Digital Imaging and Communications in Medicine (DICOM)

Supplement 229: Photoacoustic Imaging

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Closed Issues

1	Is there a use case for the event timer in PA? [Response: The existing contrast events might apply to PA. For symmetry, the event timer is supported in the PA modules (as it is supported in Ultrasound).]
2	What Dimension Indexing structure should be used for PA? [Response: PA will use dimension index values of Temporal Position Time Offset (0020,930d), Image Position (Volume) (0020,9301), and PA Reconstruction Index (gggg,ee93). In the March 2022 WG06 review, WG34 presented a dimensioning structure based on StackID, InStackPosition, and ImagePositionVolume. Feedback at the meeting indicated this usage was likely to lead to confusion as it was a different use pattern than MR/CT and it was suggested that WG34 swap the usage of the concepts of StackID and InStackPosition. After further review, WG34 has concluded that adhering more closely to the Enhanced US Volume dimension usage would be useful in the cases where PA/US fusion was intended; the inclusion of StackID and InStackPosition was dropped.]
3	Is the Ultrasound Frame of Reference appropriate for PA? [Response: Yes. The PA WG is concerned about the conflict of using the Ultrasound Frame of Reference because it is tied explicitly to ultrasound and not all PA cases would want to include ultrasound. It appears that C.8.24.2 Ultrasound Frame of Reference Module could be more generic, but no other modalities are currently using it. PA would prefer pointing to a generic instance of this module if one was created. This discussion arose from reviewing the description of C.7.6.16.2.21 Plane Position (Volume) Macro where the concept of “Volume Frame of Reference” is used. “Volume Frame of Reference” is not explicitly linked to C.8.24.2.1.1, but that is where it appears to be defined. WG-06 has agreed that it is appropriate for PA to use the Ultrasound Frame of Reference “Volume Frame of Reference” concept as it stands.]
4	Is it possible to store raw data (unprocessed channel data, for instance) in this IOD? [Response: Supplement 229 does not address raw data. For PA raw time series data, see the standard described by the IPASC data format (https://www.ipasc.science); the DICOM Raw Data IOD may also be applicable and could if desired simply encapsulate the IPASC data format to allow the object to be managed in PACS.]
5	Are example DICOM files available? [Response: As of January 2023, files following the format of Example 1 and Example 2 are available at /MEDICAL/Private/Dicom/WORKGRPS/WG34/Examples/Supp229 using temporary private tags.]

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) PA 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 (PA) image. Complementary images such as pulse/echo ultrasound are represented by their native DICOM IODs. Albeit fusing PA images with US 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. PA 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 PA device produces an image with no PA optical image, the SOP class of the structural image (e.g. ultrasound) will be used
- If a PA device creates a single image component by fusing the structural image to the PA 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 3.2

Digital Imaging and Communications in Medicine (DICOM)

Part 2: Conformance

Item: Add new SOP Class in Table A.1-2:

The SOP Classes are categorized as follows:

Table A.1-2. UID VALUES

UID Value	UID NAME	Category
…		
1.2.840.10008.xxx	**Photoacoustic Image Storage SOP Class**	**Transfer**
…		

Item: Add new Abbreviation to A.3.6:

Abbreviations should be listed here. These may be taken from the following list, deleting terms that are not used within the Conformance Statement, and adding any additional terms that are used:

…

PA

Photoacoustic

…

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

A.XX Photoacoustic Image IOD

A.XX.1 PA Image IOD Description

The Photoacoustic (PA) 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.XX.2 PA IOD Description Entity-Relationship Model

The Photoacoustic (PA) 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.XX.3 PA Image IOD Modules

Table A.XX.3-1 specifies the Modules of the PA Image IOD.

Table A.XX.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 Module	C.7.3.3	U
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Frame of Reference	C.7.4.1	U
	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
	Acquisition Context	C.7.6.14	U
	Enhanced Palette Color Lookup Table	C.7.6.23	U
	Photoacoustic Image	C.8.XX.3	M
	Photoacoustic Transducer	C.8.XX.4	U
	Photoacoustic Reconstruction	C.8.XX.5	U
	ICC Profile	C.11.15	U
	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.XX.3.1 PA Image IOD Content Constraints

A.XX.3.1.1 Modality

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

A.XX.3.1.2 ICC Profile Module

The ICC Profile Module shall be present for color images. 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.XX.3.1.3 Acquisition Context Module

The Defined TID for Acquisition Context Sequence (0040,0555) is TID YYYYY “Skin Type Acquisition Context”. The skin type values represent values observed at the time of image acquisition.

A.XX.3.1.4 Ultrasound Frame of Reference

The Ultrasound Frame of Reference C.8.24.2 is mandatory for PA 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 PA Dimension Index.

A.XX.4 Photoacoustic Functional Group Macros

Table A.XX.4-1 specifies the use of the Functional Group Macros used in the Multi-frame Functional Groups Module for the Photoacoustic IOD.

Table A.XX.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 or MONOCHROME1.
Real World Value Mapping	C.7.6.16.2.11	U - May be used only if Photometric Interpretation (0028,0004) is MONOCHROME2 or MONOCHROME1.
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.XX.6.1	U
PA Image Frame Type	C.8.XX.6.2	M - 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) equals “1.2.840.10008.xxx” (Photoacoustic Image Storage).** May be present otherwise.
…			
…			

Add a new section to C.8 Modality Specific Modules

C.8.XX Photoacoustic Modules

C.8.XX.1 Photoacoustic Dimension Organization Type

Photoacoustic Image studies include one or more PA 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.XX.1-1.

Table C.8.XX.1-1. Dimension Definition for PA Images

Item	Attribute	Tag	Value
Dimension Index Sequence		(0020,9222)	
1st	>Dimension Index Pointer	(0020,9165)	(0020,930d) Temporal Position Time Offset
	>Functional Group Pointer	(0020,9167)	(0020,9310) Temporal Position Sequence
	…		
2nd	>Dimension Index Pointer	(0020,9165)	(0020,9301) Image Position (Volume)
	>Functional Group Pointer	(0020,9167)	(0020,930E) Plane Position (Volume) Sequence
	…		
3rd	>Dimension Index Pointer	(0020,9165)	(gggg,ee93) PA Reconstruction Index
	…		

The Dimension Index Values (0020,9157) corresponding to these dimension variables positively associate frames from different SOP Instances with the same Dimension Organization UID (0020,9164) at the same temporal position, spatial position and a unique set of algorithm and excitation wavelengths.

These Dimension values shall be used even if there is only one possible value for a Dimension.

C.8.XX.2 Photoacoustic Image Type

C.8.XX.2.1 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.XX.2.2 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.XX.2.3 Image Flavor

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

Table C.8.XX.2-1 specifies the Defined Terms for PA for Value 3 for Image Type (0008,0008) and Frame Type (0008,9007).

Table C.8.XX.2-1. PA 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.XX.2.4 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.XX.3 Photoacoustic Image

This section describes the Photoacoustic Image Module.

Table C.8.XX.3-1 contains IOD Attributes that describe Photoacoustic Images

Table C.8.XX.3-1. Photoacoustic Image Module Attributes

Attribute Name	Tag	Type	Attribute Description
Excitation Wavelength Sequence	(gggg,ee94)	1	Optical excitation wavelength(s) applied to the target. Acquired data from all input wavelengths in this sequence is processed as described in Reconstruction Algorithm Sequence (0018,993D) to create the image. One or more Items shall be included in this Sequence.
>Excitation Wavelength	(gggg,eee5)	1	The wavelength in nm of the optical excitation pulse from the illuminator.
Illumination Translation Flag	(gggg,ee92)	3	Whether the position of the illumination source is changed during the frame acquisition. Enumerated Values: YES NO
Illumination Type Code Sequence	(gggg,eee6)	3	Type of illumination used. Only a single Item is permitted in this Sequence.

>Include Table 8.8-1 "Code Sequence Macro Attributes"			DCID XXYYY "Illumination Type"
Acoustic Coupling Medium Flag	(gggg,ee99)	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	(gggg,eee7)	2C	Acoustic coupling medium that was used. Required if Acoustic Coupling Medium Flag (gggg,ee99) is YES. Zero or one Item shall be included in this Sequence.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			DCID XXYYZ "Acoustic Coupling Medium"
Coupling Medium Temperature	(gggg,eee8)	3	The nominal temperature of the coupling medium in degrees Celsius at the time of acquisition.
Acquisition DateTime	(0008,002A)	1	The date and time that the acquisition of data that resulted in this image started.
Position Measuring Device Used	(0018,980C)	1	Describes the type of position measuring device used in the acquisition of the image, if any. This gives an indication of the degree of precision of Pixel Spacing (0028,0030) and the spacing between adjacent planes. Enumerated Values: RIGID The image was acquired with a position measuring device. FREEHAND The image was acquired 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)	1	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.

Event Timer Sequence	(0008,2133)	3	Sequence of time intervals of significance to this image. Each Item describes one time interval either beginning or ending at Acquisition DateTime (0008,002A). One or more Items are permitted in this Sequence.
>Event Time Offset	(0008,2134)	1	Signed value of the time between Acquisition DateTime (0008,002A) and the event, in milliseconds. Positive values indicate the event occurs after Acquisition DateTime (0008,002A).
>Event Code Sequence	(0008,2135)	1	Type of event. Only a single Item shall be included in this Sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*DCID 12031 "Protocol Interval Events"*.
>Event Timer Name(s)	(0008,2132)	3	Name that identifies the event timer. May be used in addition to Event Time Code Sequence to offer site-specific user-readable event time names. Only a single value shall be included.

C.8.XX.4 Photoacoustic Transducer Module

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

Table C.8.XX.4-1 contains IOD Attributes that describe Photoacoustic Transducers.

Table C.8.XX.4-1. 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	(gggg,ee17)	2	Characterization of the frequency response of the transducer. Zero or one Item shall be included in this Sequence.
>Center Frequency	(gggg,ee98)	3	Center Frequency of a receiver in MHz.
>Fractional Bandwidth	(gggg,ee97)	3	Fractional Bandwidth of a receiver in percent as measured in Transmit/Receive mode.
>Lower Cutoff Frequency	(gggg,ee96)	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	(gggg,ee95)	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	(gggg,ee10)	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 XXYYB “Ultrasound Transducer Technology”

C.8.XX.5 Photoacoustic Reconstruction Module

Table C.8.XX.5-1 contains Attributes that describe Photoacoustic Reconstruction.

Table C.8.XX.5-1. Photoacoustic Reconstruction Module Attributes

Attribute Name	Tag	Type	Attribute Description
Sound Speed Correction Mechanism Code Sequence	(gggg,ee14)	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 XXYYC "Speed of Sound Correction Mechanisms"
>Object Sound Speed	(gggg,ee15)	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 (gggg,ee14) is (XXXX15, DCM, "Uniform Speed of Sound Correction") or (XXXX16, DCM, "Dual Speed of Sound Correction").
>Coupling Medium Sound Speed	(gggg,ee1a)	1C	Speed of sound value in m/s used in the image reconstruction in the area attributed to the coupling medium. Required if Sound Speed Correction Mechanism (gggg,ee14) is (XXXX16, 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 PA 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 (gggg,ee14) is (XXXX17, DCM, "Speed of Sound Map Correction"). May be present otherwise.
>>Include Table 10-3 "Image SOP Instance Reference Macro Attributes"			
Reconstruction Algorithm Sequence	(0018,993D)	1	The identification assigned by a manufacturer to a specific software algorithm. Only a single Item is permitted in this Sequence.
>Include Table 10-19 "Algorithm Identification Macro Attributes"			BCID XXYYD "PA Reconstruction Algorithm Family" for Algorithm Family Code Sequence (0066,002F). A manufacturer-defined value representing "None" or "Unknown" may be provided for the Algorithm Name (0066,0036) if no algorithm is specified.
PA Reconstruction Index	(gggg,ee93)	1	Identifies the combination of the algorithm (identified by the Algorithm Name (0066,0036)) and the excitation wavelength(s) (identified in the Excitation Wavelength Sequence (gggg,ee94)), used to

			reconstruct the PA Image. The index shall be unique across the instances that share the same Dimension Organization UID (0020,9164).

C.8.XX.6 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.XX.6.1 Photoacoustic Excitation Characteristics Macro

Table C.8.XX.6.1-1. Photoacoustic Excitation Characteristics Functional Group Attributes are PA excitation attributes that are recorded during PA frame acquisition and may vary across frames.

Table C.8.XX.6.1-1. Photoacoustic Excitation Characteristics Attributes

Attribute Name	Tag	Type	Attribute Description
PA Excitation Characteristics Sequence	(gggg,eee1)	1	Characteristics of the light emitted by the illuminator, used for excitation of the target in PA Imaging of this frame. These values are recorded during PA 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 (gggg,ee94).
>Excitation Wavelength	(gggg,eee5)	1	The wavelength in nm of the optical excitation pulse from the illuminator.
>Excitation Spectral Width	(gggg,eee2)	3	Full width at half maximum (FWHM) of the emitted optical spectrum in nm.
>Excitation Energy	(gggg,eee3)	3	The optical energy of the excitation pulse in mJ.
>Excitation Pulse Duration	(gggg,eee4)	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.XX.6.2 PA Image Frame Type Macro

Table C.8.XX.6.2-1 specifies the Attributes of the PA Image Frame Type Functional Group Macro.

Table C.8.XX.6.2-1. PA Image Frame Type Macro Attributes

Attribute Name	Tag	Type	Attribute Description
PA Image Frame Type Sequence	(gggg,a001)	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.XX.2.
>Volumetric Properties	(0008,9206)	1	Indication if geometric manipulations are possible with frames in the SOP Instance. See Section C.8.16.2.1.2 for a description and Enumerated Values.
>Volume Based Calculation Technique	(0008,9207)	1	Method used for volume calculations with frames in the SOP Instance. See Section C.8.16.2.1.3 for a description and Defined Terms.

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).

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.XXXX**	**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
…				
(gggg,eee1)	PA Excitation Characteristics Sequence	PAExcitationCharacteristicsSequence	SQ	1
(gggg,eee2)	Excitation Spectral Width	ExcitationSpectralWidth	FL	1
(gggg,eee3)	Excitation Energy	ExcitationEnergy	FL	1
(gggg,eee4)	Excitation Pulse Duration	ExcitationPulseDuration	FL	1
(gggg,ee94)	Excitation Wavelength Sequence	ExcitationWavelengthSequence	SQ	1
(gggg,eee5)	Excitation Wavelength	ExcitationWavelength	FL	1
(gggg,eee6)	Illumination Type Code Sequence	IlluminationTypeCodeSequence	SQ	1
(gggg,ee92)	Illumination Translation Flag	IlluminationTranslationFlag	CS	1
(gggg,ee99)	Acoustic Coupling Medium Flag	AcousticCouplingMediumFlag	CS	1
(gggg,eee7)	Acoustic Coupling Medium Code Sequence	AcousticCouplingMediumCodeSequence	SQ	1
(gggg,eee8)	Coupling Medium Temperature	CouplingMediumTemperature	FL	1
(gggg,ee17)	Transducer Response Sequence	TransducerResponseSequence	SQ	1
(gggg,ee98)	Center Frequency	CenterFrequency	FL	1
(gggg,ee97)	Fractional Bandwidth	FractionalBandwidth	FL	1
(gggg,ee96)	Lower Cutoff Frequency	LowerCutoffFrequency	FL	1

(gggg,ee95)	**Upper Cutoff Frequency**	**UpperCutoffFrequency**	**FL**	**1**
(gggg,ee10)	**Transducer Technology Sequence**	**TransducerTechnologySequence**	**SQ**	**1**
(gggg,ee14)	**Sound Speed Correction Mechanism Code Sequence**	**SoundSpeedCorrectionMechanismCodeSequence**	**SQ**	**1**
(gggg,ee15)	**Object Sound Speed**	**ObjectSoundSpeed**	**FL**	**1**
(gggg,ee1a)	**Coupling Medium Sound Speed**	**CouplingMediumSoundSpeed**	**FL**	**1**
(gggg,ee93)	**PA Reconstruction Index**	**PAReconstructionIndex**	**UL**	**1**
(gggg,a001)	**PA Image Frame Type Sequence**	**PAImageFrameTypeSequence**	**SQ**	**1**
…				

Add to Table A-1 PS3.6 Annex A

UID Value	UID Name	UID Keyword	UID Type	Part
…				
1.2.840.10008.DD	**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.XXYYYUID	**CID XXYYY**	**Illumination Type**
1.2.840.10008.6.1.XXYYZUID	**CID XXYYZ**	**Acoustic Coupling Medium**
1.2.840.10008.6.1.XXYYBUID	**CID XXYYB**	**Ultrasound Transducer Technology**

1.2.840.10008.6.1.XXYYCUID	**CID XXYYC**	**Speed of Sound Correction Mechanisms**
...		

Changes to NEMA Standards Publications PS 3.15

Digital Imaging and Communications in Medicine (DICOM)

Part 15: Security and System Management Profiles

Add new Data Elements to PS 3.15 Annex E table. No new attributes introduced are required to be removed.

Table E.1-1. Application Level Confidentiality Profile Attributes

Attribute Name	Tag	Retd. (from PS3.6)	In Std. Comp. IOD (from PS3.3)	Basic Prof.	Rtn. Safe Priv. Opt.	Rtn. UIDs Opt.	Rtn. Dev. Id. Opt.	Rtn. Inst. Id. Opt.	Rtn. Pat. Chars. Opt.	Rtn. Long. Full Dates Opt.	Rtn. Long. Modif. Dates Opt.	Clean Desc. Opt.	Clean Struct. Cont. Opt.	Clean Graph. Opt.
...														

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

Resources:

HTML | FHIR JSON | FHIR XML | IHE SVS XML

Type:

Extensible

Version:

~~20190327~~**yyyymmdd**

UID:

1.2.840.10008.6.1.19

Table CID 29. Acquisition Modality

Coding Scheme Designator	Code Value	Code Meaning

…		
DCM	**PA**	**Photoacoustic**
…		

CID 12033 Ultrasound Transducer Geometry

Resources:

HTML| FHIR JSON|FHIR XML|IHE SVS XML

Type:

Extensible

Version:

~~**20090409**~~**yyyymmdd**

UID:

1.2.840.10008.6.1.808

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	**XXXXXA**	**Planar matrix ultrasound transducer geometry**
DCM	**XXXXXB**	**Hemispherical ultrasound transducer geometry**

Add in PS3.16 Annex B

CID XXYYY Illumination Type

Resources:

HTML| FHIR JSON|FHIR XML|IHE SVS XML

Type:

Extensible

Version:

yyyymmdd

UID:

1.2.840.10008.6.1.XXYYYUID

Table CID XXYYY. Illumination Type

Coding Scheme Designator	Code Value	Code Meaning
DCM	XXXXX1	Single-side illumination
DCM	XXXXX2	Dual-side illumination
DCM	XXXXX3	Multi-side illumination
DCM	XXXXX4	Through-transducer illumination
DCM	XXXXX5	Interstitial illumination

CID XXYYZ Acoustic Coupling Medium

Resources:

HTML| FHIR JSON|FHIR XML|IHE SVS XML

Type:

Extensible

Version:

yyyymmdd

UID:

1.2.840.10008.6.1.XXYYZUID

Table CID XXYYZ. Acoustic Coupling Medium

Coding Scheme Designator	Code Value	Code Meaning
SCT	11713004	Water (substance)
SCT	12977001	Deuterium oxide (substance)
SCT	1004163002	Ultrasound Coupling Gel
SCT	15158005	Air (substance)

CID XXYYB Ultrasound Transducer Technology

Resources:

HTML| FHIR JSON|FHIR XML|IHE SVS XML

Type:

Extensible

Version:

yyyymmdd

UID:

1.2.840.10008.6.1.XXYYBUID

Table CID XXYYB. Ultrasound Transducer Technology

Coding Scheme Designator	Code Value	Code Meaning
DCM	XXXX13	Piezocomposite Transducer
DCM	XXXX14	MEMS-based Transducer
DCM	XXXX15	Interferometric Transducer

CID XXYYC Speed of Sound Correction Mechanisms

Resources:

HTML| FHIR JSON|FHIR XML|IHE SVS XML

Type:

Extensible

Version:

yyyymmdd

UID:

1.2.840.10008.6.1.XXYYCUID

Table CID XXYYC. Speed of Sound Correction Mechanisms

Coding Scheme Designator	Code Value	Code Meaning
DCM	XXXX16	Uniform Speed of Sound Correction
DCM	XXXX17	Dual Speed of Sound Correction
DCM	XXXX18	Speed of Sound Map Correction

CID XXYYD PA Reconstruction Algorithm Family

Resources:

HTML| FHIR JSON|FHIR XML|IHE SVS XML

Type:

Extensible

Version:

yyyymmdd

UID:

1.2.840.10008.6.1.XXYYDUID

Table CID XXYYD. PA Reconstruction Algorithm Family

Coding Scheme Designator	Code Value	Code Meaning
DCM	XXXX19	Conventional Direct Reconstruction
DCM	XXXX1A	Conventional Iterative Reconstruction
DCM	XXXX1B	Machine Learning Direct Reconstruction
DCM	XXXX1C	Machine Learning Iterative Reconstruction

Add the following TID to Part 16 Annex C Acquisition Context Module, Protocol and Workflow Context Templates (Normative)

TID YYYYY Skin Type Acquisition Context

Type:
Extensible

Order:
Non-Significant

Root:
No

Table TID YYYYY. Skin Type Acquisition Context

	VT	Concept Name	VM	Req Type	Condition	Value Set Constraint
1	CODE	EV (443635002, SCT, "Fitzpatrick Skin Type")	1	U		DCID 4401 “Fitzpatrick Skin Type”

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

Annex D DICOM Controlled Terminology Definitions (Normative)

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

Code Value	Code meaning	Definition	Notes
…			
OSS	Optical Surface Scanner	An acquisition device, process or method that performs optical surface scanning.	

OT	Other Modality	Other Modality device.	
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.**	
...			
125252	Linear ultrasound transducer geometry	Ultrasonic transducer geometry characterized by parallel lines.	
125253	Curved linear ultrasound transducer geometry	Ultrasonic transducer geometry characterized by radial lines normal to the outside of a curved surface.	
125254	Sector ultrasound transducer geometry	Ultrasonic transducer geometry characterized by lines originating from a common apex.	
125255	Radial ultrasound transducer geometry	Ultrasonic transducer geometry characterized by lines emanating radially from a single point.	
125256	Ring ultrasound transducer geometry	Ultrasonic transducer geometry characterized by a circular ring of transducer elements.	
XXXXXA	**Planar matrix ultrasound transducer geometry**	**Ultrasonic transducer geometry characterized by multiple transducer elements arranged in a grid on a plane.**	
XXXXXB	**Hemispherical ultrasound transducer geometry**	**Ultrasonic transducer geometry characterized by multiple transducer elements arranged on a hemispherical surface.**	
125257	Fixed beam direction	Ultrasonic steering technique consisting of a single beam normal to the transducer face steered by the orientation of the probe.	
125258	Mechanical beam steering	Ultrasonic steering technique consisting of mechanically directing the beam.	
...			

XXXXX1	Single-side illumination	The subject is illuminated from a single direction.	
XXXXX2	Dual-side illumination	The subject is illuminated from two distinct directions.	
XXXXX3	Multi-side illumination	The subject is illuminated from more than two (potentially a very large number of) distinct directions.	
XXXXX4	Through-transducer illumination	The subject is illuminated through the transducer. Light may pass through the transducer at one or more locations.	
XXXXX5	Interstitial illumination	The subject is illuminated internally. Light is delivered via a device (other than the transducer) inside the body.	
XXXX13	Piezocomposite Transducer	Ultrasound Transducer that utilizes Piezo-composite crystalline structures.	
XXXX14	MEMS-based Transducer	Ultrasound Transducer that utilizes Micro-electro-mechanical systems (MEMS)-based structures.	
XXXX15	Interferometric Transducer	Ultrasound Transducer that utilizes interferometric detection systems.	
XXXX16	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 coupling medium (if present) is assumed to be the same as for the imaged object.	
XXXX17	Dual Speed of Sound Correction	Mechanism for correction of data using a sound propagation model based on two speeds of sound, one for the coupling medium and one for the imaged object.	

XXXX18	**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.**	
…			
113962	Filtered Back Projection	An algorithm for reconstructing an image from multiple projections by back-projecting the measured values along the line of the projection and filtering the result to reduce blurring.	
113963	Iterative Reconstruction	An algorithm for reconstructing an image from multiple projections by starting with an assumed reconstructed image, computing projections from the image, comparing the original projection data and updating the reconstructed image based upon the difference between the calculated and the actual projections.	
XXXX19	**Conventional Direct Reconstruction**	**A family of algorithms for reconstructing an image from measured data by direct reconstruction (e.g., universal backprojection, filtered backprojection)**	
XXXX1A	**Conventional Iterative Reconstruction**	**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.**	
XXXX1B	**Machine Learning Direct Reconstruction**	**A family of algorithms for reconstructing an image from measured data by direct reconstruction followed by learning-based post-processing reconstruction methods.**	

XXXX1C	**Machine Learning Iterative Reconstruction**	**A family of algorithms for reconstructing an image from measured data by model-based learned iterative reconstruction methods to minimize a cost function between the data and a numerical model.**	

Changes to NEMA Standards Publication PS 3.17

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

Add to PS3.17 Annex AXXX

Annex AXXX Photoacoustic Imaging (Informative)

AXXX.1 Introduction

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

AXXX.2 Use Cases

AXXX.2.1 Acquisition and Storage

PA Images are produced from the acquisition of tissue response to one or more Excitation Wavelength (gggg,eee5) values. These attributes are identified using the PA Reconstruction Index (gggg,ee93) Dimension Index to capture differences in wavelength absorption by various biological tissues.

PA 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).

PA Images may be acquired as a standalone modality or acquired in combination with images from other modalities. Because PA and Ultrasound systems are often implemented as coupled modalities, the PA 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 PA 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.

AXXX.2.2 Presentation and Review

Display Systems are likely to encounter PA 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. A common Dimension Organization UID (0020,9164) establishes a relationship between the PA images based on temporal position, spatial position and a unique set of algorithm and excitation wavelengths (see C.8.XX.1).

The logic for visualization of PA 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 PA 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 PA images; the processing for a PA image is generally performed by the modality (see Reconstruction Algorithm Sequence (0018,993D)).

AXXX.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 PA 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.XX.1.

AXXX.2.3 Example Workflow

A radiologist evaluating a PA acquisition could view the PA images separately, as synchronized sets of series, or fused in a display overlay (AXXX.2.2.1). An example of PA Image acquisition, storage and review is shown in Figure AXXX.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.

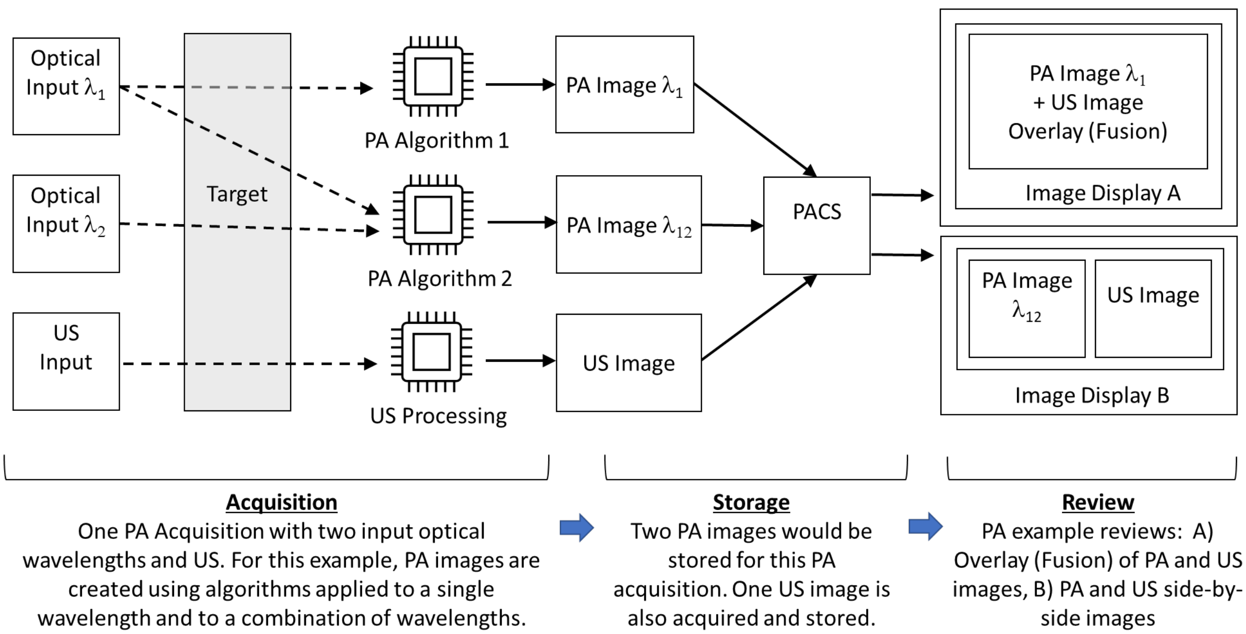

Figure AXXX.2.3-1. Example PA Image Acquisition, Storage, and Review

AXXX.3 Acquisition Examples

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

1. PA Standalone Image - a study with multiple optical wavelength images acquired over time. No complementary modality images are acquired.
    a. PA Single Wavelength Standalone Image - a study with multiple images of one optical wavelength scanned repeatedly across the target over different time points.
2. PA/US Coupled Acquisition - a study with multiple optical wavelength images and ultrasound images acquired over time.

3. Stationary tomographic 3D PA/US 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 AXXX.3.1-AXXX.3.3, the acquisition examples focus on the application of the Dimension Index.

AXXX.3.1 Example 1: PA 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.

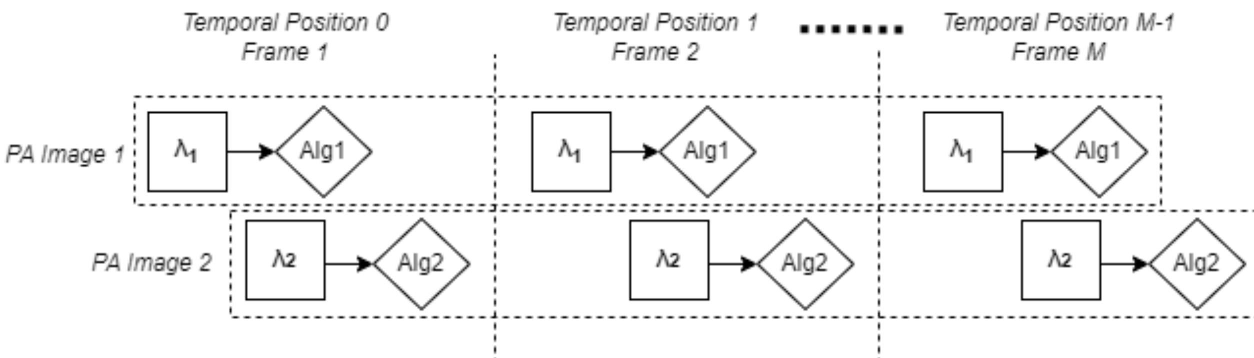

Figure AXXX.3.1-1. PA Standalone Example

AXXX.3.1.1 PA Single Wavelength Standalone Image

A PA single wavelength standalone image would be a sub-case of Example 1 (Figure AXXX.3.1-2). In a PA Microscopy example, PA 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.

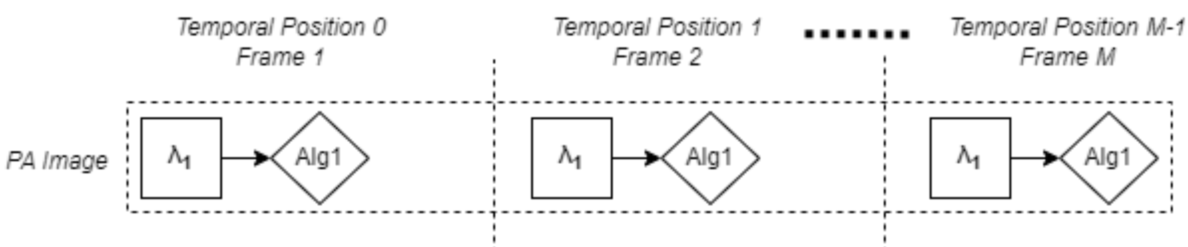

Figure AXXX.3.1-2. Example 1 Subcase: PA Single Wavelength Standalone Acquisition

AXXX.3.1.1 PA Dimension Index Sequence for Examples

The encoding examples in sections AXXX.3.1-AXXX.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 PA files in the examples is described in Table AXXX.3.1.1-1.

Table AXXX.3.1.1-1. PA 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 PA 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 PA 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 PA Image Object.
>Dimension Index Pointer	(0020,9165)	(gggg,ee93)	PA Reconstruction Index
%enditem			

AXXX.3.1.2 PA Standalone Image Per-Frame Example

In this encoding of the example shown in Figure AXXX.3.1-1, the first frame of the image is shown for two optical wavelength images (Table AXXX.3.1.2-1 and Table AXXX.3.1.2-2). For brevity, examples of PA attributes are provided in AXXX.3.4.

Table AXXX.3.1.2-1. PA Standalone Example, Wavelength 1, Frame 1

Attribute	Tag	Value	Comments
…			
>Excitation Wavelength	(gggg,eee5)	800	Optical wavelength 1 ($\boldsymbol{\lambda}_1$) is 800nm.
…			
>>Algorithm Name	(0066,0036)	WL-800	A manufacturer-specific algorithm for images as applied to the excitation wavelength of 800nm.
…			
PA Reconstruction Index	(gggg,ee93)	1	
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>>Temporal Position Time Offset	(0020,930d)	0	
…			
>PA Excitation Characteristics Sequence	(gggg,eee2)		
>%item			
>Excitation Wavelength	(gggg,eee5)	800	nm
>>Excitation Energy	(gggg,eee3)	11	mJ
>>Excitation Pulse Duration	(gggg,eee4)	8	ns

>%enditem			
…			

Table AXXX.3.1.2-2. PA Standalone Example, Wavelength 2, Frame 1

Attribute	**Tag**	**Value**	**Comments**
…			
>Excitation Wavelength	(gggg,eee5)	1064	Optical wavelength 2 (λ_2) is 1064nm.
…			
>>Algorithm Name	(0066,0036)	RC_Long	A manufacturer-specific algorithm for images as applied to the excitation wavelength of 1064nm.
…			
PA Reconstruction Index	(gggg,ee93)	2	
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>>Dimension Index Value	(0020,9157)	1\1\2	
…			
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>>Temporal Position Time Offset	(0020,930d)	0	
…			
>PA Excitation Characteristics Sequence	(gggg,eee2)		

>%item			
>Excitation Wavelength	(gggg,eee5)	1064	nm
>>Excitation Energy	(gggg,eee3)	43	mJ
>>Excitation Pulse Duration	(gggg,eee4)	8	ns
>%enditem			
…			

AXXX.3.2 Example 2: PA/US 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 PA 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 PA 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 PA device knows the spatial relationship of its image data relative to the US device and can use the Registration SOP Class to specify the relationship of the images from the two modalities.

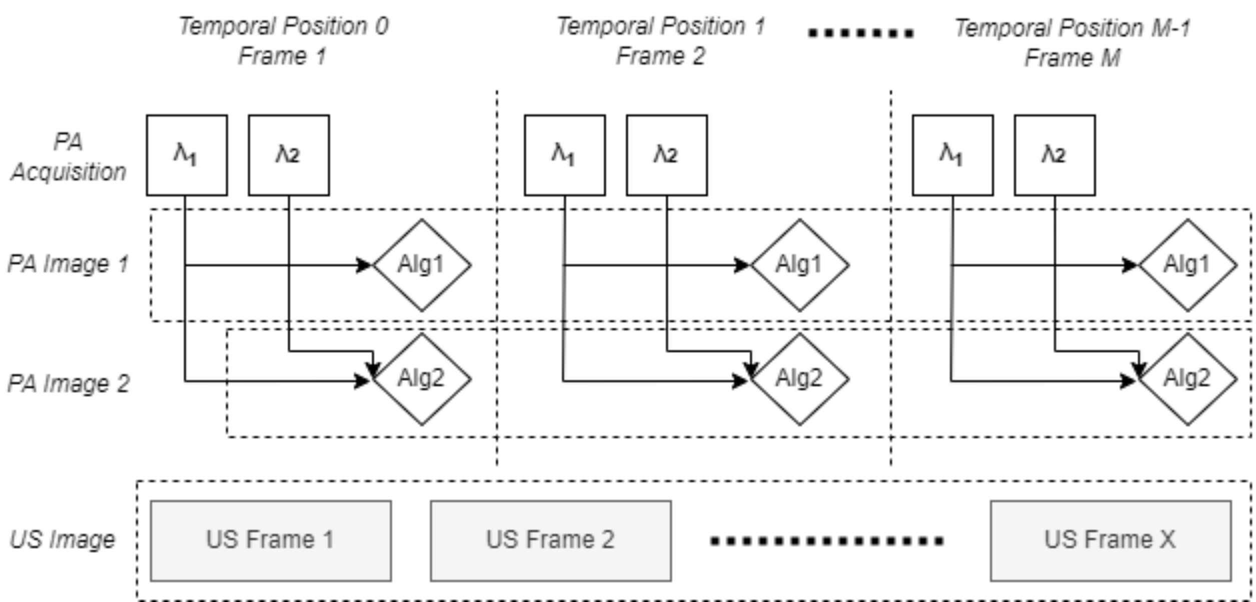

Figure AXXX.3.2-1. Example 2: PA/US Coupled Acquisition

AXXX.3.2.1 PA Dimension Index Sequence for Examples

The Dimension Index Sequence for all PA files in the encoding examples is described in Table AXXX.3.1.1-1.

AXXX.3.2.2 US Dimension Index Sequence for Examples

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

Table AXXX.3.2.2-1. US Example Dimension Index Sequence for PA/US 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			

AXXX.3.2.3 PA/US Coupled Acquisition Per-Frame Example

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

Table AXXX.3.2.3-1. PA/US Coupled Acquisition, PA Image, Algorithm 1, Frame 1

Attribute	Tag	Value	Comments
Modality	(0008,0060)	PA	Modality is PA
…			
>Excitation Wavelength	(gggg,eee5)	800	nm
…			
>>Algorithm Name	(0066,0036)	wl-1	A manufacturer-specific algorithm for images as applied to the excitation wavelength 1.
…			
PA Reconstruction Index	(gggg,ee93)	1	
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>>Frame Acquisition Date Time	(0018,9074)	20220130150251.005768	
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>>Temporal Position Time Offset	(0020,930d)	0	

…			
>PA Excitation Characteristics Sequence	(gggg,eee2)		
>%item			
>Excitation Wavelength	(gggg,eee5)	800	nm
>>Excitation Energy	(gggg,eee3)	11	mJ
>>Excitation Pulse Duration	(gggg,eee4)	8	ns
>%enditem			
…			

Table AXXX.3.2.3-2. PA/US Coupled Acquisition, PA Image, Algorithm 2, Frame 1

Attribute	**Tag**	**Value**	**Comments**
Modality	(0008,0060)	PA	Modality is PA
…			
>Excitation Wavelength	(gggg,eee5)	800	nm
>Excitation Wavelength	(gggg,eee5)	1064	nm
…			
>>Algorithm Name	(0066,0036)	RelativeOxygenation-800-1064	The manufacturer-specific spectrally unmixed algorithm for relative oxygenation using excitation wavelengths of 800nm and 1064nm.
…			
PA Reconstruction Index	(gggg,ee93)	2	
…			
Per-frame Functional Groups Sequence	(5200,9230)		

%item			
…			
>>Frame Acquisition Date Time	(0018,9074)	2022013015025 1.005770	
>>Dimension Index Value	(0020,9157)	1\1\2	
…			
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			
>>Temporal Position Time Offset	(0020,930d)	0	
…			

Table AXXX.3.2.3-3. PA/US Coupled Acquisition, US Image, Frame 1

Attribute	Tag	Value	Comments
Modality	(0008,0060)	US	Modality is US
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			
…			
>>Frame Acquisition Date Time	(0018,9074)	202201301502 51.005771	
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>>Image Position (Volume)	(0020,9301)	0\0\0	
…			

>>Temporal Position Time Offset	(0020,930d)	0	
…			
>>Data Type	(0018,9808)	TISSUE_INTENSITY	
…			

AXXX.3.3 Example 3: Stationary Tomographic 3D PA/US 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 PA 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 PA device and the US device share the same DICOM Frame of Reference for each SOP Class Instance.

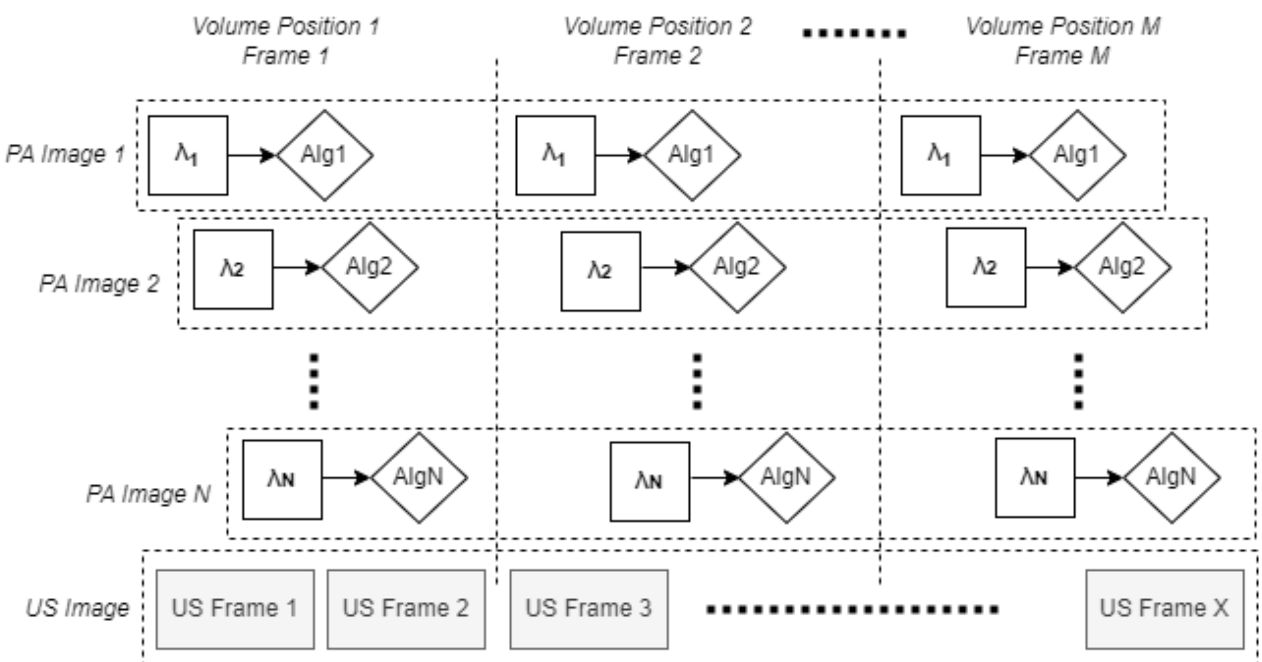

Figure AXXX.3.3-1. Example 3: Stationary Tomographic 3D PA/US Coupled Acquisition

AXXX.3.3.1 PA and US Dimension Index Sequence for Examples

The Dimension Index Sequence for all PA files in the encoding examples is described in Table AXXX.3.1.1-1. The Dimension Index Sequence for all US files in the encoding examples is described in Table AXXX.3.2.2-1.

AXXX.3.3.2 Stationary Tomographic 3D PA/US Per-Frame Example

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

Table AXXX.3.3.2-1. Stationary tomographic 3D PA/US Example, Image Position (Volume), Frame 1&2

Attribute	Tag	Value	Comments
…			
>Excitation Wavelength	(gggg,eee5)	800	nm
…			
>>Algorithm Name	(0066,0036)	proc1-800nm	The manufacturer-specific algorithm for processing an image using the excitation wavelength of 800nm.
…			
PA Reconstruction Index	(gggg,ee93)	1	
…			
Per-frame Functional Groups Sequence	(5200,9230)		
%item			Frame 1
…			
>>Dimension Index Value	(0020,9157)	1\1\1	
…			
>>Image Position (Volume)	(0020,9301)	0\0\0	Volume position 1
…			
>>Temporal Position Time Offset	(0020,930d)	0	
…			
>PA Excitation Characteristics Sequence	(gggg,eee2)		

>%item			
>Excitation Wavelength	(gggg,eee5)	800	nm
>>Excitation Energy	(gggg,eee3)	11.0	mJ
>>Excitation Pulse Duration	(gggg,eee4)	8	ns
>%enditem			
…			
%enditem			
%item			Frame 2
…			
>>Dimension Index Value	(0020,9157)	1\2\1	
…			
>>Image Position (Volume)	(0020,9301)	0\0\1	Volume position 2
…			
>>Temporal Position Time Offset	(0020,930d)	0	
…			
>PA Excitation Characteristics Sequence	(gggg,eee2)		
>%item			
>Excitation Wavelength	(gggg,eee5)	800	nm
>>Excitation Energy	(gggg,eee3)	11.2	mJ
>>Excitation Pulse Duration	(gggg,eee4)	8	ns
>%enditem			
…			

AXXX.3.4 PA Attribute Example Values

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

Table AXXX.3.4-1. PA Attribute Example

Attribute	Tag	Value	Comments
>Excitation Wavelength	(gggg,eee5)	800	nm
…			
Illumination Type Code Sequence	(gggg,eee6)		
%item			
>Code Value	(0008,0100)	XXXXX1	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	Dual side-illumination	
%enditem			
…			
Acoustic Coupling Medium Code Sequence	(gggg,eee7)		
%item			
>*Code Value*	*(0008,0100)*	11713004	
>Coding Scheme Designator	(0008,0102)	SCT	
>Code Meaning	*(0008,0104)*	Water (substance)	
%enditem			
…			

Coupling Medium Temperature	(gggg,eee8)	30	degrees Celsius
…			
Transducer Geometry Code Sequence	(0018,980D)		
%item			
>Code Value	(0008,0100)	125253	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	Curved linear ultrasound transducer geometry	
%enditem			
…			
Transducer Response Sequence	(gggg,ee17)		
%item			
>Center Frequency	(gggg,ee98)	1	MHz
>Fractional Bandwidth	(gggg,ee97)		Empty
>Lower Cutoff Frequency	(gggg,ee96)		Empty
>Upper Cutoff Frequency	(gggg,ee95)		Empty
%enditem			
…			
Transducer Technology Sequence	(gggg,ee10)		
%item			

>Code Value	(0008,0100)	XXXX14	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	MEMS-based Transducer	
%enditem			
…			
Sound Speed Correction Mechanism Code Sequence	(gggg,ee14)		
%item			
>Code Value	(0008,0100)	XXXX16	
>Coding Scheme Designator	(0008,0102)	DCM	
>Code Meaning	(0008,0104)	Dual Speed of Sound Correction	
>Object Sound Speed	(gggg,ee15)	1480	m/s
>Coupling Medium Sound Speed	(gggg,ee1a)	1500	m/s
%enditem			
…			
Frame Content Sequence	(0020,9111)		
…			
>PA Excitation Characteristics Sequence	(gggg,eee2)		
>%item			
>Excitation Wavelength	(gggg,eee5)	800	nm

>>Excitation Spectral Width	(gggg,eee2)	2	nm
>>Excitation Energy	(gggg,eee3)	11	mJ
>>Excitation Pulse Duration	(gggg,eee4)	8	ns
>%enditem			
…			

AXXX.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 PA images (and potentially images from other modalities) will likely be evaluated by the clinician in side-by-side or overlay/fusion views.

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

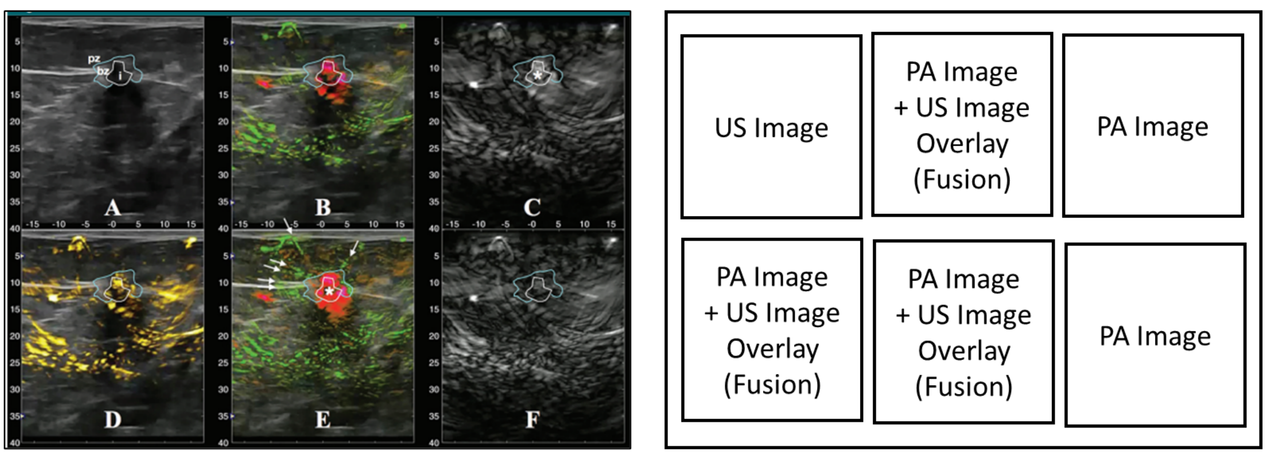

Figure AXXX.4-1. Two PA Optical Wavelengths, Processed and Fused with Ultrasound
(https://doi.org/10.1148/radiol.2017172228)

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

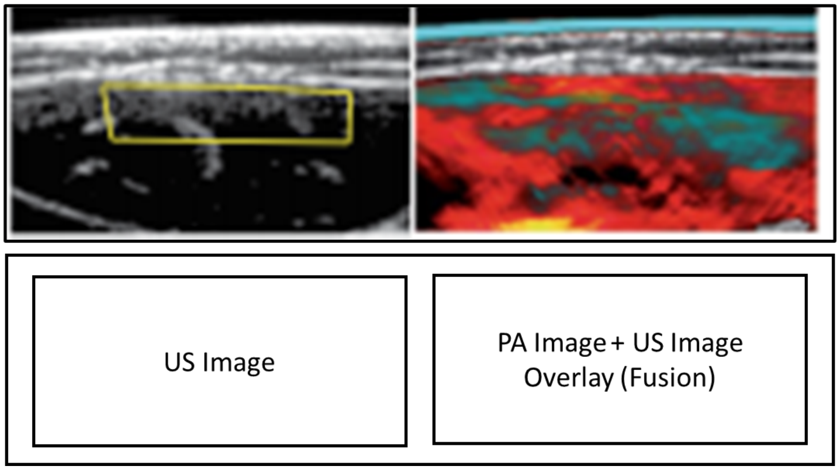

Figure AXXX.4-2. PA with Two Ranges of Multispectral Wavelengths, Processed and Fused with Ultrasound
(https://doi.org/10.1038/s41591-019-0669-y)

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

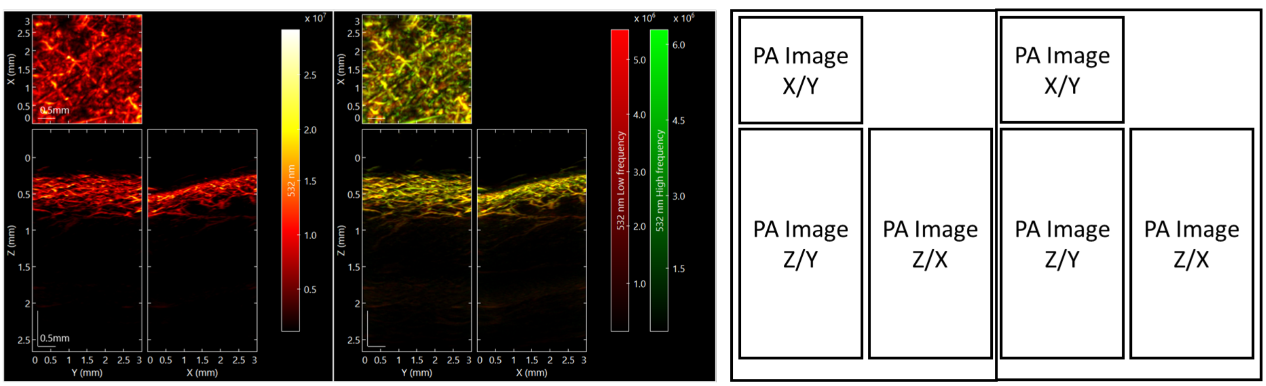

Figure AXXX.4-3. Two Algorithms for PA Wavelength Processing in Three Planes
(https://doi.org/10.1038/s41551-017-0068)