Digital Imaging and Communications in Medicine (DICOM)

Supplement 229: Photoacoustic Imaging

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Scope and Field of Application

This Supplement to the DICOM Standard introduces a new IOD and a new storage SOP Class for encoding and storing photoacoustic images.

Photoacoustic (PA) imaging is an imaging modality that enables imaging optical absorption in biological tissues with acoustic resolution. Contrast is generated through absorption by chromophores that range from intrinsic absorbers such as hemoglobin and melanin to extrinsic agents such as indocyanine green (ICG) or diverse types of nano-particles. In principle, excitation at multiple wavelengths allows the modality to discriminate individual chromophores. Prospective applications in the space of clinical imaging range from classification of breast cancer lesions through screening of sentinel lymph nodes to assessment of inflammation. Photoacoustic Imaging is in widespread use in preclinical research labs and is currently being translated to clinical applications in first commercial implementations.

Many (but not all) Photoacoustic implementations integrate active pulse/echo ultrasound in a hybrid imaging system to capitalize on well-established contrast for anatomical information. The scope of this IOD is the Photoacoustic image. Complementary images such as pulse/echo ultrasound are represented by their native DICOM IODs. Albeit fusing Photoacoustic images with Ultrasound images for display is the presently most common scenario, the particulars of the fusion are beyond the scope of this IOD but examples are provided. Photoacoustic images represent image output generated by the input of one or more optical excitation wavelengths.

The following items are considered out of scope:

- Photoacoustic specific SR file implementation is reserved for a later supplement.
- If a Photoacoustic device produces an image with no Photoacoustic optical image, the SOP class of the structural image (e.g. ultrasound) will be used
- If a Photoacoustic device creates a single image component by fusing the structural image to the Photoacoustic image for display as a single image (burned in), it will use the SOP class of the structural image.
- A closely related imaging modality is Thermoacoustic imaging (TAI) which uses microwave radiation to excite the tissue (in contrast to light pulses). The specific characteristics of TAI were not addressed in this supplement and focus was given to photoacoustic imaging as defined herein, where excitation is limited to pulsed light. Hence, this modality is excluded in this supplement to limit the scope of the present supplement.

Changes to NEMA Standards Publication PS 3.3

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions
Part 3 Additions

Modify PS3.3

Add to PS3.3 Annex A Table A.1-1a. Composite Information Object Modules Overview – Images
- New column for Photoacoustic Image with information from Table A.89.3-1
- New rows for - Enhanced Series, Photoacoustic Image, Photoacoustic Acquisition Parameters, Photoacoustic Transducer, Photoacoustic Reconstruction

Add to PS3.3 Annex A

A.89 Photoacoustic Image IOD

A.89.1 Photoacoustic Image IOD Description

The Photoacoustic Image Information Object Definition specifies an image which has been generated by the acquisition of acoustic signals from the absorption of light at one or more optical excitation wavelengths and the optional algorithmic combination of the acquired data.

A.89.2 Photoacoustic Image IOD Description Entity-Relationship Model

The Photoacoustic Image IOD uses the DICOM Composite Instance IOD Entity-Relationship Information Model defined in Section A.1.2, with the Image IE below the Series IE.

A.89.3 Photoacoustic Image IOD Module Table

Table A.89.3-1 specifies the Modules of the Photoacoustic Image IOD.

Table A.89.3-1. Photoacoustic Image IOD Modules

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	General Series	C.7.3.1	M
	Enhanced Series	C.7.3.3	M
	Clinical Trial Series	C.7.3.2	U

Frame of Reference	Frame of Reference	C.7.4.1	M
	Ultrasound Frame of Reference	C.8.24.2	M
	Synchronization	C.7.4.2	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Image	General Image	C.7.6.1	M
	General Reference	C.12.4	U
	Image Pixel	C.7.6.3	M
	Enhanced Contrast/Bolus	C.7.6.4b	C - Required if contrast media was used in this image
	Multi-frame Functional Groups	C.7.6.16	M
	Multi-frame Dimension	C.7.6.17	M
	Device	C.7.6.12	U
	Specimen	C.7.6.22	U
	Acquisition Context	C.7.6.14	M
	Supplemental Palette Color Lookup Table	C.7.6.19	C - Required if Pixel Presentation (0008,9205) in the Photoacoustic Image Module equals COLOR.
	Photoacoustic Image	C.8.34.1	M
	Photoacoustic Acquisition Parameters	C.8.34.2	M
	Photoacoustic Transducer	C.8.34.3	U

Photoacoustic Reconstruction	C.8.34.4	U
ICC Profile	C.11.15	C – Required if Pixel Presentation (0008,9205) in the Photoacoustic Image Module equals TRUE_COLOR or COLOR (A.89.3.1.2)
SOP Common	C.12.1	M
Common Instance Reference	C.12.2	U
Frame Extraction	C.12.3	C - Required if the SOP Instance was created in response to a Frame-Level retrieve request

A.89.3.1 Photoacoustic Image IOD Content Constraints

A.89.3.1.1 Modality
The value of Modality (0008,0060) shall be PA.

A.89.3.1.2 Photometric Interpretation and Pixel Presentation
If Pixel Presentation (0008,9205) in the Photoacoustic Image Module equals COLOR or MONOCHROME, the Photometric Interpretation (0028,0004) shall be MONOCHROME2.

If Pixel Presentation (0008,9205) in the Photoacoustic Image Module equals TRUE_COLOR, the Photometric Interpretation (0028,0004) shall be RGB for uncompressed or lossless compressed Transfer Syntaxes that do not have defined color space transformations, YBR_ICT for irreversible JPEG2000 Transfer Syntaxes, YBR_RCT for reversible JPEG2000 Transfer Syntaxes, YBR_PARTIAL_420 for MPEG2, MPEG-4 AVC/H.264, HEVC/H.265 Transfer Syntaxes and YBR_FULL_422 for JPEG lossy compressed Transfer Syntaxes and YBR_FULL or RGB for RLE Transfer Syntaxes. See Table C.8.34.1.3-1 for combinations of parameter values.

Note

Future lossless and lossy Transfer Syntaxes may lead to the need for new definitions and choices for Photometric Interpretation.

A.89.3.1.3 ICC Profile Module
The ICC Profile Module shall be present if Pixel Presentation (0008,9205) in the Photoacoustic Image Module equals TRUE_COLOR or COLOR. 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.89.3.1.4 Ultrasound Frame of Reference
The Ultrasound Frame of Reference C.8.24.2 is mandatory for Photoacoustic even in cases where Ultrasound is not used as a complementary modality due to the use of the Image Position (Volume) (0020,9301) in the Photoacoustic Dimension Index.

A.89.3.1.5 Real World Value Mapping
If the Real World Value Mapping Sequence (0040,9096) is present, it shall not be inconsistent with the Image Data Type Sequence (0018,9807).

A.89.4 Photoacoustic Functional Group Macros

Table A.89.4-1 specifies the use of the Functional Group Macros used in the Multi-frame Functional Groups Module for the Photoacoustic IOD.

Table A.89.4-1. Photoacoustic Functional Group Macros

Functional Group Macro	Section	Usage
Frame Content	C.7.6.16.2.2	M - May not be used as a Shared Functional Group.
Pixel Measures	C.7.6.16.2.1	M
Plane Position (Patient)	C.7.6.16.2.3	C - Required if Ultrasound Acquisition Geometry (0020,9307) has a value of PATIENT. May be present otherwise. See Section A.59.4.1.2.
Plane Orientation (Patient)	C.7.6.16.2.4	C - Required if Ultrasound Acquisition Geometry (0020,9307) has a value of PATIENT. May be present otherwise. See Section A.59.4.1.2.
Referenced Image	C.7.6.16.2.5	U
Derivation Image	C.7.6.16.2.6	C - Required if the image or frame has been derived from another SOP Instance.
Frame VOI LUT	C.7.6.16.2.10	U - May be used only if Photometric Interpretation (0028,0004) is MONOCHROME2.
Real World Value Mapping	C.7.6.16.2.11	U - May be used only if Photometric Interpretation (0028,0004) is MONOCHROME2.
Contrast/Bolus Usage	C.7.6.16.2.12	C - Required if the Enhanced Contrast/Bolus Module is present.
Patient Orientation in Frame	C.7.6.16.2.15	U
Frame Display Shutter	C.7.6.16.2.16	U
Plane Position (Volume)	C.7.6.16.2.21	M - May not be used as a Shared Functional Group. See Section A.59.4.1.2.
Plane Orientation (Volume)	C.7.6.16.2.22	M - May not be used as a Per-Frame Functional Group. See Section A.59.4.1.2.
Temporal Position	C.7.6.16.2.23	M

Photoacoustic Excitation Characteristics	C.8.34.5.1	U
Photoacoustic Image Frame Type	C.8.34.5.2	M - May not be used as a Per-Frame Functional Group
Photoacoustic Image Data Type	C.8.34.5.3	M - May not be used as a Per-Frame Functional Group
Photoacoustic Reconstruction Algorithm Macro Attributes	C.8.34.5.4	U - May not be used as a Per-Frame Functional Group

Add new defined term to PS3.3 C.7.3.1.1.1 Modality

Defined Terms:

…

PA

Photoacoustic

…

Modify table C.7.6.16-3 Frame Content Macro Attributes as follows.

Table C.7.6.16-3. Frame Content Macro Attributes

Attribute Name	Tag	Type	Attribute Description
…			

>Frame Reference DateTime	(0018,9151)	1C	The point in time that is most representative of when data was acquired for this frame. See Section C.7.6.16.2.2.1 and Section C.7.6.16.2.2.2 for further explanation. Note: The synchronization of this time with an external clock is specified in the synchronization Module in Acquisition Time synchronized (0018,1800). Required if Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and the SOP Class UID is not "1.2.840.10008.5.1.4.1.1.2.2" or "1.2.840.10008.5.1.4.1.1.4.4" or "1.2.840.10008.5.1.4.1.1.128.1" (Legacy Converted) or 1.2.840.10008.5.1.4.1.1.77.1.6 (VL Whole Slide Microscopy Image Storage). May be present otherwise.
>Frame Acquisition DateTime	(0018,9074)	1C	The date and time that the acquisition of data that resulted in this frame started. See Section C.7.6.16.2.2.1 for further explanation. Required if: • Frame Type (0008,9007) Value 1 of this frame is ORIGINAL and the SOP Class UID is not "1.2.840.10008.5.1.4.1.1.2.2" or "1.2.840.10008.5.1.4.1.1.4.4" or "1.2.840.10008.5.1.4.1.1.128.1" (Legacy Converted) or 1.2.840.10008.5.1.4.1.1.77.1.6 (VL Whole Slide Microscopy Image Storage) or, • **SOP Class UID (0008,0016) is "1.2.840.10008.5.1.4.1.1.6.3" (Photoacoustic Image Storage).** May be present otherwise.
…			
…			

Modify text in C.8.16 and C.8.16.2 to include Photoacoustic Imaging

C.8.16 Common CT, MR, ~~and~~ US, and Photoacoustic Image Descriptions

This section contains descriptions of Macros and Attributes used in Modules and Functional Group Macros that are common to the Enhanced CT Image, Enhanced MR Images, MR Spectroscopy, ~~and~~ Enhanced US Volume **and Photoacoustic Image** IODs.

…

C.8.16.2 Common CT/MR and Photoacoustic Image Description Macro

Table C.8-131 specifies the Attributes of the Common CT/MR **and Photoacoustic** Image Description Macro.

Table C.8-131. Common CT/MR and Photoacoustic Image Description Macro Attributes

…

C.8.16.2.1 Common CT/MR and Photoacoustic Image Description Attribute Description

Add a new section to C.8 Modality Specific Modules

C.8.34 Photoacoustic Modules

C.8.34.1 Photoacoustic Image

This section describes the Photoacoustic Image Module.

Table C.8.34.1-1 contains IOD Attributes that describe Photoacoustic Images

Table C.8.34.1-1. Photoacoustic Image Module Attributes

Image Type	(0008,0008)	1	Image identification characteristics. See Section C.8.34.1.1 for specialization.
Dimension Organization Type	(0020,9311)	1	Dimension organization of the Instance. Defined Terms: 3D Spatial Multi-frame image of equally spaced parallel planes (3D volume set) 3D_TEMPORAL Temporal loop of equally spaced parallel-plane 3D volume sets. See Section C.8.34.1.2 for details.
Acquisition DateTime	(0008,002A)	1	The date and time that the acquisition of data that resulted in this image started.
Include Table C.8-131 “Common CT/MR and Photoacoustic Image Description Macro Attributes”			
Samples per Pixel	(0028,0002)	1	Number of samples (planes) in this image. For Enumerated Values See Section C.8.34.1.3.
Photometric Interpretation	(0028,0004)	1	Specifies the intended interpretation of the pixel data. Enumerated Values are specified in the IOD that invokes this Module. See Section C.7.6.3.1.2 for definition of this term.
Bits Allocated	(0028,0100)	1	Number of bits allocated for each pixel sample. Each sample shall have the same number of bits allocated. For Enumerated Values See Section C.8.34.1.3.

Bits Stored	(0028,0101)	1	Number of bits stored for each pixel sample. Each sample shall have the same number of bits stored. For Enumerated Values See Section C.8.34.1.3.
High Bit	(0028,0102)	1	Most significant bit for pixel sample data. Each sample shall have the same high bit. Shall be one less than the value in Bits Stored (0028,0101).
Pixel Representation	(0028,0103)	1	Data representation of the pixel samples. Each sample shall have the same pixel representation. For Enumerated Values See Section C.8.34.1.3
Planar Configuration	(0028,0006)	1C	Indicates whether the pixel data are encoded color-by-plane or color-by-pixel. Required if Samples per Pixel (0028,0002) has a value greater than 1. See Section C.7.6.3.1.3 and Section C.8.34.1.3 fo r further explanation.

Position Measuring Device Used	(0018,980C)	1	Describes the type of position measuring device used in the acquisition of the image. This gives an indication of the degree of precision of Pixel Spacing (0028,0030) and the spacing between adjacent planes. Note *The actual precision will depend on a variety of factors such as the tracking technology used and the quality of the calibration.* Enumerated Values: RIGID The image was acquired with a position measuring device that rigidly connects the transducer to a frame of reference. TRACKED The image was acquired using freehand motion of the transducer with an associated position measuring device (i.e. tracked freehand transducer). FREEHAND The image was acquired using freehand motion of the transducer without a position measuring device.
Lossy Image Compression	(0028,2110)	1	Specifies whether an Image has undergone lossy compression (at a point in its lifetime). Enumerated Values: 00 Image has NOT been subjected to lossy compression. 01 Image has been subjected to lossy compression. Once this value has been set to 01 it shall not be reset. See Section C.7.6.1.1.5.

Lossy Image Compression Ratio	(0028,2112)	1C	Describes the approximate lossy compression ratio(s) that have been applied to this image. See Section C.7.6.1.1.5.2. Required if Lossy Image Compression (0028,2110) is “01”.
Lossy Image Compression Method	(0028,2114)	1C	A label for the lossy compression method(s) that have been applied to this image. See Section C.7.6.1.1.5.1. Required if Lossy Image Compression (0028,2110) is “01”.
Presentation LUT Shape	(2050,0020)	1C	Specifies an identity transformation for the Presentation LUT, such that the output of all grayscale transformations defined in the IOD containing this Module are defined to be P-Values. Enumerated Values: IDENTITY output is in P-Values. Required if Photometric Interpretation (0028,0004) is MONOCHROME2.
Burned In Annotation	(0028,0301)	1	Indicates whether or not image contains sufficient burned in annotation to identify the patient and date the image was acquired. Enumerated Values: NO
Recognizable Visual Features	(0028,0302)	3	Indicates whether or not the image contains sufficiently recognizable visual features to allow the image or a reconstruction from a set of images to identify the patient. Enumerated Values: YES NO If this Attribute is absent, then the image may or may not contain recognizable visual features.

Icon Image Sequence	(0088,0200)	3	This icon image is representative of the image. Only a single Item is permitted in this Sequence.
>Include Table C.7-11b “Image Pixel Macro Attributes”			See Section C.7.6.1.1.6.

C.8.34.1.1 Photoacoustic Image Type

C.8.34.1.1.1 Pixel Data Characteristics
Value 1 of Image Type (0008,0008) and Frame Type (0008,9007) is discussed in Section C.8.16.1.1.

C.8.34.1.1.2 Patient Examination Characteristics
Value 2 of Image Type (0008,0008) and Frame Type (0008,9007) is discussed in Section C.8.16.1.2.

C.8.34.1.1.3 Image Flavor
See Section C.8.16.1.3 for requirements, but not Defined Terms.

Table C.8.34.1.1.3-1 specifies the Defined Terms for Photoacoustic Images for Value 3 for Image Type (0008,0008) and Frame Type (0008,9007).

Table C.8.34.1.1.3-1. Photoacoustic Image Type and Frame Type Value 3

Defined Term Name	Defined Term Description
VOLUME	Set of frames that define a regularly sampled volume
NON_PARALLEL	Set of frames that are not parallel
PARALLEL	Set of frames that are parallel but do not constitute a regularly sampled volume

C.8.34.1.1.4 Derived Pixel Contrast
Value 4 of Image Type (0008,0008) and Frame Type (0008,9007) is discussed in Section C.8.16.1.4.

C.8.34.1.2 Photoacoustic Dimension Organization Type
Photoacoustic Image studies include one or more Photoacoustic images indexed with Multi-frame Dimensions. The Dimension Organization Type (0020,9311) specifies the general structure of the image. The concept of “multi-frame dimensions” as specified by the Dimension Index Sequence (0020,9222) and per-frame Dimension Index Values (0020,9157) is used to specify the relationships of frames within that general structure.

The Dimension Index Sequence (0020,9222) shall have at least three Items, with the dimension values described in Table C.8.34.1.2-1. I.e. these Dimension values will all be present even if there is only one value for a given Dimension.

Note

It is expected that some implementations may include additional dimensions such as Photoacoustic Excitation Characteristics Sequence (0018,9821) or Reconstruction Algorithm Sequence (0018,993D).

Table C.8.34.1.2-1. Dimension Definition for PA Images

Item	Attribute	Tag	Value
Dimension Index Sequence		(0020,9222)	
1st	>Dimension Index Pointer	(0020,9165)	Temporal Position Time Offset (0020,930d)
	>Functional Group Pointer	(0020,9167)	Temporal Position Sequence (0020,9310)
	…		
2nd	>Dimension Index Pointer	(0020,9165)	Image Position (Volume) (0020,9301)
	>Functional Group Pointer	(0020,9167)	Plane Position (Volume) Sequence (0020,930E)
	…		
3rd	>Dimension Index Pointer	(0020,9165)	Image Data Type Sequence (0018,9807)
	…		

C.8.34.1.3 Photometric Interpretation, Pixel Representation, Samples Per Pixel, Planar Configuration, Bits Allocated and Bits Stored

Table C.8.34.1.3-1 specifies the Enumerated Values and allowed combinations of Samples per Pixel (0028,0002), Planar Configuration (0028,0006), Pixel Representation (0028,0103), Bits Allocated (0028,0100) and Bits Stored (0028,0101) for each allowable Photometric Interpretation allowed by the IOD that invokes this Module.

Table C.8.34.1.3-1. Allowed Combinations of Attribute Values for Photometric Interpretation, Samples Per Pixel, Planar Configuration, Pixel Representation, Bits Allocated and Bits Stored

Photometric Interpretation	Samples per Pixel	Planar Configuration	Pixel Representation	Bits Allocated	Bits Stored
MONOCHROME2	1	-	0	8	8
MONOCHROME2	1	-	0	16	16
RGB	3	0	0	8	8
YBR_ICT	3	0	0	8	8
YBR_RCT	3	0	0	8	8
YBR_PARTIAL_420	3	0	0	8	8
YBR_FULL_422	3	0	0	8	8
YBR_FULL	3	0	0	8	8

C.8.34.2 Photoacoustic Acquisition Parameters Module

This section describes Photoacoustic Imaging parameters that are constant for the acquisition of all frames in this image.

Table C.8.34.2-1. Photoacoustic Acquisition Parameters Module Attributes

Attribute Name	Tag	Type	Attribute Description
Excitation Wavelength Sequence	(0018,9825)	1	Optical excitation wavelength(s) applied to the target. Acquired data from all input wavelengths in this sequence is processed to create the image. The processing may be described in Reconstruction Algorithm Sequence (0018,993D). One or more Items shall be included in this Sequence.
>Excitation Wavelength	(0018,9826)	1	The wavelength in nm of the optical excitation pulse from the illuminator.
Illumination Translation Flag	(0018,9828)	3	Whether the position of the illumination source is changed during the frame acquisition. Enumerated Values: YES NO
Illumination Type Code Sequence	(0022,0016)	3	Type of illumination used. Only a single Item is permitted in this Sequence.
>Include Table 8.8-1 “Code Sequence Macro Attributes”			DCID 11001 “Photoacoustic Illumination Method”
Acoustic Coupling Medium Flag	(0018,9829)	1	Whether an acoustic coupling medium was used. A value of NO indicates direct contact between the transducer and imaging subject. Enumerated Values: YES NO
Acoustic Coupling Medium Code Sequence	(0018,982A)	2C	Acoustic coupling medium that was used. Required if Acoustic Coupling Medium Flag (0018,9829) is YES. Zero or one Item shall be included in this Sequence.
>Include Table 8.8-1 “Code Sequence Macro Attributes”			DCID 11002 “Acoustic Coupling Medium”

Acoustic Coupling Medium Temperature	(0018,982B)	3	The nominal temperature of the acoustic coupling medium in degrees Celsius at the time of acquisition.

C.8.34.3 Photoacoustic Transducer Module

This section describes the Photoacoustic Transducer Module. This module contains Attributes that are specific to Photoacoustic Transducers.

Table C.8.34.3-1 contains IOD Attributes that describe Photoacoustic Transducers.

Table C.8.34.3-1. Photoacoustic Transducer Module Attributes

Attribute Name	Tag	Type	Attribute Description
Transducer Geometry Code Sequence	(0018,980D)	1	Geometric structure of the transducer. Only a single Item shall be included in this Sequence.
>Include 'Code Sequence Macro' Table 8.8-1			DCID 12033 "Ultrasound Transducer Geometry"
Transducer Response Sequence	(0018,982C)	2	Characterization of the frequency response of the transducer. Zero or one Item shall be included in this Sequence.
>Center Frequency	(0018,982D)	3	Center Frequency of a receiver in MHz.
>Fractional Bandwidth	(0018,982E)	3	Fractional Bandwidth of a receiver in percent as measured in Transmit/Receive mode.
>Lower Cutoff Frequency	(0018,982F)	3	Low end of the detectable frequency band of a receiver in MHz. This is the lowest frequency where the received signal amplitude is still within -6dB from the peak amplitude.
>Upper Cutoff Frequency	(0018,9830)	3	High end of the detectable frequency band of a receiver in MHz. This is the highest frequency where the received signal amplitude is still within -6dB from the peak amplitude.
Transducer Technology Sequence	(0018,9831)	3	The type of technology the transducer is based on. Only a single Item is permitted in this Sequence.

>Include 'Code Sequence Macro' Table 8.8-1	DCID 11003 "Ultrasound Transducer Technology"

C.8.34.4 Photoacoustic Reconstruction Module

Table C.8.34.4-1 contains Attributes that describe Photoacoustic Reconstruction.

Table C.8.34.4-1. Photoacoustic Reconstruction Module Attributes

Attribute Name	Tag	Type	Attribute Description
Sound Speed Correction Mechanism Code Sequence	(0018,9832)	1	Mechanism used to correct for the speed of sound during image reconstruction due to differences in tissue composition. Only a single Item shall be included in this Sequence.
>Include 'Code Sequence Macro' Table 8.8-1			DCID 11004 "Speed of Sound Correction Mechanisms"
>Object Sound Speed	(0018,9833)	1C	Speed of sound value in m/s used in the image reconstruction in the area attributed to the imaged object. Required if Sound Speed Correction Mechanism (0018,9832) is (130818, DCM, "Uniform Speed of Sound Correction") or (130819, DCM, "Dual Speed of Sound Correction").
>Acoustic Coupling Medium Sound Speed	(0018,9834)	1C	Speed of sound value in m/s used in the image reconstruction in the area attributed to the acoustic coupling medium. Required if Sound Speed Correction Mechanism (0018,9832) is (130819, DCM, "Dual Speed of Sound Correction").
>Referenced Image Sequence	(0008,1140)	1C	A Parametric Map (see A.75) image which provides the speed of sound correction in m/s applied during the Photoacoustic image reconstruction on a per-pixel basis. The content of the Quantity Definition Sequence (0040,9220) in the referenced Parametric Map shall be (246205007, SCT, "Quantity") = (110832, DCM, "Speed of sound"). Only a single Item shall be included in this Sequence.

			Required if Sound Speed Correction Mechanism (0018,9832) is (130820, DCM, “Speed of Sound Map Correction”). May be present otherwise.
>>Include Table 10-3 “Image SOP Instance Reference Macro Attributes”			

C.8.34.5 Photoacoustic Functional Group Macros

The following sections contain Functional Group Macros specific to the Photoacoustic IOD.

Note

The Attribute descriptions in the Functional Group Macros are written as if they were applicable to a single frame (i.e., the Macro is part of the Per-frame Functional Groups Sequence). If an Attribute is applicable to all frames (i.e., the Macro is part of the Shared Functional Groups Sequence) the phrase “this frame” in the Attribute description shall be interpreted to mean “ for all frames”.

C.8.34.5.1 Photoacoustic Excitation Characteristics Macro

Table C.8.34.5.1-1. Photoacoustic Excitation Characteristics Functional Group Attributes are Photoacoustic excitation attributes that are recorded during Photoacoustic frame acquisition and may vary across frames.

Table C.8.34.5.1-1. Photoacoustic Excitation Characteristics Attributes

Attribute Name	Tag	Type	Attribute Description
Photoacoustic Excitation Characteristics Sequence	(0018,9821)	1	Characteristics of the light emitted by the illuminator, used for excitation of the target in Photoacoustic Imaging of this frame. These values are recorded during Photoacoustic frame acquisition. One or more Items shall be included in this Sequence. The number of items shall correspond to the items in the Excitation Wavelength Sequence (0018,9825).
>Excitation Wavelength	(0018,9826)	1	The wavelength in nm of the optical excitation pulse from the illuminator.
>Excitation Spectral Width	(0018,9822)	3	Full width at half maximum (FWHM) of the emitted optical spectrum in nm.
>Excitation Energy	(0018,9823)	3	The optical energy of the excitation pulse in mJ.
>Excitation Pulse Duration	(0018,9824)	3	The pulse duration of the excitation pulse in ns, measured as the time interval between the half-power points on the leading and trailing edges of the pulse.

C.8.34.5.2 Photoacoustic Image Frame Type Macro

Table C.8.34.5.2-1 specifies the Attributes of the Photoacoustic Image Frame Type Functional Group Macro.

Table C.8.34.5.2-1. Photoacoustic Image Frame Type Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Photoacoustic Image Frame Type Sequence	(0018,9835)	1	Identifies the characteristics of this frame. Only a single Item shall be included in this Sequence.
>Frame Type	(0008,9007)	1	Type of frame. A multi-valued Attribute analogous to Image Type (0008,0008). Enumerated Values and Defined Terms are the same as those for the four values of Image Type (0008,0008), except that the value MIXED is not allowed. See Section C.8.34.1.1.
>Include Table C.8-131 “Common CT/MR and Photoacoustic Image Description Macro Attributes”			

If Volumetric Properties (0008,9206) is VOLUME and Volume Based Calculation Technique (0008,9207) is NONE, all frames in the frame set shall be spaced the same Z-distance from adjacent frames (i.e., spacing between slices is constant).

C.8.34.5.3 Photoacoustic Image Data Type Macro

Table C.8.34.5.3-1 specifies the Attributes of the Photoacoustic Image Data Type Functional Group Macro.

Table C.8.34.5.3-1. Photoacoustic Image Data Type Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Image Data Type Sequence	(0018,9807)	1	Identifies the data type characteristics of this frame. One or more Items shall be included in this Sequence.
>Image Data Type Code Sequence	(0018,9836)	1	Data type of frame.
>>Include Table 8.8-1 “Code Sequence Macro Attributes”			DCID 11006 “Photoacoustic Imaged Property”

C.8.34.5.4 Photoacoustic Reconstruction Algorithm Macro

Table C.8.34.5.4-1 specifies the Attributes of the Photoacoustic Reconstruction Algorithm Functional Group Macro.

Table C.8.34.5.4-1. Photoacoustic Reconstruction Algorithm Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Reconstruction Algorithm Sequence	(0018,993D)	3	The identification assigned by a manufacturer to a specific software algorithm or algorithms. One or more Items are permitted in this Sequence.
>Include Table 10-19 "Algorithm Identification Macro Attributes"			BCID 11005 "Photoacoustic Reconstruction Algorithm Family" for Algorithm Family Code Sequence (0066,002F).

Changes to NEMA Standards Publication PS 3.4

Digital Imaging and Communications in Medicine (DICOM)

Part 4: Service Class Specifications

Add SOP to Table B.5-1 in PS3.4 Annex B.5.

Table B.5-1 Standard SOP Classes

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
Photoacoustic Image Storage	1.2.840.10008.5.1.4.1.1.6.3	Photoacoustic Image IOD

Changes to NEMA Standards Publication PS 3.6

Digital Imaging and Communications in Medicine (DICOM)

Part 6: Data Dictionary

Add the following Data Elements to Table 6-1, Section 6, Registry of DICOM data elements:

Tag	Name	Keyword	VR	VM
(0018,9821)	Photoacoustic Excitation Characteristics Sequence	PhotoacousticExcitationCharacteristicsSequence	SQ	1
(0018,9822)	Excitation Spectral Width	ExcitationSpectralWidth	FD	1
(0018,9823)	Excitation Energy	ExcitationEnergy	FD	1
(0018,9824)	Excitation Pulse Duration	ExcitationPulseDuration	FD	1
(0018,9825)	Excitation Wavelength Sequence	ExcitationWavelengthSequence	SQ	1
(0018,9826)	Excitation Wavelength	ExcitationWavelength	FD	1
(0018,9828)	Illumination Translation Flag	IlluminationTranslationFlag	CS	1
(0018,9829)	Acoustic Coupling Medium Flag	AcousticCouplingMediumFlag	CS	1
(0018,982A)	Acoustic Coupling Medium Code Sequence	AcousticCouplingMediumCodeSequence	SQ	1
(0018,982B)	Acoustic Coupling Medium Temperature	AcousticCouplingMediumTemperature	FD	1
(0018,982C)	Transducer Response Sequence	TransducerResponseSequence	SQ	1
(0018,982D)	Center Frequency	CenterFrequency	FD	1
(0018,982E)	Fractional Bandwidth	FractionalBandwidth	FD	1
(0018,982F)	Lower Cutoff Frequency	LowerCutoffFrequency	FD	1
(0018,9830)	Upper Cutoff Frequency	UpperCutoffFrequency	FD	1

(0018,9831)	Transducer Technology Sequence	TransducerTechnologySequence	SQ	1
(0018,9832)	Sound Speed Correction Mechanism Code Sequence	SoundSpeedCorrectionMechanismCodeSequence	SQ	1
(0018,9833)	Object Sound Speed	ObjectSoundSpeed	FD	1
(0018,9834)	Acoustic Coupling Medium Sound Speed	AcousticCouplingMediumSoundSpeed	FD	1
(0018,9835)	Photoacoustic Image Frame Type Sequence	PhotoacousticImageFrameTypeSequence	SQ	1
(0018,9836)	Image Data Type Code Sequence	ImageDataTypeCodeSequence	SQ	1

Add to Table A-1 PS3.6 Annex A

UID Value	UID Name	UID Keyword	UID Type	Part
1.2.840.10008.5.1.4.1.1.6.3	Photoacoustic Image Storage	PhotoacousticImageStorage	SOP Class	PS 3.4

Add to Table A-3 PS3.6 Annex A

Context UID	Context Identifier	Context Group Name
1.2.840.10008.6.1.1471	CID 11001	Photoacoustic Illumination Method
1.2.840.10008.6.1.1472	CID 11002	Acoustic Coupling Medium
1.2.840.10008.6.1.1473	CID 11003	Ultrasound Transducer Technology
1.2.840.10008.6.1.1474	CID 11004	Speed of Sound Correction Mechanisms
1.2.840.10008.6.1.1475	CID 11005	Photoacoustic Reconstruction Algorithm Family
1.2.840.10008.6.1.1476	CID 11006	Photoacoustic Imaged Property

Changes to NEMA Standards Publication PS 3.16

Digital Imaging and Communications in Medicine (DICOM)

Part 16 Content Mapping Resource

Modify tables in PS3.16 Annex B

CID 29 Acquisition Modality

Version:

~~20190327~~**20230626**

Table CID 29. Acquisition Modality

Coding Scheme Designator	Code Value	Code Meaning
…		
DCM	**PA**	**Photoacoustic**
…		

CID 12033 Ultrasound Transducer Geometry

Version:

~~20090409~~**20230626**

Table CID 12033. Ultrasound Transducer Geometry

Coding Scheme Designator	Code Value	Code Meaning
DCM	125251	Non-imaging Doppler ultrasound transducer geometry
DCM	125252	Linear ultrasound transducer geometry
DCM	125253	Curved linear ultrasound transducer geometry
DCM	125254	Sector ultrasound transducer geometry

DCM	125255	Radial ultrasound transducer geometry
DCM	125256	Ring ultrasound transducer geometry
DCM	**130808**	**Planar matrix ultrasound transducer geometry**
DCM	**130809**	**Hemispherical ultrasound transducer geometry**

Add in PS3.16 Annex B

CID 11001 Photoacoustic Illumination Method

Type:

Extensible

Version:

20230626

UID:

1.2.840.10008.6.1.1471

Table CID 11001. Photoacoustic Illumination Method

Coding Scheme Designator	Code Value	Code Meaning
DCM	130810	Single-side illumination
DCM	130811	Dual-side illumination
DCM	130812	Multi-side illumination
DCM	130813	Through-transducer illumination
DCM	130814	Interstitial illumination

CID 11002 Acoustic Coupling Medium

Type:

Extensible

Version:

20230626

UID:

1.2.840.10008.6.1.1472

Table CID 11002. Acoustic Coupling Medium

Coding Scheme Designator	Code Value	Code Meaning
SCT	11713004	Water
SCT	12977001	Deuterium oxide
SCT	1004163002	Ultrasound coupling gel
SCT	15158005	Air

CID 11003 Ultrasound Transducer Technology

Type:

Extensible

Version:

20230626

UID:

1.2.840.10008.6.1.1473

Table CID 11003. Ultrasound Transducer Technology

Coding Scheme Designator	Code Value	Code Meaning
DCM	130815	Piezocomposite Transducer
DCM	130816	MEMS-based Transducer
DCM	130817	Interferometric Transducer

CID 11004 Speed of Sound Correction Mechanisms

Type:

Extensible

Version:

20230626

UID:

1.2.840.10008.6.1.1474

Table CID 11004. Speed of Sound Correction Mechanisms

Coding Scheme Designator	Code Value	Code Meaning
DCM	130818	Uniform Speed of Sound Correction
DCM	130819	Dual Speed of Sound Correction
DCM	130820	Speed of Sound Map Correction

CID 11005 Photoacoustic Reconstruction Algorithm Family

Type:

Extensible

Version:

20230626

UID:

1.2.840.10008.6.1.1475

Table CID 11005. Photoacoustic Reconstruction Algorithm Family

Coding Scheme Designator	Code Value	Code Meaning
DCM	130821	Spherical Back Projection
DCM	130822	Numerical Acoustic Model

CID 11006 Photoacoustic Imaged Property

Type:

Extensible

Version:

20230626

UID:

1.2.840.10008.6.1.1476

Table CID 11006. Photoacoustic Imaged Property

Coding Scheme Designator	Code Value	Code Meaning
DCM	110819	Blood Oxygenation Level
DCM	130823	Blood Deoxygenation Level
SCT	38082009	Hemoglobin
DCM	110830	Elasticity
DCM	110831	Perfusion
SCT	59094002	Melanin
SCT	11713004	Water
SCT	70106000	Lipid

Modify the following definitions to Part 16 Annex D DICOM Controlled Terminology Definitions (Normative) – Modify Table D-1

Table D-1. DICOM Controlled Terminology Definitions (Coding Scheme Designator "DCM" Coding Scheme Version "01")

Code Value	Code meaning	Definition	Notes
110819	Blood Oxygenation Level	Signal intensity of a Blood Oxygenation Level image. **Used in Photoacoustic Imaging and functional MR. In functional MR** BOLD imaging **it is used for detecting brain activation and** is	

		sensitive to blood oxygenation (but also to cerebral blood flow and volume). ~~**This modality is essentially used for detecting brain activation (functional MR).**~~	

Add the following definitions to Part 16 Annex D DICOM Controlled Terminology Definitions (Normative) – Modify Table D-1

PA	Photoacoustic	An acquisition device, process or method that performs imaging by means of tissue excitation through the absorption of short light pulses and detection of the resultant acoustic emission.	
130808	Planar matrix ultrasound transducer geometry	Ultrasonic transducer geometry characterized by multiple transducer elements arranged in a grid on a plane.	
130809	Hemispherical ultrasound transducer geometry	Ultrasonic transducer geometry characterized by multiple transducer elements arranged on a hemispherical surface.	
130810	Single-side illumination	The subject is illuminated from a single direction.	
130811	Dual-side illumination	The subject is illuminated from two distinct directions.	
130812	Multi-side illumination	The subject is illuminated from more than two (potentially a very large number of) distinct directions.	
130813	Through-transducer illumination	The subject is illuminated through the transducer. Light may pass through the transducer at one or more locations.	
130814	Interstitial illumination	The subject is illuminated internally. Light is delivered via a device (other than the transducer) inside the body.	

130815	Piezocomposite Transducer	Ultrasound Transducer that utilizes Piezo-composite crystalline structures.	
130816	MEMS-based Transducer	Ultrasound Transducer that utilizes Micro-electro-mechanical systems (MEMS)-based structures.	
130817	Interferometric Transducer	Ultrasound Transducer that utilizes interferometric detection systems.	
130818	Uniform Speed of Sound Correction	Mechanism for correction of data using a sound propagation model based on a single speed of sound, where the speed for the acoustic coupling medium (if present) is assumed to be the same as for the imaged object.	
130819	Dual Speed of Sound Correction	Mechanism for correction of data using a sound propagation model based on two speeds of sound, one for the acoustic coupling medium and one for the imaged object.	
130820	Speed of Sound Map Correction	Mechanism for correction of data using a sound propagation model based on a speed of sound map that defines the speed of sound on a per-pixel basis.	
130821	Spherical Back Projection	A family of algorithms for reconstructing an image from measured data by back-projection over spheres or parts of spheres. May include linear or nonlinear processing steps before and/or after the back-projection step. Includes methods termed ‘beamforming’ and ‘delay-and-sum’.	
130822	Numerical Acoustic Model	A family of algorithms for reconstructing an image from measured data by iteratively adjusting the image to minimize a cost function between the data and a numerical model or that uses non-iterative (e.g. time-	

		reversal) methods, or that performs inversion of a forward model matrix.	
130823	Blood Deoxygenation Level	Signal intensity of a Blood Deoxygenation Level image.	

Changes to NEMA Standards Publication PS 3.17

Digital Imaging and Communications in Medicine (DICOM)
Part 17: Explanatory Information

Add to PS3.17 Annex AAAAA

Annex AAAAA Photoacoustic Imaging (Informative)

AAAAA.1 Introduction

Photoacoustic imaging is an imaging modality that enables imaging optical absorption in biological tissues with acoustic resolution. Many (but not all) PA implementations integrate active pulse/echo ultrasound in a hybrid imaging system to capitalize on ultrasound contrast for anatomical information. Because of this relationship, it is envisioned that Photoacoustic images will often be presented side-by-side with or fused with ultrasound images (for a real-world presentation example, see Figure AAAAA.4-1. Two Photoacoustic Optical Wavelengths, Processed and Fused with Ultrasound).

AAAAA.2 Use Cases

AAAAA.2.1 Acquisition and Storage

Photoacoustic Images are produced from the acquisition of tissue response to one or more Excitation Wavelength (0018,9826) values. These attributes are identified using the Excitation Wavelength Sequence (0018,9825) Dimension Index to capture differences in wavelength absorption by various biological tissues. The property represented by the tissue response is identified by the Image Data Type Sequence (0018,9807) Dimension Index.

Photoacoustic Images are acquired with a volume-based Frame of Reference recorded by the Dimension Index of Image Position (Volume) (0020,9301). The acquisition device may be mounted on a rigid system (tomographic or microscopic system) or freehand. The image frames may be acquired over time as described by the Dimension Index of Temporal Position Time Offset (0020,930d).

Photoacoustic Images may be acquired as a standalone modality or acquired in combination with images from other modalities. Because Photoacoustic and Ultrasound systems are often implemented as coupled modalities, the Photoacoustic Image IOD includes modules and functional group macros similar to those in use in the A.59 Enhanced US Volume IOD. Any complementary images such as pulse/echo ultrasound are acquired and stored as separate images represented by their native DICOM IODs.

In the case of a Photoacoustic device coupled with another acquisition modality, one acquisition device may know the spatial relationship of its image data relative to the other. One of the acquisition devices may use the Registration SOP Class to specify the relationship of the images from the two modalities. In the most direct case, the data of both modalities are in the same DICOM Frame of Reference for each SOP Class Instance and the Registration object is containing a one-to-one translation.

AAAAA.2.2 Presentation and Review

Display Systems are likely to encounter Photoacoustic data sets that have been acquired and organized in a variety of ways. Data sets may include images from one or more optical wavelengths, possibly processed with several different algorithms to represent one or more imaged properties. A common Dimension Organization UID (0020,9164) establishes a relationship between the Photoacoustic images based on temporal position, spatial position and a unique set of imaged properties and excitation wavelengths (see C.8.34.1.2).

The logic for visualization of Photoacoustic images on an Image Display workstation is similar to the logic for visualizing 3D Ultrasound Volume data. The workstation should be capable of displaying multiple 3D image objects simultaneously. To allow the most effective use of the Photoacoustic studies, the workstation should be capable of using Hanging Protocols and Advanced Blending Presentation State objects (C.11.33).

The Image Display workstation is not expected to be capable of creating algorithmic combinations of Photoacoustic images; the processing for a Photoacoustic image is generally performed by the modality (see Reconstruction Algorithm Sequence (0018,993D)).

AAAAA.2.2.1 Fusion Visualization with Complementary Imaging Modalities

In the fusion use case, an Image Display workstation is used for synchronized display or overlay (fusion) of multiple Photoacoustic images and/or images from another complementary acquisition modality.

The process for such fusion is not described in further detail, however the Advanced Blending Presentation State object (C.11.33) is recommended with the complementary modality utilizing temporal and volumetric dimensions as described in the Multi-frame Dimension Indices specified in C.8.34.1.2.

AAAAA.2.3 Example Workflow

A radiologist evaluating a Photoacoustic acquisition could view the Photoacoustic images separately, as synchronized sets of series, or fused in a display overlay (AAAAA.2.2.1). An example of Photoacoustic Image acquisition, storage and review is shown in Figure AAAAA.2.3-1. In this example, the Image Displays are capable of fusion or side-by-side display of two or more images. The different views on the workstations may be based on user preference or manufacturer recommendation and may be stored in a Hanging Protocol.

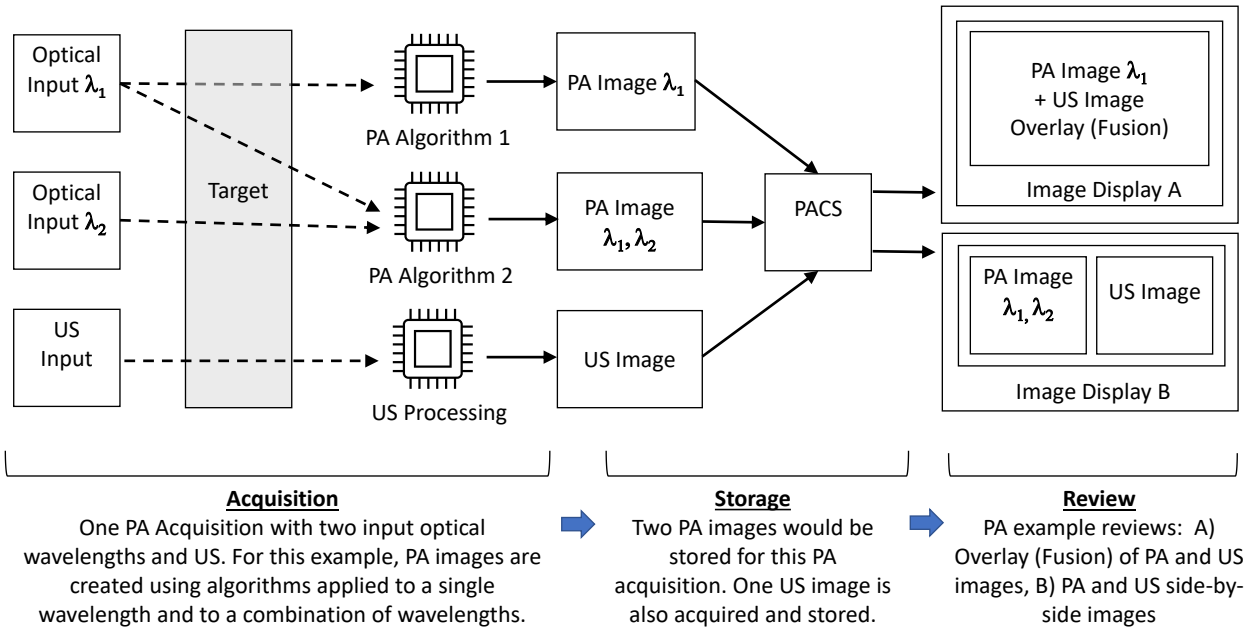

Figure AAAAA.2.3-1. Example Photoacoustic (PA) Image Acquisition, Storage, and Review

AAAAA.3 Acquisition Examples

Three common acquisition examples illustrate the breadth of Photoacoustic Image applications:

1. Photoacoustic Standalone Image - a study with multiple optical wavelength images acquired over time. No complementary modality images are acquired.
    a. Photoacoustic Single Wavelength Standalone Image - a study with multiple images of one optical wavelength scanned repeatedly across the target over different time points (microscopy use case).

2. Photoacoustic/Ultrasound Coupled Acquisition - a study with multiple optical wavelength images and ultrasound images acquired over time.
3. Stationary tomographic 3D Photoacoustic/Ultrasound Coupled Acquisition - a study with multiple optical wavelength images and ultrasound images acquired over time where the transducer is mounted on a tomographic frame.

As illustrated in Section AAAAA.3.1, Section AAAAA.3.2 and Section AAAAA.3.3, the acquisition examples focus on the application of the Dimension Index.

AAAAA.3.1 Example 1: Photoacoustic Standalone Image

The following is a non-comprehensive illustration of an encoding of Photoacoustic data captured without a conventional ultrasound system in either handheld or stationary acquisition mode.

At each of M Temporal Positions, N optical excitation wavelengths are applied in rapid succession and images acquired for each wavelength (in this example, N=2). Although the images at each Temporal Position are separated by some milliseconds, they are nominally at the same temporal position.

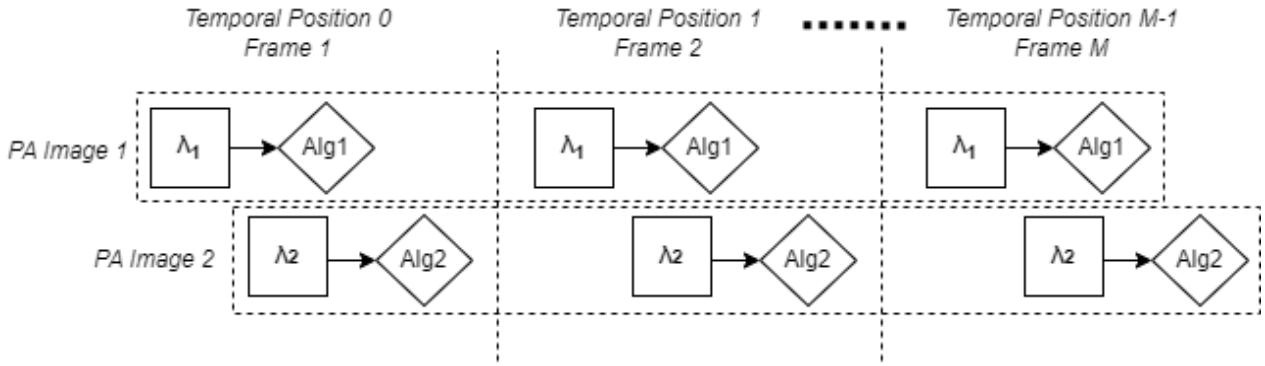

Figure AAAAA.3.1-1. Photoacoustic (PA) Standalone Example

AAAAA.3.1.1 Photoacoustic Single Wavelength Standalone Image

A Photoacoustic single wavelength standalone image would be a sub-case of Example 1 (Figure AAAAA.3.1.1-1). In a Photoacoustic Microscopy example, Photoacoustic Image frames are produced by raster-scanning an object at one Temporal Position. One complete acquisition sequence produces a single 2D or 3D image. A repetition of the bespoke scanning sequence in stationary mode capturing a new time point of the same imaged object will increment the Temporal Position Time Offset only.

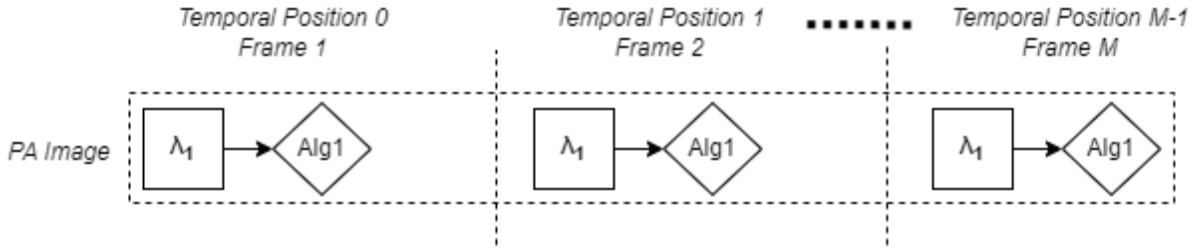

Figure AAAAA.3.1.1-1. Example 1 Subcase: Photoacoustic (PA) Single Wavelength Standalone Acquisition

AAAAA.3.1.2 Photoacoustic Dimension Index Sequence for Examples

The encoding examples in Section AAAAA.3.1, Section AAAAA.3.2 and Section AAAAA.3.3 follow the same Dimension Index Sequence structures. For brevity, the generic structure is illustrated in this section to be applied in each example. The Dimension Index Sequence for all Photoacoustic files in the examples is described in Table AAAAA.3.1.2-1.

Table AAAAA.3.1.2-1. Photoacoustic Example Dimension Index Sequence

Attribute	Tag	Value	Comments
Dimension Index Sequence	(0020,9222)		
%item			
>Dimension Organization UID	(0020,9164)	1.2.3.4	UID for the Photoacoustic Image Object.
>Dimension Index Pointer	(0020,9165)	(0020,930d)	Temporal Position Time Offset
>Functional Group Pointer	(0020,9167)	(0020,9310)	Temporal Position Sequence
%enditem			
%item			
>Dimension Organization UID	(0020,9164)	1.2.3.4	UID for the Photoacoustic Image Object.
>Dimension Index Pointer	(0020,9165)	(0020,9301)	Image Position (Volume)
>Functional Group Pointer	(0020,9167)	(0020,930E)	Plane Position (Volume) Sequence
%enditem			
%item			
>Dimension Organization UID	(0020,9164)	1.2.3.4	UID for the Photoacoustic Image Object.
>Dimension Index Pointer	(0020,9165)	(0018,9825)	Excitation Wavelength Sequence
%enditem			
%item			
>Dimension Organization UID	(0020,9164)	1.2.3.4	UID for the Photoacoustic Image Object.
>Dimension Index Pointer	(0020,9165)	(0018,9807)	Image Data Type Sequence

%enditem			

AAAAA.3.1.3 Photoacoustic Standalone Image Per-Frame Example

In this encoding of the example shown in Figure AAAAA.3.1-1, the first frame of the image is shown for two optical wavelength images (Table AAAAA.3.1.3-1 and Table AAAAA.3.1.3-2). For brevity, examples of Photoacoustic attributes are provided in Section AAAAA.3.4.

Table AAAAA.3.1.3-1. Photoacoustic Standalone Example, Wavelength 1, Frame 1

Attribute	Tag	Value	Comments
Coding Scheme Identification Sequence	(0008,0110)		
>Coding Scheme Designator	(0008,0102)	99ACME	In the Image Data Type Sequence (0018,9807), Blood Oxygenation XYZ Level is not defined by CID 7180; a private extension is being used.
…			
Excitation Wavelength Sequence	(0018,9825)		
>Excitation Wavelength	(0018,9826)	800	Optical wavelength 1 (λ_1) is 800nm.
…			
Shared Functional Groups Sequence	(5200,9229)		
…			
>Image Data Type Sequence	(0018,9807)		
>>Image Data Type Code Sequence	(0018,9836)		
>>>Code Value	(0008,0100)	445566	
>>>Coding Scheme Designator	(0008,0102)	99ACME	
>>>Code Meaning	(0008,0104)	Blood Oxygenation XYZ Level	
>>>Context Group Extension Flag	(0008,010B)	Y	
>>>Context Group Local Version	(0008,0107)	20230323	

>>Context Group Extension Creator UID	(0008,010D)	1.3.4.34	
…			
>Reconstruction Algorithm Sequence	(0018,993D)		
>>Algorithm Name	(0066,0036)	WL-800	A manufacturer-specific algorithm for images as applied to the excitation wavelength of 800nm.
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>Frame Content Sequence	(0020,9111)		
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>Plane Position (Volume) Sequence	(0020,930E)		
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			
>Photoacoustic Excitation Characteristics Sequence	(0018,9821)		
>>Excitation Wavelength	(0018,9826)	800	nm
>>Excitation Energy	(0018,9823)	11	mJ
>>Excitation Pulse Duration	(0018,9824)	8	ns
…			

Table AAAAA.3.1.3-2. Photoacoustic Standalone Example, Wavelength 2, Frame 1

Attribute	Tag	Value	Comments

…			
Excitation Wavelength Sequence	(0018,9825)		
>Excitation Wavelength	(0018,9826)	1064	Optical wavelength 2 (λ_2) is 1064nm.
…			
Shared Functional Groups Sequence	(5200,9229)		
…			
>Image Data Type Sequence	(0018,9807)		
>>Image Data Type Code Sequence	(0018,9836)		
>>>Code Value	(0008,0100)	110819	
>>>Coding Scheme Designator	(0008,0102)	DCM	
>>>Code Meaning	(0008,0104)	Blood Oxygenation Level	
…			
>Reconstruction Algorithm Sequence	(0018,993D)		
>>Algorithm Name	(0066,0036)	RC_Long	A manufacturer-specific algorithm for images as applied to the excitation wavelength of 1064nm.
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>Frame Content Sequence	(0020,9111)		
>>Dimension Index Value	(0020,9157)	1\1\2	
…			
>Plane Position (Volume) Sequence	(0020,930E)		
>>Image Position (Volume)	(0020,9301)	0\0\0	

…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			
>Photoacoustic Excitation Characteristics Sequence	(0018,9821)		
>>Excitation Wavelength	(0018,9826)	1064	nm
>>Excitation Energy	(0018,9823)	43	mJ
>>Excitation Pulse Duration	(0018,9824)	8	ns
…			

AAAAA.3.2 Example 2: Photoacoustic/Ultrasound Coupled Acquisition

The following is a non-comprehensive illustration of an encoding of Photoacoustic data captured with a coupled conventional ultrasound system in either handheld or stationary acquisition mode. At each of M Temporal Positions, N optical excitation wavelengths are applied in rapid succession and Photoacoustic Images are acquired for each wavelength (in this example, N=2). Ultrasound images are also acquired however the timing of the ultrasound acquisition is not synchronized with the Photoacoustic wavelength temporal position boundaries; it is left to the implementation to determine which ultrasound frames belong with each Temporal Position Time Offset. In this example, the Photoacoustic device knows the spatial relationship of its image data relative to the Ultrasound device and can use the Registration SOP Class to specify the relationship of the images from the two modalities.

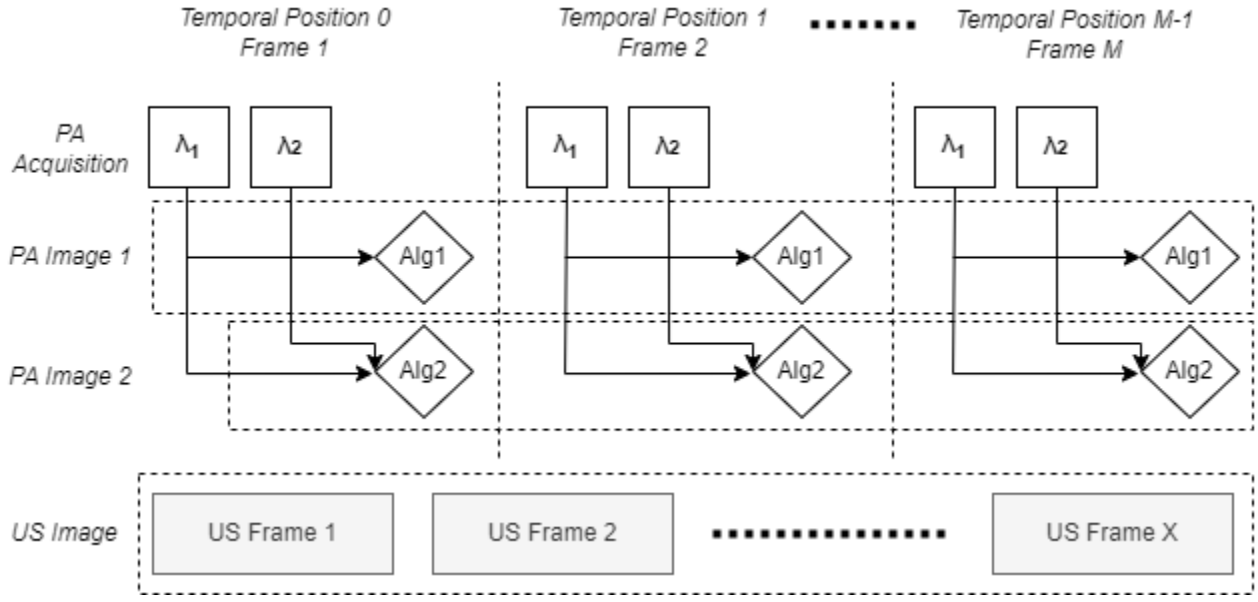

Figure AAAAA.3.2-1. Example 2: Photoacoustic (PA)/Ultrasound (US) Coupled Acquisition

AAAAA.3.2.1 Photoacoustic Dimension Index Sequence for Examples

The Dimension Index Sequence for all Photoacoustic Image files in the encoding examples is described in Table AAAAA.3.1.2-1.

AAAAA.3.2.2 Ultrasound Dimension Index Sequence for Examples

The structure of the Dimension Index Sequence for a US Modality image is given in Table AAAAA.3.2.2-1 for use in encoding examples which include Photoacoustic/Ultrasound coupled acquisition modalities (examples shown in Section AAAAA.3.2 and Section AAAAA.3.3).

Table AAAAA.3.2.2-1. US Example Dimension Index Sequence for Photoacoustic/Ultrasound Coupled Acquisition

Attribute	Tag	Value	Comments
Dimension Index Sequence	(0020,9222)		
%item			
>Dimension Organization UID	(0020,9164)	5.6.7.8	UID for the US Image Object.
>Dimension Index Pointer	(0020,9165)	(0020,930d) Temporal Position Time Offset	
>Functional Group Pointer	(0020,9167)	(0020,9310) Temporal Position Sequence	
%enditem			
%item			
>Dimension Organization UID	(0020,9164)	5.6.7.8	UID for the US Image Object.
>Dimension Index Pointer	(0020,9165)	(0020,9301) Image Position (Volume)	
>Functional Group Pointer	(0020,9167)	(0020,930e) Plane Position (Volume) Sequence	
%enditem			
%item			
>Dimension Organization UID	(0020,9164)	5.6.7.8	UID for the US Image Object.
>Dimension Index Pointer	(0020,9165)	(0018,9808) Data Type	
>Functional Group Pointer	(0020,9167)	(0018,9807) Image Data Type	

%enditem			
%endseq			

AAAAA.3.2.3 Photoacoustic/Ultrasound Coupled Acquisition Per-Frame Example

In this encoding of the example shown in Figure AAAAA.3.2-1, the first frame of the image is shown for three images: one Photoacoustic image processed from one excitation wavelength, one Photoacoustic image processed from two excitation wavelengths, and one ultrasound image (Table AAAAA.3.2.3-1, Table AAAAA.3.2.3-2, Table AAAAA.3.2.3-3). For brevity, examples of other Photoacoustic attributes are provided in Section AAAAA.3.4.

Table AAAAA.3.2.3-1. Photoacoustic/Ultrasound Coupled Acquisition, Photoacoustic Image, Algorithm 1, Frame 1

Attribute	Tag	Value	Comments
Modality	(0008,0060)	PA	
…			
Excitation Wavelength Sequence	(0018,9825)		
>Excitation Wavelength	(0018,9826)	800	nm
…			
Shared Functional Groups Sequence	(5200,9229)		
…			
>Image Data Type Sequence	(0018,9807)		
>>Image Data Type Code Sequence	(0018,9836)		
>>>Code Value	(0008,0100)	110831	
>>>Coding Scheme Designator	(0008,0102)	DCM	
>>>Code Meaning	(0008,0104)	Perfusion	
…			
>Reconstruction Algorithm Sequence	(0018,993D)		
>>Algorithm Name	(0066,0036)	wl-1	A manufacturer-specific algorithm for images as applied to the excitation wavelength 1.
…			

Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>Frame Content Sequence	(0020,9111)		
>>Frame Acquisition Date Time	(0018,9074)	20220130150251.005768	
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>Plane Position (Volume) Sequence	(0020,930E)		
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			

Table AAAAA.3.2.3-2. Photoacoustic/Ultrasound Coupled Acquisition, Photoacoustic Image, Algorithm 2, Frame 1

Attribute	Tag	Value	Comments
Modality	(0008,0060)	PA	
…			
Excitation Wavelength Sequence	(0018,9825)		
%item			
>Excitation Wavelength	(0018,9826)	800	nm
%enditem			
%item			
>Excitation Wavelength	(0018,9826)	1064	nm

%enditem			
…			
Shared Functional Groups Sequence	(5200,9229)		
…			
>Image Data Type Sequence	(0018,9807)		
>>Image Data Type Code Sequence	(0018,9836)		
>>>Code Value	(0008,0100)	110819	
>>>Coding Scheme Designator	(0008,0102)	DCM	
>>>Code Meaning	(0008,0104)	Blood Oxygenation Level	Although imaging based on a single wavelength was used to represent Blood Oxygenation Level in Example 1, in this example, images from two wavelengths are used to compute a relative oxygenation image.
…			
Reconstruction Algorithm Sequence	(0018,993D)		
>Algorithm Name	(0066,0036)	RelativeOxygenation-800-1064	The manufacturer-specific spectrally unmixed algorithm for relative oxygenation using excitation wavelengths of 800nm and 1064nm.
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>Frame Content Sequence	(0020,9111)		
>>Frame Acquisition Date Time	(0018,9074)	20220130150251.005770	
>>Dimension Index Value	(0020,9157)	1\1\2	
…			

>Plane Position (Volume) Sequence	(0020,930E)		
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			

Table AAAAA.3.2.3-3. Photoacoustic/Ultrasound Coupled Acquisition, Ultrasound Image, Frame 1

Attribute	Tag	Value	Comments
Modality	(0008,0060)	US	
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>Frame Content Sequence	(0020,9111)		
>>Frame Acquisition Date Time	(0018,9074)	20220130150251.005771	
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>Plane Position (Volume) Sequence	(0020,930E)		
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			
>Image Data Type Sequence	(0018,9807)		
>>Data Type	(0018,9808)	TISSUE_INTENSITY	
…			

AAAAA.3.3 Example 3: Stationary Tomographic 3D Photoacoustic/Ultrasound Coupled Acquisition

The following is a non-comprehensive illustration of an encoding of a hybrid Photoacoustic/Ultrasound coupled acquisition modality with images acquired over time where the transducer is mounted on a tomographic frame. The acquisition unit is spatially translated to form a three-dimensional volume representation of the imaged object

At each of M Temporal Positions, N optical excitation wavelengths are applied in rapid succession and Photoacoustic Images are acquired for each wavelength. The Temporal Position Time Offset is incremented upon repetition of the same volume spatial scanning pattern. Ultrasound images are also acquired with the timing of the ultrasound acquisitions aligned with the scan positions In this example, the data from the Photoacoustic device and the Ultrasound device share the same DICOM Frame of Reference for each SOP Class Instance.

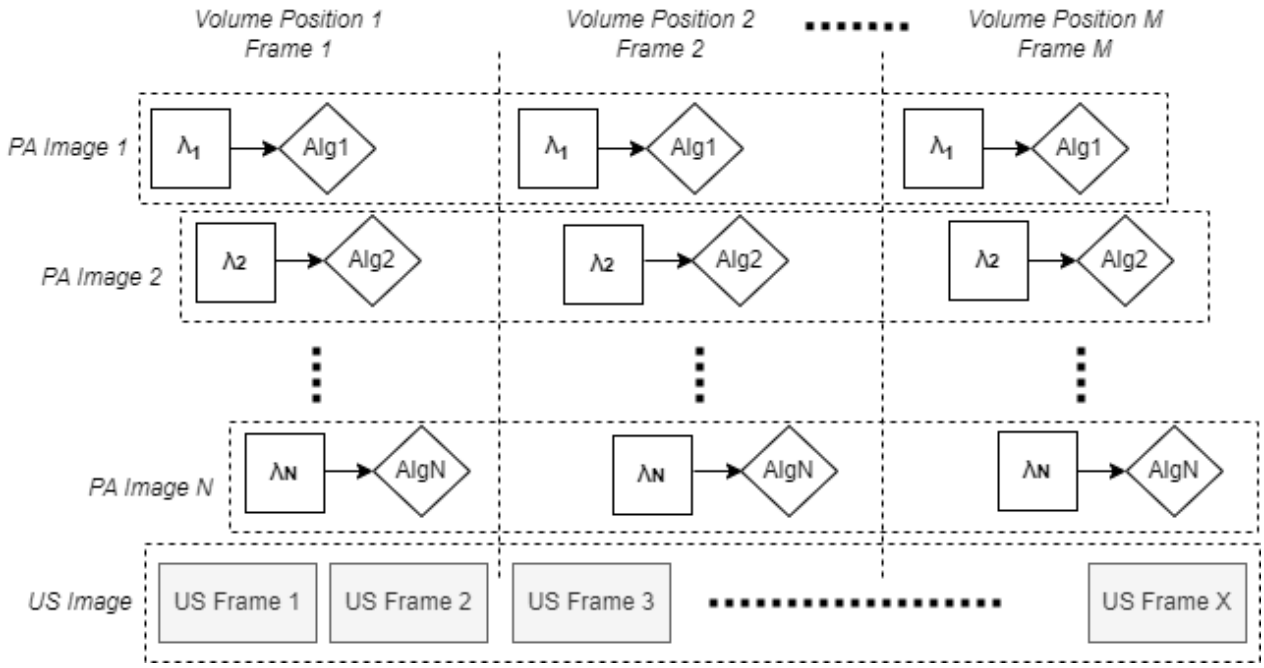

Figure AAAAA.3.3-1. Example 3: Stationary Tomographic 3D Photoacoustic (PA)/Ultrasound (US) Coupled Acquisition

AAAAA.3.3.1 Photoacoustic and Ultrasound Dimension Index Sequence for Examples

The Dimension Index Sequence for all Photoacoustic Image files in the encoding examples is described in Table AAAAA.3.1.2-1. The Dimension Index Sequence for all US files in the encoding examples is described in Table AAAAA.3.2.2-1.

AAAAA.3.3.2 Stationary Tomographic 3D Photoacoustic/Ultrasound Per-Frame Example

In this encoding example of Figure AAAAA.3.3.2-1, the first two frames are shown to illustrate the variation in image position for one Photoacoustic image (Table AAAAA.3.3-1). Examples of other Photoacoustic attributes are provided in AAAAA.3.4.

Table AAAAA.3.3.2-1. Stationary tomographic 3D Photoacoustic/Ultrasound Example, Image Position (Volume), Frames 1&2

Attribute	Tag	Value	Comments
…			
Excitation Wavelength Sequence	(0018,9825)		
>Excitation Wavelength	(0018,9826)	800	nm
…			
Shared Functional Groups Sequence	(5200,9229)		
…			
>Image Data Type Sequence	(0018,9807)		
>>Image Data Type Code Sequence	(0018,9836)		
>>>Code Value	(0008,0100)	110830	
>>>Coding Scheme Designator	(0008,0102)	DCM	
>>>Code Meaning	(0008,0104)	Elasticity	
…			
Reconstruction Algorithm Sequence	(0018,993D)		
>Algorithm Name	(0066,0036)	proc1-800nm	The manufacturer-specific algorithm for processing an image using the excitation wavelength of 800nm.
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			Frame 1
…			
>Frame Content Sequence	(0020,9111)		
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>Plane Position (Volume) Sequence	(0020,930E)		
>>Image Position (Volume)	(0020,9301)	0\0\0	Volume position 1

…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			
>Photoacoustic Excitation Characteristics Sequence	(0018,9821)		
>Excitation Wavelength	(0018,9826)	800	nm
>>Excitation Energy	(0018,9823)	11.0	mJ
>>Excitation Pulse Duration	(0018,9824)	8	ns
…			
%enditem			
%item			Frame 2
…			
>Frame Content Sequence	(0020,9111)		
>>Dimension Index Value	(0020,9157)	1\2\1	
…			
>Plane Position (Volume) Sequence	(0020,930e)		
>>Image Position (Volume)	(0020,9301)	0\0\1	Volume position 2
…			
>Temporal Position Sequence	(0020,9310)		
>>Temporal Position Time Offset	(0020,930D)	0	
…			
>Photoacoustic Excitation Characteristics Sequence	(0018,9821)		
>Excitation Wavelength	(0018,9826)	800	nm
>>Excitation Energy	(0018,9823)	11.2	mJ
>>Excitation Pulse Duration	(0018,9824)	8	ns

…

AAAAA.3.4 Photoacoustic Attribute Example Values

This section provides encoding examples of Photoacoustic attributes for the Photoacoustic Transducer Module and Photoacoustic Reconstruction Module. For brevity, these attributes were omitted from the encoding examples in Section AAAAA.3.1, Section AAAAA.3.2 and Section AAAAA.3.3.

Table AAAAA.3.4-1. Photoacoustic Attribute Example

Attribute	Tag	Value	Comments
…			
Illumination Type Code Sequence	(0022,0016)		
>Code Value	(0008,0100)	130810	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	Dual side-illumination	
…			
Acoustic Coupling Medium Code Sequence	(0018,982A)		
>Code Value	(0008,0100)	11713004	
>Coding Scheme Designator	(0008,0102)	SCT	
>Code Meaning	(0008,0104)	Water (substance)	
…			
Acoustic Coupling Medium Temperature	(0018,982B)	30	degrees Celsius
…			
Transducer Geometry Code Sequence	(0018,980D)		
>Code Value	(0008,0100)	125253	

>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	Curved linear ultrasound transducer geometry	
…			
Transducer Response Sequence	(0018,982C)		
>Center Frequency	(0018,982D)	1	MHz
>Fractional Bandwidth	(0018,982E)		Empty
>Lower Cutoff Frequency	(0018,982F)		Empty
>Upper Cutoff Frequency	(0018,9830)		Empty
…			
Transducer Technology Sequence	(0018,9831)		
>Code Value	(0008,0100)	130816	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	MEMS-based Transducer	
…			
Sound Speed Correction Mechanism Code Sequence	(0018,9832)		
>Code Value	(0008,0100)	130819	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	Dual Speed of Sound Correction	
>Object Sound Speed	(0018,9833)	1480	m/s

>Acoustic Coupling Medium Sound Speed	(0018,9834)	1500	m/s
…			

AAAAA.4 Real World Display Examples

These examples show real world examples of different display arrangements (as could be achieved by Hanging Protocols and Blending Presentation States). The emphasis here is to illustrate that multiple Photoacoustic images (and potentially images from other modalities) will likely be evaluated by the clinician in side-by-side or overlay/fusion views.

Figure AAAAA.4-1 (reference [Neuschler 2018]) illustrates a Photoacoustic (PA) acquisition with two input wavelengths and ultrasound (US), displayed in six different panels with Photoacoustic Images (C, F), US images (A), and three overlay (fusion) images with Photoacoustic and US (B, D, E) representing three imaged properties, generated from three algorithms for processing the Photoacoustic wavelengths and fusing with ultrasound. This case is similar to the pattern of attributes shown in AAAAA.3.2 Example 2: Photoacoustic/US Coupled Acquisition, however five Photoacoustic images and one US image would be captured.

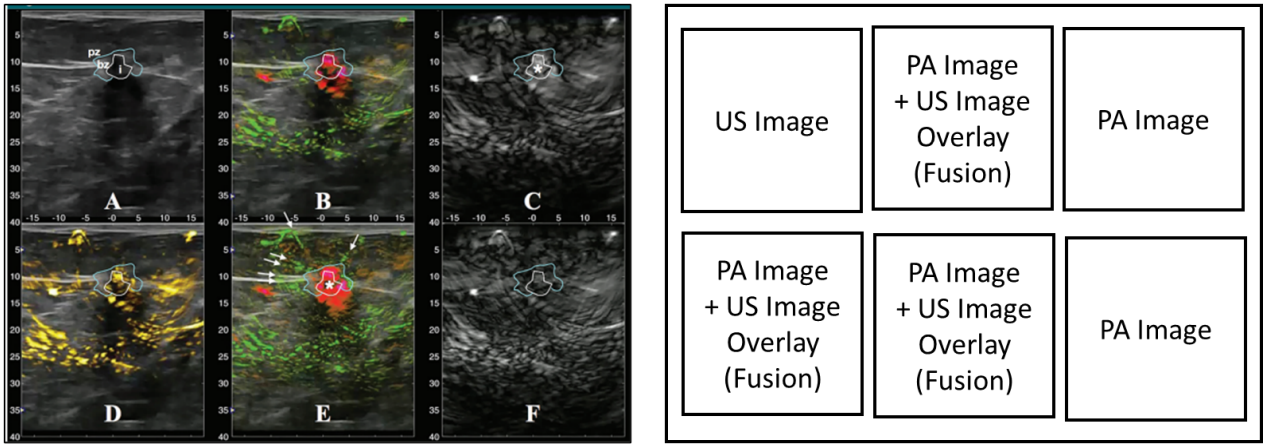

Figure AAAAA.4-1. Two Photoacoustic (PA) Optical Wavelengths, Processed and Fused with Ultrasound (US)

Figure AAAAA.4-2 (reference [Regensburger 2019]) illustrates a Photoacoustic (PA) acquisition with two ranges of multispectral input wavelengths and ultrasound (US), displayed in two different panels with the US image (left) and the Photoacoustic image (right) representing two imaged properties, generated from two algorithms for processing of the Photoacoustic wavelength in a “cyan” and a “hot” colormap and fusing with ultrasound. This case is similar to the pattern of attributes shown in AAAAA.3.2 Example 2: Photoacoustic/US Coupled Acquisition, where two Photoacoustic images and one US image would be captured.

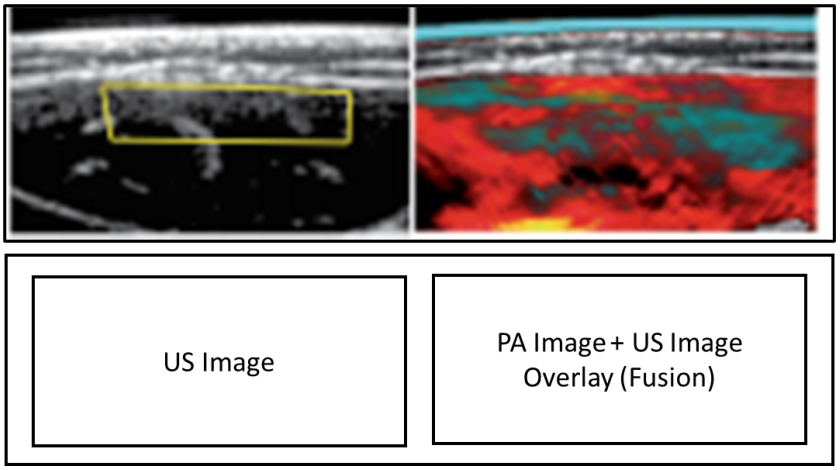

Figure AAAAA.4-2. Photoacoustic (PA) with Two Ranges of Multispectral Wavelengths, Processed and Fused with Ultrasound (US)

Figure AAAAA.4-3 (reference [Aguirre 2017]) illustrates a Photoacoustic (PA) acquisition with one input wavelength displayed as a Photoacoustic image in three planes (left) and a Photoacoustic image (right) representing a range of imaged properties, processed with an algorithm to show frequency separation in three planes. This case is similar to the pattern of attributes shown in AAAAA.3.1.1 Photoacoustic Single Wavelength Standalone Image, however three Photoacoustic images would be captured from the single input wavelength.

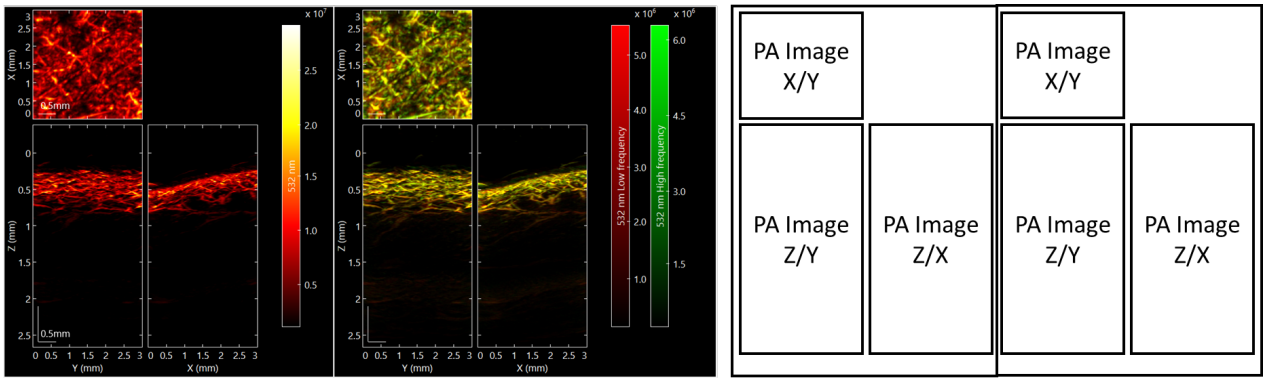

Figure AAAAA.4-3. Two Algorithms for Photoacoustic (PA) Wavelength Processing in Three Planes

AAAAA.5 References

Neuschler EI, Butler R, Young CA, Barke LD, Bertrand ML, Böhm-Vélez M, et al. A Pivotal Study of Optoacoustic Imaging to Diagnose Benign and Malignant Breast Masses: A New Evaluation Tool for Radiologists. Radiology. 2018 May;287(2):398–412. doi:10.1148/radiol.2017172228

Regensburger AP, Fonteyne LM, Jüngert J, Wagner AL, Gerhalter T, Nagel AM, et al. Detection of collagens by multispectral optoacoustic tomography as an imaging biomarker for Duchenne muscular dystrophy. Nat Med. 2019 Dec;25(12):1905–15. doi:10.1038/s41591-019-0669-y

Aguirre J, Schwarz M, Garzorz N, Omar M, Buehler A, Eyerich K, et al. Precision assessment of label-free psoriasis biomarkers with ultra-broadband optoacoustic mesoscopy. Nat Biomed Eng. 2017 May 10;1(5):0068. doi:10.1038/s41551-017-0068