Status	Submitted
Date of Last Update	2016/10/21
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Submission Date	2016/09/02

Correction Number CP-1665
Log Summary: Add MR Diffusion Model Quantities and Parameters for Parametric Maps and ROI Measurements
Name of Standard PS3.3, PS3.16, PS3.17

Rationale for Correction:

Appropriate codes exist to communicate in parametric maps and SR measurement reports that values are (G-C1C6, SRT, "Quantity") = (113041, DCM, "Apparent Diffusion Coefficient") and that the units are (mm2/s, UCUM, "mm2/s"), when a mono-exponential model characterized by a single value is used. Other diffusion models exist that produce other quantities than ADC (e.g., fast and slow compartment coefficients and their relative fraction for bi-exponential models)

Further, the interpretation of the ADC and similar values may depend on the method of fitting and specific techniques used, as well as the b-values of the acquired images used as input.

Accordingly, additional concepts are added for different quantities, methods and parameters, with examples of their use.

Also, allow CT and MR Image and Frame Type Value 3 and Value 4 defined terms (as is already the case for Value 4 MR terms) for parametric maps (needed, if for no other reason, for consistency with the IHE DIFF profile to allow DIFFUSION for value 3).

The choice of units for diffusion coefficients is also discussed.

[Ed. Note. TODO: Units for other quantities than ADC ... do we want to add a Units column to the context groups that pairs quantities and units?]

[Ed. Note. Question for WG 6: Unit code meanings should probably not be spelled out fully ... do we want to fix this, or create another CP to do it?]

[Ed. Note. TODO: Add parameters of Truncated Gaussian model]

[Ed. Note. TODO: Do we need to describe encoding of Goodness of fit explciitly .. already have an R^2 concept in the standard]

[Ed. Note. TODO. Do we need to describe model fitting failure reasons?]

[Ed. Note. TODO. Add GE's suggestions and harmonize with Sup 181 tractography-related model context groups:

- *Diffusion imaging methods/models:*
- *NODDI - Neurite orientation dispersion and density imaging*
- *HYDI - Hybrid diffusion imaging*
- *HARDI - High angular resolution diffusion-weighted imaging*
- *DSI - Diffusion Spectrum Imaging*
- *Diffusion parameters:*
- *Apparent fiber density - a possible replacement for fractional anisotropy (FA)*
- *Orientation dispersion index (ODI) - based of NODDI*
- *Orientation distribution function (ODF) - to describe the directionality of multimodal diffusion*

]

[Ed. Note. TODO: Review against Lin M, Yu X, Chen Y, Ouyang H, Wu B, Zheng D, et al. Contribution of mono-exponential, bi-exponential and stretched exponential model-based diffusion-weighted MR imaging in the diagnosis and differentiation of uterine cervical carcinoma. European Radiology. 2016;1–11.

Correction Wording:

*Amend DICOM PS3.3 as follows (changes to existing text are bold and **underlined** for additions and ~~struckthrough~~ for removals):*

C.7.6.16.2.11.1.2 Real World Values Mapping Sequence Attributes

...

The physical units for the real world values obtained from the sequence item are given by the Measurement Units Code Sequence (0040,08EA).

The quantity that the real world values represent may be described by the Quantity Definition Sequence (0040,9220), which consists of a list of name-value pairs, in which the coded concept name specifies what aspect of the physical quantity is being described.

Note

1. For example, Cerebral Blood Flow (CBF) may be described by units and quantity as follows:
   - Measurement Units Code Sequence (0040,08EA) = (ml/[100]g/min, UCUM, "milliliter per 100 gram per minute")
   - Quantity Definition Sequence (0040,9220):
     - (G-C1C6, SRT, "Quantity") = (113055, DCM, "Regional Cerebral Blood Flow")
2. **<u>For example, the Apparent Diffusion Coefficient (ADC) may be described by units and quantity as follows:</u>**
   - **<u>Measurement Units Code Sequence (0040,08EA) = (mm2/s, UCUM, "mm2/s")</u>**
   - **<u>Quantity Definition Sequence (0040,9220):</u>**
     - **<u>(G-C1C6, SRT, "Quantity") = (113041, DCM, "Apparent Diffusion Coefficient")</u>**

   <u>Additional information about how the ADC was derived, e.g., the model used, method of fitting and acquisition b-values used, can also be encoded as name-value pairs in the Quantity Definition Sequence (0040,9220). Other diffusion models and quantities are also defined. See the example in PS3.17 Annex XXX.</u>

The Quantity Definition Sequence (0040,9220) describes only the stored pixel values that are mapped using the Real World Values Mapping, and does not describe derived values from multiple pixels to which the Real World Values Mapping applies.

Note

I.e., the mapping is a "point" operation, and as a consequence various modifiers that might be applied to a group of pixels, such as in an ROI, should not be used. E.g., an ROI encoded in a Structured Report using TID 1419 "ROI Measurements" might be the mean or maximum value (e.g., SUVbw mean or SUVbw max), and be encoded with (121401, DCM, "Derivation") = (R-00317, SRT, "Mean") or (G-A437, SRT, "Maximum"), respectively. These would not be appropriate to use within Quantity Definition Sequence (0040,9220), unless the individual pixel values were themselves derived in such a manner, e.g., when multiple images are averaged together. Thus the content items used in an SR to describe an ROI might be a superset of the name-value pairs used in Quantity Definition Sequence (0040,9220).

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C.8.32.2 Parametric Map Image Module

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Table C.8.32-2. Parametric Map Image Module Attributes

Attribute Name	Tag	Type	Attribute Description
Image Type	(0008,0008)	1	Image identification characteristics. **Enumerated Values for Value 1:** **DERIVED** **Enumerated Values for Value 2:** **PRIMARY** Value 3 shall be Image Flavor, **common** Defined Terms for which are specified in Section C.8.16.1.3**, CT-specific Defined Terms for which are specified in Section C.8.15.2.1.1.3 and MR-specific Defined Terms for which are specified in Section C.8.13.1.1.1.3**. Value 4 shall be Derived Pixel Contrast, common Defined Terms for which are specified in Section C.8.16.1.4**, CT-specific Defined Terms for which are specified in Section C.8.15.2.1.1.4** and MR-specific Defined Terms for which are specified in Section C.8.13.1.1.1.4.

C.8.32.3.1 Parametric Map Frame Type Macro

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Table C.8.32-3. Parametric Map Frame Type Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Parametric Map Frame Type Sequence	(0040,9092)	1	Identifies the characteristics of this Parametric Map 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.8.32.2.

*Amend DICOM PS3.16 as follows (changes to existing text are bold and **underlined** for additions and ~~**struckthrough**~~ for removals):*

CID 7180 Abstract Multi-dimensional Image Model Component Semantics

Type: **Extensible**
Version: ~~**20160314**~~**yyyymmdd**

Table CID 7180. Abstract Multi-dimensional Image Model Component Semantics

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
Include CID 4033 "MR Proton Spectroscopy Metabolites"				
DCM	113063	T1		
DCM	113065	T2		
DCM	113064	T2*		
DCM	113058	Proton Density		

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
DCM	110800	Spin Tagging Perfusion MR Signal Intensity		
DCM	113070	Velocity encoded		
DCM	113067	Temperature encoded		
DCM	110801	Contrast Agent Angio MR Signal Intensity		
DCM	110802	Time Of Flight Angio MR Signal Intensity		
DCM	110803	Proton Density Weighted MR Signal Intensity		
DCM	110804	T1 Weighted MR Signal Intensity		
DCM	110805	T2 Weighted MR Signal Intensity		
DCM	110806	T2* Weighted MR Signal Intensity		
Include Section CID nnn1 "MR Diffusion Component Semantics"				
Include Section CID nnn2 "MR Diffusion Model Parameters"				
~~**DCM**~~	~~**113043**~~	~~**Diffusion weighted**~~		
DCM	110807	Field Map MR Signal Intensity		
~~**DCM**~~	~~**110808**~~	~~**Fractional Anisotropy**~~		
~~**DCM**~~	~~**110809**~~	~~**Relative Anisotropy**~~		
~~**DCM**~~	~~**113041**~~	~~**Apparent Diffusion Coefficient**~~		
~~**DCM**~~	~~**110810**~~	~~**Volumetric Diffusion Dxx Component**~~		
~~**DCM**~~	~~**110811**~~	~~**Volumetric Diffusion Dxy Component**~~		
~~**DCM**~~	~~**110812**~~	~~**Volumetric Diffusion Dxz Component**~~		
~~**DCM**~~	~~**110813**~~	~~**Volumetric Diffusion Dyy Component**~~		
~~**DCM**~~	~~**110814**~~	~~**Volumetric Diffusion Dyz Component**~~		
~~**DCM**~~	~~**110815**~~	~~**Volumetric Diffusion Dzz Component**~~		
DCM	110816	T1 Weighted Dynamic Contrast Enhanced MR Signal Intensity		
DCM	110817	T2 Weighted Dynamic Contrast Enhanced MR Signal Intensity		
DCM	110818	T2* Weighted Dynamic Contrast Enhanced MR Signal Intensity		
DCM	110819	Blood Oxygenation Level		
DCM	110820	Nuclear Medicine Projection Activity		
DCM	110821	Nuclear Medicine Tomographic Activity		
DCM	110822	Spatial Displacement X Component		
DCM	110823	Spatial Displacement Y Component		
DCM	110824	Spatial Displacement Z Component		
DCM	110825	Hemodynamic Resistance		
DCM	110826	Indexed Hemodynamic Resistance		
DCM	112031	Attenuation Coefficient		
DCM	110827	Tissue Velocity		
DCM	110828	Flow Velocity		
SRT	P0-02241	Power Doppler	425704008	C1960437
DCM	110829	Flow Variance		

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
DCM	110830	Elasticity		
DCM	110831	Perfusion		
DCM	110832	Speed of sound		
DCM	110833	Ultrasound Attenuation		
DCM	113068	Student's T-test		
DCM	113071	Z-score		
DCM	113057	R-Coefficient		
DCM	126220	R2-Coefficient		
DCM	110834	RGB R Component		
DCM	110835	RGB G Component		
DCM	110836	RGB B Component		
DCM	110837	YBR FULL Y Component		
DCM	110838	YBR FULL CB Component		
DCM	110839	YBR FULL CR Component		
DCM	110840	YBR PARTIAL Y Component		
DCM	110841	YBR PARTIAL CB Component		
DCM	110842	YBR PARTIAL CR Component		
DCM	110843	YBR ICT Y Component		
DCM	110844	YBR ICT CB Component		
DCM	110845	YBR ICT CR Component		
DCM	110846	YBR RCT Y Component		
DCM	110847	YBR RCT CB Component		
DCM	110848	YBR RCT CR Component		
DCM	110849	Echogenicity		
DCM	110850	X-Ray Attenuation		
DCM	112031	Attenuation Coefficient		
DCM	110852	MR signal intensity		
DCM	110853	Binary Segmentation		
DCM	110854	Fractional Probabilistic Segmentation		
DCM	110855	Fractional Occupancy Segmentation		
DCM	126393	R1		
DCM	126394	R2		
DCM	113098	Magnetization Transfer Ratio		
Include CID 4107 "Tracer Kinetic Model Parameters"				
Include CID 4108 "Perfusion Model Parameters"				
Include CID 4109 "Model-Independent Dynamic Contrast Analysis Parameters"				
DCM	126400	Standardized Uptake Value		
DCM	126401	SUVbw		
DCM	126402	SUVlbm		
DCM	126405	SUVlbm(Janma)		

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
DCM	126403	SUVbsa		
DCM	126404	SUVibw		

CID 7181 Abstract Multi-dimensional Image Model Component Units

Type: **Extensible**
Version: **~~20141110~~yyyymmdd**

Table CID 7181. Abstract Multi-dimensional Image Model Component Units

Coding Scheme Designator	Code Value	Code Meaning
Include CID 3500 "Pressure Units"		
Include CID 3502 "Hemodynamic Resistance Units"		
Include CID 3503 "Indexed Hemodynamic Resistance Units"		
Include CID 7460 "Units of Linear Measurement"		
Include CID 7461 "Units of Area Measurement"		
Include CID 7462 "Units of Volume Measurement"		
Include CID 84 "PET Units"		
UCUM	1	no units
UCUM	{ratio}	ratio
UCUM	[hnsf'U]	Hounsfield Unit
UCUM	{counts}	Counts
UCUM	{counts}/s	Counts per second
UCUM	[arb'U]	arbitrary unit
UCUM	cm/s	centimeter/second
UCUM	mm/s	millimeter/second
UCUM	dB	decibel
UCUM	Cel	degrees Celsius
UCUM	ml/min	milliliter per minute
UCUM	ml/s	milliliter per second
UCUM	ms	millisecond
UCUM	s	second
UCUM	Hz	Hertz
UCUM	mT	milliTesla
UCUM	{Particles}/[100]g{Tissue}	number particles per 100 gram of tissue
UCUM	mm2/s	square millimeter per second
UCUM	**um2/ms**	**um2/ms**
UCUM	**um2/s**	**um2/s**
UCUM	**10-6.mm2/s**	**10-6.mm2/s**
UCUM	s/mm2	second per square millimeter
UCUM	ml/[100]g/min	milliliter per 100 gram per minute
UCUM	ml/[100]ml	milliliter per 100 milliliter

Coding Scheme Designator	Code Value	Code Meaning
UCUM	mmol/kg{WetWeight}	millimoles per kg wet weight
UCUM	/min	/min
UCUM	/s	/s

Add new Context Groups to DICOM PS3.16 as follows:

CID nnn1 MR Diffusion Component Semantics

Type: **Extensible**
Version: **yyyymmdd**

Table CID nnn1. MR Diffusion Component Semantics

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
DCM	113043	Diffusion weighted		
DCM	110808	Fractional Anisotropy		
DCM	110809	Relative Anisotropy		
DCM	110810	Volumetric Diffusion Dxx Component		
DCM	110811	Volumetric Diffusion Dxy Component		
DCM	110812	Volumetric Diffusion Dxz Component		
DCM	110813	Volumetric Diffusion Dyy Component		
DCM	110814	Volumetric Diffusion Dyz Component		
DCM	110815	Volumetric Diffusion Dzz Component		

CID nnn2 MR Diffusion Model Parameters

Type: **Extensible**
Version: **yyyymmdd**

Table CID nnn2. MR Diffusion Model Parameters

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-CT Concept ID	UMLS Concept Unique ID
DCM	113041	Apparent Diffusion Coefficient		C3890194
DCM	xxx099	Diffusion Coefficient		
DCM	xxx100	Mono-exponential Apparent Diffusion Coefficient		
DCM	xxx101	Slow Diffusion Coefficient		
DCM	xxx102	Fast Diffusion Coefficient		
DCM	xxx103	Fast Diffusion Coefficient Fraction		
DCM	xxx104	Kurtosis Diffusion Coefficient		
DCM	xxx105	Gamma Distribution Scale Parameter		
DCM	xxx106	Gamma Distribution Shape Parameter		
DCM	xxx107	Gamma Distribution Mode		
DCM	xxx108	Distributed Diffusion Coefficient		
DCM	xxx109	Anomalous Exponent Parameter		

CID nn11 MR Diffusion Models

Type: **Extensible**
Version: **yyyymmdd**

Table CID nn11. MR Diffusion Models

Coding Scheme Designator	Code Value	Code Meaning
DCM	xxxx10	Mono-exponential diffusion model
DCM	xxxx11	Bi-exponential (IVIM) diffusion model
DCM	xxxx12	Kurtosis diffusion model
DCM	xxxx13	Gamma distribution model
DCM	xxxx14	Stretched exponential diffusion model
DCM	xxxx15	Truncated Gaussian diffusion model

Note

CID nn12 MR Diffusion Model Fitting Methods

Type: **Extensible**
Version: **yyyymmdd**

Table CID nn12. MR Diffusion Model Fitting Methods

Coding Scheme Designator	Code Value	Code Meaning
DCM	xxxx20	Log of ratio of two samples
DCM	xxxx21	Least squares fit of multiple samples
DCM	xxxx25	Levenberg–Marquardt
DCM	xxxx26	Trust-Region
DCM	xxxx27	Fixed-Dp
DCM	xxxx28	Segmented-Unconstrained
DCM	xxxx29	Segmented-Constrained
DCM	xxxx30	Bayesian-Probability

Note

CID nn13 MR Diffusion Model Specific Methods

Type: **Extensible**
Version: **yyyymmdd**

Table CID nn13. MR Diffusion Model Specific Methods

Coding Scheme Designator	Code Value	Code Meaning
DCM	xxxx55	Voxelwise selection of b-value

Note

CID nn14 MR Diffusion Model Inputs

Type: **Extensible**
Version: **yyyymmdd**

Table CID nn14. MR Diffusion Model Inputs

Coding Scheme Designator	Code Value	Code Meaning
DCM	xxxxx1	Source image diffusion b-value

Note

*Amend DICOM PS3.16 as follows (changes to existing text are bold and **underlined** for additions and ~~**struckthrough**~~ for removals):*

D DICOM Controlled Terminology Definitions (Normative)

Table D-1. DICOM Controlled Terminology Definitions

Code Value	Code Meaning	Definition	Notes
113041	Apparent Diffusion Coefficient	Values are derived by calculation of the apparent diffusion coefficient. **This concept may be used for the diffusion coefficient of various different models, e.g., mono-exponential (ADC_m), kurtosis (ADC_k), stretched-exponential (ADC_s).** **The "apparent" appellation is because the diffusion images from which the ADC is computed may also be affected by T2 contrast (T2 "shine-through"), so this concept is distinguished from a "pure" diffusion coefficient that is not so affected.**	**Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time.** **Graessner J. Frequently Asked Questions: Diffusion-Weighted Imaging (DWI). MAGNETOM Flash. Siemens. 2011 Jan. http://clinical-mri.com/wp-content/uploads/software_hardware_updates/Graessner.pdf** **Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482**
121050	Equivalent Meaning of Concept Name	The human readable meaning of the name component of a name-value pair that is equivalent to the post-coordinated meaning conveyed by the coded name and its concept modifier children.	
121322	Source image for image processing operation	Image used as the source for an image processing operation.	
121401	Derivation	Method of deriving or calculating a measured value. E.g., mean, or maximum of set.	
126220	R2-Coefficient	Coefficient of determination, R^2. An indication of goodness of fit.	
...	...	...	...

Code Value	Code Meaning	Definition	Notes
xxxxx1	Source image diffusion b-value	.	
xxxxx2	Model fitting method	.	
...	...	...	...
xxxx10	Mono-exponential diffusion model	Mono-exponential (single compartment) Apparent Diffusion Coefficient (ADC) model.	Burdette JH, Elster AD, Ricci PE. Calculation of apparent diffusion coefficients (ADCs) in brain using two-point and six-point methods. J Comput Assist Tomogr. 1998 Oct;22(5):792–4. http://journals.lww.com/jcat/pages/articleviewer.aspx?year=1998&issue=09000&article=00023&type=abstract Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482
xxxx11	Bi-exponential (IVIM) diffusion model	Bi-exponential intravoxel incoherent motion (IVIM) model.	Merisaari H, Movahedi P, Perez IM, Toivonen J, Pesola M, Taimen P, et al. Fitting methods for intravoxel incoherent motion imaging of prostate cancer on region of interest level: Repeatability and gleason score prediction. Magnetic Resonance in Medicine. 2016. http://dx.doi.org/10.1002/mrm.26169 Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482 Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765
xxxx12	Kurtosis diffusion model	.	Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482
xxxx13	Gamma distribution model	.	Oshio K, Shinmoto H, Mulkern RV. Interpretation of diffusion MR imaging data using a gamma distribution model. Magn Reson Med Sci. 2014;13: 191–195. http://dx.doi.org/10.2463/mrms.2014-0016

Code Value	Code Meaning	Definition	Notes
xxxx14	Stretched exponential diffusion model	.	Bennett KM, Schmainda KM, Bennett RT, Rowe DB, Lu H, Hyde JS. Characterization of continuously distributed cortical water diffusion rates with a stretched-exponential model. Magn Reson Med. 2003;50: 727–734. http://dx.doi.org/10.1002/mrm.10581 Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482
xxxx15	Truncated Gaussian diffusion model	.	Yablonskiy DA, Bretthorst GL, Ackerman JJH. Statistical model for diffusion attenuated MR signal. Magnetic Resonance in Medicine. 2003;50(4):664–9. http://dx.doi.org/10.1002/mrm.10578
...	...	...	...
xxxx20	Log of ratio of two samples	Model fitting by using the log of the ratio of the two samples.	Burdette JH, Elster AD, Ricci PE. Calculation of apparent diffusion coefficients (ADCs) in brain using two-point and six-point methods. J Comput Assist Tomogr. 1998 Oct;22(5):792–4. http://journals.lww.com/jcat/pages/articleviewer.aspx?year=1998&issue=09000&article=00023&type=abstract
xxxx21	Least squares fit of multiple samples	Model fitting by least squares method from more than two samples.	Burdette JH, Elster AD, Ricci PE. Calculation of apparent diffusion coefficients (ADCs) in brain using two-point and six-point methods. J Comput Assist Tomogr. 1998 Oct;22(5):792–4. http://journals.lww.com/jcat/pages/articleviewer.aspx?year=1998&issue=09000&article=00023&type=abstract
xxxx25	Levenberg–Marquardt	Model fitting by Levenberg–Marquardt method.	Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765
xxxx26	Trust-Region	Model fitting by Trust-Region method.	Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765
xxxx27	Fixed-Dp	Model fitting by Fixed-Dp method.	Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765
xxxx28	Segmented-Unconstrained	Model fitting by Segmented-Unconstrained method.	Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765

Code Value	Code Meaning	Definition	Notes
xxxx29	Segmented-Constrained	Model fitting by Segmented-Constrained method.	Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765
xxxx30	Bayesian-Probability	Model fitting by Bayesian-Probability method.	Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765 Neil JJ, Bretthorst GL. On the use of bayesian probability theory for analysis of exponential decay date: An example taken from intravoxel incoherent motion experiments. Magnetic Resonance in Medicine. 1993;29(5):642–7. http://dx.doi.org/10.1002/mrm.1910290510
...	...	...	...
xxxx55	Voxelwise selection of b-value	Diffusion modeling by voxelwise selection of b-values.	Gatidis S, Schmidt H, Martirosian P, Nikolaou K, Schwenzer NF. Apparent diffusion coefficient-dependent voxelwise computed diffusion-weighted imaging: An approach for improving SNR and reducing T2 shine-through effects. Journal of Magnetic Resonance Imaging. 2016;43(4):824–32. http://dx.doi.org/10.1002/jmri.25044
...	...	...	...
xxx099	Diffusion Coefficient	The pure diffusion coefficient, i.e., one that is not affected by T2 contrast effects.	Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time. Graessner J. Frequently Asked Questions: Diffusion-Weighted Imaging (DWI). MAGNETOM Flash. Siemens. 2011 Jan. http://clinical-mri.com/wp-content/uploads/software_hardware_updates/Graessner.pdf
xxx100	Mono-exponential Apparent Diffusion Coefficient	The diffusion coefficient of a mono-exponential diffusion model (ADC_m).	Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time. Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482

Code Value	Code Meaning	Definition	Notes
xxx101	Slow Diffusion Coefficient	The slow diffusion coefficient (D_s) of a bi-exponential intravoxel incoherent motion (IVIM) diffusion model.	Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time. Merisaari H, Movahedi P, Perez IM, Toivonen J, Pesola M, Taimen P, et al. Fitting methods for intravoxel incoherent motion imaging of prostate cancer on region of interest level: Repeatability and gleason score prediction. Magnetic Resonance in Medicine. 2016. http://dx.doi.org/10.1002/mrm.26169 Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482 Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765
xxx102	Fast Diffusion Coefficient	The fast diffusion coefficient (D_f) of a bi-exponential intravoxel incoherent motion (IVIM) diffusion model.	Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time. Merisaari H, Movahedi P, Perez IM, Toivonen J, Pesola M, Taimen P, et al. Fitting methods for intravoxel incoherent motion imaging of prostate cancer on region of interest level: Repeatability and gleason score prediction. Magnetic Resonance in Medicine. 2016. http://dx.doi.org/10.1002/mrm.26169 Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482 Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765

Code Value	Code Meaning	Definition	Notes
xxx103	**Fast Diffusion Coefficient Fraction**	**The fast diffusion fraction of a bi-exponential intravoxel incoherent motion (IVIM) diffusion model..**	**Units are dimensionless {0:1}.** **Merisaari H, Movahedi P, Perez IM, Toivonen J, Pesola M, Taimen P, et al. Fitting methods for intravoxel incoherent motion imaging of prostate cancer on region of interest level: Repeatability and gleason score prediction. Magnetic Resonance in Medicine. 2016. http://dx.doi.org/10.1002/mrm.26169** **Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482** **Barbieri S, Donati OF, Froehlich JM, Thoeny HC. Impact of the calculation algorithm on biexponential fitting of diffusion-weighted MRI in upper abdominal organs. Magnetic Resonance in Medicine. 2016;75(5):2175–84. http://dx.doi.org/10.1002/mrm.25765**
xxx104	**Kurtosis Diffusion Coefficient**	**The diffusion coefficient of a kurtosis diffusion model (ADC_k).**	**Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time.** **Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482**
xxx105	**Gamma Distribution Scale Parameter**	**The scale (theta) parameter of a gamma distribution diffusion model.**	**Units are dimensionless.** **Oshio K, Shinmoto H, Mulkern RV. Interpretation of diffusion MR imaging data using a gamma distribution model. Magn Reson Med Sci. 2014;13: 191–195. http://dx.doi.org/10.2463/mrms.2014-0016**
xxx106	**Gamma Distribution Shape Parameter**	**The shape (k) parameter of a gamma distribution diffusion model.**	**Units are dimensionless.** **Oshio K, Shinmoto H, Mulkern RV. Interpretation of diffusion MR imaging data using a gamma distribution model. Magn Reson Med Sci. 2014;13: 191–195. http://dx.doi.org/10.2463/mrms.2014-0016**
xxx107	**Gamma Distribution Mode**	**The mode (maximum value of probability density function) of a gamma distribution diffusion model. Computed as (k-1)*theta, for k >= 1.**	**Units are dimensionless.** **https://en.wikipedia.org/wiki/Gamma_distribution**

Code Value	Code Meaning	Definition	Notes
xxx108	**Distributed Diffusion Coefficient**	**The distributed diffusion coefficient of a stretched-exponential diffusion model (ADC_s).**	**Units are mm2/s, um2/ms, um2/s, 10-6.mm2/s or other scaled variants of area/time.** **Bennett KM, Schmainda KM, Bennett RT, Rowe DB, Lu H, Hyde JS. Characterization of continuously distributed cortical water diffusion rates with a stretched-exponential model. Magn Reson Med. 2003;50: 727–734. http://dx.doi.org/10.1002/mrm.10581** **Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482**
xxx109	**Anomalous Exponent Parameter**	**The anamalous exponent (stretching, alpha) parameter of a stretched-exponential diffusion model. This describes the deviation of the signal attenuation from mono-exponential behavior**	**Units are dimensionless {0:1}.** **Bennett KM, Schmainda KM, Bennett RT, Rowe DB, Lu H, Hyde JS. Characterization of continuously distributed cortical water diffusion rates with a stretched-exponential model. Magn Reson Med. 2003;50: 727–734. http://dx.doi.org/10.1002/mrm.10581** **Toivonen J, Merisaari H, Pesola M, Taimen P, Boström PJ, Pahikkala T, et al. Mathematical models for diffusion-weighted imaging of prostate cancer using b values up to 2000 s/mm2: Correlation with Gleason score and repeatability of region of interest analysis. Magnetic Resonance in Medicine. 2015;74(4):1116–24. http://dx.doi.org/10.1002/mrm.25482**

Add new Annex to DICOM PS3.17 as follows:

XXX Encoding Diffusion Model Parameters for Parametric Maps and ROI Measurements (Informative)

This Annex contains examples of how to encode diffusion models and acquisition parameters within the Quantity Definition Sequence of Parametric Maps and in ROIs in Measurement Report SR Documents.

The approach suggested is to describe that an ADC value is being measured by using ADC (generic) as the concept name of the numeric measurement, and to add post-coordinated concept modifiers to describe:

- the model (e.g., mono-exponential, bi-exponential or other multi-compartment models) (drawn from CID nn11 “MR Diffusion Models”)
- the method of fitting the data points to that model (e.g., for mono-exponential models, log of ratio of two samples, linear least-squares for log-intensities of all b-values) (drawn from CID nn12 “MR Diffusion Model Fitting Methods”)
- relevant numeric parameters, such as the b-values used during acquisition of the source images (drawn from CID nn13 “MR Diffusion Model Specific Methods”)

The model and method of fitting are encoded separately since even though the method of fitting is sometimes dependent on the model, the model may be known but not the method of fitting, or there may be no code for the method of fitting.

Note

1. The generic concept of ADC, (113041, DCM, "Apparent Diffusion Coefficient"), is used, rather than the specific concept of ADC_m, (xxx100, DCM, "Mono-exponential Apparent Diffusion Coefficient"), since the model is expressed in a post-coordinated manner. Most clinical users will not be concerned with which model was used, and so the ability to display and query for a single generic concept is preferred. However, model-specific pre-coordinated concepts for ADC are provided, as are concepts for other model parameters when a single ADC concept is inappropriate, e.g., for the fast and slow components of a bi-dimensional model.

2. The generic concept of (G-C306, SRT, "Measurement Method") is used to describe the model, rather than being used to described the fitting method, since the model is the more important aspect of the measurement to distinguish. This pattern is consistent with historical precedent (e.g., in PS3.17 RRR.3 the model (Extended Tofts) for DCE-MR measurements is described using the Measurement Method and the fitting method is not described).

Also illustrated is how the (121050, DCM, "Equivalent Meaning of Concept Name") can be used to communicate a single human readable textual description for the entire concept.

XXX.1 Encoding Diffusion Model Parameters for Parametric Maps

This example shows how to use the PS3.3 Table C.7.6.16-12b "Real World Value Mapping Item Macro Attributes" to describe pixel values of an ADC parametric map obtained from a pair of B0 and B1000 images using an XXX fit to a mono-exponential function (single compartment model). It elaborates on the simple example provided in PS3.3 Section C.7.6.16.2.11.1.2 by adding coded concepts that describe the model, the method of fitting and listing the b-values used.

- Real World Value MappingSequence (0040,9096)
  - ...
  - Real World Value Intercept (0040,9225) = "0"
  - Real World Value Slope (0040,9225) = "1E-06"
  - LUT Explanation (0028,3003) = "ADC mm2/s mono-exponential log ratio B0 and B1000"
  - LUT Label (0040,9210) = "ADC mm2/s"
  - Measurement Units Code Sequence (0040,08EA) = (mm2/s, UCUM, "mm2/s")
  - Quantity Definition Sequence (0040,9220):
    - CODE (G-C1C6, SRT, "Quantity") = (113041, DCM, "Apparent Diffusion Coefficient")
    - CODE (G-C306, SRT, "Measurement Method") = (xxxx10, DCM, "Mono-exponential ADC model")
    - CODE (xxxxx2, DCM, "Model fitting method") = (xxxx20, DCM, "Log of ratio of two samples")
    - NUMERIC (xxxxx1, DCM, "Source image diffusion b-value") = 0 (s/mm2, UCUM, "s/mm2")
    - NUMERIC (xxxxx1, DCM, "Source image diffusion b-value") = 1000 (s/mm2, UCUM, "s/mm2")
    - TEXT (121050, DCM, "Equivalent Meaning of Concept Name") = "ADC mono-exponential log ratio B0 and B1000"

In this usage, the text of the (121050, DCM, "Equivalent Meaning of Concept Name") is redundant with the value of LUT Explanation (0028,3003); either or both could be omitted.

The parameter describing a b-value of 0 is expected to be sent, and one should not assume that a b-value of 0 is used if it is absent, since some methods may use a low b-value (e.g., 50), which is not 0.

There is no concensus in the MR community or scientific literature as to the appropriate units to use to report diffusion coefficient values to the user, nor amongst the MR vendors as to how to encode them. In this example, the units are specified as "s/mm2". If the diffusion coefficient pixel values were encoded as integers with such a unit, they could then be encoded with a Rescale Slope of 1E-06, given the typical range of values encountered. Alternatively, the pixel values could be encoded as floating point pixel data values with identity rescaling. Or, if the units were specified "um2/s" (or "10-6.mm2/s", which is the same thing), then integer pixels could be used with a Rescale Slope of 1. Application software can of course rescale the values for display and convert the units as appropriate to the user's preference, as long as they are unambiguously encoded.

XXX.2 Encoding Diffusion Model Parameters for ROIs in Measurement Report SR Documents

This example shows how to describe the mean ADC value of a region of interest on a volume of ADC values obtained from a pair of B0 and B1000 images using an XXX fit to a mono-exponential function (single compartment model). In this case the template used is TID 1419 ROI Measurements.

- NUM (113041, DCM, "Apparent Diffusion Coefficient") = 0.75E-3 (mm2/s, UCUM, "mm2/s")
  - *HAS CONCEPT MOD* CODE (G-C306, SRT, "Measurement Method") = (xxxx10, DCM, "Mono-exponential ADC model")
  - *HAS CONCEPT MOD* CODE (xxxxx2, DCM, "Model fitting method") = (xxxx20, DCM, "Log of ratio of two samples")
  - *HAS CONCEPT MOD* CODE (121401, DCM, "Derivation") = (R-00317, SRT, "Mean")
  - *INFERRED FROM* NUM (xxxxx1, DCM, "Source image diffusion b-value") = 0 (s/mm2, UCUM, "s/mm2")
  - *INFERRED FROM* NUM (xxxxx1, DCM, "Source image diffusion b-value") = 1000 (s/mm2, UCUM, "s/mm2")
  - *HAS CONCEPT MOD* TEXT (121050, DCM, "Equivalent Meaning of Concept Name") = "Mean ADC mono-exponential log ratio B0 and B1000"

XXX.3 Relationship of Derived Diffusion Model Parametric Maps to Diffusion Weighted Source Images

This example illustrates how to describe the manner in which an ADC Parametric Map image was derived from B0 and B1000 images. The intent is to provide links to the images, not to replicate all the information that can be provided in the Quantity Definition Sequence.

This particular example illustrates the reference from an ADC Parametric Map to a pair of Enhanced MR images, one for each b-value (or a pair of subsets of frames of a single Enhanced MR image), but the same principle is applicable when single frame IODs are used as source or derived image.

- Derivation Image Sequence (0008,9124)
  - Derivation Description (0008,2111) = "Calculation of mono-exponential ADC from log of ratio of B0 and B1000 images"
  - Derivation Code Sequence (0008,9215)
    - (113041, DCM, "Apparent Diffusion Coefficient")
    - (xxxx10, DCM, "Mono-exponential ADC from log of ratio of two samples")
  - Source Image Sequence (0008,2112)
    - Item 1:
      - Referenced SOP Class UID (0008,1150) of B0 image
      - Referenced SOP Instance UID (0008,1155) of B0 image
      - Referenced Frame Number (0008,1160) of B0 frames in image
      - Purpose of Reference Code Sequence
        - (121322, DCM, "Source image for image processing operation")
    - Item 2:
      - Referenced SOP Class UID (0008,1150) of B1000 image
      - Referenced SOP Instance UID (0008,1155) of B1000 image

    - Referenced Frame Number (0008,1160) of B1000 frames in image
    - Purpose of Reference Code Sequence
        - (121322, DCM, "Source image for image processing operation")

In this approach:

- since multiple items are permitted in the Derivation Code Sequence (0008,9215), both the general concept (calculation of ADC) and the specific method have been listed; alternatively, just one or the other could be provided
- a textual description has also be provided, which in this case provides more information than the structured content (i.e., about the b-values used)
- a generic purpose of reference code has been used, since only a single code is permitted and there is no mechanism (other then creating pre-coordinated codes for every possible b-value) to convey which image (set) was acquired with which b-value; the more specific alternative of a coded concept for "source image for ADC calculation" would add no value over the concept already described in Derivation Code Sequence
- the SOP Instance UID in the first and second items may be the same, but a different range of frames referenced, e.g., if all of the source frames (all of the b-values) are in the same instance, as is required by the IHE Diffusion (DIFF) profile (http://wiki.ihe.net/index.php/MR_Diffusion_Imaging); if all of the frames in a single source image are used, then only a single item is necessary and the Referenced Frame Number can be omitted.
- all of the images have been listed in a single item of Derivation Image Sequence (0008,9124); alternatively, multiple items of Derivation Image Sequence (0008,9124) could be sent. one for each of the different b-values used; this would allow Derivation Description (0008,2111) to communicate which set contained which b-value, but there is no structured way to communicate such numeric parameters (other then creating pre-coordinated codes for every possible b-value)

XXX.4 Image and Frame of Derived Diffusion Model Parametric Maps

This example illustrates how to encode the Image and Frame Type values of an ADC Parametric Map image.

Parametric maps are of the enhanced multi-frame family, so they use the standard roles of Image Flavor for Value 3 and Derived Pixel Contrast for Value 4.

The specific requirement are defined in PS3.3 Section C.8.32.2 "Parametric Map Image Module" and PS3.3 Section C.8.32.3.1 Parametric Map Frame Type Macro.

Since this is a derived diffusion image that contains ADC value, suitable values are:

- Image Type (0008,0008) = "DERIVED\PRIMARY\DIFFUSION\ADC"

This usage is consistent with the requirements for Image and Frame Type in the IHE Diffusion (DIFF) profile (http://wiki.ihe.net/index.php/MR_Diffusion_Imaging).

XXX.5 Informative References

This section lists useful references related to the taxonomy of ADC calculation methods.

XXX.5.1 ADC Method Descriptions

[Burdette 1998] *J Comput Assist Tomogr*. Burdette JH, Elster AD, and Ricci PE. 1998. 22. 5. 792–4. “Calculation of apparent diffusion coefficients (ADCs) in brain using two-point and six-point methods”. http://journals.lww.com/jcat/pages/articleviewer.aspx?year=1998&issue=09000&article=00023&type=abstract .

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[Yablonskiy 2003] *Magnetic Resonance in Medicine*. Yablonskiy DA, Bretthorst GL, and Ackerman JJH. 2003. 50. 4. 664–9. “Statistical model for diffusion attenuated MR signal”. http://dx.doi.org/10.1002/mrm.10578 .