe cardiopulmonary disease, varicose veins, history of pulmonary embolism (PE), obesity, smoking, anaesthesia risk, prolonged immobility, and any other cardiovascular risk factors, with some measure of severity and current treatment;

NOTE Additional definitions and risk factors can be found in clinical society and consensus publications^[37]-^[41].
 - 2) summary of previous cardiovascular interventions, including non-surgical interventions and cardiovascular implants;
 - 3) relevant medications (e.g. anticoagulants, thrombolytics);
 - 4) diagnostic criteria:
 - i) clinical assessment;
 - ii) objective assessment of access vessel characteristics and other relevant factors (e.g. size of vena cava and presence and site of thrombus);
- c) procedural data:
 - 1) name of implanting physician;
 - 2) date of procedure;
 - 3) identification data for the filter system(s), including product name, model number, filter traceability, size and orientation;
 - 4) urgency of intervention (i.e. urgent, emergent or elective);
 - 5) information regarding the procedure (e.g. adjunctive vascular procedures performed, type of anaesthesia, total fluoroscopy time);
 - 6) relevant procedural medications (e.g. anticoagulants);
 - 7) geometric configuration and orientation (e.g. tilt) following deployment from the filter system;
 - 8) position of filter (e.g. distance from anatomical landmarks, filter extending outside cava wall, haemorrhage, filter interacting with adjacent anatomical structures);
 - 9) assessment of procedural outcome (e.g. technical success, filter integrity, filter thrombosis);
 - 10) record device and clinical effects of failure and adverse events [see 8.7.4 f)];
 - 11) date of hospital discharge;
 - 12) ability to visualize filter and delivery system on imaging;
- d) follow-up data:
 - 1) interval of follow-up (e.g. discharge, 30-day, 12-month);

- 2) date of follow-up visit;
 - 3) relevant interventions or surgeries since last follow-up;
 - 4) clinical assessment including evaluation for PE and clinical perforation/penetration;
 - 5) imaging assessment, as applicable:
 - i) presence or absence of planned imaging surveillance and modality;
 - ii) objective assessment of filter geometric configuration and orientation (e.g. tilt) filter integrity, filter position (e.g. distance from anatomical landmarks, caval perforation/penetration);
 - 6) relevant medications, such as anticoagulants or antiplatelets;
 - 7) record device and clinical effects of failure, and adverse events [see [8.7.4 f\)](#)];
- e) filter retrieval or conversion data (if applicable):
- 1) date of procedure;
 - 2) access site;
 - 3) retrieval or conversion device(s) used, including product name, model number, size and traceability;
 - 4) details of procedure, including any adjunctive vascular procedures performed;
 - 5) relevant medications;
 - 6) assessment of access, handling visualization, deliverability and withdrawal of retrieval system or conversion system;
 - 7) documentation of clinical decision not to retrieve or convert filter (e.g. thrombus formation), if applicable;
 - 8) assessment of the ability to retrieve or convert filter;
 - 9) integrity inspection of retrieved filter(s);
 - 10) configuration and/or status of converted filter device;
 - 11) record device and clinical effects of failure, and adverse events [see [8.7.4 f\)](#)];
- f) device and clinical effects of failure, and adverse events:
- 1) type of effect or event, date of occurrence, severity, management (e.g. none, medical treatment, secondary endovascular procedure, open surgical procedure), outcome (e.g. continuing, resolved, unknown, death);
 - 2) documentation of filter involvement;
 - 3) documentation of probably causative factors (e.g. caused by the filter, patient factors, technical factors);
- g) death:
- 1) date;
 - 2) whether autopsy was performed, and if so, the findings;
 - 3) cause of death:
 - i) whether or not the death was related to the filter or the procedure;

- ii) summary of explant analyses (if applicable);
- h) patient withdrawal:
 - 1) date;
 - 2) months of study completed;
 - 3) reason for withdrawal (e.g. lost to follow-up, withdrew consent, removed from study per physician recommendation).

8.7.5 Final report

The final report shall include the following:

- a) study protocol, including at a minimum:
 - 1) study description (e.g. study design designation, control arm, number of sites, number of patients);
 - 2) primary and secondary end points, hypotheses and definitions of success;
 - 3) source of the data (e.g. site, core lab);
 - 4) definition of study success;
 - 5) subject population (i.e. selection criteria);
 - 6) follow-up intervals;
 - 7) methods of assessment (e.g. clinical, venography, duplex ultrasound);
 - 8) data analysis plan including methods to address missing data;
 - 9) definitions of technical and procedural success, device and clinical effects of failure, and adverse events;
- b) rationale, based on the risk assessment and questions to be answered, for selection of the following:
 - 1) study size;
 - 2) choice of control;
 - 3) measurement methods;
 - 4) statistical analyses employed;
 - 5) patient follow-up intervals;
- c) number of patients treated at each investigational site;
- d) follow-up accountability (e.g. number of patients eligible for each follow-up interval and the number with specified follow-up data), including rationale for the exclusion of data from the primary end point analyses;
- e) demographics and risk factors;
- f) significant and/or relevant deviations from the clinical protocol and the manner in which deviations were addressed in the data presentation;
- g) results:
 - 1) technical success;
 - 2) procedural success;
 - 3) retrieval or conversion success;

- 4) safety:
 - i) primary and secondary end point outcomes;
 - ii) summary of peri-procedural (less than or equal to 30 days, or prior to hospital discharge) or filter-related surgical interventions needed post-filtering, if any, to optimize results;
 - iii) summary of peri-procedural and late deaths;
- 5) effectiveness:
 - i) primary and secondary end point outcomes;
 - ii) summary of secondary interventions (e.g. placement of additional filter);
- 6) conclusions from the study, including results of hypothesis testing and achievement of success as defined by the protocol.

9 Post-market experience

A systematic procedure to review post-market experience gained from implants shall be in place using the principles given in ISO 14630:2012, 7.4, ISO 14155, ISO/TR 20416 and ISO 14971, or equivalent publications.

10 Manufacturing

Filter systems, retrieval systems and conversion systems shall be manufactured in such a way that the design attributes are achieved. Requirements are specified in other related international standards.

The requirements of ISO 13485 and ISO 14630:2012, Clause 8 shall apply.

11 Sterilization

11.1 Products supplied sterile

Filter systems, retrieval systems and conversion systems that are labelled “sterile” shall comply with international, national or regional standards and have a sterility assurance level (SAL) of 10^{-6} . Sterilization processes shall be validated and routinely controlled.

NOTE Information on sterility assurance level can be found in ANSI/AAMI ST67.

- a) For systems that are to be sterilized by ethylene oxide, ISO 11135 shall apply.
- b) For systems that are to be sterilized by moist heat, ISO 17665-1 shall apply.
- c) For systems that are to be sterilized by radiation, the ISO 11137 series shall apply.
- d) For systems that are to be sterilized by other sterilization processes, ISO 14937 shall apply.

11.2 Sterilization residuals

The requirements of ISO 14630:2012, 9.4 shall apply.

12 Packaging

12.1 General

12.1.1 General

The requirements of ISO 14630:2012, Clause 10 shall apply.

12.1.2 Unit container

Each filter system, retrieval system and conversion system shall be packaged in a unit container providing a sterile barrier, if applicable. It shall be readily apparent if the unit container has been opened.

12.1.3 Outer container

Each unit container shall be packaged in an outer container. This outer container shall be designed to protect the unit container from damage caused by storage.

12.1.4 Shipping container

Each outer container, or a number of outer containers not necessarily of the same type, shall be packaged in a shipping container designed to protect the contents under normal conditions of handling, transit and storage.

12.1.5 Maintenance of sterility in transit

For filter systems, retrieval systems and conversion systems supplied sterile, the unit container shall be designed to maintain the sterility of the system under normal conditions of handling, transit and storage, and to permit the contents to be presented for use in an aseptic manner.

The packaging shall conform to ISO 11607-1.

12.2 Labelling

12.2.1 Container label

Filter system, retrieval system and conversion system shall be accompanied by a label(s) on an appropriate container(s).

NOTE Information regarding labelling is provided in ISO 15223-1.

12.2.2 Filter systems

At least the following information shall be provided in words, phrases, symbols or drawings on the label(s):

- a) filter system information, including at least:
 - 1) dimensions: size of introducer (internal diameter), maximum size of guidewire and usable, working or effective length of the catheter;
 - 2) filter system orientation.
- b) description of the package contents and/or list of the package contents;
- c) name and/or trademark, address and contact information of the manufacturer;
- d) product name;
- e) the material(s) of construction;

- f) configuration (see [4.2](#)), if applicable;
- g) dimensions, i.e. the designated length and diameter(s) after expansion;
- h) model/reference number;
- i) lot/serial number;
- j) sterilization method and the word “STERILE”;
- k) single use;
- l) expiry/expiration date;
- m) warnings or reference to read the manual (symbol);
- n) recommended caval diameters;
- o) warning against the use of the filter if the package is open or damaged;
- p) manufacturer’s recommendation for storage, if applicable;
- q) the chemical nature of any storage medium in the unit container, with appropriate hazard warning.

12.2.3 Retrieval systems

At least the following information shall be provided in words, phrases, symbols or drawings on the label(s):

- a) applicable information as described in [12.2.2](#);
- b) retrieval system information, including at least:
 - 1) dimensions, i.e. the size of introducer (internal diameter), the required size of guidewire and the usable, working or effective length of the catheter;
 - 2) recommended accessory devices;
 - 3) retrieval system orientation.

12.2.4 Conversion systems

At least the following information shall be provided in words, phrases, symbols or drawings on the label(s):

- a) applicable information as described in [12.2.2](#);
- b) conversion system information, including at least:
 - 1) dimensions, i.e. the size of introducer (internal diameter), the required size of guidewire and the usable, working or effective length of the catheter;
 - 2) recommended accessory devices;
 - 3) conversion system orientation.

12.2.5 Record label

Each filter system should be supplied with transferable record labels suitable for attachment to the records of the patient receiving the filter. The record label should include the following information:

- a) manufacturer’s identification;
- b) product name;
- c) manufacturer’s batch and/or sterile lot number;

- d) part or model number (manufacturer's catalogue number).

12.3 Information supplied by the manufacturer

12.3.1 General

The requirements of ISO 14630:2012, 11.3 shall apply.

12.3.2 Information and instructions for use

Each unit container or outer container of which the contents are identical shall be supplied with the IFU of the device or instructions on how to access an electronic version of the IFU. The instructions shall include the following information to use the device safely and properly, taking into account the training and knowledge of the potential users:

- a) name, address and/or trademark of the manufacturer;
- b) product name;
- c) device description and materials of construction;
 - 1) material of construction of the filter;
 - 2) description of the location(s) of markers for visualization, if applicable;
- d) indications for use and as applicable intended use;
- e) contraindications, cautions and warnings;
- f) recommendations for filter sizing, including vena cava diameters, as applicable;
- g) potential adverse events;
- h) data from clinical studies, if applicable;
- i) recommended methods for the aseptic presentation and the preparation of the filter and delivery system;
- j) recommended methods for vessel preparations, such as pre-dilatation, and methods for access, delivery of the filter, retrieval of the filter, conversion of the filter and withdrawal of the system;
- k) applicable information regarding the sterility of the device, in prominent form:
 - 1) NON-STERILE;
 - 2) STERILE;
 - 3) STERILE – DO NOT RESTERILIZE;
- l) statement that the device is single use only in prominent form;
- m) resterilization information, if applicable;
- n) notification of additives or leachable components (if applicable);
- o) recommendations for storage, if applicable;
- p) date of or reference relating to the publication of the IFU, indicating when the IFU was last revised;
- q) recommendations for visualization;
- r) MRI safety information;
- s) recommended method, where appropriate for retrieval or conversion of the filter; for convertible filters, include the time to conversion; for retrievable filters, include the statement(s) that vena cava filter

should be retrieved as soon as clinically warranted (e.g. once prevention of symptomatic PE is no longer required) and presentation of filter retrieval data (e.g. data for time to filter retrieval attempt, filter retrieval outcome data, adverse events associated with retrieval), unless otherwise justified.

Annex A

(informative)

Relationship between testing requirements, device attributes and potential failure modes, and guidance for the creation of a device evaluation strategy

A.1 Device evaluation strategy introduction and rationale for bench testing and analyses

A device evaluation strategy provides the rationale for the evaluation plan for a device. The rationale for the evaluations required by this document that are applicable to most filters is described in [Tables A.3](#) to [A.9](#). Identification of the appropriate testing for a device evaluation strategy involves describing each device-related and procedure-related function needed to achieve the desired performance (i.e. device attributes) and the associated relationships between device attributes, potential failure modes and testing requirements.

Potential device effects of failure are categorized into two categories: initial effects and subsequent effects of failure. Subsequent effects are defined as a secondary effect of device failure after an initial effect. For example, filter migration can lead to filter fracture. In this example, filter migration would be listed under “initial effect(s)” and filter fracture would be listed under “subsequent effect(s).”

Potential adverse clinical effects (ACE) of failure that are commonly grouped together have been listed in ACE1, ACE2 or ACE3 groups, as described in [Table A.2](#). These abbreviated terms are used throughout this document to minimize redundancy. A non-specific clinical event or use of additional devices or procedures, designated as ACE3 in [Table A.2](#), only appears in [Tables A.3](#) to [A.9](#) when it is the only identified potential clinical effect of failure. This effect is applicable for all potential failure modes, but not repeated to decrease redundancy.

To reduce redundancy, some potential failure modes associated with individual device and procedure related functions are not repeated if covered under previously identified functions.

Table A.1 — Explanation of [Tables A.3](#) through [A.9](#) column headings

Device attributes/ procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Nonclinical device testing
		Device effect(s) of failure		Clinical effect(s) of failure	
Initial effect(s)	Subsequent effect(s)				
Each individual device-related and procedure-related function required for the device to achieve the overall desired performance. Functions should be attributes of the device or procedure and therefore should be stated in the positive.	The specific failures that can occur and can result in consequences (effects) to the device or patient if the function is not attained. Individual failure modes should be addressed separately. They should be presented in separate rows for an attribute, as they can have different effects of failure and can be mitigated with different testing.	The potential effect(s) of the failure mode on the device. Device effects of failure describe what happens to the device as a result of the failure and can be important to capture, whether or not there is an associated clinical effect of failure.	The potential additional device effect(s), if any, resulting from one of the effects listed in the previous column.	The potential effect(s) of the failure mode on the patient.	Bench tests and analyses of the device to evaluate the function and the potential failure mode.

Table A.2 — Clinical effects of failure for each ACE group

ACE1: Local effects		ACE2: Regional or systemic effects		ACE3: Non-specific effects
—	Caval injury or damage	—	Arrhythmia	A non-specific clinical event or the use of additional devices or procedures
—	Clinical perforation/penetration	—	Cardiac damage	
—	Caval haemorrhage	—	Cardiac tamponade	
—	Damage to adjacent anatomical structures	—	Caval injury or damage	
—	Caval occlusion	—	Oedema	
—	Embolization of filter system components	—	Embolization of filter system components	
—	Access site haematoma	—	Embolization of biologic material (e.g. thrombus)	
—	Access vessel trauma	—	Filter thrombosis	
		—	Lung damage	
		—	Intimal tear	
		—	Pulmonary embolism	
		—	Vascular trauma	
		—	Vessel occlusion	

Table A.3 — Rationale for bench testing and analyses for the filter system

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect (s) of failure	Subsequent effect(s)		
Ability to access	Inability to load filter (if applicable)	Delivery failure	None	—	— ACE3 — Failure to complete device implantation	Simulated use
	Filter system is incompatible with accessory devices	— Access failure	Foreign body embolization	—	— ACE2	— Dimensional verification and component dimensional compatibility — Simulated use
		— Accessory device failure		—	— Access vessel trauma	
		— Delivery failure		—	— Failure to complete device implantation	
		— Delivery system failure		—	—	
	Inability to advance filter system to target site	— Access failure	Foreign body embolization	—	— ACE2	Simulated use
		— Delivery failure		—	— Access vessel trauma	
		— Delivery system failure		—	— Failure to complete device implantation	
		— Filter damage		—	—	
	Premature release of filter	Delivery failure Deployment failure	— Excessive filtration	—	— ACE2 — Failure to complete device implantation	Simulated use
			— Inadequate filtration	—		
			— Filter fracture	—		
			— Filter migration	—		
			— Filter embolization	—		
			— Inadequate filter formation	—		
			— Unacceptable filter tilting	—		

Table A.3 (continued)

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect(s) of failure	Subsequent effect(s)		
Ability to deploy	Inability to activate de- ployment mechanism or procedure	— Delivery system failure	None	None	— ACE3	— Force to deploy
		— Inability to deploy			— Failure to complete device implantation	— Simulated use
	Improper filter positioning, configuration, or orientation	— Inaccurate deployment	Foreign body embolization	ACE2		Simulated use
		— Excessive filtration				
		— Inadequate filtration				
		— Filter fracture				
		— Filter migration				
		— Filter embolization				
		— Unacceptable filter tilting				
		— Inadequate filter formation				
Inability to completely release filter from delivery system	Deployment failure	None	ACE3	Simulated use		
Partial deployment of filter	Deployment failure	None	— ACE1 — Clinical perforation/ penetration	Simulated use		
	Ability to withdraw	Damage of implant compo- nents by other components (e.g. delivery system snag- ging on filter)	— Excessive filtration	ACE2	— Dimensional verification and component dimensional compatibility — Simulated use — Tensile bond strength — Torsional bond strength	
— Inadequate filtration						
— Embolization of biologic material (e.g. thrombus)						
— Embolization of filter system components						
— Filter migration						
— Filter embolization						
— Inadequate filter formation						
— Unacceptable filter tilting						
— Foreign body embolization						

Table A.3 (continued)

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect (s) of failure	Subsequent effect(s)		
Filter system integrity	Separation of delivery system components (e.g. bond failures, complete tip separation)	—	Delivery system failure	—	—	—
		—	Bond joint failure	—	—	—
				Delivery system failure Foreign body embolization	ACE2 Failure to complete device implantation Vascular trauma	Simulated use Tensile bond strength Torsional bond strength

Table A.4 — Rationale for bench testing and analyses for the vena cava filter

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect(s) of failure	Subsequent effect(s)		
Fixation effective- ness	Excessive radial force	None		None	— Caval injury or damage — Caval haemorrhage — Trauma to adjacent anatomical structures	Radial force
	Inadequate fixation	— Filter migration		— Excessive filtration	ACE2	— Migration resistance
		— Unacceptable filter tilting		— Inadequate filtration		— Radial force
				— Inadequate filter formation		
				— Filter fracture		
				— Filter embolization		

Table A.4 (continued)

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect(s) of failure	Subsequent effect(s)		
Filter integrity	Structural failure of filter (includes loss of integrity due to any cause)	Filter fracture	—	Excessive filtration	ACE2	—
			—	Inadequate filtration		—
			—	Inadequate filter formation		—
			—	Unacceptable filter tilting		—
			—	Filter migration		—
			—	Filter embolization		—
	Bond joint failure		—	Excessive filtration	ACE2	—
			—	Inadequate filtration		—
			—	Filter damage		—
			—	Filter fracture		—
Filtration	Corrosion	— Bond joint failure — Filter fracture	—	Unacceptable filter tilting	ACE2	—
			—	Inadequate filter formation		—
			—	Filter migration		—
			—	Filter embolization		—
			—	Inadequate filtration		—
			—	Change in filter formation		—
	Ineffective clot capture	Inadequate filtration	—	Unacceptable filter tilting	Embolization of biologic material (e.g. thrombus)	—
			—	Filter migration		—
			—	Filter embolization		—
			—	Filter embolization		—

Table A.4 (continued)

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect(s) of failure	Subsequent effect(s)		
Appropriate sizing recommendations	Excessive oversizing	— Excessive filtration	—	Foreign body embolization	— ACE2	— Filter dimensional verification
		— Filter damage	—	Filter migration	— Clinical perforation/penetration	— Radial force
		— Filter fracture	—		— Caval occlusion	— Simulated use
		— Inadequate filter formation	—			
		— Unacceptable filter tilting	—			
	Undersizing	— Unacceptable filter tilting	—	Excessive filtration	ACE2	— Filter dimensional verification
		— Filter migration	—	Inadequate filtration		
			—	Filter fracture		
			—	Filter embolization		
			—	Inadequate filter formation		
MRI	Heating	None	None	None	Vascular trauma	Radiofrequency induced heating
	Lack of quality MR imaging	None	None	None	— Inability to monitor filter over time with MR imaging	MR imaging artefact
					— Inadequate MR imaging	
	Movement of filter	— Filter migration		Excessive filtration	— ACE2	MR displacement and torque
		— Unacceptable filter tilting		Inadequate filtration		
				Filter fracture	— Vascular trauma	
				Filter embolization		
				Inadequate filter formation		

Table A.5 — Rationale for bench testing and analyses for optional filters

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure		Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect (s) of failure Subsequent effect (s)		
Ability to engage filter	Inability to engage filter	— Retrieval failure	— Excessive filtration	ACE2	Simulated use
		— Retrieval system failure	— Filter fracture		
		— Filter damage	— Filter migration		
		— Unacceptable filter tilting	— Filter embolization		
Ability to retrieve filter	Inability to detach filter from vena cava	— Retrieval system failure	— Excessive filtration	ACE2	None
		— Filter damage	— Caval injury or damage		
		— Filter fracture	— Caval haemorrhage		
		— Bond joint failure	— Filter migration		
	Inability to collapse filter	— Unacceptable filter tilting	— Filter embolization	ACE2	Simulated use
		— Retrieval system failure	— Retrieval failure		
		— Filter damage	— Excessive filtration		
		— Filter fracture	— Inadequate filtration		
	Bond joint or material failure	— Bond joint failure	— Filter migration	ACE2	Filter tensile strength
		— Unacceptable filter tilting	— Filter embolization		
		— Retrieval system failure	— Retrieval failure		
		— Filter damage	— Inadequate filtration		
Structural integrity	Engagement mechanism deformation/fracture	— Filter damage	— Filter migration	ACE2	Force to retrieve
		— Filter fracture	— Filter embolization		
		— Unacceptable filter tilting	— Retrieval failure		
		— Engagement mechanism damage	— Embolization of filter or retrieval system components		
		— Bond joint failure	Retrieval failure	ACE2	

Table A.6 — Rationale for bench testing and analyses for convertible filters

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect (s) of failure	Subsequent effect(s)		
Ability to engage filter	Inability to engage filter	—	Conversion failure	—	ACE2	Simulated use
		—	Conversion system failure	—		
		—	Filter damage	—		
		—	Unacceptable filter tilting	—		
Ability to convert filter	Inability to convert filter	—	Filter damage	—	ACE2	Simulated use
		—	Bond joint failure	—		
		—	Unacceptable filter tilting	—		
		—	Filter fracture	—		
		—	Filter migration	—		
		—	Filter embolization	—		
Structural integrity	Bond joint or material failure	—	Conversion system failure	—	ACE2	Filter tensile strength
		—	Filter damage	—		
		—	Filter fracture	—		
		—	Unacceptable filter tilting	—		
	Engagement mechanism deformation/fracture	—	Conversion system failure	—	ACE2	Force to convert
		—	Engagement mechanism damage	—		
		—	Bond joint failure	—		
		—	Conversion failure	—		

Table A.7 — Rationale for bench testing and analyses for retrieval systems

Device attributes / procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect (s) of failure	Subsequent effect(s)		
Ability to reach the filter location (i.e. only to tip of sheath)	Retrieval system is incom- patible with introducer sheath	Retrieval system failure	—	Failure to complete retrieval	ACE3	— Dimensional verification and component dimensional compatibility
			—	Embolization of filter or retrieval system components		— Simulated use
	Inability to advance retrieval system to target site	None		Retrieval failure		Simulated use
Ability to engage filter	Inability to engage filter	None		Retrieval failure	— ACE3 — Failure to complete retrieval	Simulated use
				Retrieval failure	— ACE3 — Failure to complete retrieval	Simulated use
Ability to retrieve filter	Inability to detach filter from vena cava	Retrieval system failure	—	Excessive filtration	ACE3	— Simulated use
		Filter damage	—	Filter migration		— Force to retrieve/convert
		Filter fracture	—	Inadequate filter formation		
Ability to retrieve filter	Inability to retrieve filter	Unacceptable filter tilting	—	Embolization of filter or retrieval system components	ACE3	Simulated use
		Bond joint failure	—	Retrieval failure		
			—	Excessive filtration		
Ability to withdraw retrieval system	Damage retrieval system	Retrieval system failure	—	Inadequate filter formation	ACE2	— Simulated use
		Bond joint failure	—	Embolization of filter or retrieval system components		— Tensile bond strength
			—	Caval damage		— Torsional bond strength
Ability to withdraw retrieval system			—	Retrieval failure	ACE2	— Simulated use
			—	Embolization of filter or retrieval system components		— Tensile bond strength
			—	Retrieval failure		— Torsional bond strength

Table A.8 — Rationale for bench testing and analyses for conversion systems

Device attributes/ procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect (s) of failure	Subsequent effect(s)		
Ability to reach the filter location (i.e. only to tip of sheath)	Conversion system is in- compatible with introducer sheath	Conversion system failure	Conversion failure	Conversion failure	— ACE3 — Failure to complete conversion	— Dimensional verification and component dimensional compatibility — Simulated use
	Inability to advance conver- sion system to target site	Conversion system failure	Conversion failure	Conversion failure	— ACE3 — Failure to complete conversion	Simulated use
Ability to engage filter	Inability to engage filter	Conversion system failure	Conversion failure	Conversion failure	— ACE3 — Failure to complete conversion	Simulated use
Ability to convert filter	Inability to convert filter	Conversion system failure	Conversion failure	Conversion failure	ACE2	— Simulated use — Force to retrieve / convert
		Filter fracture	Conversion failure	Conversion failure		
		Unacceptable filter tilting	Excessive filtration	Excessive filtration		
		Filter migration	Embolization of filter or conversion system components	Embolization of filter or conversion system components		
		Filter embolization	Embolization of filter or conversion system components	Embolization of filter or conversion system components		
Ability to withdraw conversion system and introducer sheath	Damage to conversion system	Bond joint failure	Conversion system failure	Conversion failure	ACE2	— Simulated use — Tensile bond strength — Torsional bond strength
		Conversion system failure	Conversion system failure	Conversion failure		

Table A.9 — Rationale for bench testing and analyses for filter systems, retrieval systems and conversion systems

Device attributes/ procedure related function(s)	Potential failure mode(s)	Potential effect(s) of failure			Clinical effect(s) of failure	Nonclinical device testing
		Initial effect(s)	Device effect(s) of failure	Subsequent effect(s)		
Visualization	Inability to safely and effectively access, deploy, retrieve, convert, or withdraw	All device effects associated with access, deployment, retrieval, conversion and withdrawal	None	None	All clinical effects of failure associated with inability to access, deploy, retrieve, convert or withdraw	Visibility
	Inadequate visibility of the filter	None	None	None	Inability to monitor the filter over time	Visibility
Biocompatibility	Non-biocompatible	None	None	None	Adverse biological response	Biocompatibility
Sterility	Non-sterile product	None	None	None	— Insertion site infection — Filter infection	Sterilization assurance
	Inadequate haemostasis	None	None	None	Blood loss	— Dimensional verification and component dimensional compatibility — Haemostasis
Atraumatic introduction, tracking and withdrawal	Embol generation	None	None	None	Embolization of biologic material (e.g. thrombus)	None
	Particulate generation	None	None	None	— Adverse biological response — Ischaemia	Simulated use
	Trauma to vasculature	None	None	None	— Access vessel trauma — Vascular trauma	— Dimensional verification and component dimensional compatibility — Simulated use
	Inability to obtain cavagram	Inadequate contrast flow	— Catheter leakage — Catheter burst	ACE 1		Simulated use

A.2 Device specific evaluation strategy table

A.2.1 General and focused device evaluation strategy

A.2.1.1 General

For a specific device design either a focused device strategy or a comprehensive device evaluation strategy table may be used to provide the rationale for the testing strategy for the device. The focused device evaluation strategy table can be more efficient for device designs when there are discrete design characteristics that can affect device performance that can require specific testing, or for modifications in the device design or intended use resulting in the need to conduct testing associated with the modifications, rather than repeating all of the testing listed in this document. The comprehensive device evaluation strategy table is recommended for device designs that are significantly different from available technology.

The information provided in [Tables A.3 to A.9](#) can be used to populate the device-specific evaluation strategy table. The nonclinical testing column may include information on preclinical in vivo evaluation of the device as related to the evaluation of a particular attribute or potential failure mode, as well as bench tests and analyses as shown in [Tables A.3 to A.9](#).

For a new device, it can be most efficient to provide a device evaluation strategy table that is focused on the unique aspects of a device design. This would involve first describing the potential effect of the in vivo environment on the device (see [Table A.11](#)) and presenting a device evaluation strategy table that only includes information specific to the unique aspects of the device and the proposed intended use (see [Table A.14](#)).

For a device design modification or change in intended use, a similar approach can be taken, describing the change in the device and/or intended use (see [Table A.12](#) and/or [Table A.13](#), as applicable) and presenting a device evaluation strategy table (see [Table A.14](#)) that only includes information specific to the modifications.

For re-registration of an existing device, provide a device evaluation strategy table (see [Table A.14](#)) that compares available information to the requirements of this document.

The four categories of focused device evaluation strategy and the associated evaluation guidance tables are described in [Table A.10](#).

Table A.10 — Focused device evaluation strategy table applicability

	Table A.11 : Effects of the in vivo environment on the device evaluation	Table A.12 : Design comparison between a previously evaluated device and the modified device	Table A.13 : IFU comparison of a previously evaluated device and the study device	Table A.14 : Focused device evaluation strategy
New device	✓			✓
Device design modification		✓		✓
Change in intended use			✓	✓
Re-registration				✓

A.2.1.2 Identification of potentially affected attributes for focused device evaluation strategy

A.2.1.2.1 General

Information to support the focused device evaluation strategy table should include identification of unique or changed parameters and the associated procedure-related functions or performance-related functions required for the device to achieve the desired performance that can be affected by the parameters. For a new device, this would involve addressing the in vivo environment per [A.2.1.2.2](#). For a device design modification or change in intended use, this would involve addressing the differences between the modified and previously evaluated device per [A.2.1.2.3](#).

The respective tables should be complemented by a rationale to explain why other attributes would not likely be affected by the unique device characteristics or changes in the device and/or the indications for use.

A.2.1.2.2 In vivo environment

To aid in explaining why the testing strategy for a device is adequate, it can be helpful to identify the unique aspects of the proposed intended use that can have an impact on the device evaluation strategy, the specific parameters that are associated with each aspect, the attributes of the device and the procedure that can be affected by the parameter, and the test methods that can be impacted by the in vivo conditions. This helps to explain why some testing is needed and how tests are designed to simulate in vivo conditions. An example is provided in [Table A.11](#).

Table A.11 — Effects of the in vivo environment on the device evaluation

Unique aspects of the intended use	In vivo parameters	Potentially affected attributes	Affected test methods
List each unique aspect associated with the intended use (e.g. implant location, disease state) that can be important in assessing device performance.	Identify each in vivo parameter that can be affected by the unique aspect. Examples of in vivo parameters include blood vessel size, angulation, movement, tortuosity, compliance and flow characteristics.	List each procedure-related function or performance-related function required for the device to achieve the desired performance that can be affected by the in vivo parameters.	List the tests associated with the evaluation of the attributes that would be affected by the in vivo parameters.

A.2.1.2.3 Device design or intended use comparison

For a device design modification or change in the intended use, any design differences and differences in the intended in vivo environment should be described with identification of the attributes of the device and procedure that can be affected by the differences and the tests that would be associated with the evaluation of the attribute. Examples are provided in [Tables A.12](#) and [A.13](#).

Table A.12 — Design comparison between a previously evaluated device and the modified device

Device design rationale	Design differences	Comparison of design feature characteristics		Potentially affected device- or procedure-related functions	Affected tests
		Previously evaluated device name	Modified device name		
State the expected benefits of the modified device design as compared to the previously evaluated device. Examples of expected benefits of design differences include improved deployment accuracy.	List each design feature that is different between the previously evaluated device and the modified device to achieve the benefit. Examples of design feature differences include filter material and filter geometry.	Provide a detailed description of relevant design feature characteristics of the previously evaluated device, including quantitative values as appropriate. Examples of design feature characteristics that can be associated with a filter material and geometry include filter material processing and thickness.	Provide a detailed description of the design feature characteristics of the modified device, including appropriate quantitative values.	List each device-related and procedure-related function that can be affected by the design differences.	List the tests associated with the evaluation of the attributes that would be affected by the design differences.

Table A.13 — Indication for use comparison of a previously evaluated device and the study device

Differences in the in vivo environment	Comparison of in vivo parameters		Potentially affected device- or procedure-related functions	Affected tests
	Prior intended use	New intended use		
List each in vivo parameter associated with the different intended use (e.g. implant location, anatomical dimensional requirements, disease state) that can be important in assessing device performance. Examples of in vivo parameters include blood vessel sizes, angulation, movement, tortuosity, compliance and flow characteristics.	Describe the in vivo parameter for the previously evaluated intended use.	Describe the in vivo parameter for the new intended use.	Identify each individual device-related and procedure-related function that can be affected by the difference of the in vivo parameter.	List the tests associated with the evaluation of the attributes that would be affected by the difference of the in vivo parameters.

A.2.1.3 Focused device evaluation strategy table

A focused device evaluation table should address the device-related and procedure-related attributes identified in the tables described in [A.2.1.1](#), as applicable, as well as attributes that are relevant to the unique aspects of the device design.

The columns for a device-specific device evaluation strategy table may include those outlined in [Table A.1](#); however, additional columns may be added. For example, a column identifying the unique or modified device characteristics is needed to focus the table on relevant attributes. In addition, a column on device design information may be included that identifies the key design characteristics intended to provide the function or to address or mitigate the potential failure mode. This column may also include relevant information about the design of the device (i.e. design input) that will aid in understanding the testing selected to address the attribute or potential failure mode. An example of the columns for a focused device evaluation strategy table is provided in [Table A.14](#).

Table A.14 — Focused device evaluation strategy

Unique or modified design feature or difference in the in vivo environment	Device- or procedure-related attribute potentially impacted by the unique characteristics or differences or the new intended use	Potential failure modes	Potential effects of failure		Device design information	Value of information from previously evaluated device for modified devices	Nonclinical device testing
			Potential device effects of failure	Potential clinical effects of failure			
Identify each unique or modified design feature or each difference in the in vivo environment, as applicable.	List each device-related and procedure-related function or feature that can be affected by the device design or the difference(s) identified in A.2.1 .	State the failures that can occur and can result in consequences (effects) to the device or patient if the function is not maintained or improved.	List the potential effect(s) of the failure mode on the device. Describe any potential difference in the type or severity of the device effects of failure as compared to the previously evaluated device for modified devices.	List the potential effect(s) of failure mode on the patient. Describe any potential differences in the type and severity of the clinical effects of failure as compared to the previously evaluated device for modified devices.	Discuss the relevant information considered in the design of the device to provide the function or to mitigate the potential failure mode or to explain why the function will be maintained or improved for a modified device.	Provide an explanation of the usefulness of the information obtained from the assessment of the previously evaluated device. ^a	Identify the bench tests and analyses appropriate to evaluate the function and the potential failure mode(s). Take into consideration the information available from a previously evaluated device, if applicable.
^a For example, explain how the information from the previously evaluated device reflects on: <ul style="list-style-type: none"> — the potential for the device to achieve the desired function, — the likelihood of the device to pose a significant safety risk, or — the appropriate testing to address the desired function of the device (e.g. available information that indicates the most relevant test(s) to assess a specific attribute to predict clinical performance). 							

A.2.2 Comprehensive device evaluation strategy

It can be helpful to support a comprehensive device evaluation strategy by providing information on the in vivo conditions applicable to the intended use for a device, as described in [A.2.1.2.1](#).

A comprehensive device evaluation strategy should address all device-related and procedure-related attributes applicable to the device. The columns for the comprehensive device evaluation strategy table may include those outlined in [Table A.1](#), with the addition of a column for the device design information.

A.3 Testing summary

It is helpful to clarify the applicability of each test described in this document to a specific device or modification and to state if and how the test protocol was tailored for the device design, implant location or intended use, and to identify any additional tests that have been conducted. This is best presented in tabular format with the following information: the test (i.e. standard testing and additional tests); the purpose of the test; an explanation of the applicability of each standard test to the device; and a brief description of how a test has been designed to incorporate unique aspects of the device design or the intended use/implant location. An example is provided in [Table A.15](#).

Table A.15 — Test summary

Test	Purpose of test	Applicability	Impact of device or implant location
List the tests from this document (see Annex D) and any additional tests.	State the purpose of each test.	Discuss if each of the standard tests are applicable to the device or modification.	Discuss if the test protocol for each standard test has been modified or how each new test has been designed to incorporate the device design or implant location/intended use.

Annex B

(informative)

Description of clinical effects of failure

Event	Description
Adverse biological response	Unspecified clinical adverse event caused by use of a non-biocompatible material. NOTE This clinical effect is not commonly reported. It is often impossible to link an adverse event to a particular material. These events are mitigated through appropriate biocompatibility testing.
Arrhythmia	Development of a new atrial or ventricular arrhythmia or an exacerbation of a prior arrhythmia requiring treatment (i.e. medical therapy, cardioversion, pacemaker) within 30 days of the procedure.
Blood loss	Any blood loss requiring intervention (i.e. transfusion, medical therapy, surgical repair).
Cardiac damage	Injury to any section of the heart related to filter embolization or filter system component embolization.
Cardiac tamponade	Mechanical compression of the heart by large amounts of fluid or blood within the pericardial space that limits the normal range of motion and function of the heart.
Caval injury or damage	Vessel injury or damage to the vena cava observed on imaging study or by direct visualization that requires intervention or surgical repair to address condition.
Caval occlusion	Presence of an occluding thrombus in the IVC, occurring after filter insertion and documented by ultrasound, CT, MRI, venography or autopsy.
Clinical perforation/ penetration (clinical or autopsy finding)	Protrusion of filter components (e.g. struts, anchors) through the vena cava wall causing haemorrhage or haematoma, or interacting with another organ (e.g. liver, bowel, aorta, psoas muscle, vertebral body, lymph nodes), and resulting in adverse clinical symptoms (e.g. abdominal or back pain) or autopsy findings.
Caval stenosis	A narrowing of more than 50 % of the lumen diameter of the vena cava at the filter implant site, with or without haemodynamic significance confirmed by imaging.
Deep vein thrombosis	A thrombus which forms in a deep vein of the body, usually occurring in the deep veins of the lower limb(s), iliac or other pelvic veins or the vena cava.
Oedema	An abnormal excess accumulation of serous fluid in connective tissue, typically seen in the periphery, due to venous occlusion.
Failure to complete device implantation	Inability to implant a filter due to an inability to access the intended site or to deploy the filter.
Failure to complete filter conversion	Inability to convert a convertible filter due to an inability to access the intended site, engage or convert the filter.
Failure to complete filter implantation	Inability to retrieve and optional filter due to an inability to access the intended site, engage or retrieve the filter.
Filter infection	Development of a confirmed filter infection occurring at any time following filter placement. The aetiology (e.g. device sterility, endocarditis) should be reported if known.
Filter thrombosis	Haemodynamically significant clot formation within the lumen of the filter occurring at any time following filter placement. The degree of narrowing, the timing of the thrombosis in relation to the procedure and the imaging modality should be specified.
Foreign body embolization	Intraluminal migration of a filter, fragments of the filter, or pieces of the filter system (e.g. pieces of delivery system).
Haematoma	Development of a haematoma related to the endovascular procedure requiring medical intervention.
Inability to monitor filter over time	Inability to monitor device integrity and position over time due to an inability to visualize the filter.
Insertion site infection	Development of an infection at the insertion site.
Intimal tear	Disruption or tear of the inner lining of the caval wall that results in a clinically significant compromise of the lumen or thrombosis confirmed on imaging studies.
Ischaemia	Oxygen supply decrease due to inadequate blood supply.
Lung damage	Injury to a section of the lung related to filter embolization or filter system component embolization.
Obstruction of blood flow	Restriction of blood flow through the vena cava.
Pulmonary embolism	A blood clot or emboli in the pulmonary vasculature, confirmed by high probability ventilation perfusion (VQ) scan, CT scan, pulmonary angiography or autopsy. PE will be classified as symptomatic or asymptomatic and can be categorized by type (e.g. low-risk, submassive, massive).

ISO 25539-3:2024(en)

Event	Description
Vascular trauma	Injury to a vessel as a result of the filter procedure.
Access vessel trauma	Injury to a vessel at the access site during the filter procedure which can result in hematoma, false aneurysm or arteriovenous fistula.
Vessel occlusion	Occlusion of flow within the target or other vessel which was previously documented to be patent. Can be due to twisting or kinking of the filter, failure of the filter to fully open, filter fragment, dissection or any other cause.

Annex C (informative)

Description of device effects of failure

Event	Description
Access failure	Failure to reach the intended site with the filter system due to mechanical failure or patient anatomy.
Accessory device failure	Inability to use the accessory device as intended due to mechanical failure.
Bond joint failure	Complete or partial separation of discrete structural or material elements of the filter, delivery system, retrieval system as applicable or conversion systems as applicable at bond joints. NOTE This is a failure of the bond joint and not the base material.
Catheter burst	Loss of catheter integrity due to internal pressurization.
Caval perforation/penetration (imaging finding)	Imaging (e.g. venography, CT) showing filter components (e.g. struts, anchors) extending more than 5 mm outside the wall of the vena cava.
Change in filter formation	A change with respect to the manufacturer's specified final expanded geometric configuration of the filter.
Conversion failure	Inability to fully convert the filter as intended (e.g. due to filter position, mechanical failure, patient anatomy).
Conversion system failure	Inability to advance the conversion system to the intended location, actuate the conversion system as intended or withdraw the conversion system (e.g. due to mechanical failure, patient anatomy, user error).
Delivery failure	Inability to load and/or deliver the filter to the intended location (e.g. due to mechanical failure, patient anatomy or user error).
Delivery system damage	Damage incurred to the delivery system (e.g. kink, bond failures, complete tip separation).
Deployment failure	Inability to deploy the filter per the instructions for use.
Engagement mechanism damage	Damage to a component of the filter that is designed for retrieval/conversion.
Excessive filtration	Clinically significant occlusion of the vena cava associated with the filter (e.g. due to filter design, or patient factors such as anatomy or excessively large clots).
Excessive oversizing	The filter is too large for the vena cava (e.g. possibly causing caval or clinical perforation/penetration).
Excessive radial force	Excessive radial force exerted by filter element(s) on the vena cava wall (e.g. possibly causing caval or clinical perforation/penetration).
Filter damage	Damage to the vena cava filter by any cause, such as by an accessory device or the delivery system.
Filter embolization	Post-placement movement of the filter or a piece thereof to a distant anatomic site completely out of the target zone (e.g. heart or lungs) that can result in medical or surgical intervention as documented by imaging or autopsy.
Filter fracture	Breakage or separation of any portion of the filter that can result in a medical or surgical intervention as documented by imaging or autopsy.
Filter migration	A change in filter position compared to its deployed position (either cephalad or caudal) of more than 2 cm as documented by plain film imaging, CT or venography.
Heating	Radio-frequency-induced temperature rise of a filter during MRI.
Inability to convert filter	Unable to structurally alter an implanted vena cava filter to an implanted non-filtering device.
Inability to engage filter	Unable to connect optional filter with retrieval system or convertible filter with conversion system.
Inability to load filter (if applicable)	Unable to place filter into delivery system.
Inaccurate deployment	Improper positioning, configuration or orientation of the filter during deployment.
Inadequate contrast flow	Inability to inject sufficient volumes of contrast media through the delivery system, retrieval system as applicable, conversion system as applicable at the necessary rate to properly visualize the implantation site and/or patient anatomy.
Inadequate filter formation	A filter which does not deploy in the intended specified configuration (e.g. due to mechanical failure, patient anatomy or user error).
Inadequate filtration	Inability of filter to capture clinically significant clots as intended.
Inadequate visibility	Inability to image the filter or a necessary portion of the filter according to the requirements of the IFU.
Bond fracture	Fracture or breakage of bonds (e.g. welds, glue joints) between components.
Particulate generation	Release of particles associated with the filter system.
Retrieval failure	Inability to fully retrieve the filter as intended (e.g. due to filter position, mechanical failure, patient anatomy, tissue ingrowth).

Annex D **(informative)**

Test methods

D.1 General

The information included in this annex is intended to provide guidance for preclinical in vitro testing performed in order to verify the design of the filter system, the retrieval system and the conversion system. Guidance for reporting the test results is also provided. It is recognized that not all of the tests described in this annex are applicable to all filter designs. It is also recognized that testing intended to ensure that the device meets specifications during manufacture may be conducted according to the details outlined in this annex.

Guidance for developing appropriate test methods is included in this annex allowing flexibility in designing appropriate methodologies for specific device designs and indications for use. To ensure consistency in the testing of devices, use of the methods developed based on the steps and concepts outlined in this annex is recommended. If alternative methods are employed, these methods should be justified. It is recognized that some tests listed in this annex can be combined. For combined tests, the report should provide the individual test results for each of the tests listed in this annex, if appropriate.

As identified in [Table D.1](#), some requirements in this document do not have an associated test method guidance in this annex, as the methodologies are better addressed by other standards (e.g. MRI safety).

Modifications to existing test methods or inclusion of additional test methods can be required for various filter formations (e.g. crossed legs). When identifying testing conditions, attention should be paid to the relevant physiological conditions. A simulated physiological environment (e.g. a temperature-controlled water bath) should be used when appropriate.

To ensure valid results, measurement equipment used during testing should have appropriate accuracy and should be calibrated or verified against traceable measurement standards, as appropriate. The accuracy should be adequate to determine the measured value relative to the acceptance criteria.

D.2 Sampling

A sampling plan shall be utilized which ensures that adequate representation of the design has been obtained for each characteristic measured. It should be verified that the design attributes of the filter system, the retrieval system or the conversion system are representative of the devices to be released for distribution including all sizes, configurations and components.

The sampling shall fully represent the range of device sizes and does not necessarily require testing of each size. It can be necessary to conduct an analysis to identify the size(s) of the device with the greatest potential for failure.

Multiple approaches to sample selection should be considered, depending on whether there are differences in relevant attributes of different device sizes (e.g. strut thickness, length, diameter) and the parameter under test (e.g. radial force).

The samples selected for each test shall represent the adequately challenging case(s). Consideration shall be given to filter size and orientation, delivery system sizes (diameter and length) and implant conditions (e.g. intended vena cava size and shape). It can be necessary to conduct an analysis to identify the samples with the greatest potential for failure under specified implant conditions.

A rationale should be provided for sample selection. For all tests, the number of samples should be justified.

Additional recommendations regarding sampling may be included in individual test methods, as appropriate.

NOTE Additional guidance regarding sampling can be found in ASTM F3172.

D.3 Conditioning of test samples

All samples should be subjected to sterilization, including multiple sterilizations, if appropriate, unless justification is provided for use of non-sterilized products.

Samples should be subjected to conditions that are normally encountered that can affect the performance of the device and test results. Examples of conditioning are preparation of the filter system, loading of the filter inside the delivery system, tracking of the filter system through relevant simulated tortuous vasculature and deployment of the filter.

D.4 Reporting

For the purposes of this annex, reporting relates to requests from a national regulatory authority.

The design evaluation report should include an appropriate table of contents and four main sections: background, an executive summary, individual test summaries and appendices that include the device evaluation strategy and the detailed reports. Pages should be numbered sequentially throughout the document (including appendices).

- a) The background section should describe the device design concept.
- b) The executive summary should include:
 - a description of the bench testing and analyses that have been performed;
 - a summary of the device evaluation strategy, including justification for the omission of tests identified in this document;
 - a table to summarize the testing completed, with the following columns: name of test, test purpose, test sample description, number of samples, acceptance criteria, summary of results and conclusions, and cross references to the test summary and full test report;
 - a summary conclusion statement.
- c) Individual test summaries should include:
 - a brief summary of the purpose, methods and results;
 - the significance of the test results:
 - a justification for the criteria for tests with acceptance criteria, or
 - an explanation of the relevance of the results for characterization tests.
- d) Individual test reports should include the following information:
 - purpose: state the purpose of the test as it corresponds to this document;
 - materials: list significant materials (e.g. test articles with lot/serial numbers or other appropriate means of traceability, critical equipment) used in the test, using figures and diagrams as appropriate;
 - sampling: state the sampling plan, including the basis for and the number of samples tested and justification for the selection of test articles (e.g. sizes, conditioning);
 - acceptance criteria, if applicable:
 - the International Standard used (i.e. ISO 25539-3:2024);

- the method used (if the standard includes several);
- the result(s), including a reference to the clause which explains how the results were calculated;
- any deviations from the procedure;
- any unusual features observed;
- the date of the test;
- the criteria for the test results, including either justification or clinical relevance, or both.

Clinical applicability of the acceptance criteria shall take into consideration the anatomical and physiological conditions of the intended use:

- test method: describe in detail the method used to perform the test, including any prospectively defined inspection procedures, and provide a justification for relevant test parameters;
- protocol deviations: describe any deviations and their potential significance on the interpretation of the results;
- expression of results: report testing results expressed in units as indicated in the test method;
- discussion, if applicable: include a discussion on the potential clinical significance of the results;
- conclusions: state conclusions based on the comparison of results to acceptance criteria or provide an explanation of the relevance of the results for characterization tests.

D.5 Test method development guidance

D.5.1 General

[Clause D.5](#) lists guidelines for tests where appropriate. An index of test methods is given in [Table D.1](#). Additional guidance for developing test methods can be found in the standards listed in [Table D.1](#), which are included for reference purposes and are not required for conformance to this document.

Table D.1 — Index of device evaluation test methods

Subclause of this document	Test	Subclause of Annex D	Reference
8.5.2	Filter system	D.5.2	
8.5.2.2	Dimensional verification and component dimensional compatibility	D.5.2.1	
8.5.2.3	Force to deploy	D.5.2.2	
8.5.2.4	Simulated use	D.5.2.3	
8.5.2.5	Tensile bond strength	D.5.2.4	ISO 10555-1
8.5.2.6	Torsional bond strength	D.5.2.5	
8.5.3	Vena cava filter	D.5.3	
8.5.3.2	Clot trapping	D.5.3.1	
8.5.3.3	Corrosion	D.5.3.2	See test method in D.5.3.2 .
8.5.3.4	Fatigue and durability – Computational analyses	D.5.3.3	ASME V&V40
8.5.3.5	Fatigue and durability – In vitro testing	D.5.3.4	ASTM F3211
8.5.3.5.3	Compression fatigue and durability	D.5.3.4.2	
8.5.3.6	Dimensional verification of the filter	D.5.3.5	
8.5.3.7	Filter tensile strength	D.5.3.6	
8.5.3.8	Migration resistance	D.5.3.7	
8.5.3.9	Magnetic resonance imaging	See appropriate international standards.	
8.5.3.10	Radial force	D.5.3.8	
8.5.4	Optional filter	D.5.4	
8.5.4.2	Filter tensile strength	D.5.4.1	
8.5.4.3	Force to retrieve	D.5.4.2	
8.5.4.4	Simulated use	D.5.4.3	
8.5.5	Convertible filter	D.5.5	
8.5.5.2	Filter tensile strength	D.5.5.1	
8.5.5.3	Force to convert	D.5.5.2	
8.5.5.4	Simulated use	D.5.5.3	
8.5.6	Retrieval system	D.5.6	
8.5.6.2	Dimensional verification and component dimensional compatibility	D.5.6.1	
8.5.6.3	Force to retrieve	D.5.6.2	
8.5.6.4	Simulated use	D.5.6.3	
8.5.6.5	Torsional bond strength	D.5.6.4	
8.5.6.6	Tensile bond strength	D.5.6.5	ISO 10555-1
8.5.7	Conversion system	D.5.7	
8.5.7.2	Dimensional verification and component dimensional compatibility	D.5.7.1	
8.5.7.3	Force to convert	D.5.7.2	
8.5.7.4	Simulated use	D.5.7.3	
8.5.7.5	Torsional bond strength	D.5.7.4	
8.5.7.6	Tensile bond strength	D.5.7.5	ISO 10555-1
8.5.8	Filter system, retrieval system and conversion system	D.5.8	
8.5.8.2	Visibility	D.5.8.1	ASTM F640
8.5.8.3	Biocompatibility	See ISO 10993-1 and other appropriate parts of the ISO 10993 series.	
8.5.8.4	Sterilization assurance	See appropriate international standards.	
8.5.8.5	Haemostasis	No test method is proposed. Haemostasis may be evaluated as part of the in vivo animal study or as an alternate.	
8.5.8.6.2	Acute particulate generation	D.5.8.2	ASTM F2743, AAMI TIR42, ISO 25539-4, ISO/TS 17137
8.5.9	Coating on delivery system or filter	not applicable	ISO 25539-4
8.5.10	Absorbable filter or coating	not applicable	ISO/TS 17137

D.5.2 Filter system

D.5.2.1 Dimensional verification and component dimension compatibility

D.5.2.1.1 Purpose

The purpose of this test is to determine the filter system dimensions, including the usable or working length, profile, and all other appropriate dimensions, for conformance with design specifications, and to determine the dimensions for compatibility with the dimensions of recommended accessories.

D.5.2.1.2 Materials

The following materials apply:

- filter system (except for filter);
- accessory devices as specified in the IFU;
- equipment for establishing the profile of the filter system:
 - measuring equipment for diameters (e.g. micrometer, optical profile projector, laser micrometer)
 - appropriate profile hole gauges;
- measuring equipment for length.

D.5.2.1.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.2.1.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.2.1.5 Test method

Develop a test method based on the following steps:

- a) Insert an appropriately sized pin gauge or mandrel into the system components to verify lumen dimensions.
- b) Establish the profile of the filter system along the usable or working length using one of the following methods:
 - 1) measure the maximum outer diameter of the filter system using the appropriate measuring instrument; or
 - 2) verify that the outer diameter fits through the appropriately sized profile hole gauge; consideration should be given to the potential for asymmetry.
- c) Measure the usable or working length of the filter system using an appropriate measuring instrument.
- d) Measure all other appropriate dimensions.
- e) Verify dimensional compatibility between system components and recommended accessory devices.

D.5.2.1.6 Expression of results

Length shall be expressed in centimetres (cm). Other dimensions shall be expressed in millimetres (mm). Results regarding the compatibility of the recommended accessory devices and the verification of the lumen and outer diameters, if applicable, should be documented.

D.5.2.1.7 Test report

The test report shall be in accordance with [Clause D.4](#). The test report shall include the maximum, minimum, mean and standard deviation of all measured dimensions, the results of any verified dimensions, and the results of the observations of the accessory compatibility.

D.5.2.2 Force to deploy

D.5.2.2.1 Purpose

The purpose of this test is to determine the force to deploy the filter by the operator under simulated anatomical conditions. All applicable steps of the deployment process (e.g. unsheathing filter, releasing filter) should be evaluated.

D.5.2.2.2 Materials

The following materials apply:

- filter system;
- accessory devices necessary to accomplish deployment according to the IFU;
- anatomical model that includes a delivery pathway and a deployment location; the angulation, tortuosity and diameter of the intended filter deployment location and delivery pathway (including access pathway) should be representative of a challenging anatomical configuration.

An assessment of the parameters that affect the force to deploy a particular system design shall be considered in designing an appropriate anatomical model. Literature and patient data are appropriate sources to identify challenging anatomy. Selection of the model material and model geometry should take into consideration the compliance of the vasculature being represented by the model. The expected response of the in vivo vessel to the insertion of accessory devices (e.g. guidewire, introducer sheath) and the filter system, and the friction associated with the model material, should also be considered when selecting the model material and test fluid for:

- the measuring mechanism (e.g. force gauge, mechanical testing system);
- the gripping fixture;
- the test fluid (e.g. simulated blood, saline, water);
- the temperature-controlled environment (37 ± 2) °C.

D.5.2.2.3 Sampling

Sampling shall be in accordance with [Clause D.2](#). Filter systems to be tested should be representative of the devices that have the potential for the highest deployment force.

D.5.2.2.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.2.2.5 Test method

Develop a test method based on the following steps.

- a) Prepare the filter system per the IFU.
- b) Insert the filter system into the anatomical model.
- c) Attach the deployment mechanism to the load measuring equipment.

- d) Allow the device to stabilize at physiological temperatures.
- e) Initiate and complete the deployment per the IFU at a rate that simulates clinical use while measuring the force to deploy the filter. If multiple mechanisms are required for deploying a filter (e.g. unsheathe, disengage), the force to deploy should be measured for each of these relevant deployment steps.
- f) Record any anomalous observations (e.g. buckling) for each test sample.

D.5.2.2.6 Expression of results

For each deployment mechanism, the maximum force required to deploy the filter is recorded in newtons (N) or newton-meters (N·m), as appropriate. Record any anomalous observations (e.g. buckling) for each test sample.

D.5.2.2.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the maximum, minimum, mean and standard deviation of the deployment forces, and any anomalous observations. The report shall include a description of and justification for the anatomical model (e.g. angulation, tortuosity, diameter and construction of material of the model).

D.5.2.3 Simulated use

D.5.2.3.1 Purpose

The purpose of this test is to evaluate ability of the filter system to be advanced through the introducer sheath, deployed and withdrawn (e.g. pushability, flexibility, trackability, torquability, as applicable), including deployment accuracy and contrast injection as applicable, using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population. This test is also intended to evaluate the compatibility of the filter system with accessory devices. Additionally, this test is intended to evaluate the ability of the filter to take the proper configuration following deployment from the filter system.

D.5.2.3.2 Materials

The following materials apply:

- filter system;
- accessory devices necessary to accomplish deployment according to the IFU (e.g. guidewire, introducer sheath);
- anatomical model that includes a delivery pathway and a deployment location. The angulation, tortuosity and diameter of the intended implant location and delivery pathway (including access pathway) of the model should be based on the expected anatomy in the intended patient population and can include three-dimensional tortuosity. Multiple models with varied anatomy or materials of construction can be necessary to sufficiently challenge the relevant characteristics of the device.

Literature and patient data are appropriate sources to identify the expected anatomy. The limits set in the IFU regarding anatomy are also important to consider when selecting the anatomical model(s). The selection of the model material and model geometry(ies) should take into consideration the compliance of the vasculature being represented by the model. The expected response of the in vivo vessel to the insertion of accessory devices (e.g. guidewire, introducer sheath) and the filter system and the friction associated with the model material should also be considered in selecting the model material and test fluids:

- test fluid (e.g. simulated blood, saline, water);
- temperature-controlled fluid environment (37 ± 2) °C;
- measuring equipment for distance.

D.5.2.3.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.2.3.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.2.3.5 Test method

Develop a test method based on the following steps.

- a) Connect the anatomical model to or immerse in the fluid system and allow the test system temperature to stabilize.
- b) Following the IFU and using the appropriate accessory devices (e.g. guidewire, introducer sheath), insert, deliver and deploy the filter, while evaluating the following:
 - 1) Evaluate the ability of the filter system to be advanced to, and positioned in, the targeted deployment location of the anatomical model(s) without compromising the function of the delivery system. This testing shall include, during the advancement of the system, the ability to torque the system without negatively affecting the ability to deploy. Note any anomalies and their impact on the performance of the filter system.
 - 2) For filters requiring rotational orientation for appropriate position, evaluate the ability of the filter system to provide sufficient rotation to the distal (leading) end in order to position the filter in the target orientation.
 - 3) Evaluate the ease and the ability to deploy the filter.
 - 4) Determine the accuracy of deployment by identifying the target deployment location and measuring the post deployment location relative to the target location using a pre-defined coordinate system to indicate directionality.
 - 5) Evaluate the ability to withdraw the delivery system and accessory devices from the anatomical model(s) and note any anomalies, such as delivery system failure, filter dislodgement or filter damage.
 - 6) Evaluate the compatibility of the filter system with the accessory devices (e.g. guidewire, introducer sheath) and when appropriate, the compatibility of the accessory devices with the filter.
- c) Visually inspect the deployed filter in the anatomical model. Evaluate and record the conformability of the filter to the model vessel wall, positioning (including orientation, if applicable), absence of anomalies (e.g. crossed filter components, component separation, filter damage) and the type and location of any filter damage or any other anomalies. Visually inspect the delivery system and record the type and location of any damage or any other anomalies.
- d) Visually inspect the accessory devices and record the type and location of any clinically relevant damage or other anomalies.

D.5.2.3.6 Expression of results

The results of the evaluation in the simulated use test shall be expressed descriptively. Distances shall be expressed in millimetres (mm).

D.5.2.3.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include all results and abnormal observations. The report shall include a description of the anatomical model(s) used and justification of how the model(s) is representative of the anatomical variation in the intended patient population (i.e. angulation, tortuosity and diameter). The test fluid and the model material of construction shall be reported and justified. The results for advancement, withdrawal (e.g. pushability, flexibility, trackability, torquability, as applicable)

and compatibility between the accessory devices and the filter system shall each be reported. Additionally, observed anomalies identified during deployment, the conformability of the deployed filter to the vessel wall, filter positioning (including orientation, if applicable) and observed filter anomalies shall be reported. Deployment accuracy shall be reported taking into account directionality, including the maximum, minimum, mean and standard deviation. The type and location of any filter or delivery system damage and any clinically relevant accessory device damage shall be reported.

D.5.2.4 Tensile bond strength

D.5.2.4.1 Purpose

The purpose of this test is to determine the tensile strength of all joints and/or fixed connections of the filter system (e.g. distal tip, hub bond). The strength of the segments adjacent to the bonds of the filter system shall be evaluated separately or concurrently with the bond strength determination.

D.5.2.4.2 Materials

The following materials apply:

- filter system or appropriate component joints and/or fixed connections;
- recommended guidewire or equivalent, if appropriate;
- mechanical testing system with a constant crosshead speed, a suitable load cell and appropriate gripping fixtures;
- temperature-controlled environment $(37 \pm 2) ^\circ\text{C}$, as appropriate.

D.5.2.4.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.2.4.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#). Conditioning of the test samples should include loading, tracking (access and withdrawal) and deployment. Multiple tracking cycles through an appropriate anatomical model should be considered. Information regarding an appropriate anatomical model is provided in [D.5.2.3.2](#). Filter systems from completed simulated use testing (see [D.5.2.3](#)) may be used for this test.

D.5.2.4.5 Test method

For bonds that will be subjected to physiological temperatures, testing should be performed at $(37 \pm 2) ^\circ\text{C}$.

Develop a test method based on the following steps:

- a) Insert the delivery system or component of the guidewire if appropriate.
- b) Using a mechanical testing system with an appropriate crosshead speed (e.g. 200 mm/min), apply tension to the bonded joint or to a series of bonded joints until a bond breaks or loses functional integrity. Ensure that the guidewire is not gripped at both ends.
- c) Record the peak force at which failure occurs and describe the type and location of the failure.

D.5.2.4.6 Expression of results

Bond strength shall be expressed in newtons (N).

D.5.2.4.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the type and location of the failure and the maximum, minimum, mean and standard deviation of the bond strength(s).

The acceptance criteria for the bond strength(s) should take into consideration the expected forces applied to the delivery system during clinical use [e.g. tracking (access and withdrawal) and deployment].

D.5.2.5 Torsional bond strength

D.5.2.5.1 Purpose

The purpose of this test is to evaluate the torsional strength of the joints and/or fixed connections in the segments of the filter system that are subjected to torsion during clinical use. The torsional strength of the segments adjacent to the bonds of the filter system shall be evaluated separately or concurrently with the torsional bond strength evaluation.

D.5.2.5.2 Materials

The following materials apply:

- filter system or appropriate component joints and/or fixed connections;
- recommended guidewire or equivalent, if appropriate;
- torque testing system with a suitable torque gauge;
- temperature-controlled environment $(37 \pm 2) ^\circ\text{C}$, as appropriate.

D.5.2.5.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.2.5.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#). Conditioning of the test samples should include loading, tracking (access and withdrawal) and deployment. Multiple tracking cycles through an appropriate anatomical model should be considered. Information regarding an appropriate anatomical model is provided in [D.5.2.3.2](#). Filter systems from completed simulated use testing (see [D.5.2.3](#)) may be used for this test.

D.5.2.5.5 Test method

For bonds that will be subjected to physiological temperatures, testing should be performed at $(37 \pm 2) ^\circ\text{C}$.

Develop a test method based on the following steps.

- a) Insert the filter system or component over the guidewire, if appropriate.
- b) Affix one end of the test sample in a clamping apparatus.
- c) Attach the other end of the test sample to the torque gauge. The test gauge length shall be long enough to avoid influence of the clamping apparatus and short enough to ensure uniform torsional loading.
- d) Rotate the sample at a rate characteristic of that used in a typical clinical use to one end of the sample until either of the following predetermined conditions is achieved:
 - 1) test failure (i.e. the joint and/or delivery system breaks or loses functional integrity); or

- 2) test to predetermined, clinically relevant number of rotations to the filter system.
- e) Record either of the following predetermined test end points:
 - 1) the torque or number of rotations at which failure occurs and the failure mode and location; or
 - 2) whether the predetermined number of rotations was achieved without failure.

D.5.2.5.6 Expression of results

Torsional bond strength (torque strength) shall be expressed in newton-metres (N·m) or number of rotations.

D.5.2.5.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the mode and location of the failure and the maximum, minimum, mean and standard deviation of the torsional bond strength.

The results shall be evaluated in relation to the torque level necessary to access, deploy and withdraw the system.

D.5.3 Vena cava filter

D.5.3.1 Clot trapping

D.5.3.1.1 Purpose

The purpose of this test is to determine the in vitro clot trapping ability of the vena cava filter in an anatomical model.

D.5.3.1.2 Materials

The following material apply:

- filter;
- anatomical model such as a mock vena cava of the appropriate diameter and length; the geometry of the mock vena cava should be chosen such that flow patterns are adequately representative of challenging in vivo conditions,^{[34]–[36]} and anatomical features expected to impact clot trapping should be considered (e.g. infrarenal curvature);
- adequately challenging filter conditions should be tested in the model (e.g. maximum indicated vessel diameter, filter tilt);
- clots of multiple sizes should be coagulated animal blood; however, equivalent natural and synthetic materials may be used if justified (e.g. realistic clot-to-fluid density ratio representative of gravitational and buoyance forces that can impact clot transport and trapping^[1]);

NOTE 1 It is important to ensure that the clots do not deteriorate over time or through multiple uses.

- test fluid simulating the viscosity of blood should be used unless testing in a different environment (e.g. distilled water) can be justified;

NOTE 2 It is important to ensure that the test fluid does not have an adverse effect on the clots used for the evaluation of the device (e.g. by causing the clots to break up prematurely).

- circulating pump capable of producing clinically relevant flow rates (e.g. 1 l/min to 6 l/min);
- temperature-controlled environment (37 ± 2) °C;
- pressure gauge(s) capable of measuring clinically relevant pressures.

D.5.3.1.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.3.1.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.3.1.5 Test method

Develop a test method based on the following steps.

- a) Establish the clinically relevant conditions under which samples will be tested. References [\[48\]](#), [\[52\]](#), [\[73\]](#), [\[75\]](#), [\[80\]](#), [\[82\]](#) to [\[86\]](#) and [\[104\]](#) to [\[106\]](#) provide information on clot trapping. Conditions should include flow, device configuration (e.g. centred, tilted), model configuration (e.g. horizontal, vertical), adequately challenging mock vessel dimensions and multiple clot sizes. Additional conditions can include multiple fluid flow rates.
- b) Assemble the test fixture including the filter in the anatomical model, the pressure gauge, the circulating pump and the temperature-controlled reservoir.
- c) Establish the clot size(s) and maximum number of clots per test run, the time(s) between clot releases and the time(s) of observation of captured clots.
- d) Inject clots serially into the system at the predetermined intervals until the total number of clots is reached. Record any anomalous observations for each test sample.
- e) Record maximum pressure gradient across the filter and the flow rate after each clot is injected. Also record the number of clots in the filter during the measurements.
- f) Repeat procedure per sampling plan (e.g. different clot sizes, different device configurations).

D.5.3.1.6 Expression of results

Clot-trapping ability is reported as the percentage of injected clots retained by the filter versus the number released. Pressure gradient across the filter should be recorded in millimetres of mercury (mm Hg).

D.5.3.1.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the minimum, maximum, mean and standard deviation of the clot-trapping ability and the pressure gradient for each condition tested. The number of associated clots, device configuration, model configuration and clot size should also be reported. The anatomical model, including diameter(s) and length(s), clot material, test fluid and flow rate(s) used during testing should also be reported. Any anomalous observations should be reported as well.

D.5.3.2 Corrosion

D.5.3.2.1 Purpose

The purpose of this assessment is to evaluate the susceptibility of a filter with metallic materials to corrosion.

NOTE This annex does not include specific methodology for corrosion testing. Guidance is provided regarding the assessment of corrosion using various sources (e.g. literature, historical clinical data) and through reference to other standards.

D.5.3.2.2 Materials

The following materials apply:

- filter or appropriate test samples of the filter (e.g. segments, sections, components, subassemblies) that have undergone actual or simulated manufacturing processes; the test sample shall be appropriate to the type of corrosion under evaluation (e.g. crevice, pitting, fretting, galvanic);
- materials as specified in the test methods selected for this evaluation;
- reference sample, as appropriate.

D.5.3.2.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.3.2.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#) and shall include actual or simulated loading and deployment.

D.5.3.2.5 Test method

The susceptibility of the metallic materials of the filter to corrosion should be assessed. Corrosion assessment includes, but is not limited to, evaluation of test results, review of literature and consideration of the historical clinical performance of the material(s) under assessment. Guidance on corrosion assessment can be found from a variety of sources (e.g. literature, textbooks, standards, regulatory guidance documents). Depending on the surface finish and the corrosion testing results, the potential for ion release should also be considered.

Examples of references regarding corrosion terminology, equipment, test procedures and methods are:

- ISO 17475,
- ISO 16429,
- ASTM F2129,
- ASTM F3044,
- ASTM F3306,
- ASTM G5,
- ASTM G61,
- ASTM G71,
- ASTM G102.

D.5.3.2.6 Expression of results

Test data shall be expressed in units appropriate to the methods selected.

D.5.3.2.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the complete corrosion assessment, including a summary of all test data, analyses and referenced information, comparisons to applicable controls, any appropriate comparison between in vivo and in vitro performance and conclusions regarding the anticipated corrosion resistance of the filter. For quantitative data, the maximum, minimum, mean and standard deviation shall be included. Applicable requirements indicated in documents used for testing should also be included.

D.5.3.3 Fatigue and durability — Computational analyses**D.5.3.3.1 Purpose**

The purpose of the computational analyses is to calculate the magnitude and location of the maximum stresses and/or strains for each appropriate loading scenario based upon the intended clinical application and device design. Appropriate computational analysis tools, such as FEA, can be used to calculate the stresses and/or strains. The stresses and/or strains can be compared to material characteristics to calculate the fatigue safety factor.

Computational analyses may also be used to establish appropriate test conditions and to select test articles for fatigue and durability testing.

D.5.3.3.2 Model inputs and tools

The following model inputs and tools apply:

- structural design of the filter and, if appropriate, a representation of the in vivo environment (e.g. blood vessel);
- material properties (e.g. modulus, fatigue limit, vessel compliance) and constitutive models (e.g. linear elastic) for all materials under evaluation;
- the information needed to establish boundary conditions related to manufacturing (e.g. compressed diameter required to achieve delivery system profile), deployment (e.g. implant diameter) and, if appropriate, interaction between filter and the surrounding tissue;
- the information needed to establish boundary conditions (e.g. constraints and loads) that are representative of the intended clinical use (e.g. vessel diameters, deformation, curvature);
- appropriate modelling tools, such as finite element analysis and computer aided design software to model the filter and, if appropriate, the in vivo environment (e.g. blood vessel).

D.5.3.3.3 Analysis

The analyses shall be performed on the sizes and configurations necessary to ensure an adequate evaluation of the filter.

Perform computational analyses based on the following steps.

- a) Establish the purpose of each computational analysis.
 - 1) Establish the purpose of each computational model analysis. For example, the computational analysis may be used to identify the filter size and configuration that is expected to perform with the lowest fatigue safety factor.
 - 2) Select computational software with the capabilities to perform the analysis.
- b) Define the model geometry.
 - 1) Identify the sizes and configurations of the filters to be evaluated.
 - 2) Establish the filter geometry and, if appropriate, mock or diseased vessel geometry. The geometry should be representative of the finished product. Consideration shall be given to the allowed variability of the dimensions when selecting the geometry for analysis.
 - 3) All appropriate deformation modes should be considered when selecting the extent of the filter to be modelled or when applying symmetry assumptions.
- c) Establish the material properties. Determine the properties of the materials of the finished filter necessary to conduct the analysis. If appropriate, establish the material properties for the representative vessel.

- d) Define the constitutive model.
 - 1) For each material in the analysis, determine the appropriate constitutive model (i.e. the relationship between stress and strain), such as superelasticity, hyperelasticity and plasticity. The material properties that are used to develop the constitutive models should represent the final, processed materials (e.g. final heat treatment).
 - 2) Confirm that the constitutive model(s) represents the behaviour of the material within the applicable stress or strain range using an appropriate test method(s) (e.g. tensile, bending).
- e) Create the finite element mesh. Create a mesh and specify the element type(s), shape(s) and formulation(s) (e.g. shape function) to model the filter and, if appropriate, the representative vessel.
- f) Apply the constraints to the mesh.
- g) Apply the loading conditions.
 - 1) Apply the loading conditions to represent delivery system loading (e.g. compressed diameter required to achieve the delivery system profile), filter deployment (e.g. implant diameter) and recoil, if applicable.
 - 2) Apply the representative loading conditions (e.g. cyclic deformation from respiration or Valsalva) that the filter is expected to experience in vivo.
- h) Apply solution methodology and execute the analysis.
 - 1) Select the appropriate solution techniques and tolerances for the formula(e) being solved.
 - 2) Incorporate any additional boundary conditions necessary to ensure model stability. It is important to ensure that the applied boundary conditions do not over-constrain and/or do not add unintended loadings, rotations or contact.
- i) Verify the solution. Conduct a mesh sensitivity analysis to demonstrate that further mesh refinement does not significantly change the computational results (e.g. the maximum strain does not change significantly when additional elements are used).
- j) Validate the computational model. Obtain test data to allow comparison of the appropriate output(s) of the model to the physical behaviour of the filter.
- k) Analyse results.
 - 1) Compute the appropriate stress or strain quantities (e.g. principal stresses, equivalent strains).
 - 2) Calculate fatigue safety factors using the appropriate failure criteria (e.g. constant life diagram). Identify the location associated with the lowest fatigue safety factor (e.g. high stress/strain regions).

D.5.3.3.4 Expression of results

Stress shall be expressed in megapascals (MPa). Strain shall be expressed as a percentage (%) or dimensionless. Locations of critical stresses and/or strains should be depicted in colour figures with legends. Diagrams for fatigue analysis shall be provided (e.g. constant life, Morrow analysis, Goodman analyses).

D.5.3.3.5 Report

NOTE 1 The computational analysis report is intentionally different from the standard test reports described in [Clause D.4](#).

The report shall include the following:

- a) background and purpose:
 - 1) provide a brief device description and the intended use environment;

- 2) state the purpose of each analysis;
- b) geometry:
- 1) report the sizes and configurations of the filters selected for evaluation;
 - 2) provide diagrams and a brief description of the model(s);
 - 3) provide a justification for the sizes and configurations of the filters for evaluation;
 - 4) if only a portion of the filter was modelled, provide a justification for the geometry analysed (e.g. the use of symmetry);
 - 5) provide a justification for how the model geometry is representative of the finished product and, if appropriate, the mock or diseased vessel (e.g. size, disease state);
 - 6) report the dimensions selected in the context of the expected variability;
- c) material properties:
- 1) list all the materials in the model and report the relevant material property values (e.g. modulus, yield strength, fatigue limit);
 - 2) provide and justify the source of the material properties (e.g. literature, test data and conditions) for the filter and, if appropriate, for the representative vessel;
 - 3) provide a justification for why the material properties are representative of the final, processed material (e.g. final heat treatment) in the intended in vivo environment (e.g. 37 °C) if applicable, describe tests conducted to determine the material properties;
- d) constitutive model:
- 1) for each material, provide the relationship between stress and strain (i.e. constitutive model) including a graphical representation and/or the associated formulae;
 - 2) for each material, discuss how the constitutive model captures the material behaviour (e.g. loading, unloading, plastic deformation);
 - 3) provide a justification for the assumptions in the constitutive model used to represent each material;
 - 4) provide a summary of the methodology and data for any testing conducted to support the constitutive model;
- e) mesh:
- 1) describe the element type, shape and formulation for the mesh used in the analysis;
 - 2) provide a representative image of the mesh in the areas of high stress/strain;
 - 3) provide a justification for why the elements selected adequately represent the spatial distribution of the stress/strain under the prescribed loading;
- f) constraints:
- 1) report the boundary conditions (e.g. rigid cylinder for vessel, fixed degrees of freedom), including a graphical representation if appropriate;

- 2) provide a justification for the boundary conditions used to restrict motion of the model or to isolate specific deformations;
- g) loading conditions:
 - 1) report the loading parameters (e.g. location, magnitude and direction of loading, number of cycles) and the sequence of the loads applied to the model to represent delivery system loading, filter deployment and recoil, if appropriate;
 - 2) report the loading conditions (e.g. cyclic deformation from respiration or Valsalva) applied to the model to represent deformation(s) or load(s) the filter is expected to experience in vivo;
 - 3) provide a justification that the delivery system loading and the filter deployment simulation are representative of actual delivery system loading (e.g. compressed diameter required to achieve the delivery system profile) in accordance with manufacturing and filter deployment in accordance with the IFU;
 - 4) provide a justification for the values used for the expected in vivo loading conditions;
- h) solution methodology:
 - 1) report the formula solution techniques and tolerances; describe the software package and any user subroutines that were implemented;
 - 2) provide a justification for any additional boundary conditions used to enhance model stability;
- i) solution verification:
 - 1) report the results of the mesh sensitivity analysis, demonstrating that further mesh refinement does not significantly change the computational results (e.g. the maximum strain does not change significantly when additional elements are used);
 - 2) provide a justification for the computational result (e.g. maximum strain) used to establish the adequacy of the mesh density;
- j) validation:
 - 1) provide an adequate description of the test method (e.g. radial outward force) used to assess the ability of the computational model to adequately predict the behaviour of the filter; this description may include illustrations to show similarities between the model and the test article in the fixture;
 - 2) provide a comparison of the test results to the values predicted by the computational model over a region relevant to the analysis objectives; provide an assessment of the significance of any relevant differences between the measured and predicted values;
 - 3) provide a justification for the mode of loading used to assess the ability of the computational analysis to adequately predict the behaviour of the filter;
- k) results: for each computational analysis, report the magnitude and illustrate the physical location(s) of the relevant quantitative results (e.g. maximum principal stresses, mean and alternating equivalent strain, fatigue safety factors);
- l) discussion/conclusions:
 - 1) discuss the results in the context of the stated purpose of the computational model (e.g. identifying the filter configuration and size with, and the location of, the lowest fatigue safety factor, assessing the acceptability of the fatigue safety factors), including any limitations and conservative modelling conditions;
 - 2) when applicable, discuss the implications of the computational analysis with respect to related testing; for example, explain how the computational analysis complements accelerated durability testing conclusions.

NOTE 2 As a potential alternative or supplement to a traditional 'test-to-success' fatigue testing paradigm, interested readers can find information on the 'fatigue-to-fracture' methodology in ASTM F3211.

NOTE 3 Additional information regarding computational model verification and validation can be found in ASME V&V40.

D.5.3.4 Fatigue and durability — In vitro testing

D.5.3.4.1 General

D.5.3.4.1.1 Purpose

The purpose of this assessment is to evaluate the long-term structural integrity of the filter under cyclic loading conditions (e.g. compression from respiration and compression from Valsalva manoeuvre) that represent the in vivo environment. This can require different test configurations.

Device durability may be evaluated in separate individual tests, tests that apply multiple sequential deformation modes, or tests that apply simultaneous deformation modes. When combining deformation modes under a single test, the relative rate of occurrence of the deformation modes should be considered in developing appropriate test methods, particularly with accelerated testing.

The information included in this subclause are applicable to compression fatigue and durability that follow in [D.5.3.4.2](#). Specific considerations for the development of test methods are included in the individual clause.

For the purpose of this subclause, displacement is defined as the movement of a test fixture, a test article, or mock vessel (e.g. diametrical, linear, rotational) in response to the action of a test apparatus. Deformation is defined as the change in shape of a test article or filter in response to a displacement(s) or an applied load(s).

NOTE As a potential alternative or supplement to a traditional 'test-to-success' fatigue testing paradigm, interested readers can find information on the 'fatigue-to-fracture' methodology in ASTM F3211.

Fatigue and durability testing is intended to evaluate aspects of the long-term structural integrity of the filter under cyclic loading conditions that represent the in vivo environment.

Appropriate test methods should be developed to simulate physiological deformation of the filter. These test methods should describe how to attain deformations of the test article through the application of forces and/or displacements to the test fixture or a mock vessel.

Potential failure modes that can be evaluated in these tests include filter fracture, and wear or abrasion between components.

The fatigue and durability tests are not intended to fully evaluate potential failure modes related to corrosion, wear between the filter and the recipient vessel, or filter migration. Consideration should be given as to whether such observations during testing indicate an increased potential for these failure modes to occur clinically.

D.5.3.4.1.2 Materials

The following materials apply:

- filter system;

NOTE This test is not designed to evaluate the entire system; however, the system is required to deploy the filter that is under test.

- if applicable, accessory devices necessary to accomplish deployment in accordance with the IFU (e.g. guidewire, introducer sheath);
- if applicable, a mock vessel with a diameter and properties appropriate to enable simulation of the loading mode under study;
- appropriately sized to represent the vessel diameter for the loading conditions under test;

- constructed of a material (e.g. silicone) capable of maintaining consistent deformation of the test article under cyclic loading, without creating unwanted deformation of the test article;
- capable of withstanding the test conditions at the test frequency and temperature for the duration of the test;
- designed and/or modified to minimize test article migration;
- fatigue test system capable of applying cyclic loads and/or displacement to the test article;
- measurement system(s) (e.g. load cell, strain gauge high speed camera) capable of quantifying appropriate loads, displacements and/or deformations;
- cycle counting system for measuring the number of cycles applied to the test articles;
- fluid fixture capable of maintaining buffered saline (PBS) (unless testing in a different fluid can be justified) at physiological temperature (37 ± 2) °C;
- inspection equipment [e.g. light microscope, lighted magnifying glass, radiography, scanning electron microscopy (SEM)].

D.5.3.4.1.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

Sampling shall allow for the evaluation of the structural integrity of all relevant parts of the filter.

The filter size(s) and configurations with the greatest potential for fatigue failure shall be identified and justified using computational modelling (e.g. finite element analysis), engineering analysis and/or clinical data. Alternatively, samples representing the range of sizes may be chosen for testing.

Segments or portions of the complete filter may be used as the test article if appropriately justified.

D.5.3.4.1.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

The filter system should be tracked through an anatomical model prior to fatigue and durability testing unless appropriate justification is provided.

D.5.3.4.1.5 Test method

This subclause includes general considerations for the development of all types of fatigue and durability tests:

- a) define the test conditions:
 - 1) establish loading conditions; the effect of the filter on the overall deformation expected in vivo should be considered when establishing the loading conditions. The direction and magnitude of the applied displacement or force should be justified based on physiologically relevant data (e.g. literature, clinical data) for the specific anatomical location, patient age or condition being treated. Computational modelling may be used with the physiologically relevant data to determine the appropriate loading conditions;
 - 2) mock vessel; there is no general guidance beyond those included in the general materials subclause (see [D.5.3.4.1.2](#)). See the individual fatigue and durability test methods;
 - 3) test frequency; the test frequency shall be selected to maintain the test article deformation within the pre-defined limits for the duration of the test and to avoid undesirable harmonics, localized heating of the filter and rate-dependent effects on material properties;
 - 4) displacement conditions/control; the gripping technique, slip between the mock vessel (if used) and the test article, or dynamic forces can result in deformations other than intended during

testing; establish the method to control displacement or the application of force during testing and verify that each test article achieves the intended deformation during the cyclic loading at the test frequency over the duration of the test;

- b) set up:
 - 1) either deploy the test article in accordance with the IFU directly into the test fixture or deploy the filter in accordance with the IFU and secure the test article (i.e. either the complete filter or a segment or portion of the filter) to the test fixture;
 - 2) inspect the test article(s) using appropriate visual aids, and record the location and severity of any anomalies (e.g. non-uniform filter expansion);
 - 3) allow the test articles to reach the pre-defined test temperature before initiating test;
- c) testing: after initiation of testing, at periodic intervals, monitor the test conditions and equipment operation to ensure that the test article does not migrate and experiences the intended displacements or forces; because the relationship between the intended displacements or forces and test article deformation can change over time, it can be necessary to verify that the test article is deforming as intended; the methodology to verify that the displacements and/or deformations are as intended shall be described in the test method; if appropriate, stop the test at periodic intervals for inspection of the test article(s); removing the test article from a mock vessel for the periodic inspection is not recommended. However, if removing the test article from a mock vessel is necessary, care shall be taken to remove and re-deploy in a manner that minimizes the effect on the test article;
- d) termination: terminate the test after the desired number of cycles has been achieved or a pre-specified end point has been observed;
- e) post-test inspection: carefully remove the test articles from the test apparatus and mock vessel, if applicable; completely visually inspect each test article for evidence of macroscopic damage; if anomalies are identified, if fractures cannot be visually identified due to the size or design of the filter, or if additional evaluation of regions of interest (e.g. potential areas of high stress/strain or wear) is needed, use appropriate methodologies (e.g. light microscopy, scanning electron microscopy, radiography) to further inspect for evidence of damage; identify and document the presence and location of any anomalies, including the following:
 - pre-specified failure modes under evaluation in the test, such as filter fracture;
 - additional observations, such as migration of filter within mock vessel;
 - failure modes that can be related to corrosion, wear between the filter and the recipient vessel, or filter migration; considerations should be given as to whether such observations indicate an increased potential for these failure modes to appear clinically.

SEM images can be taken of fracture surfaces and fracture locations to characterize the nature and origin of the fracture. When evaluating fractures, consider the potential for artefactual filter fracture related to the test apparatus (e.g. gripping method) or testing parameters.

D.5.3.4.1.6 Expression of results

There is no general guidance. See the expression of results subclause of the individual fatigue and durability test methods.

D.5.3.4.1.7 Test report

The test report should be done according to [Clause D.4](#). The intended and measured displacements and/or deformations shall be reported.

Results of all inspections, including the cycle count at which the inspections took place and the number and location of any observed anomalies, including fractures, shall be reported. The test report should include a discussion on the potential causes (e.g. fatigue failure, material inclusion, pre-existing sample damage, mock

vessel friction) and clinical relevance of the observations. Results should be considered and interpreted in relation to any applicable in vivo data.

D.5.3.4.2 Compression fatigue and durability

D.5.3.4.2.1 Purpose

NOTE The information in [D.5.3.4.2](#) is specific to the compression fatigue and durability test, and is used in conjunction with [D.5.3.4.1](#) which describes general fatigue and durability considerations.

The purpose of this test is to evaluate the long-term structural integrity of the filter when subjected to cyclic compressive loading conditions perpendicular to the filter axis (e.g. compression along the entire length, compression along a specified region) appropriate for the device design and intended clinical use.

D.5.3.4.2.2 Materials

Refer to the materials listed in the general materials subclause (see [D.5.3.4.1.2](#)).

D.5.3.4.2.3 Sampling

Refer to the information in the general sampling subclause (see [D.5.3.4.1.3](#)).

D.5.3.4.2.4 Conditioning

Refer to the information in the general conditioning subclause (see [D.5.3.4.1.4](#)).

D.5.3.4.2.5 Test method

Refer to the information in the general test method subclause (see [D.5.3.4.1.5](#)) with the following: this test method describes a compression fatigue and durability test that subjects the test article to a specified amount of cyclic compressive deformation (i.e. compression in one direction that is perpendicular to the test article axis). Testing is performed with a fatigue tester that induces physiologically relevant compressive deformation of the test article and can be performed with or without a mock vessel. Each test article should be inspected periodically during the test for the occurrence of fracture and other aspects of structural integrity; the compression of the test article can be applied along the entire length of the filter (e.g. flat plates) or a specified region of the filter (e.g. cylindrical bar) depending on the anticipated clinical environment;

a) define test conditions:

- 1) establish loading conditions; refer to the information in the general test method, establish loading conditions subclause [see [D.5.3.4.1.5](#) a) 1)] with the following: the loading conditions of the test, that is, the intended minimum and maximum compressive deformations, are based on the anticipated clinical compression; force equilibrium models, finite element analysis or experimental evaluation can be used to establish the target minimum and maximum compression;
- 2) mock vessel (if applicable): refer to the information regarding the mock vessel in the general materials subclause (see [D.5.3.4.1.2](#)) with the following:
- 3) test frequency: refer to the information in the general test method, test frequency subclause [see [D.5.3.4.1.5](#) a) 3)];
- 4) displacement conditions/control: refer to the information in the general test method, displacement conditions/control [see [D.5.3.4.1.5](#) a) 4)] with the following: establish the method to control the compressive displacement applied during the cyclic loading at the test frequency using a representative sample; the results of this verification activity should be used to establish the procedure for controlling the displacement of the compression testing apparatus adequately

correlates with the intended deformation of the filter, then this may be used to control the applied displacement during testing;

- b) set up: refer to the information in the general test method, set up subclause [see [D.5.3.4.1.5](#) b) 1) to 3)] with the following: adjust the test apparatus to yield the desired compressive displacement; when calculating percent compression, the following formula should be used:

$$Co = \left[\frac{(D_{\max} - D_{\min})}{D_{\max}} \right] \times 100$$

where

Co is the percent compressive displacement;

D_{\max} is the maximum dimension along the line of compression of the test article on the test apparatus;

D_{\min} is the minimum dimension along the line of compression of the test article on the test apparatus through fatigue cycle;

- c) testing: refer to the information in the general test method, testing subclause [see [D.5.3.4.1.5](#) c)] with the following:
- 1) set the frequency to the established rate and adjust the test system to achieve the intended minimum and maximum test article compression; verify that the test article deformations are as intended; after the minimum and maximum test article compressive targets are achieved, begin counting the cycles;
 - 2) verify minimum and maximum test article compression at regular time intervals to ensure that the target values are maintained; adjust the system as necessary to maintain the desired operational target;
- d) termination: refer to the information in the general test method, termination subclause [see [D.5.3.4.1.5](#) d)];
- e) post-test inspection: refer to the information in the general test method, post-test inspection subclause [see [D.5.3.4.1.5](#) e)].

D.5.3.4.2.6 Expression of results

The test frequency shall be expressed in cycles per second (Hz). Displacements shall be expressed in millimetres (mm). Compressive deformation shall be expressed as a percentage (%).

D.5.3.4.2.7 Test report

Refer to the information in the general test method, test report subclause (see [D.5.3.4.1.7](#)) with the following: the intended and measured minimum and maximum test article compressive displacement shall be reported.

D.5.3.5 Dimensional verification of the filter

D.5.3.5.1 Purpose

The purpose of this test is to determine the deployed filter dimensions including outer diameter(s), length(s), for verification to design specifications.

D.5.3.5.2 Materials

The following materials apply:

- filter system;

NOTE This test is not designed to evaluate the entire system; however the system is required to deploy the filter that is under test.

- measuring equipment for out diameters (e.g. micrometre, optical profile projector, laser-micrometre, calibrated calipers);
- measuring equipment for lengths (e.g. micrometre, optical profile projector, laser-micrometre, calibrated calipers);
- temperature-controlled environment (37 ± 2) °C for filter with dimensions that are sensitive to changes between ambient and physiological temperatures.

D.5.3.5.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.3.5.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#) and shall include loading, preconditioning and deployment.

D.5.3.5.5 Test method

Outer diameter(s) shall be measured at appropriate locations after deployment in accordance with the IFU. For non-circular cross-sections, it can be appropriate to measure and report the maximum and minimum values.

D.5.3.5.6 Expression of results

Diameters shall be expressed in millimetres (mm). Lengths shall be expressed in millimetres (mm) or centimetres (cm).

D.5.3.5.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the maximum, minimum, mean and standard deviation of all measured and calculated dimensions.

D.5.3.6 Filter tensile strength

D.5.3.6.1 Purpose

The purpose of this test is to determine the tensile strength of bonds, joints or components of the filter.

D.5.3.6.2 Materials

The following materials apply:

- filter or appropriate components;
- mechanical testing system with a constant crosshead speed, a suitable load cell and appropriate gripping fixtures;
- temperature-controlled environment (37 ± 2) °C, as appropriate.

D.5.3.6.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.3.6.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.3.6.5 Test method

Develop a test method based on the following steps.

- a) Use a mechanical testing system with an appropriate crosshead speed, apply tension to each filter component until failure is achieved.
- b) Record the force at which failure occurs and describe the type and location of the failure.

D.5.3.6.6 Expression of results

Tensile strength should be expressed in newtons (N).

D.5.3.6.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the type and location of the failure, and the maximum, minimum, mean and standard deviation of tensile strength.

D.5.3.7 Migration resistance

D.5.3.7.1 Purpose

The purpose of this test is to determine the migration resistance of a filter through measurement of the pressure gradient necessary to cause a clot-loaded filter, or the force required to cause a non-loaded filter, to migrate in the cephalad direction in an anatomical model.

NOTE This method is not appropriate for testing migration resistance in the caudal direction.

D.5.3.7.2 Materials

The following materials apply:

- filter system;

NOTE This test is not designed to evaluate the entire system; however, the system can be required to deploy the filter that is under test.

- accessory devices necessary to accomplish deployment in accordance with the IFU;
- anatomical model: biological or synthetic mock vena cava with appropriate diameter and length. Adequately challenging filter conditions should be tested in the model (e.g. maximum indicated diameter, minimum fixation condition). Test conditions can include alternative device configurations (e.g. centred, tilted) or alternative mock vessel dimensions (e.g. oval vessels, smaller diameters). Also, the validity of the mock vena cava (e.g. synthetic material) for the assessment of the acute migration should be justified;
- temperature-controlled environment (37 ± 2) °C for filters with material properties that are sensitive to changes between ambient and physiological temperatures;
- measuring equipment for lengths (e.g. ruler, caliper).

The following materials apply for migration pressure gradient measurement:

- suitable reference sample (e.g. filter with an adequate clinical history of use), or rationale for maximum pressure gradient without migration;
- clots should be coagulated animal blood or equivalent natural or synthetic materials;
- test fluid simulating the viscosity of blood should be used unless testing in a different environment (e.g. distilled water) can be justified;
- circulating pump capable of producing clinically relevant flow conditions (e.g. flow rates of 1 l/min to 6 l/min);

- pressure gauge(s) capable of measuring clinically relevant pressures.

The following materials apply for migration force measurement:

- suitable reference sample (e.g. filter with an adequate clinical history of use) or rationale for maximum force without migration;
- mechanical testing system with a constant crosshead speed, a suitable load cell and appropriate gripping fixtures.

D.5.3.7.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.3.7.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#) and shall include loading and preconditioning.

D.5.3.7.5 Test method

D.5.3.7.5.1 Migration pressure gradient measurement

Develop a test method based on the following steps.

- Establish the conditions under which the samples will be tested. These conditions include establishing the clot size, fluid flow rates, pressures and mock vessel dimensions.
- Assemble the test fixture including the filter in the anatomical model, the circulating pump and the temperature-controlled fluid reservoir.
- Visually inspect the filter in the anatomical model. Note any critical observations (e.g. tilting, crossed struts, inadequate formation).
- Mark initial filter position.
- Inject clots into the system until filter migrates or peak pressure differential across the filter is reached. Record the peak pressure differential across the filter at the point where migration occurs. It should be noted that it is considered normal for the filter to settle and move slightly as a clot builds up during this simulated test.
- Record any anomalous observations for each test sample.

D.5.3.7.5.2 Migration force measurement

Develop a test method based on the following steps.

- Establish the mock vessel material and dimensions in which samples will be tested.
- Deploy the filter into the mock vessel.
- Visually inspect the filter in the anatomical model. Note any critical observations (e.g. tilting, crossed struts, inadequate formation).
- Mark initial filter position.
- Using a mechanical testing system with an appropriate crosshead speed (e.g. 200 mm/min), pull the filter in the cephalad direction until migration of the filter occurs.
- Record the peak force at which migration occurs.
- Record any anomalous observations for each test sample.

D.5.3.7.6 Expression of results

The migration resistance is reported as the peak pressure differential, expressed in kilopascals (kPa), or the peak force, expressed in newtons (N) that the filter is able to withstand without migration. Any anomalous observations should be reported.

D.5.3.7.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall report the presence of migration and include the maximum, minimum, mean and standard deviation of the peak pressure differential across the filter, or peak force, for each condition tested. The anatomical model, including diameter(s) and material should be reported. For the migration pressure gradient measurement, the clot material, the clot size(s), the test fluid, the flow rate(s) and pressure used during testing should also be reported.

D.5.3.8 Radial force**D.5.3.8.1 Purpose**

The purpose of this test is to determine the force exerted on the surrounding tissue by a filter as a function of filter formation and anatomical dimensions, under the conditions of expansion.

NOTE This test is not intended to mimic forces generated during in vivo cycling of the device after initial deployment.

D.5.3.8.2 Materials

The following materials apply:

- filter system;

NOTE 1 This test is not designed to evaluate the entire system; however, the system is required to deploy the filter that is under test.

- appropriate mechanical testing equipment, such as:
 - mechanical testing system equipped with a suitable load cell, a constant rate of traverse, appropriate gripping fixtures and circumferential tension devices (e.g. loop snares); or
 - mechanical radial force testing system (e.g. iris tester) equipped with a suitable load cell and a constant rate of traverse;
- temperature-controlled environment (37 ± 2) °C for filters with material properties that are sensitive to changes between ambient and physiological temperatures.

NOTE 2 When selecting the test fixture, it is important to consider the width or area under study, the effects of friction and the influence of the fixture geometry on the measure loads.

D.5.3.8.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.3.8.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#) and shall include loading and preconditioning.

D.5.3.8.5 Test method

Develop a test method based on the following steps.

- a) Deploy the filter within the fixture such that the initial diameter is less than or equal to the minimum vessel diameter indicated in the IFU.

- b) Measure the radial force as a function of diameter as the filter is expanded to the maximum indicated vessel diameter. The speed of testing should be such that the results represent static conditions.

D.5.3.8.6 Expression of results

Radial force should be expressed in newtons (N).

D.5.3.8.7 Test report

The test report shall be in accordance with [Clause D.4](#) and should include a description of the filter feature(s) tested (e.g. fixation legs), the minimum, maximum, mean and standard deviation of the radial force at the minimum and maximum diameters for each device size tested. Results from expansion should be reported, with the respective speeds used during testing.

D.5.4 Optional filter

D.5.4.1 Filter tensile strength

The purpose of the filter tensile strength test is to determine the tensile strength of bonds, joints or components of the optional filter.

For the test method, see [D.5.3.6](#).

D.5.4.2 Force to retrieve

The purpose of the force to retrieve test is to determine the force to retrieve the vena cava filter in an anatomical model using the retrieval system as specified in the IFU.

For the test method, see [D.5.6.2](#).

D.5.4.3 Simulated use

The purpose of the simulated use test is to evaluate the ability of the optional filter to be engaged during retrieval and the ability to be retrieved using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population.

For the test method, see [D.5.6.3](#).

D.5.5 Convertible filter

D.5.5.1 Filter tensile strength

The purpose of the filter tensile strength test is to determine the tensile strength of bonds, joints or components of the convertible filter.

For the test method, see [D.5.3.6](#).

D.5.5.2 Force to convert

The purpose of the force to convert test is to determine the force to convert the vena cava filter in a simulated anatomical model using the conversion system as specified in the IFU.

For the test method, see [D.5.6.2](#).

D.5.5.3 Simulated use

The purpose of the simulated use test is to evaluate the ability to be engaged during conversion and the ability to be converted using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population.

For the test method, see [D.5.6.3](#).

D.5.6 Retrieval system

D.5.6.1 Dimensional verification and component dimensional compatibility

D.5.6.1.1 Purpose

The purpose of this test is to determine the retrieval system dimensions, including the usable or working length, profile, and all other appropriate dimensions, for conformance with design specifications, and to determine the dimensions for compatibility with the dimensions of recommended accessories.

D.5.6.1.2 Materials

The following materials apply:

- retrieval system;
- accessory devices as specified in the IFU;
- equipment for establishing the profile of the retrieval system:
 - measuring equipment for diameters (e.g. micrometer, optical profile projector, laser micrometer);
 - appropriate profile hole gauges;
- measuring equipment for length.

For the test method, see [D.5.2.1](#).

D.5.6.2 Force to retrieve

D.5.6.2.1 Purpose

The purpose of this test is to determine the force to retrieve the vena cava filter in a simulated anatomical model using the retrieval system as specified in the IFU.

D.5.6.2.2 Materials

The following materials apply:

- retrieval system;
- accessory devices necessary to accomplish retrieval in accordance with the IFU;
- anatomical model such as a mock vena cava of the appropriate diameter and length; adequately challenging filter conditions should be tested in the model (e.g. tilting);
- fluid; testing should be conducted in an appropriate test solution (e.g. water);
- temperature-controlled environment (37 ± 2) °C;
- force measuring mechanism (e.g. force gauge, mechanical testing system).

D.5.6.2.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.6.2.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.6.2.5 Test method

Develop a test method based on the following steps.

- a) Establish the conditions under which the filter and retrieval system will be tested (e.g. centred, tilted, mock vena cava diameter).
- b) Assemble the test system including the filter in the anatomical model and the temperature-controlled fluid reservoir. Attach the force measuring mechanism to the retrieval device.
- c) Make sure the system temperature is stabilized before testing. Visually inspect the filter in the anatomical model. Note any critical observations.
- d) Engage the filter with the retrieval device and retrieve the filter in accordance with the device IFU.
- e) Record the peak force measured during filter removal.
- f) Record any anomalous observations for each test sample.

D.5.6.2.6 Expression of results

Peak force is reported in newtons (N). Any anomalous observations should be recorded as well.

D.5.6.2.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the maximum, minimum, mean and standard deviation of the peak force and observations. The report shall include a description of and justification for the anatomical model (e.g. angulation, tortuosity, diameter and construction of material of the model).

D.5.6.3 Simulated use

D.5.6.3.1 Purpose

The purpose of this test is

- to evaluate the ability to be advanced through the introducer sheath,
- to engage the filter,
- to retrieve the filter, and
- to withdraw the retrieval system including filter (e.g. pushability, flexibility, trackability, torquability, as applicable) using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population.

This test is also intended to evaluate the compatibility of the retrieval system with accessory devices.

D.5.6.3.2 Materials

The following materials apply:

- retrieval system;
- optional filter;
- accessory devices necessary to accomplish retrieval according to the IFU;
- anatomical model – the angulation, tortuosity and diameter of the intended implant location and delivery pathway (including access pathway) of the model should be based on the expected anatomy in the intended patient population and can include three-dimensional tortuosity; multiple models with

varied anatomy or materials of construction can be necessary to sufficiently challenge the relevant characteristics of the device;

- test fluid (e.g. simulated blood, saline, water);
- temperature-controlled fluid environment (37 ± 2) °C.

D.5.6.3.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.6.3.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.6.3.5 Test method

Develop a test method based on the following steps:

- a) Establish the conditions under which the filter and retrieval system will be tested (e.g. centred, tilted, mock vena cava diameter).
- b) Connect the anatomical model to or immerse in the fluid system and allow the test system temperature to stabilize.
- c) Following the IFU and using the appropriate accessory devices (e.g. guidewire, introducer sheath), deploy the filter in the model, insert the retrieval system, retrieve the filter and withdraw the system while evaluating the following applicable attributes:
 - 1) the ability to access the retrieval location in the anatomical model (e.g. pushability, flexibility, trackability, torquability, as applicable). Note any anomalies and their impact on the performance of the retrieval system;
 - 2) the ability to deliver the retrieval system to the filter location;
 - 3) the ability to engage the filter with the system;
 - 4) the ability to retrieve the filter;
 - 5) the ability to withdraw the system;
- d) Note any damage, such as kinking or buckling of the system, the inability to fully and accurately retrieve the filter, and any other appropriate observations.

D.5.6.3.6 Expression of results

The results of the evaluation in the simulated use test shall be expressed descriptively.

D.5.6.3.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include all results and abnormal observations. The report shall include a description of the anatomical model(s) used and justification of how the model(s) is representative of the anatomical variation in the intended patient population (i.e. angulation, tortuosity and diameter). The test fluid and the model material of construction shall be reported and justified. The applicable results for pushability, flexibility, torquability, trackability and compatibility between the accessory devices and the retrieval system shall each be reported. Additionally, observed anomalies identified during retrieval shall be reported. The type and location of any retrieval system damage and any clinically relevant accessory device damage shall be reported.

D.5.6.4 Torsional bond strength

The purpose of the torsional bond strength test is to evaluate the torsional strength of the joints and/or fixed connections in the segments of the retrieval system that are subjected to torsion during clinical use. The torsional strength of the segments adjacent to the bonds of the retrieval system shall be evaluated separately or concurrently with the torsional bond strength evaluation.

For the test method, see [D.5.2.5](#).

D.5.6.5 Tensile bond strength

The purpose of the tensile bond strength test is to determine the bond strength of all joints and/or fixed connections of the retrieval system (e.g. distal tip, hub bond). The strength of the segments adjacent to the bonds of the retrieval system shall be evaluated separately or concurrently with the bond strength determination.

For the test method, see [D.5.2.4](#).

D.5.7 Conversion system**D.5.7.1 Dimensional verification and component dimensional compatibility****D.5.7.1.1 Purpose**

The purpose of this test is to determine the conversion system dimensions, including the usable or working length, profile, and all other appropriate dimensions, for conformance with design specifications, and to determine the dimensions for compatibility with the dimensions of recommended accessories.

D.5.7.1.2 Materials

The following materials apply:

- conversion system;
- accessory devices as specified in the IFU;
- equipment for establishing the profile of the conversion system:
 - measuring equipment for diameters (e.g. micrometer, optical profile projector, laser micrometer),
 - appropriate profile hole gauges;
- measuring equipment for length.

For the test method, see [D.5.2.1](#).

D.5.7.2 Force to convert**D.5.7.2.1 Purpose**

The purpose of this test is to determine the force to convert the vena cava filter in a simulated anatomical model using the conversion system as specified in the IFU.

D.5.7.2.2 Materials

The following materials apply:

- conversion system;
- accessory devices necessary to accomplish conversion in accordance with the IFU;

- anatomical model, such as a mock vena cava of the appropriate diameter and length; adequately challenging filter conditions should be tested in the model (e.g. tilting);
- fluid; testing should be conducted in an appropriate test solution (e.g. water);
- temperature-controlled environment (37 ± 2) °C;
- force measuring mechanism (e.g. force gauge, mechanical testing system).

D.5.7.2.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.7.2.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.7.2.5 Test method

Develop a test method based on the following steps.

- Establish the conditions under which the filter and conversion system will be tested (e.g. centred, tilted, mock vena cava diameter).
- Assemble the test system including the filter in the anatomical model and the temperature-controlled fluid reservoir. Attach the force measuring mechanism to the conversion device.
- Make sure the system temperature is stabilized before testing. Visually inspect the filter in the anatomical model. Note any critical observations.
- Engage the filter with the conversion device and convert the filter in accordance with the device IFU.
- Record the peak force measured during filter conversion.
- Record any anomalous observations for each test sample.

D.5.7.2.6 Expression of results

Peak force is reported in newtons (N). Any anomalous observations should be recorded as well.

D.5.7.2.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the maximum, minimum, mean and standard deviation of the peak force and observations. The report shall include a description of and justification for the anatomical model (e.g. angulation, tortuosity, diameter and construction of material of the model).

D.5.7.3 Simulated use

D.5.7.3.1 Purpose

The purpose of this test is

- to evaluate the ability to be advanced through the introducer sheath,
- to engage the filter,
- to convert the filter, and

- to withdraw the conversion system (e.g. pushability, flexibility, trackability, torquability, as applicable), using an anatomical model(s) that is (are) representative of the anatomical variation in the intended patient population.

This test is also intended to evaluate the compatibility of the conversion system with accessory devices.

D.5.7.3.2 Materials

The following materials apply:

- conversion system;
- convertible filter;
- accessory devices necessary to accomplish conversion according to the IFU;
- anatomical model – the angulation, tortuosity and diameter of the intended implant location and delivery pathway (including access pathway) of the model should be based on the expected anatomy in the intended patient population and can include three-dimensional tortuosity; multiple models with varied anatomy or materials of construction can be necessary to sufficiently challenge the relevant characteristics of the device;
- test fluid (e.g. simulated blood, saline, water);
- temperature-controlled fluid environment (37 ± 2) °C.

D.5.7.3.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.7.3.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.7.3.5 Test method

Develop a test method based on the following steps.

- a) Connect the anatomical model to or immerse in the fluid system and allow the test system temperature to stabilize.
- b) Following the IFU and using the appropriate accessory devices (e.g. guidewire, introducer sheath), deploy the filter in the model, insert the conversion system, convert the filter and withdraw the system while evaluating the following applicable attributes:
 - 1) the ability to access the conversion location in the anatomical model: this testing shall include the evaluation of pushability, flexibility, trackability and torquability as applicable; note any anomalies and their impact on the performance of the conversion system;
 - 2) the ability to deliver the conversion system to the filter location;
 - 3) the ability to engage the filter with the system;
 - 4) the ability to convert the filter;
 - 5) the ability to withdraw the system.
- c) Note any damage, such as kinking or buckling of the system, the inability to fully and accurately convert the filter, and any other appropriate observations.
- d) Visually inspect the converted filter in the anatomical model; note any damage and any other critical observations.

D.5.7.3.6 Expression of results

The results of the evaluation in the simulated use test shall be expressed descriptively.

D.5.7.3.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include all results and abnormal observations. The report shall include a description of the anatomical model(s) used and justification of how the model(s) is representative of the anatomical variation in the intended patient population (i.e. angulation, tortuosity and diameter). The test fluid and the model material of construction shall be reported and justified. The results for compatibility between the accessory devices, including pushability, flexibility, trackability, torquability, as applicable, and the retrieval/conversion system shall each be reported. Additionally, observed anomalies identified during conversion shall be reported. The type and location of any conversion system damage and any clinically relevant accessory device damage shall be reported.

D.5.7.4 Torsional bond strength

The purpose of this test is to evaluate the torsional strength of the joints and/or fixed connections in the segments of the conversion system that are subjected to torsion during clinical use. The torsional strength of the segments adjacent to the bonds of the conversion system shall be evaluated separately or concurrently with the torsional bond strength evaluation.

For the test method, see [D.5.2.5](#).

D.5.7.5 Tensile bond strength

The purpose of this test is to determine the bond strength of all joints and/or fixed connections of the conversion system (e.g. distal tip, hub bond). The strength of the segments adjacent to the bonds of the conversion system shall be evaluated separately or concurrently with the bond strength determination.

For the test method, see [D.5.2.4](#).

D.5.8 Filter system, retrieval system and conversion system

D.5.8.1 Visibility

D.5.8.1.1 Purpose

The purpose of this test is to evaluate the ability to visualize the filter systems, retrieval systems and conversion systems using imaging techniques specified in the IFU.

D.5.8.1.2 Materials

The following material apply:

- filter system, retrieval system and/or conversion system;
- accessory device necessary to accomplish deployment, retrieval and/or conversion according to the IFU;
- phantom tissue model or equivalent (e.g. water, metal, large animal model);
- imaging machine (e.g. fluoroscopy) capable of operating at clinically relevant power levels.

Visibility is significantly affected by variations in equipment and parameter settings. In the selection of the equipment use for this evaluation, consideration should be given to this variability.

D.5.8.1.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.8.1.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.8.1.5 Test method

Develop a test method based on the following steps:

- a) Position the system in the phantom tissue model.
- b) Position the model relative to the imaging machine to simulate clinical conditions.
- c) Use the imaging system to visualize the system and any identification markers.
- d) Evaluate the images for ease of visibility. For example, the degree of visibility can be assessed by locating the exact ends, orientation of critical points and/or parts of the filter system, the retrieval system and the conversion system. Alternatively, the degree of visibility may be compared to a specified material or device with known visibility.
- e) Repeat steps a) through step d) to evaluate the filter.

D.5.8.1.6 Expression of results

The results of the assessments shall be expressed descriptively, with representative images as appropriate.

D.5.8.1.7 Test report

The test report shall be in accordance with [Clause D.4](#) and shall include the assessment of visibility for all applicable components at the various stages of testing. Describe the results of the assessments and/or include visual results (e.g. representative fluoroscopic images). The test report shall also include the make and model of the imaging equipment, the relevant imaging parameters and details of the phantom tissue model.

NOTE Additional information regarding visibility can be found in ASTM F640.

D.5.8.2 Acute particulate generation

D.5.8.2.1 Purpose

The purpose of this test is to evaluate the number of particles generated acutely from the filter system, the retrieval system and the conversion system that can be associated with advancement, deployment, retrieval, conversion and/or withdrawal.

D.5.8.2.2 Materials

The following materials apply:

- filter system, retrieval system and/or conversion system;
- accessory devices necessary to accomplish deployment, retrieval and/or conversion according to the IFU (e.g. guidewire, introducer sheath);
- anatomical model that includes a delivery pathway and a deployment location;
- fixture capable of delivering or maintaining particle-free water or appropriate fluid at physiological temperature (37 ± 2) °C;
- particle counting system with applicable equipment (e.g. particulate analyser, microscope) capable of achieving a ≥ 90 % recovery demonstrated for ≥ 10 μm and ≥ 75 % recovery for ≥ 50 μm particle size ranges.

D.5.8.2.3 Sampling

Sampling shall be in accordance with [Clause D.2](#).

D.5.8.2.4 Conditioning

Conditioning shall be in accordance with [Clause D.3](#).

D.5.8.2.5 Test method

NOTE Acute particulate testing of filter systems for absorbable and coated filters is not within the scope of this test method and guidance can be found in ASTM F2743, AAMI TIR42, ISO 12417-1, ISO/TS 17137 and ISO 25539-4.

Develop a test method based on the following steps.

- a) Connect the anatomical model to the fluid system and allow the test system to stabilize at the relevant temperature and other relevant conditions; or alternatively, fill the anatomical model with fluid and allow the test system to stabilize at temperature.
- b) Determine the baseline number and size of particles from the test apparatus.
- c) Following the IFU and using the appropriate accessory devices, advance, deploy, retrieve or convert, and withdraw the filter system, the retrieval system and/or the conversion system, and count the number of particles in each size range.
- d) Flush the anatomical model and when appropriate, other associated fluid contact regions of the test apparatus until the detected particle counts match the baseline or other test termination criteria.

D.5.8.2.6 Expression of results

Particle size shall be expressed in micrometres (μm) and should be presented in appropriate size bins (e.g. $\geq 10 \mu\text{m}$, $\geq 25 \mu\text{m}$, $\geq 50 \mu\text{m}$).

D.5.8.2.7 Test report

The test report shall be in accordance with [Clause D.4](#). The maximum, minimum, mean and standard deviation of the particle counts in each size bin shall be reported.

Annex E

(informative)

Examples of general issues related to the clinical use of vena cava filters

Examples of general issues related to the clinical use of vena cava filters are [\[46\]](#)-[\[107\]](#):

- general issues and reporting standards, [\[37\]](#)-[\[41\]](#)
- access-site thrombosis, [\[42\]](#)[\[50\]](#)
- arrhythmia, [\[43\]](#)[\[51\]](#)
- cardiac damage, [\[44\]](#)[\[45\]](#)
- cardiac tamponade, [\[45\]](#)
- caval injury or damage, [\[46\]](#)
- caval thrombosis, [\[47\]](#)-[\[49\]](#)
- caval occlusion, [\[50\]](#)
- caval perforation [\[52\]](#)
- caval penetration [\[43\]](#), [\[51\]](#)-[\[54\]](#)
- caval stenosis, [\[42\]](#)
- deep vein thrombosis, [\[55\]](#)
- deployment failure, [\[43\]](#)[\[47\]](#)[\[51\]](#)[\[56\]](#)[\[58\]](#)
- excessive oversizing, [\[58\]](#)
- embolization, [\[44\]](#)
- excessive filtration, [\[48\]](#)
- excessive procedural bleeding, [\[48\]](#)[\[60\]](#)
- extravasation of contrast, [\[42\]](#)
- filter damage, [\[43\]](#)[\[51\]](#)
- filter-related death, [\[48\]](#)
- filter fracture, [\[53\]](#)[\[55\]](#)[\[69\]](#)[\[70\]](#)[\[71\]](#)[\[72\]](#)[\[73\]](#)[\[74\]](#)
- filter migration, [\[65\]](#)[\[75\]](#)[\[76\]](#)[\[77\]](#)[\[78\]](#)
- filter thrombosis, [\[68\]](#)[\[81\]](#)
- filter tilting, [\[55\]](#)[\[83\]](#)[\[84\]](#)
- foreign body embolization, [\[54\]](#)
- haemodynamics,
- inadequate filter formation, [\[55\]](#)[\[85\]](#)[\[86\]](#)[\[87\]](#)

- inadequate filtration (clot trapping),[\[88\]](#)[\[89\]](#)[\[90\]](#)[\[91\]](#)[\[92\]](#)[\[93\]](#)
- intimal tear,[\[94\]](#)[\[54\]](#)
- late mortality,[\[95\]](#)
- leakage of contrast media,[\[54\]](#)
- magnetic resonance imaging,[\[96\]](#)
- pulmonary embolism,[\[64\]](#)[\[97\]](#)[\[99\]](#)
- retrieval failure,[\[88\]](#)[\[100\]](#)
- trauma to adjacent structures,[\[60\]](#)[\[103\]](#)[\[104\]](#)[\[105\]](#)[\[106\]](#)[\[107\]](#)
- undersizing,
- vascular trauma,[\[56\]](#)
- vessel occlusion.

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