Digital Imaging and Communications in Medicine (DICOM)

Supplement 173: Wide Field Ophthalmic Photography Image Storage SOP Classes

Prepared by:

DICOM Standards Committee
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VERSION: Public Comment, September 10th, 2014
Developed pursuant to DICOM Work Item: 2013-12-A
Open Issues

1. The supplement does not record the method for calculating the 2D to 3D points in the 3D SOP Classes, such as interpolation used, etc.? Should this be included? If yes, what should be recorded?
2. The ICC Profile module is mandatory for all SOP Classes. Should it be Conditional for OP images that are generated using only two color channels (i.e. RG)?
3. The supplement generates a definition called “Ophthalmic Coordinate System” It defines the origin (Frame of Reference) for the 2D to 3D SOP Classes 3D coordinate values. Do we need to define an origin for the 3D SOP classes or can the origin be arbitrary. Currently we specify the corneal vertex as the origin.
4. Need input on what codes should be used to provide quality metrics for the SOP Classes, will need to update Context ID 4242 Ophthalmic Quality Metric Type.

Closed Issues

1. Should wide field abilities be added to the Stereo relationship IOD? - No
2. The wide field IODs use the existing OP IODs and expands them with the modules needed to capture the projection of the wide field to 3D Cartesian coordinates. Since, we are expanding the OP object, should we changed the design of the OP object to include the enhanced capabilities such as the functional groups module, etc. (as used by enhanced CT, MR, US, OPT and others). Or should we continue to follow the multi-frame mechanism as already defined by the “narrow field” OP? -

WG9/WG6 has decided it is best to follow the currently defined OP multi-frame mechanism. The wide field extension is a feature already supported by multiple vendors and this important feature can be implemented based upon current solutions that are widely implemented by the ophthalmic community. Creating an “Enhanced OP” is a different solution that would require much more time to develop and implement by the vendors, and provides no additional user benefits. Our thoughts are this choice would delay the use of wide field images significantly (as has been shown when other IODs decided to generate an Enhanced IOD).

3. Should we support 8 and 16 bit in IODs (as already defined for OP) or combine into one SOP Class?

Decided to define two SOP Classes to be consistent with the current OP SOP Classes. Requiring implementations to support 16 bits (especially 16 bit color) is not widely implemented, therefore we do not wish to “raise the bar” for such an uncommonly used feature.

4. Can and/or should we use the Deformable Spatial Registration Module to encode the projection 3D Cartesian coordinates? This module is specifically for transforming data into a new grid that enables registration of two data objects. Our objective is to define a space for measurement only and that is defined in a fundamentally different way: it defines x,y,z coordinates in a Euclidean space rather than a transformation field from one grid space to another grid space. Therefore, we are not able to use this module.

After further investigation between WG6/WG9 we determined to use a 5-tuple encoding to convey the row, columns, x coord, y coord, z coord. Created a new Attribute Two Dimensional to Three Dimensional Map Data.

5. Should we support a 3D coordinate set of SOP Classes plus other SOP Classes specific to the 2D Stereographic projection?

WG9 decided to support both solutions. It is understood that the 3D solution can support all cases, but it requires the architecture to understand 3D based solutions. Many of the current eye
care implementations are based upon the 2D architecture and supporting stereographic project method is expected to speed up adoption for wide field photography. Another important reason is the SP solution is currently implemented by vendors so this design is well known.
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A.bb.4 Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image IOD Content Constraints

C.7.4.1.1.2 Position Reference Indicator

Changes to NEMA Standards Publication PS 3.4

Part 4: Service Class Specifications

B.5 Standard SOP Classes

I.4 Media Standard Storage SOP Classes

Changes to NEMA Standards Publication PS 3.6

Part 6: Data Dictionary

Changes to NEMA Standards Publication PS 3.16

Part 16: Content Mapping Resource

CID 42x1 Wide Field Ophthalmic Photography Projection Method

Annex D DICOM Controlled Terminology Definitions (Normative)

Annex U Ophthalmology Use Cases (Informative)

U.x Wide Field Ophthalmic Use Cases

U.x.1 Routine Wide Field Image for Surveillance for Diabetic Retinopathy

U.x.2 Patient with Myopia

U.x.3 Patient with Diabetes

U.x.4 Patient with Diabetes

U.y.1 Stereographic Projection (SP)

U.x.6 Distance

U.x.7 Area

U.x.8 Angle

U.z Introduction to 2D to 3D Map for Wide Field Ophthalmic Photography

U.z.1 Measuring the length of a path

U.z.2 Shortest distance between two points

U.z.3 Computing the area of a region of interest

U.z.4 Projection Method Code Sequence
Scope and Field of Application

Storage SOP Classes to enable anatomically correct measurements on wide field ophthalmic photography 8 bit and 16 bit images.

Vendors have implemented new technology that enables the acquisition of OP images using wide field fundus photography. Since the back of the eye is approximately a concave sphere, taking a very wide field image of it introduces large error in any attempt to measure a lesion in that image (the error is very large when using a single value for the DICOM Pixel Spacing Attribute.). Therefore, DICOM WG 9 (Ophthalmology) has determined that a new Information Object Definition (IOD) is necessary to adequately represent wide field fundus photography. The OP IOD does not address wide fields, varied pixel spacing, and proper measurement of a stereographic projection or other methods of projection.

Manufacturers of ophthalmic photographic imaging devices have been developing OP images (using a narrow field) for many years in DICOM (i.e., these SOP Classes are widely supported by the DICOM ophthalmic community). Therefore, the wide field OP image storage SOP Classes are an extension to already existing narrow field DICOM SOP Classes.

The expected use cases are described below in an informative annex that will become part of the standard.
Changes to NEMA Standards Publication PS 3.2
Digital Imaging and Communications in Medicine (DICOM)
Part 2: Conformance

Item: Add to table A.1-2 categorizing SOP Classes:

The SOP Classes are categorized as follows:

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Changes to NEMA Standards Publication PS 3.3

Digital Imaging and Communications in Medicine (DICOM)
Part 3: Information Object Definitions
Part 3 Additions

Add definition to PS3.3 3.17

Ophthalmic Coordinate System
The Ophthalmic Coordinate System is used as the frame of reference that establishes the spatial relationship for the corneal vertex. The corneal vertex is the point located at the intersection of the patient's line of sight (visual axis) and the corneal surface. See section C.8.30.3.1.4 for further explanation.

Modify PS3.3 Table A.1-1 to add new IODs for Wide Field Ophthalmic Photography (8 and 16 bit) Images

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Modify PS3.3 Annex A

#### A.xx Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image Information Object Definition

This Section defines an Information Object to be used with several types of ophthalmic photographic imaging devices that generate wide field OP 8 bit images, including fundus cameras, slit lamp cameras, scanning laser ophthalmoscopes, stereoscopic cameras, video equipment and digital photographic equipment. It uses the stereographic projection method to represent on-face images of the 3D human retina in 2D on which geometric measurements can be made when the correct mathematical formulae are used.
A.xx.1 Wide Field Ophthalmic Photography Image Stereographic 8 bit Projection IOD Description

The Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image IOD specifies a single-frame or a multi-frame image acquired on a digital photographic DICOM modality. This IOD can be used to encode single wide field 8 bit ophthalmic images and other combinations including cine sequences. This IOD captures the projection of the wide field 2D Pixel image to enable anatomically-correct geometric measurements of the retina by taking into account the curved shape of the eye using a sphere to approximate shape.

A.xx.2 Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image IOD Entity-Relationship Model

The E-R Model in Section A.1.2 of this Part depicts those components of the DICOM Information Model that directly reference the Wide Field Ophthalmic Photography Stereographic Projection 8 bit IOD, with exception of the Curve, VOI LUT, Frame of Reference and Modality LUT entities, which are not used. Table A.xx-1 specifies the Modules of the Wide Field Ophthalmic Photography 8 bit Image IOD.

A.xx.3 Wide Field Ophthalmic Photography Stereographic Projection Image 8 bit IOD Modules

### Table A.xx-1
WIDE FIELD OPHTHALMIC PHOTOGRAPHY STEREOSCOPIC PROJECTION 8 BIT IMAGE IOD MODULES

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### A.xx.4 Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image IOD Content Constraints

The following constraints on Series and Image attributes take precedence over the descriptions given in the Module Attribute Tables.

#### A.xx.4.1 Bits Allocated, Bits Stored, and High Bit

For Wide Field Ophthalmic Photography 8 bit images, the Enumerated Value of Bits Allocated (0028,0100) (Image Pixel Module, C.7.6.3) shall be 8; the Enumerated Value of Bits Stored (0028,0101) shall be 8; and the Enumerated Value of High Bit (0028,0102) shall be 7.

#### A.xx.4.2 Contrast/Bolus Agent Sequence

For Contrast/Bolus Agent Sequence (0018,0012), the defined CID 4200 shall be used.

#### A.xx.4.3 ICC Profile Module

The ICC Profile Module shall always be present. If the color space to be used is not calibrated (i.e., a device-specific ICC Input Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.

### A.yy Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image Information Object Definition

This Section defines an Information Object to be used with several types of ophthalmic photographic imaging devices that generate wide field OP 16 bit images, including fundus cameras, slit lamp cameras, scanning laser ophthalmoscopes, stereoscopic cameras, video equipment and digital photographic equipment. It uses the stereographic projection method to represent on-face images of the 3D human retina in 2D on which geometric measurements can be made when the correct mathematical formulae are used.

#### A.yy.1 Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image IOD Description

The Wide Field Ophthalmic Photography Stereographic Projection 16 bit IOD specifies a single-frame or a multi-frame image acquired on a digital photographic DICOM modality.
IOD can be used to encode single wide field 16 bit ophthalmic images and other combinations including cine sequences. This IOD captures the projection of the wide field 2D Pixel image to enable anatomically-correct geometric measurements of the retina by taking into account the curved shape of the eye using a sphere to approximate shape.

A.yy.2 Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image IOD Entity-Relationship Model

The E-R Model in Section A.1.2 of this Part depicts those components of the DICOM Information Model that directly reference the Wide Field Ophthalmic Photography Stereographic Projection 16 bit IOD, with exception of the Curve, VOI LUT, Frame of Reference and Modality LUT entities, which are not used. Table A.yy-1 specifies the Modules of the Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image IOD.

A.yy.3 Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image IOD Modules

<table>
<thead>
<tr>
<th>IE</th>
<th>Module</th>
<th>Reference</th>
<th>Usage</th>
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<tbody>
<tr>
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</tr>
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<td>Study</td>
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<td>Clinical Trial Study</td>
<td>C.7.2.3</td>
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</tr>
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<td>C.7.3.1</td>
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<td>Clinical Trial Series</td>
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<tr>
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<td>C.7.4.1</td>
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<td>Equipment</td>
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<td>C – Required if contrast was administered; see A.42.4.2</td>
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<tr>
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</tr>
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<table>
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<tr>
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<th>C.8.17.y</th>
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<td>Ophthalmic Photography Acquisition Parameters</td>
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</tr>
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<td>SOP Common</td>
<td>C.12.1</td>
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</tr>
</tbody>
</table>

**A.yy.4 Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image IOD Content Constraints**

The following constraints on Series and Image attributes take precedence over the descriptions given in the Module Attribute Tables.

**A.yy.4.1 Bits Allocated, Bits Stored, and High Bit**

For Wide Field Ophthalmic Photography 16 bit images, the Enumerated Value of Bits Allocated (0028,0100) (Image Pixel Module, C.7.6.3) shall be 16; the Enumerated Value of Bits Stored (0028,0101) shall be 16; and the Enumerated Value of High Bit (0028,0102) shall be 15.

**A.yy.4.2 Contrast/Bolus Agent Sequence**

For Contrast/Bolus Agent Sequence (0018,0012), the defined CID 4200 shall be used.

**A.yy.4.3 ICC Profile Module**

The ICC Profile Module shall always be present. If the color space to be used is not calibrated (i.e., a device-specific ICC Input Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.

**A.aa Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image Information Object Definition**

This Section defines an Information Object to be used with several types of ophthalmic photographic imaging devices that generate wide field OP 8 bit images, including fundus cameras, slit lamp cameras, scanning laser ophthalmoscopes, stereoscopic cameras, video equipment and digital photographic equipment.

**A.aa.1 Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image IOD Description**

The Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image IOD specifies a single-frame or a multi-frame image acquired on a digital photographic DICOM modality. This IOD can be used to encode single wide field ophthalmic images and other combinations including cine sequences. This IOD captures the projection of the wide field 2D Pixel image to 3D (x,y,z) Cartesian coordinates.
A.aa.2 Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image IOD Entity-Relationship Model

The E-R Model in Section A.1.2 of this Part depicts those components of the DICOM Information Model that directly reference the Wide Field Ophthalmic Photography 3D Coordinates 8 bit IOD, with exception of the Curve, VOI LUT, Frame of Reference and Modality LUT entities, which are not used. Table A.aa-1 specifies the Modules of the Wide Field Ophthalmic Photography 3D Coordinate 8 bit Image IOD.

A.aa.3 Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image IOD Modules

<table>
<thead>
<tr>
<th>IE</th>
<th>Module</th>
<th>Reference</th>
<th>Usage</th>
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<tbody>
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<td>C – Required if contrast was administered; see A.42.4.2</td>
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A.aa.4 Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image IOD Content Constraints

The following constraints on Series and Image attributes take precedence over the descriptions given in the Module Attribute Tables.

A.aa.4.1 Bits Allocated, Bits Stored, and High Bit

For Wide Field Ophthalmic Photography 8 bit images, the Enumerated Value of Bits Allocated (0028,0100) (Image Pixel Module, C.7.6.3) shall be 8; the Enumerated Value of Bits Stored (0028,0101) shall be 8; and the Enumerated Value of High Bit (0028,0102) shall be 7.

A.aa.4.2 Contrast/Bolus Agent Sequence

For Contrast/Bolus Agent Sequence (0018,0012), the defined CID 4200 shall be used.

A.aa.4.3 ICC Profile Module

The ICC Profile Module shall always be present. If the color space to be used is not calibrated (i.e., a device-specific ICC Input Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.

A.bb Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image Information Object Definition

This Section defines an Information Object to be used with several types of ophthalmic photographic imaging devices that generate wide field OP 16 bit images, including fundus cameras, slit lamp cameras, scanning laser ophthalmoscopes, stereoscopic cameras, video equipment and digital photographic equipment.

A.bb.1 Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image IOD Description

The Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image IOD specifies a single-frame or a multi-frame image acquired on a digital photographic DICOM modality. This IOD can be used to encode single wide field ophthalmic images and other combinations including cine sequences. This IOD captures the projection of the wide field 2D Pixel image to 3D (x,y,z) Cartesian coordinates.

A.bb.2 Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image IOD Entity-Relationship Model

The E-R Model in Section A.1.2 of this Part depicts those components of the DICOM Information Model that directly reference the Wide Field Ophthalmic Photography 3D Coordinates 16 bit IOD, with exception of the Curve, VOI LUT, Frame of Reference and Modality LUT entities, which are not used. Table A.bb-1 specifies the Modules of the Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image IOD.
### Table A.bb-1

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<tr>
<th>IE</th>
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<td>Equipment</td>
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<td>C – Required if contrast was administered; see A.42.4.2</td>
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<td>Cine</td>
<td>C.7.6.5</td>
<td>C - Required if there is a sequential temporal relationship between all frames</td>
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</table>
A.bb.4

Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image

IOD Content Constraints

The following constraints on Series and Image attributes take precedence over the descriptions given in the Module Attribute Tables.

A.bb.4.1

Bits Allocated, Bits Stored, and High Bit

For Wide Field Ophthalmic Photography 16 bit images, the Enumerated Value of Bits Allocated (0028,0100) (Image Pixel Module, C.7.6.3) shall be 16; the Enumerated Value of Bits Stored (0028,0101) shall be 16; and the Enumerated Value of High Bit (0028,0102) shall be 15.

A.bb.4.2

Contrast/Bolus Agent Sequence

For Contrast/Bolus Agent Sequence (0018,0012), the defined CID 4200 shall be used.

A.bb.4.3

ICC Profile Module

The ICC Profile Module shall always be present. If the color space to be used is not calibrated (i.e., a device-specific ICC Input Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.

Add Text to Annex C section C.8.30.3.1.4 to introduce the term Ophthalmic Coordinate System.

Also add Figure C.8.30.3.1-6 to Annex C section C.8.30.3.1.4 (note the entire section is shown below to give context, only the figure and referencing the figure is new)

C.8.30.3.1.4

Corneal Vertex Location

The Corneal Vertex Location (0046,0202) establishes the reference point for the corneal vertex, called the Ophthalmic Coordinate System. It is used as the frame of reference that establishes the spatial relationship for the corneal vertex (i.e. used within corneal topography maps) for a set of Images within a Series. It also allows Images across multiple Series to share the same corneal vertex Frame Of Reference.

The corneal vertex is the point located at the intersection of the patient’s line of sight (visual axis) and the corneal surface. It is represented by the corneal light reflex when the cornea is illuminated coaxially with fixation.

Note: Since the criteria used to group images into a Series is application specific, it is possible for imaging applications to define multiple Series within a Study that share the same imaging space. Therefore the images with the same Frame of Reference UID (0020,0052) Attribute value share the same corneal vertex location within the patient’s eye.

Figure C.8.30.3.1-3 illustrates the representation of corneal topography. The corneal vertex lies at the center of the rulers. Typical circular grids are 3, 5, 7, and 9 mm diameters centered on the vertex. The annotations in the figures are R, right; L, left; H = Head; F = Foot.
Numerical position data shall use the Cartesian (i.e. two dimensional rectangular) coordinate system. The direction of the axes are determined by the Patient Orientation (0020,0020), see C.7.6.1.1.1 for further explanation.

Devices that internally capture data in polar coordinates will need to convert to Cartesian coordinates, see Figure C.8.30.3.1-4.
When using the 3 dimensional coordinates (X, Y, Z), the Z axis shall represent corneal elevation. Z shall be measured from the length of a vector normal to the plane that is normal to and intersects the corneal vertex at the intersection of the x, y, z, axes. It is shown in the diagram as “+” (0.0, 0.0, 0.0). The Z axis shall be positive towards the anterior direction of the eye; (i.e., it is a right-hand rule coordinate system. Thus the Z values (see Figures C.8.30.3.1-5 and C.8.30.3.1-6) will be predominantly negative, as they are posterior to the plane of the corneal vertex.
Figure C.8.30.3.1-5 Schematic of the 3-Dimensional Representation of Corneal Elevation

Figure C.8.30.3.1-6 Schematic of the Ophthalmic Coordinate System of the 3-Dimensional Representation used in Wide Field Measurements
Modify text to C.7.4.1.1.2 to specify that Ophthalmic Coordinate System is based upon the corneal vertex.

C.7.4.1.1.2 Position Reference Indicator

For an Ophthalmic Coordinate System, the Frame of Reference is based upon the corneal vertex. The corneal vertex is determined by the measuring instrument and shall be identified in this attribute with the value CORNEAL_VERTEX_R (for the right eye) or CORNEAL_VERTEX_L (for the left eye). The Ophthalmic Coordinate System corneal vertex based coordinate system is described in C.8.30.3.1.4.

Modify PS3.3 Annex C

C.8.17.x Wide Field Ophthalmic Photography Stereographic Projection Module

Table C.8.17.x-1 specifies the Attributes that describe an extension to the Ophthalmic Image module for wide field ophthalmic images where the images are represented as stereographic projections of a sphere with a diameter equal to the Ophthalmic Axial Length where the projection plane is through the equator of the eye and the foveal pit is the center of the projection plane.

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Include ‘General Anatomy Mandatory Macro’ Table 10-5</td>
<td></td>
<td></td>
<td>The concept code for Anatomic Region Sequence (0008,2218) shall be (T-AA000, SRT, “Eye”), and Defined Context ID 244 shall be used for Anatomic Region Modifier Sequence (0008,2220). Only a single Item shall be permitted in this sequence.</td>
</tr>
<tr>
<td>Projection Method Algorithm Sequence</td>
<td>(00gg,0013)</td>
<td>1</td>
<td>Software algorithm used to provide stereographic projection method. Only a single Item shall be permitted in this sequence.</td>
</tr>
<tr>
<td>Ophthalmic Axial Length</td>
<td>(0022,1019)</td>
<td>1</td>
<td>The axial length measurement used for the stereographic projection, in mm.</td>
</tr>
<tr>
<td>Ophthalmic Axial Length Method</td>
<td>(00gg,0015)</td>
<td>1</td>
<td>The method used to obtain the Ophthalmic Axial Length. Enumerated values: MEASURED = Measured axial length. ESTIMATED = An estimated value based upon performing the examination (i.e. based upon surrogate markers of axial length).</td>
</tr>
<tr>
<td>Attribute</td>
<td>Value</td>
<td>Description</td>
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<tr>
<td>---------------------------------</td>
<td>--------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>POPULATION</td>
<td></td>
<td>A length that represents a population norm (i.e. not based upon a measured axial length or surrogate markers of axial length).</td>
<td></td>
</tr>
<tr>
<td>Center Pixel View Angle</td>
<td>(00gg,0028)</td>
<td>Horizontal XCENTERPIXELVIEWANGLE (first value) and YCENTERPIXELVIEWANGLE (second value), vertical angles covered on the sphere by the center pixel of the projected image, as measured from the center of the sphere, in degrees. See section C.8.17.x.1.1 for further explanation.</td>
<td></td>
</tr>
<tr>
<td>Ophthalmic FOV</td>
<td>(00gg,0017)</td>
<td>The field of view used to capture the ophthalmic image, in degrees. The field of view is the maximum image size displayed on the image plane, expressed as the angle subtended at the exit pupil of the eye by the maximum dimension 2r (where r equals the radius).</td>
<td></td>
</tr>
</tbody>
</table>

### C.8.17.x.1 Wide Field Ophthalmic Photography Stereographic Projection Attribute Descriptions

#### C.8.17.x.1.1 Center Pixel View Angle

The Center Pixel View Angle (00gg,0028) comprises two real numbers XCENTERPIXELVIEWANGLE and YCENTERPIXELVIEWANGLE that represent in degrees the angles along the horizontal axis and the vertical axis respectively covered by the center pixel in the image, where this angle is measured from the center of the sphere. These are used to convert pixel locations in the image to their corresponding locations on a sphere. x and y are pixel locations (may be sub pixels) in the image, x running from 0 to XPIXELS from the left-hand side of the image to the right-hand side, and y running from 0 to YPIXELS from top to bottom, and if λ denotes the azimuth or longitude on the sphere and φ the elevation or latitude on the sphere, both in degrees, then,

\[
\lambda = \tan^{-1} \left( \frac{xy}{\rho + \tan(c)} \right)
\]

\[
\phi = \sin^{-1} \left( \frac{yr \sin(c)}{\rho} \right)
\]
\[ \tan^{-1} \] used to define \( \lambda \) represents the two-argument inverse tangent function.

\[
\begin{align*}
\arctan \frac{y}{x} & \quad x > 0 \\
\arctan \frac{y}{x} + \pi & \quad y \geq 0, x < 0 \\
\arctan \frac{y}{x} - \pi & \quad y < 0, x < 0 \\
\frac{\pi}{2} & \quad y > 0, x = 0 \\
- \frac{\pi}{2} & \quad y < 0, x = 0 \\
\text{undefined} & \quad y = 0, x = 0
\end{align*}
\]

Where

\[ xr = x - \frac{xPIXELS}{2} XCENTERPIXELVIEWANGLE \]
\[ yr = y - \frac{yPIXELS}{2} YCENTERPIXELVIEWANGLE \]

\[ \rho = \sqrt{xr^2 + yr^2} \]
\[ c = 2 \tan^{-1} \left( \frac{\rho}{2180} \right) \]

### C.8.17.z Wide Field Ophthalmic Photography 3D Coordinates Module

Table C.8.17.z-1 specifies the Attributes that describe an extension to the Ophthalmic Image module for wide field ophthalmic images capture the projection of the wide field 2D Pixel image to 3D (x,y,z) Cartesian coordinates.

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Include 'General Anatomy Mandatory Macro' Table 10-5</td>
<td></td>
<td></td>
<td>The concept code for Anatomic Region Sequence (0008,2218) shall be (T-AA000, SRT, &quot;Eye&quot;), and Defined Context ID 244 shall be used for Anatomic Region Modifier Sequence (0008,2220). Only a single Item shall be permitted in this sequence.</td>
</tr>
<tr>
<td>Projection Method Code Sequence</td>
<td>(00gg,0012)</td>
<td>1</td>
<td>Method used to project the 2D Pixel Image data (0028,0100) in this SOP Instance to the 3D Cartesian coordinates in the Dimensional to Three Dimensional Map Sequence (00gg,0018). Only a single Item shall be permitted in this sequence. See Section C.8.17.z.1.1 for further explanation.</td>
</tr>
<tr>
<td>Projection Method Algorithm Sequence</td>
<td>(00gg,0013)</td>
<td>1</td>
<td>Software algorithm used to provide projection method. Only a single Item shall be permitted in this sequence.</td>
</tr>
</tbody>
</table>
The axial length measurement used when performing the 2D pixel image projection into 3D Cartesian coordinates, in mm.

The method used to obtain the Ophthalmic Axial Length. Enumerated values:
- MEASURED = Measured axial length.
- ESTIMATED = An estimated value based upon performing the examination (i.e. based upon surrogate markers of axial length).
- POPULATION = A length that represents a population norm (i.e. not based upon a measured axial length or surrogate markers of axial length).

The field of view used to capture the ophthalmic image, in degrees. The field of view is the maximum image size displayed on the image plane, expressed as the angle subtended at the exit pupil of the eye by the maximum dimension 2r (where r equals the radius).

A sparsely sampled map of 2D image pixels (with sub pixel resolution) to 3D coordinates. Each frame shall be referenced once and only once in this sequence in Referenced Frame Numbers (0040,A136). One or more items are permitted in this sequence.

References one or more frames within this SOP Instance to which this sequence item applies. The first frame shall be denoted as frame number one.

Specifies the number of points in the map. Shall include one or more points.

See C.8.17.z.1.2 for further explanation.

---

**C.8.17.z.1** Wide Field Ophthalmic Photography 3D Coordinates Attribute Descriptions

**C.8.17.z.1.1** Projection Method Code Sequence

If Projection Method Code Sequence (00gg,0012) is (DCM, xxx1, “Spherical projection”) all the coordinates in the Two Dimensional to Three Dimensional Map Data (00gg,0031) are expected to lie on a sphere with a diameter that shall be equal to Ophthalmic Axial Length (0022,1019).

If Projection Method Code Sequence (00gg,0012) is (DCM, xxx2, “Surface contour projection”) the coordinates in the Two Dimensional to Three Dimensional Map Data (00gg,0031) are based upon the contour of the eye, therefore it cannot be assumed to be a spherical surface.
C.8.17.z.1.2 Two Dimensional to Three Dimensional Map Data

Two Dimensional to Three Dimensional Map Data (00gg,0031) is used to convey a sparsely sampled map of 2D image pixels (with sub pixel resolution) to 3D coordinates.

The origin of the 3D points shall be the Ophthalmic Coordinate System which is based upon the corneal vertex (i.e. the x, y and z coordinates of 0.0, 0.0, 0.0, in mm). See section C.8.30.3.1.4.

All data points are encoded as a floating point 5-tuple where the values are:

- 1st value = 2D horizontal location (a sub pixel location between 0 and image width)
- 2nd value = 2D vertical location (a sub pixel location between 0 and image height)
- 3rd value = x 3D-coordinate
- 4th value = y 3D-coordinate
- 5th value = z 3D-coordinate

So the ordering is 2D horizontal location₁, 2D vertical location₁, x₁, y₁, z₁, … 2D horizontal locationₙ, 2D vertical locationₙ, xₙ, yₙ, zₙ.

C.8.17.y Wide Field Ophthalmic Photography Quality Rating Module

Table C.8.1.y-1 specifies the Attributes that evaluate the quality of the projection used for a wide field ophthalmic photography image.

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Field Ophthalmic Photography Quality Rating Sequence</td>
<td>(00gg,0025)</td>
<td>1</td>
<td>Type of metric and metric value used to evaluate the quality of the projection used for the wide field ophthalmic photography image for this SOP Instance. Only a single Item shall be permitted in this sequence.</td>
</tr>
<tr>
<td>&gt;Include ‘Numeric Value Macro’ Table 10-26</td>
<td></td>
<td></td>
<td>Defined Context ID 4243 shall be used for Concept Name Code Sequence (0040,A043)</td>
</tr>
<tr>
<td>&gt;Wide Field Ophthalmic Photography Quality Threshold Sequence</td>
<td>(00gg,0026)</td>
<td>1</td>
<td>Quality threshold value and software algorithm used to provide the wide field ophthalmic photography projection quality rating for this SOP Instance. Only a single Item shall be permitted in this sequence.</td>
</tr>
<tr>
<td>&gt;&gt;Wide Field Ophthalmic Photography Threshold Quality Rating</td>
<td>(00gg,0027)</td>
<td>1</td>
<td>Quality rating threshold value for acceptable wide field ophthalmic photography projection. Note: The units of this Attribute is the same as defined in Measurement Unit Code Sequence (0040,08EA) of the Wide Field Ophthalmic Photography Quality Rating Sequence (00gg,0025). The threshold value is not the same as the attribute Numeric Value (0049,A30A) of the Wide Field Ophthalmic Photography Quality Rating Sequence (00gg,0025). Therefore, it conveys the least stringent value that is acceptable, not the actual rating for this SOP Instance.</td>
</tr>
<tr>
<td>&gt;&gt;Include ‘Algorithm Identification Macro’ Table 10-19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Modify PS3.3, C.8.17.2, Ophthalmic Photography Image Module for Attribute Pixel Spacing

C.8.17.2 Ophthalmic Photography Image Module

Table C.8.17.2-1 specifies the Attributes that describe an Ophthalmic Photography Image produced by Ophthalmic Photography equipment (OP) imaging Modalities.

Table C.8.17.2-1

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
</tr>
<tr>
<td>Pixel Spacing</td>
<td>(0028,0030)</td>
<td>1C</td>
<td>Nominal physical distance at the focal plane (in the retina) between the center of each pixel, specified by a numeric pair - adjacent row spacing (delimiter) adjacent column spacing in mm. See 10.7.1.3 for further explanation of the value order.</td>
</tr>
<tr>
<td>Note:</td>
<td></td>
<td></td>
<td>These values are specified as nominal because the physical distance may vary across the field of the images and the lens correction is likely to be imperfect.</td>
</tr>
<tr>
<td>Required when Acquisition Device Type Code Sequence (0022,0015) contains an item with the value (SRT, R-1021A,&quot;Fundus Camera&quot;). Shall not be sent when Two Dimensional to Three Dimensional Map Sequence (00gg,0018) or Center Pixel View Angle (00gg,0028) is present. May be present otherwise.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
</tr>
</tbody>
</table>

Modify the name of Content ID 4243 to be more generic in tables C.8.28.3-1 and C.8.25.14.5 – delete Axial Length

C.8.28.3 Ophthalmic Thickness Map Quality Rating Module

Table C.8.28.3-1 specifies the Attributes that describe the quality rating for the ophthalmic mapping.

Table C.8.28.3-1. Ophthalmic Thickness Map Quality Rating Module Attributes

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ophthalmic Thickness Map Quality Rating Sequence</td>
<td>(0022,1470)</td>
<td>1</td>
<td>Type of metric and metric value used to evaluate the quality of the ophthalmic mapping for grading and diagnostic purposes for this SOP Instance. Only a single Item shall be included in this sequence.</td>
</tr>
</tbody>
</table>

>Include Table 10-26 "Numeric Value Macro Attributes"

Defined CID 4243 “Ophthalmic Axial Length Quality Metric Type” shall be used for Concept Name Code Sequence (0040,A043)
C.8.25.14.5 Ophthalmic Axial Measurements Quality Metric Macro

Table C.8.25.14-6 describes the attributes for the Ophthalmic Axial Length Quality Metric Macro.

Table C.8.25.14-6. Ophthalmic Axial Length Quality Metric Macro Attributes

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Tag</th>
<th>Type</th>
<th>Attribute Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Name Code Sequence</td>
<td>(0040,A043)</td>
<td>1</td>
<td>Type of metric used to evaluate the quality of the ophthalmic axial length. Only a single Item shall be included in this sequence.</td>
</tr>
</tbody>
</table>

>Include Table 8.8-1 “Code Sequence Macro Attributes” Defined CID 4243 “Ophthalmic Axial Length Quality Metric Type”

Changes to NEMA Standards Publication PS 3.4

Digital Imaging and Communications in Medicine (DICOM)

Part 4: Service Class Specifications

Add to PS3.4 Annex B.5.

B.5 Standard SOP Classes

Table B.5-1

<table>
<thead>
<tr>
<th>SOP Class Name</th>
<th>SOP Class UID</th>
<th>IOD (See PS 3.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.xxxx</td>
<td>Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image</td>
</tr>
<tr>
<td>Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.yyyy</td>
<td>Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image</td>
</tr>
<tr>
<td>Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.aaaa</td>
<td>Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image Storage</td>
</tr>
</tbody>
</table>
Add to PS3.4 Annex I.4.

### I.4 Media Standard Storage SOP Classes

**Table I.4-1**

<table>
<thead>
<tr>
<th>SOP Class Name</th>
<th>SOP Class UID</th>
<th>IOD (See PS 3.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.xxxx</td>
<td>Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image Storage</td>
</tr>
<tr>
<td>Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.yyy</td>
<td>Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image Storage</td>
</tr>
<tr>
<td>Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.aaaa</td>
<td>Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image Storage</td>
</tr>
<tr>
<td>Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image Storage</td>
<td>1.2.840.10008.5.1.4.1.1.bbbb</td>
<td>Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image Storage</td>
</tr>
</tbody>
</table>
# Changes to NEMA Standards Publication PS 3.6

Digital Imaging and Communications in Medicine (DICOM)

## Part 6: Data Dictionary

Add to PS3.6 Annex A

<table>
<thead>
<tr>
<th>UID Value</th>
<th>UID NAME</th>
<th>UID TYPE</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.840.10008.5.1.4.1.1.xxxx</td>
<td>Wide Field Ophthalmic Photography Stereographic Projection 8 bit Image Storage</td>
<td>SOP Class</td>
<td>PS 3.4</td>
</tr>
<tr>
<td>1.2.840.10008.5.1.4.1.1.yyyy</td>
<td>Wide Field Ophthalmic Photography Stereographic Projection 16 bit Image Storage</td>
<td>SOP Class</td>
<td>PS 3.4</td>
</tr>
<tr>
<td>1.2.840.10008.5.1.4.1.1.aaaa</td>
<td>Wide Field Ophthalmic Photography 3D Coordinates 8 bit Image Storage</td>
<td>SOP Class</td>
<td>PS 3.4</td>
</tr>
<tr>
<td>1.2.840.10008.5.1.4.1.1.bbbb</td>
<td>Wide Field Ophthalmic Photography 3D Coordinates 16 bit Image Storage</td>
<td>SOP Class</td>
<td>PS 3.4</td>
</tr>
</tbody>
</table>
### Add to PS3.6 the following Data Elements to Section 6, Registry of DICOM data elements:

<table>
<thead>
<tr>
<th>Tag</th>
<th>Name</th>
<th>Keyword</th>
<th>VR</th>
<th>VM</th>
</tr>
</thead>
<tbody>
<tr>
<td>(00gg,0012)</td>
<td>Projection Method Code Sequence</td>
<td>ProjectionMethodCodeSequence</td>
<td>SQ</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0013)</td>
<td>Projection Method Algorithm Sequence</td>
<td>ProjectionMethodAlgorithmSequence</td>
<td>LO</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0015)</td>
<td>Ophthalmic Axial Length Method</td>
<td>OphthalmicAxialLengthMethod</td>
<td>CS</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0017)</td>
<td>Ophthalmic FOV</td>
<td>OphthalmicFOV</td>
<td>FL</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0018)</td>
<td>Two Dimensional to Three Dimensional Map Sequence</td>
<td>TwoDimensionaltoThreeDimensionalMapSequence</td>
<td>SQ</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0025)</td>
<td>Wide Field Ophthalmic Photography Quality Rating Sequence</td>
<td>WideFieldOphthalmicPhotographyQualityRatingSequence</td>
<td>SQ</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0026)</td>
<td>Wide Field Ophthalmic Photography Quality Threshold Sequence</td>
<td>WideFieldOphthalmicPhotographyQualityThresholdSequence</td>
<td>SQ</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0027)</td>
<td>Wide Field Ophthalmic Photography Threshold Quality Rating</td>
<td>WideFieldOphthalmicPhotographyThresholdQualityRating</td>
<td>FL</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0028)</td>
<td>Center Pixel View Angle</td>
<td>CenterPixelViewAngle</td>
<td>FL</td>
<td>2</td>
</tr>
<tr>
<td>(00gg,0030)</td>
<td>Number Of Map Points</td>
<td>NumberOfMapPoints</td>
<td>UL</td>
<td>1</td>
</tr>
<tr>
<td>(00gg,0031)</td>
<td>Two Dimensional to Three Dimensional Map Data</td>
<td>TwoDimensionaltoThreeDimensionalMapData</td>
<td>OF</td>
<td>1</td>
</tr>
</tbody>
</table>
Add the following definitions to Part 16 Annex B DCMR Context Groups (Normative)

CID 42x1  Wide Field Ophthalmic Photography Projection Method

Context ID 42x1

Wide Field Ophthalmic Photography Projection Method

<table>
<thead>
<tr>
<th>Coding Scheme Designator (0008,0102)</th>
<th>Code Value</th>
<th>Code Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCM</td>
<td>Xxx1</td>
<td>Spherical projection</td>
</tr>
<tr>
<td>DCM</td>
<td>Xxx2</td>
<td>Surface contour projection</td>
</tr>
</tbody>
</table>

Modify the name of Content ID 4243 to be more generic – delete Axial Length

CID 4243 Ophthalmic Axial Length Quality Metric Type

Type: Extensible
Version: 20100623

Table CID 4243. Ophthalmic Axial Length Quality Metric Type

<table>
<thead>
<tr>
<th>Coding Scheme Designator</th>
<th>Code Value</th>
<th>Code Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCM</td>
<td>111786</td>
<td>Standard Deviation of measurements used</td>
</tr>
<tr>
<td>DCM</td>
<td>111787</td>
<td>Signal to Noise Ratio</td>
</tr>
</tbody>
</table>
Add the following definitions to Part 16 Annex D DICOM Controlled Terminology Definitions (Normative)

### Annex D  DICOM Controlled Terminology Definitions (Normative)

<table>
<thead>
<tr>
<th>Code Value</th>
<th>Code Meaning</th>
<th>Definition</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xxx1</td>
<td>Spherical projection</td>
<td>Projection from 2D image pixels to 3D Cartesian coordinates based on a spherical mathematical model.</td>
<td></td>
</tr>
<tr>
<td>Xxx2</td>
<td>Surface contour projection</td>
<td>Projection from 2D image pixels to 3D Cartesian coordinates based on a surface contour. E.g. of the retina, derived via a measurement technology such as Optical Coherence Tomography, Ultrasound etc.</td>
<td></td>
</tr>
</tbody>
</table>
Changes to NEMA Standards Publication PS 3.17
Digital Imaging and Communications in Medicine (DICOM)
Part 17: Explanatory Information

Add to PS3.17 Annex U

Annex U Ophthalmology Use Cases (Informative)

U.x Wide Field Ophthalmic Use Cases

Any 2-dimensional representation of a 3-dimensional object must undergo some kind of projection to form the planar image. Within the context of imaging of the retina, we can approximate the eye as a sphere and make use of mathematical cartography to understand the impact of projecting a spherical retina on to a planar image. When projecting a spherical geometry on a planar geometry, one cannot retain all metric properties at the same time; some distortion will be introduced. However, if the projection is known it may be possible to perform calculations "in the background" that can compensate for these distortions.

We start with an example. In Figure U.x-1 we show an ultra-wide field image of the human retina. The original image has been remapped to a stereographic projection according to an optical model of the scanning laser ophthalmoscope it was captured on. Two circles have been annotated with an identical pixel count. The circle focused on the fovea (A) has an area 4.08 mm² whereas the circle nasally in the periphery (B) has an area of 0.97 mm², both as measured with the Area Measurement using the Stereographic Projection method. The difference in measurement is more than 400 %, which indicates how measurements on large views of the retina can be deceiving.

The fact that correct measurement on the retina in physical units is difficult to do is acknowledged in the original DICOM OP SOP Classes in the description of the Pixel Spacing (0028,0030) tag:

Note: These values are specified as nominal because the physical distance may vary across the field of the images and the lens correction is likely to be imperfect.

So far, all attempts to correctly measure on the retina are developed as propriety solutions in vendor-specific software. DICOM OP offers no solution to deliver the information required to make anatomically-correct measurements.
The following use cases are examples of how the DICOM Wide Field Ophthalmology Photography objects may be used.

**U.x.1 Routine Wide Field Image for Surveillance for Diabetic Retinopathy**

On routine wide-field imaging for annual surveillance for diabetic retinopathy a patient is noted to have no retinopathy, but demonstrates a pigmented lesion of the mid-periphery of the right eye. Clinically this appears flat or minimally elevated, irregularly pigmented without lacunae, indistinct margins on two borders, and has a surface that is stippled with orange flecks. The lesion is approximately 3 X 5 DD. This lesion appears clinically benign, but requires serial comparison to r/o progression requiring further evaluation. Careful measurements are obtained in 8 cardinal positions using a standard measurement tool in the reading software that calculates the shortest distance in mm between these points. The patient was advised to return in 6 months for repeat imaging and serial comparison for growth or other evidence of malignant progression.

**U.x.2 Patient with Myopia**

A patient with a history of high myopia has noted recent difficulties descending stairs. She believes this to be associated with a new onset blind spot in her inferior visual field of both eyes, right eye greater than left. On examination she shows a bullous elevation of the retina in the superior periphery of both eye due to retinoschisis, OD>OS. There is no evidence of inner or outer layer breaks, and the maculae is not threatened, so a decision is made to follow closely for progression suggesting a need for intervention. Wide field imaging of both fundi is obtained, with clear depiction of the posterior extension of the retinoschisis. Careful measurements of the shortest distance in mm between the posterior edge of the retinal splitting and the fovea is made using the diagnostic display measurement tool, and the patient was advised to return in 4 months for repeat imaging and serial comparison of the posterior location of the retinoschisis.

**U.x.3 Patient with Diabetes**

Patients with diabetes are enrolled in a randomized clinical trial to prospectively test the impact of disco music on the progression of capillary drop out in the retinal periphery. The retinal capillary drop-out is demonstrated using wide-field angiography with expanse of this drop-out determined serially using diagnostic display measurement tools, and the area of the drop-out reported in mm². Regional areas of capillary drop out are imaged such that the full expanse of the defect is...
captured. In some cases this involves eccentric viewing with the fovea positioned in other than the center of the image. Exclusion criteria for patient enrollment include refractive errors greater than 8D of Myopia and 4D of hyperopia.

**U.x.4 Patient with Diabetes**

Patients with ARMD and subfoveal subretinal neovascular membranes but refusing intravitreal injections are enrolled in a randomized clinical trial to test the efficacy of topical anti-VEGF eye drops on progression of their disease. The patients are selected such that there is a wide range of lesion size (area measured in mm²) and retinal thickening. This includes patients with significant elevation of the macula due to subretinal fluid.

**U.y.1 Stereographic Projection (SP)**

Every 2-dimensional image that represents the back of the eye is a projection of a 3-dimensional object—the retina—into a 2-dimensional space—the image. Therefore, every image acquired with a fundus camera or scanning laser ophthalmoscope is a particular projection. In ophthalmoscopy we project part of the spherical retina—the back of the eye can be approximated by a sphere—to a plane, i.e., a 2-dimensional image.

The projection used for a specific retinal image depends on the ophthalmoscope; its optical system comprising lenses, mirrors and other optical elements, dictates how the image is formed. These projections are not well-characterized mathematical projections, but they can be reversed to return to a sphere. Once in spherical geometry, the image can then be projected once more. This time we can use any mathematical projection and preferably we use one that enables correct measurements. Many projections are described in the literature, so which one do we choose?

Certain projections are more suitable for a particular task than others. Conformal projections preserve angle, which is a property that applies to points in the plane of projection which are locally distortion-free. Practically speaking, this means that the projected meridian and parallel through the point intersect at right angles and are equiscaled. Therefore, measuring angles on the 2-dimensional image yields the same results as measuring these on the spherical representation, i.e., the retina. Conformal projections are particularly suitable for tasks where the preservation of shapes is important. Therefore, we propose to use the stereographic projection explained in Figure U.y-1 for images on which to perform anatomically-correct measurements. The stereographic projection with $z=0$ means the projection plane intersects the equator of the eye where the fovea and cornea are poles. The points Fovea, p and q on the sphere (retina) are projected onto the projection plane (image in stereographic projection) along lines through the cornea where they intersect with the project plane creating points $F'$, $p'$ and $q'$ respectively.
Note that in the definition of stereographic projection we have the fovea conceptually in the center of the image. For the mathematics below to work correctly, it is critical that each image is projected such that conceptually the fovea is in the center, even if the fovea is not in the image. This is not difficult to achieve as a similar result is achieved when creating a montage of fundus images; each image is re-projected relative to the area it covers on the retina. Most montages place the fovea in the center. An example of two images of the same eye in Figures U.y-2 and U.y-3 taken from different angles and then transformed to adhere to this principle are in Figures U.y-4 and U.y-5 respectively.
Figure U.y-2: Image taken on-axis, i.e., centered on the fovea

Figure U.y-3: Image acquired superiorly-patient looking up
Figure U.y-4: Fovea in the center and clearly visible

Figure U.y-5: Fovea barely visible, but the transformation ensures it is still in the center
Furthermore the mathematical "background calculations" are well known for images in stereographic projection. Given points (pixels) on a retinal image, we can directly locate these points on the sphere and perform geometric measurements, i.e., area and distance measurements, on the sphere to obtain the correct values. The mathematical details behind the calculations for locating points on a sphere are presented in C.8.17.x.1.1.

U.x.6 Distance

The shortest distance between two points on a sphere lie on a "great circle", which is a circle on the sphere's surface that is concentric with the sphere. The great-circle section that connects the points (the line of shortest distance) is called a geodesic. There are several equations that approximate the distance between two points on the back of the eye along the great circle through those points (the arc length of the geodesic), with varying degrees of accuracy. The simplest method uses the "spherical law of cosines". Let \( \lambda_s, \phi_s ; \lambda_f, \phi_f \) be the longitude and latitude of two points \( s \) and \( f \), and \( \Delta \lambda \equiv |\lambda_f - \lambda_s| \) the absolute difference of the longitudes, then the central angle is defined as

\[
\Delta \hat{\alpha} = \arccos \left( \sin \phi_s \sin \phi_f + \cos \phi_s \cos \phi_f \cos \Delta \lambda \right)
\]

where the central angle is the angle between the two points via the center of the sphere, e.g. angle \( \alpha \) in Figure U.y-6. If the central angle is given in radians, then the distance \( d \), known as arc length, is defined as \( R \Delta \hat{\alpha} \) where \( R \) is the radius of the sphere.

This equation leads to inaccuracies both for small distances and if the two points are opposite each other on the sphere. A more accurate method that works for all distances is the use of the Vincenty formulae. Now the central angle is defined as

\[
\Delta \hat{\alpha} = \arctan \left( \frac{\sqrt{(\cos \phi_f \sin \Delta \lambda)^2 + (\cos \phi_s \sin \phi_f - \sin \phi_s \cos \phi_f \cos \Delta \lambda)^2}}{\sin \phi_s \sin \phi_f + \cos \phi_s \cos \phi_f \cos \Delta \lambda} \right)
\]

Figure U.y-6: Example of a polygon on the service of a sphere

Example U.y.6 is an example of a polygon made up of three geodesics \( G_a, G_b, G_c \), describing the shortest distances on the sphere between the polygon vertices \( x_1, x_2, x_3 \). Angle \( \gamma \) is the angle on the surface between geodesics \( G_a \) and \( G_b \). Angle \( \alpha \) is the central angle (angle via the sphere's center) of geodesic \( G_a \).

U.x.7 Area

To measure an area \( A \) defined by a polygon where angle \( \alpha_i \) for \( i = 1, \ldots, n \) for \( n \) angles internal to the polygon and \( R \) the radius of the sphere, we use the following formula, which makes use of the "angle excess".

\[
A = R^2 \left( \sum_{i=1}^{n} \alpha_i - (n - 2) \pi \right)
\]
This yields a result in physical units (e.g. millimetre² if \( R \) was given in mm), but if \( R^2 \) is omitted in the above formula, a result is obtained in units relative to the sphere, in steradians (sr), the unit of solid angle.

**U.x.8 Angle**

In practice, if the length of the straight arms of the calipers used to measure angle are short then the angle measured on the image is equivalent to its representation on the sphere, which is a direct result of using the stereographic projection as it is conformal.

**U.z Introduction to 2D to 3D Map for Wide Field Ophthalmic Photography**

A 2D to 3D map includes 3D coordinates of all or a subset of pixels (namely coordinate points) to the 2D image. Implementations choose the interpolation type used, but it is recommended to use a spline based interpolation. See figure U.z.1

Pixels’ 3D coordinates could be used for different analyses and computations e.g. measuring the length of a path, and calculating the area of region of interest, 3D computer graphics, registration, shortest distance computation, etc. Some examples of methods using 3D coordinates are listed in the following:

![Figure U.z-1: Map pixel to 3D coordinate](image)

**U.z.1 Measuring the length of a path**

Let the path between points \( A \) and \( B \) be represented by set of \( N \) following pixels \( P = \{ p_i \} \) and \( p_0 = A \) and \( p_N = B \). The length of this path can be computed from the partial lengths between path points by:

\[
l = \sum_{i=0}^{i=N-1} l_i
\]

\[
l_i = \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2 + (z_i - z_{i+1})^2}
\]

Where \( x_i, y_i, z_i \) are the 3D coordinates of the point \( p_i \) which is either available in the 2D to 3D map if \( p_i \) is a coordinate point or it is computed by interpolation. Here it is assumed that the sequence of path points is known and the path is 4- or 8 connected (i.e. the path points are neighbors with no more than one pixel distance in horizontal, vertical, or diagonal direction). It is recommendable to support sub-pixel processing by using interpolation.
U.z.2 Shortest distance between two points

Shortest distance between two points along the surface of a sphere, known as the great-circle or orthodromic distance, can be computed from:

\[ d = r \Delta \sigma \]

\[ \Delta \sigma = \arctan \left( \frac{|n_1 \times n_2|}{n_1 \cdot n_2} \right) \]

where \( r \) is the radius of the sphere and the central angle \( \Delta \sigma \) is computed from the Cartesian coordinate of the two points in radians. Here \((n_1)\) and \((n_2)\) are the normals to the ellipsoid at the two positions. The above equations can also be computed based on longitudes and latitudes of the points.

However, the shortest distance in general can be computed by algorithms such as Dijkstra which compute the shortest distance on graphs. In this case the image is represented as a graph in which the nodes refer to the pixels and the weight of edges is defined based on the connectivity of the points and their distance.

U.z.3 Computing the area of a region of interest

Let \( R \) be the region of interest on the 2D image and it is tessellated by set of unit triangles \( T = \{ T_i \} \).

By unit triangle we refer to isosceles right triangle that the two equal sides have one pixel distance.
(4-connected neighbors). The area of the region of interest can be computed as the sum of partial areas of the unit triangles in 3D. Let \( \{a_i, b_i, c_i\} \) be the 3D coordinates of the three points of unit triangle \( T_i \). The 3D area of this triangle is

\[
A_i = \frac{1}{2} \left( \| (b_i - a_i) \times (c_i - a_i) \| \right)
\]

and the total area of \( R \) is:

\[
A = \sum A_i
\]

where ( \( \| \| \) ) and ( \( \times \) ) refer to the magnitude and cross product, respectively. Consider that \( a_i \), \( b_i \), and \( c_i \) are the 3D coordinates not the 2D indices of the unit triangle points on the image.

**U.z.4 Projection Method Code Sequence**

If Projection Method Code Sequence (00gg,0012) is (DCM, xxx1, “Spherical projection”) is used then all coordinates in the 3CC (00gg,0019) are expected to lie on a sphere with a diameter that is equal to Ophthalmic Axial Length (0022,1019).

The use of this model for representing the 3D retina enables the calculation of the shortest distance between two points using great-circles as per U.z.2 “Shortest distance between two points”.