Digital Imaging and Communications in Medicine (DICOM)

Supplement 181: MR Diffusion Tractography Storage SOP Class

Prepared by:

DICOM Standards Committee, Working Group 16 (MR) & 24 (Surgery)

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DOCUMENT HISTORY

Document Version	Date	Content
01	01-Aug-2014	Initial Draft
02	xx-Sep-2014	Incorporated proposals after T-Con on 08-Aug-2014
03a / 03b	xx-Sep-2014	Different approaches on how to add additional data for discussion in T-Con on 08-Aug-2014
04	10-Oct-2014	Incorporated proposals after T-Con on 08-Aug-2014 for discussion in T-Con on 21-Oct-2014
05	16-Oct-2014	Incorporated feedback via email for discussion in T-Con on 21-Oct-2014
06	27-Oct-2014	Added text to Scope and Field, some descriptions
		Added proposal from D. Clunie in order to store additional values and statistics
		Updated CID XXX2 (algorithms) and added definitions according to J. Reuss mail from 21-Oct-2014
		Updated CID XXX4 (value types) and added definitions according to J. Reuss mail from 23-Oct-2014
		Minor feedback from T-Con Session
07	02-Dec-2014	Moved literatures to the notes column. And add any missing ones (see white paper).
08	09-Dec-2014	Updated Scope and Field
		Incorporated minor changes from RSNA meeting
		Divided algorithm description into: acquisition, model and tracking algorithm
		Description for PS 3.7 See also closed issue Rev06_01
09	19-Dec-2014	Merged Sonia Pujol proposal on CID XXX1 … XXX3.
		Potential proposal for Reference Instance Sequence by different reasons
		Replaced EPI with DTI and DSI
		Add TRACT as Modality

		Added codes Single Shot EPI, Multiple Shot EPI, SENSE to Acquisition types
		Consolidated literature, added missing definitions for Annex D
10	08-Jan-2015	Reverted: Potential proposal for Reference Instance Sequence by different reasons Not needed (t-con 07-Jan-2014)
11	15-Jan-2015	Added Part 17, Example
12	15-Jan-2015	Public Comment

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Scope and Field

This Supplement to the DICOM Standard specifies a new DICOM Information Object for storing magnetic resonance diffusion tractography (MR DT) results (tracks and measurements), which is referred to as MR Diffusion Tractography IOD. It also includes the corresponding Storage SOP Class so that this IOD can be used for network and media storage exchanges.

During the last decades, new MRI and computational methods have emerged that provide invaluable information about white matter fiber tracts in healthy and diseased brains. An MR diffusion *acquisition* sequence (e.g. EPI, HARDI, etc.) collects data reflecting the diffusivity of water and the directionality of its movement. Based upon a *model* of diffusion in tissue (e.g. simple tensor, multiple-tensor, etc.) this information can be used by *tracking algorithms* to estimate the pathways followed by the white matter fiber tracts. The widespread adoption of MR diffusion measurement in the clinical workflow, particularly diffusion tensor imaging (DTI) and tractography, has opened an entirely new non-invasive window on white matter connectivity of the human brain and spinal cord.

MR diffusion tractography uses magnetic resonance imaging and software which is specialized to detect water diffusion in tissue. Molecular diffusion refers to the random movement of molecules (Brownian motion). In densely packed white matter the direction of diffusion is mainly restricted to the local direction of fiber tracts. MRI diffusion imaging is able to quantify diffusion of water along certain directions, typically on a spatial grid with a resolution of 2mm. The commonly-used diffusion tensor model is a simple model that is able to describe the statistical diffusion process accurately at most white matter positions. To calculate diffusion tensors, a base-line MRI without diffusion-weighting and at least six differently weighted diffusion MRIs have to be acquired. After some preprocessing of the data, at each grid point a diffusion tensor can be calculated. This gives rise to a tensor volume that is the basis for tracking. Later refinements to the diffusion model and acquisition method include HARDI, Q-Ball, diffusion spectrum imaging (DSI) and diffusion kurtosis imaging (DKI). These have expanded the directionality information available beyond the simple tensor model, enhancing tracking through crossings, adjacent fibers, sharp turns, and other difficult scenarios.

A tracking algorithm produces tracks (i.e. fibers) which are collected into track sets. A track contains the set of x, y and z coordinates of each point making up the track. Depending upon the algorithm and software used, additional quantities like Fractional Anisotropy (FA) values or color etc. may be associated with the data, by track set, track or point, either to facilitate further filtering or for clinical use. Descriptive statistics of quantities like FA may be associated with the data by track set or track.

Examples of tractography applications include:

- Visualization of white matter tracks to aid in resection planning or to support image guided (neuro)surgery;
- Determination of proximity and/or displacement versus infiltration of white matter by tumor processes;
- Assessment of white matter health in neurodegenerative disorders, both axonal and myelin integrity, through sampling of derived diffusion parameters along the white matter tracks.

OPEN ISSUES

1	Relevant codes for CID XXX4 Diffusion Tractography Value Types have been factored out of CID 7180 Abstract Multi-dimensional Image Model Component Semantics, and some new concepts added. Are there any other concepts required, and do the additional CID XXX4 concepts need to be added to CID 7180 for use outside the tractography object (probably, yes)?
2	The definitions of new concepts in PS3.16 will be updated with proper bibliographic entries before letter ballot (Vancouver Style with links).
3	How much information about the MR acquisition needs to be replicated from the original MR images? The Diffusion Acquisition Sequence contains a subset of image acquisition information that is considered to be important in the context of diffusion tractography (see section C.8.X.1.2). This information may already be part of the original MR images (e.g. “Echo Planar Pulse Sequence”, “Parallel Acquisition” or “Parallel Acquisition Technique”), but by replicating it in the tractography object makes it available without having to loading (or require access to) the images.

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CLOSED ISSUES

Rev02_01	Reuse of Segment Description Macro not suitable, because it contained attributes that are unspecific for fibers. Included needed attributes directly and renamed to avoid confusion with “Segment…”.
Rev02_02	Store multiple track sets in one IOD. ➔ Yes, this shall be supported.
Rev03_01	How to add additional data. Rev 3a and 3b were presented. DTI Subgroup decided to go with variant 3b but to exchange the attribute Additional Diffusion Tractography Parameter Type by a Code Sequence.
Rev03_03	Removed CID XXX1 White Matter Types, replaced by CP1407
Rev04_01	Would it make sense to remove the attribute Algorithm Family Code Sequence for the DTI use-case? ⇨ Clarified the usage of the algorithm macro: • Algorithm Family Code Sequence (0066,002F) specifies the type of the algorithm • Algorithm Name Code Sequence (0066,0030) is manufactor dependent and shall not be standardized any further. • Merge of CID XXX2 and XXX3.
Rev04_02	Changed type and clarified presence of Track Summary Statistics Sequence (gggg,0024) and Floating Point Values (gggg,0025)
Rev04_03	Moved Referenced Instance Sequence (0008,114A) to top level. Since the instances will always be the same for all track sets.
Rev01_01	Missing descriptions for “Scope and Field”, “A.X.1”, “A.X.2” ⇨ Done
Rev04_04	E. Seeberger: Proposal from on how to store statistics; using Include Table C.18.1-1 “Numeric Measurement Macro Attributes” and CID 3488 “Min/Max/Mean” (for details see mails on DTI list) Proposal from J. Reuss: keep as is ⇨ Added proposal from D. Clunie in Rev.06
Rev04_05	J. Reuss: ‘Track Set Property’ seems vague if this refers specifically to CP 1047 anatomical terms. Something like ‘anatomical site’ or ‘structure label’? ⇨ Renamed to “Track Set Anatomical Type Code Sequence” and “Track Set Anatomical Type Modifier Code Sequence”
Rev04_06	W. Corbijn: Several Type 3 issues in Track Point Values Sequence ⇨ refactored with Rev04_04
Rev06_01	Revise: PS 3.3, Section 7.X How to extend the Real World Model (Chap 7)? ⇨ (03-Dec-2014) describe changes textual only.

Rev06_02	The actual statistic value is stored in attributes “Numeric Value”. This is a DS (decimal string). Do we need additional attributes like Floating Point Value, Rational Numerator Value, Rational Denominator Value? ⇨ (Meeting 03-Dec-2014) Keep Floating Point Value, drop rational numbers (no real use case right now, if a real use case appears, it can be added again)
Rev06_03	How to reference literature in DICOM? - Notes column seems not the correct place. - Links vs. Author + Publication Year ⇨ (Meeting 03-Dec-2014) Keep it as is for now
Rev03_02	Add example use cases This should be covered: • Standard Use Cases of transferring Fibers • Additional Data Use Case • Referenced Instance Sequence (0008,114A)

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DICOM PS 3.2 Conformance

80 **Item: Add SOP Class to Table A.1-2**

Table A.1-2
82 **UID VALUES**

UID Value	UID NAME	Category
…		
XXX	MR Diffusion Tractography Storage	Transfer
…		

DICOM PS 3.3: Information Object Definitions

Item: Change Figure 7-1a. DICOM Model of the Real World:

Add "Tractography" to be contained in the Series.

Item: Change Figure 7-2a. DICOM Information Model:

Add "Tractography IOD" to the same level as Surface IOD.

Item: Add in Section A.1.4, rows and column to Table A.1-2

A.1.4 Overview of the Composite IOD Module Content

IODs Modules	**MR Diffusion Tractography Storage**
Patient	**M**
Specimen	**U**
Clinical Trial Subject	**U**
General Study	**M**
Patient Study	**U**
Clinical Trial Study	**U**
General Series	**M**
Clinical Trial Series	**U**
Frame of Reference	**M**
Diffusion Tractography	**M**
General Equipment	**M**
Enhanced General Equipment	**M**
Common Instance Reference	**M**
SOP Common	**M**

Item: Add in the following new section in Annex A

A.X MR DIFFUSION TRACTOGRAPHY STORAGE IOD

A.X.1 MR Diffusion Tractography Storage IOD Description

The MR Diffusion Tractography Storage IOD specifies a DICOM object for storing diffusion tractography results into a collection of track sets. A track set itself collects a set of tracks containing the set of x, y and z coordinates of each point making up the track.

Additional quantities like FA values, color, descriptive statistical values, etc. may be associated, as the case may be, by track set, track or point.

A.X.2 MR Diffusion Tractography Storage IOD Entity-Relationship Model

The E-R Model in Section A.1.2 of this Part depicts those components of the DICOM Information Model that directly reference the MR Diffusion Tractography IOD. Below the Diffusion Tractography IE is used for representation of track sets.

A.X.3 MR Diffusion Tractography Storage IOD Module Table

Table A.X-1. MR Diffusion Tractography Storage IOD Modules

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Specimen	C.7.1.2	U
	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
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Diffusion Tractography	Diffusion Tractography	C.X.1	M
	Common Instance Reference	C.12.2	M
	SOP Common	C.12.1	M

Change: C.7.3.1.1.1 Modality

…

STAIN Automated Slide Stainer

TRACT Diffusion Tractography

TG Thermography

…

Item: Add in the following new sections in C

C.8.X Diffusion Tractography Storage Modules

This Section describes Diffusion Tractography Modules.

C.8.X.1 Diffusion Tractography Module

Table C.8.X-1 contains IOD Attributes that describe a diffusion tractography.

Table C.8.X-1
DIFFUSION TRACTOGRAPHY MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Include Table 10-12 "Content Identification Macro Attributes"			
Content Date	(0008,0023)	1	The date the content creation started.
Content Time	(0008,0033)	1	The time the content creation started.
Track Set Sequence	(gggg,eee1)	1	Describes the track sets that are contained within the data. One or more Items shall be included in this sequence.
>Track Set Number	(gggg,eee5)	1	Identification number of the Track Set. The value of Track Set Number (gggg,eee5) shall be unique within this instance, start at a value of 1, and increase monotonically by 1.
>Track Set Label	(gggg,eee6)	1	User-defined label identifying this Track Set. This may be the same as Code Meaning (0008,0104) of Track Set Property Type Code Sequence (gggg,eee8).
>Track Set Description	(gggg,eee7)	3	User-defined description for this Track Set.
>Track Set Anatomical Type Code Sequence	(gggg,eee8)	1	Sequence defining the specific property type of this Track Set. Only a single item shall be included in this sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Baseline CID cp1407_SSS.*
>>Track Set Anatomical Type Modifier Code Sequence	(gggg,eee9)	3	Sequence defining the modifier of the property type of this Track Set. One or more Items are permitted in this sequence.

>>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Baseline CID 244 "Laterality".*
>Track Sequence	(gggg,eee2)	1	Describes individual tracks part of the track set.
>>Point Coordinates Data	(0066,0016)	1	Point coordinates that define the track, encoded as successive x,y,z points, in mm in the patient-based coordinate system associated with the Frame of Reference. The order of the encoded points is from the first point to the last point of a track.
>>Track Point Values Sequence	(gggg,0021)	3	Values for some or all points of this track. See section C.8.X.1.1 for more details. One or more items may be present in this Sequence.
>>>Track Point Value Type Code Sequence	(gggg,0022)	1	Defines the type of value data stored in this Item. Only a single item shall be included in this sequence.
>>>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID XXX4 Diffusion Tractography Value Types*
>>>Measurement Units Code Sequence	(0040,08EA)	1	Units of measurement for the statistic.
>>>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID 82 "Units of Measurement".*
>>>Floating Point Values	(gggg,0025)	1C	A value for every point stored in Point Coordinate Data (0066, 0016). Number of values shall match the numbers of points stored in Point Coordinates Data (0066, 0016), and be encoded in the same order so as to correspond. Required if Coordinate Value Pairs Sequence (gggg,0026) is not present.
>>>Coordinate Value Pairs Sequence	(gggg,0026)	1C	The value for a subset of points stored in Point Coordinates Data (0066, 0016). Required if Floating Point Values (gggg,0025) is not present.
>>>>Point Index	(gggg,0029)	1	The index of an (x,y,z) point encoded in Point Coordinates Data (0066,0016) such that the first point ((x,y,z) tuple) is numbered 1, the second point is 2, etc. Note: This is the index of the (x,y,z) tuple, not the offset of the individual x, y and z values. I.e., the second point is 2, not 4.
>>>>Floating Point Value	(0040,A161)	1	The value for the point specified by Point Index (gggg,0029).

>>Summary Statistics Sequence	(gggg,0024)	3	Statistics derived from the values for this Track. One or more items may be present in this Sequence. Note: Statistics may be present even if the individual values are not (i.e., Track Point Values Sequence (gggg,0021) is absent.
>>>Include Table C8.X-2 "Summary Statistics Macro Attributes"			*Defined CID for Value Summarized Type Code Sequence (gggg,0027) is CID XXX4 Diffusion Tractography Value Types*
>>Recommended Display CIELab Value List	(gggg,eee3)	1C	Default triplet values in which it is recommended that the point shall be rendered. The units are specified in PCS-Values and the value is encoded as CIELab. See Section C.10.7.1.1. The number of triplets shall match the number of points stored in Point Coordinate Data (0066, 0016), and be encoded in the same order so as to correspond. Shall be present if Recommended Display CIELab Value (0062, 000D) is not present in this Sequence Item nor in the containing Track Set Sequence (gggg,eee1) Item.
>>Recommended Display CIELab Value	(0062,000D)	1C	Default triplet value in which it is recommended that the track shall be rendered. The units are specified in PCS-Values and the value is encoded as CIELab. See Section C.10.7.1.1. Shall be present if Recommended Display CIELab Value List (gggg,eee3) is not present in this Sequence Item and Recommended Display CIELab Value (0062, 000D) is not present in the containing Track Set Sequence (gggg,eee1) Item.
>Recommended Display CIELab Value	(0062,000D)	1C	Default triplet value in which it is recommended that the track set be rendered. The units are specified in PCS-Values, and the value is encoded as CIELab. See Section C.10.7.1.1. Shall be present if neither Recommended Display CIELab Value (0062, 000D) nor Recommended Display CIELab Value List (gggg,eee3) are present in every Item of the Track Sequence (gggg,eee2).
>Summary Statistics Sequence	(gggg,0024)	3	Statistics derived from the values for this Track Set. One or more items may be present in this Sequence.

>>Include Table C8.X-2 "Summary Statistics Macro Attributes"			*Defined CID for Value Summarized Type Code Sequence (gggg,0027) is CID XXX4 Diffusion Tractography Value Types*
>Diffusion Acquisition Sequence	(gggg,eee5)	1	The diffusion acquisition (including post-processing) used to derive this track set. See section C.8.X.1.2 for more details. Only a single item shall be included in this sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID XXX1 Diffusion Acquisition Value Types*
>Diffusion Model Sequence	(gggg,eee6)	1	The diffusion model used to derive this track set. See section C.8.X.1.2 for more details. Only a single item shall be included in this sequence.
>>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID XXX2 Diffusion Model Value Types*
>Tracking Algorithm Identification Sequence	(gggg,eee4)	1	The tractography algorithms used to derive this track set. See section C.8.X.1.2 for more details. One or more items shall be included in this sequence.
>>Include Table 10-19 "Algorithm Identification Macro Attributes"			*For Algorithm Family Code Sequence (0066,002F) Defined CID XXX3 "MR Diffusion Tractography Algorithm Families".*
Referenced Instance Sequence	(0008,114A)	1	A Sequence that defines the set of images used for tractography by their SOP Class/Instance pair. One or more items shall be included in this Sequence.
>Include Table 10-3 "Image SOP Instance Reference Macro Attributes"			

C.8.X.1.1 Diffusion Tractography Module Attributes

This Module encodes one or more Track Sets, each of which consists of one or more Tracks, which is defined by one or more points. For each Track, optionally one or more values may be defined, either for every point or a subset of points. The values are described by coded type and units. For each Track and/or Track Set, summary statistics derived from point values may be included (whether or not the actual values are encoded).

For a particular value type (item of Track Point Values Sequence (gggg,0021)), when a value is encoded for every point in a track, then Floating Point Values (gggg,0025) contains the corresponding value for every point. When only a subset of points in a track are encoded with values then one or more (point index, value) tuples are encoded in Coordinate Value Pairs Sequence (gggg,0026).

More than one Track Point Values Sequence (gggg,0021) Item may be used, for example to encode different types of value, such as FA and ADC, or to encode different components of a value that is a tuple,

e.g. a diffusion tensor. In the later case, which component, and which tensor, will be identified by the fully pre-coordinated code in the Track Point Value Type Code Sequence (gggg,0022).

C.8.X.1.2 Acquisition, Model and Algorithm Attributes

The attributes Diffusion Acquisition Sequence (gggg,eee5), Diffusion Model Sequence (gggg,eee6) and Tracking Algorithm Identification Sequence (gggg,eee4) describe the main parameters influencing the tractography calculation. They are for documentation purposes. With these parameters it is for example possible to make assumptions on the reliability / quality of the tractography result.

C.8.X.2 Summary Statistics Macro

This Macro encodes summary statistics derived from a set of values.

Table Table C.8.X-2
Summary Statistics Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Value Summarized Type Code Sequence	(gggg,0027)	1	The value (quantity) for which the statistic is a summary.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			*CID defined by invocation*
Summary Statistic Type Code Sequence	(gggg,0028)	1	The type of the statistic.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID 7464 General Region of Interest Measurement Modifiers.*
Measurement Units Code Sequence	(0040,08EA)	1	Units of measurement for the statistic.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			*Defined CID 82 "Units of Measurement".*
Numeric Value	(0040,A30A)	1	The value of the statistic. Only a single value shall be present.
Floating Point Value	(0040,A161)	1C	The floating point representation of Numeric Value (0040,A30A). Only a single value shall be present. Required if Numeric Value (0040,A30A) has insufficient precision to represent the value as a string. May be present otherwise.

For reference (unchanged):

10.16 Algorithm Identification Macro

Table 10-19 describes the Attributes for encoding the algorithm used to create or derive a SOP Instance contents. An algorithm is described by the Algorithm Family, a specific Algorithm Name, and an Algorithm Version. A character string containing parameters that were used in the algorithm can be included.

Table 10-19. Algorithm Identification Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Algorithm Family Code Sequence	(0066,002F)	1	The family of algorithm(s) that best describes the software algorithm used. Only a single item shall be included in this sequence.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			Context ID may be defined in the macro invocation.
Algorithm Name Code Sequence	(0066,0030)	3	The code assigned by a manufacturer to a specific software algorithm. Only a single item is permitted in this sequence.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			*No Baseline CID is defined.*
Algorithm Name	(0066,0036)	1	The name assigned by a manufacturer to a specific software algorithm.
Algorithm Version	(0066,0031)	1	The software version identifier assigned by a manufacturer to a specific software algorithm.
Algorithm Parameters	(0066,0032)	3	The input parameters used by a manufacturer to configure the behavior of a specific software algorithm.
Algorithm Source	(0024,0202)	3	Source of the algorithm, e.g., the name of the manufacturer, researcher, university, etc.

DICOM PS 3.6: Data Dictionary

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Amend DICOM PS 3.6 – Data Dictionary – Section 6 Registry of DICOM Data Elements as follows:

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Table 6-1. Registry of DICOM Data Elements

Tag	Name	Keyword	VR	VM	
...	...	...	...	...	
(gggg,eee1)	Track Set Sequence	TrackSetSequence	SQ	1	
(gggg,eee2)	Track Sequence	TrackSequence	SQ	1	
(gggg,eee3)	Recommended Display CIELab Value List	RecommendedDisplayCIELabValueList	OW	1	
(gggg,eee4)	Tracking Algorithm Identification Sequence	TrackingAlgorithmIdentificationSequence	SQ	1	
(gggg,eee5)	Track Set Number	TrackSetNumber	US	1	
(gggg,eee6)	Track Set Label	TrackSetLabel	LO	1	
(gggg,eee7)	Track Set Description	TrackSetDescription	ST	1	
(gggg,eee8)	Track Set Anatomical Type Code Sequence	TrackSetAnatomicalTypeCodeSequence	SQ	1	
(gggg,eee9)	Track Set Property Type Modifier Code Sequence	TrackSetPropertyTypeModifierCodeSequence	SQ	1	
(gggg,ee21)	Track Point Values Sequence	TrackPointValuesSequence	SQ	1	
(gggg,ee22)	Track Point Value Type Code Sequence	TrackPointValueTypeCodeSequence	SQ	1	
(gggg,0024)	Summary Statistics Sequence	SummaryStatisticsSequence	SQ	1	
(gggg,0025)	Floating Point Values	FloatingPointValues	OF	1	
(gggg,0026)	Coordinate Value Pairs Sequence	CoordinateValuePairsSequence	SQ	1	
(gggg,0027)	Value Summarized Type Code Sequence	ValueSummarizedTypeCodeSequence	SQ	1	
(gggg,0028)	Summary Statistic Type Code Sequence	SummaryStatisticTypeCodeSequence	SQ	1	

Tag	Name	Keyword	VR	VM	
(gggg,0029)	**Point Index**	**PointIndex**	**UL**	**1**	
...	...	...	...	...	

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DICOM PS 3.16: Content Mapping Resource

Item: Add in Section B DCMR Context Groups (Normative)

CID XXX1 Diffusion Acquisition Value Types

Type: **Extensible**
Version: **YYYYMMDD**

Table CID XXX1. Diffusion Acquisition Value Types

Coding Scheme Designator	Code Value	Code Meaning
DCM	sup181_aa01	HARDI
DCM	sup181_aa02	DKI
DCM	sup181_aa03	DTI
DCM	sup181_aa04	DSI
DCM	sup181_aa05	LSDI
DCM	sup181_aa06	Single Shot EPI
DCM	sup181_aa07	Multiple Shot EPI
DCM	sup181_aa08	Parallel Imaging

CID XXX2 Diffusion Model Value Types

Type: **Extensible**
Version: **YYYYMMDD**

Table CID XXX2. Diffusion Model Value Types

Coding Scheme Designator	Code Value	Code Meaning
DCM	sup181_bb01	Single Tensor
DCM	sup181_bb02	Multi Tensor
DCM	sup181_bb03	Model Free
DCM	sup181_bb04	CHARMED
DCM	sup181_bb05	DSI
DCM	sup181_bb06	DOT
DCM	sup181_bb07	PAS
DCM	sup181_bb08	Spherical Deconvolution

CID XXX3 MR Diffusion Tractography Algorithm Families

Type: **Extensible**
Version: **YYYYMMDD**

Table CID XXX3. MR Diffusion Tractography Algorithm Families

Coding Scheme Designator	Code Value	Code Meaning
DCM	sup181_ee01	Deterministic
DCM	sup181_ee02	Probabilistic
DCM	sup181_ee03	Global
DCM	sup181_ee04	FACT
DCM	sup181_ee05	Streamline
DCM	sup181_ee06	TEND
DCM	sup181_ee07	Bootstrap
DCM	sup181_ee08	Euler
DCM	sup181_ee09	Runge-Kutta

CID XXX4 Diffusion Tractography Value Types

Type: **Extensible**
Version: **YYYYMMDD**

Table CID XXX4. Diffusion Tractography Value Types

Coding Scheme Designator	Code Value	Code Meaning
DCM	sup181_dddd01	Trace
DCM	sup181_dddd02	Mean Diffusivity
DCM	113041	Apparent Diffusion Coefficient
DCM	110808	Fractional Anisotropy
DCM	110809	Relative Anisotropy
DCM	sup181_dddd03	Radial Diffusivity
DCM	sup181_dddd04	Axial Diffusivity
DCM	sup181_dddd05	Mean Kurtosis
DCM	sup181_dddd06	Apparent Kurtosis Coefficient
DCM	sup181_dddd07	Radial Kurtosis
DCM	sup181_dddd08	Axial Kurtosis

Coding Scheme Designator	Code Value	Code Meaning
DCM	sup181_dddd09	Fractional Kurtosis 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

190 **Item: Add +/- update definitions in Annex D**

Code Value	Code Meaning	Definition	Notes
110808	Fractional Anisotropy	Coefficient reflecting the fractional anisotropy of the tissues, derived from a diffusion weighted MR image. Fractional anisotropy is proportional to the square root of the variance of the Eigen values divided by the square root of the sum of the squares of the Eigen values.	
110809	Relative Anisotropy	Coefficient reflecting the relative anisotropy of the tissues, derived from a diffusion weighted MR image.	
110810	Volumetric Diffusion Dxx Component	Dxx Component of the diffusion tensor, quantifying the molecular mobility along the X axis.	
110811	Volumetric Diffusion Dxy Component	Dxy Component of the diffusion tensor, quantifying the correlation of molecular displacements in the X and Y directions.	
110812	Volumetric Diffusion Dxz Component	Dxz Component of the diffusion tensor, quantifying the correlation of molecular displacements in the X and Z directions.	
110813	Volumetric Diffusion Dyy Component	Dyy Component of the diffusion tensor, quantifying the molecular mobility along the Y axis.	
110814	Volumetric Diffusion Dyz	Dyz Component of the diffusion tensor, quantifying the correlation of molecular displacements in the Y	

	Component	and Z directions.	
110815	Volumetric Diffusion Dzz Component	Dzz Component of the diffusion tensor, quantifying the molecular mobility along the Z axis.	
113041	Apparent Diffusion Coefficient	The image is derived by calculation of the apparent diffusion coefficient.	
…	…	…	…
sup181_dddd01	Trace	Tr = λ1+ λ2+ λ3 sum of the diffusion tensor eigenvalues, where λ1 ≥ λ2 ≥ λ3	Winston GP 2012, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3533595/
sup181_dddd02	Mean Diffusivity	MD = (λ1+ λ2+ λ3)/3 average of the diffusion tensor eigenvalues in all directions	Winston GP 2012, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3533595/
sup181_dddd03	Radial Diffusivity	DR= (λ2+ λ3)/2 average of the two non-principal (i.e. perpendicular) diffusion tensor eigenvalues (a/k/a transverse, perpendicular)	Winston GP 2012, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3533595/
sup181_dddd04	Axial Diffusivity	DA = λ1 diffusion tensor eigenvalue of the principal axis (a/k/a longitudinal, parallel)	Winston GP 2012, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3533595/
sup181_dddd05	Mean Kurtosis	MK = diffusional kurtosis averaged over all gradient directions, analogous to MD	Tabesh A 2011, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3042509/; Liu C 2010, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2824337/
sup181_dddd06	Apparent Kurtosis Coefficient	AKC = diffusional kurtosis in a given direction, analogous to ADC	Liu C 2010, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2824337/
sup181_dddd09	Fractional Kurtosis	FKA = fractional kurtosis of diffusion in	Liu C 2010, http://www.ncbi.nlm.nih

	Anisotropy	tissues, analogous to FA	.gov/pmc/articles/PMC2824337/
sup181_dddd08	Axial Kurtosis	KA = diffusional kurtosis in the direction of the highest diffusion (a/k/a longitudinal, parallel), analogous to DA	Tabesh A 2011, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3042509/
sup181_dddd07	Radial Kurtosis	KR = diffusional kurtosis perpendicular to the direction of the highest diffusion (a/k/a transverse, perpendicular), analogous to DR	Tabesh A 2011, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3042509/
…	…	…	…
sup181_ee01	Deterministic	Tracking based on local directionality	Descoteaux M 2009, http://www.ncbi.nlm.nih.gov/pubmed/19188114
sup181_ee02	Probabilistic	Tracking using local fiber orientation likelihood derive global connectivity likelihood	Descoteaux M 2009, http://www.ncbi.nlm.nih.gov/pubmed/19188114
sup181_ee03	Global	Tracking all fibers simultaneously, searching for a global optimum.	Reisert M, Mader I, Anastasopoulos C, Weigel M, Schnell S, Kiselev V. Global fiber reconstruction becomes practical. NeuroImage. 2011 Jan 15;54(2):955–62.
sup181_ee04	FACT	Fiber Assessment by Continuous Tracking	Mori S 1999, http://www.ncbi.nlm.nih.gov/pubmed/9989633; Descoteaux M 2009, http://www.ncbi.nlm.nih.gov/pubmed/19188114
sup181_ee05	Streamline	Generic; streamlines tracking techniques (STT)	Basser PJ 2000, http://www.ncbi.nlm.nih.gov/pubmed/11025519
sup181_ee06	TEND	Tensor Deflection	Lazar M 2003, http://www.ncbi.nlm.nih.gov/pubmed/12632468
sup181_ee07	Bootstrap	Non-parametric estimation of fiber tracking dispersion	Lazar M 2003, http://www.ncbi.nlm.nih.gov/pubmed/15627594 Jones DK 2005,

			http://www.ncbi.nlm.nih.gov/pubmed/15844149
sup181_ee08	Euler	Integration method, 1st order	Basser PJ 2000, http://www.ncbi.nlm.nih.gov/pubmed/11025519; Descoteaux M, http://www.ncbi.nlm.nih.gov/pubmed/19188114
sup181_ee09	Runge-Kutta	Integration method, 2nd or 4th order	Basser PJ 2000, http://www.ncbi.nlm.nih.gov/pubmed/11025519;
…	…	…	…
sup181_aa01	HARDI	High Angular Resolution Diffusion Imaging	Tuch DS 2002, http://www.ncbi.nlm.nih.gov/pubmed/12353272; Descoteaux M, http://www.ncbi.nlm.nih.gov/pubmed/19188114
sup181_aa02	DKI	Diffusion(al) Kurtosis Imaging	Jensen JH 2005, http://www.ncbi.nlm.nih.gov/pubmed/15906300
sup181_aa03	DTI	Diffusion Tensor Imaging	Winston GP 2012, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3533595/
sup181_aa04	DSI	Diffusion Spectrum Imaging	Wedeen VJ 2008, http://www.ncbi.nlm.nih.gov/pubmed/18495497; Hagmann P 2006, http://www.ncbi.nlm.nih.gov/pubmed/17050517
sup181_aa05	LSDI	Line Scan Diffusion Imaging sequence	Gudbjartsson H 1996, http://www.ncbi.nlm.nih.gov/pubmed/8892201
sup181_aa06	Single shot EPI	Echo Planar Imaging sequence	Turner 1991. http://www-ncbi-nlm-nih-gov.ezp-prod1.hul.harvard.edu/pubmed/1881311
sup181_aa07	Multi shot EPI	Multi Shot Echo Planar Imaging sequence	Robson 1997. http://www-ncbi-nlm-nih-gov.ezp-prod1.hul.harvard.edu/pubmed/9211383

sup181_aa08	Parallel Imaging	Sensitivity Encoding (parallel imaging)	Pruessmann KP 2009. http://www.ncbi.nlm.nih.gov/pubmed/10542355
...	...	...	...
sup181_bb01	Single Tensor	Modeling anisotropic diffusion in a volume with a tensor following a Gaussian distribution (six degrees of freedom)	Basser PJ 1994. http://www.ncbi.nlm.nih.gov/pubmed/8019776 Hagmann P 2006, http://www.ncbi.nlm.nih.gov/pubmed/17050517
sup181_bb02	Multi Tensor	Modeling anisotropic diffusion in a volume by fitting of multiple tensors	Ozarslan E 2003, http://www.ncbi.nlm.nih.gov/pubmed/14587006; Pasternak O 2008, http://www.ncbi.nlm.nih.gov/pubmed/18524529
sup181_bb03	Model Free	Reconstruction of anisotropic diffusion in a volume without imposing an underlying statistical model (data-driven approach)	Wedeen VJ 2005, http://www.ncbi.nlm.nih.gov/pubmed/16247738; Hagmann P 2006, http://www.ncbi.nlm.nih.gov/pubmed/17050517
sup181_bb04	CHARMED	Composite Hindered and Restricted Model of Diffusion	Assaf Y 2005, http://www.ncbi.nlm.nih.gov/pubmed/15979342
sup181_bb05	DSI	Diffusion Spectrum Imaging	Wedeen VJ 2008, http://www.ncbi.nlm.nih.gov/pubmed/18495497; Hagmann P 2006, http://www.ncbi.nlm.nih.gov/pubmed/17050517
sup181_bb06	DOT	Diffusion Orientation Transform	Ozarslan E 2006, http://www.ncbi.nlm.nih.gov/pubmed/16546404
sup181_bb07	PAS	Persistent Angular Structure	Jansons KM, 2003 http://www.ncbi.nlm.nih.gov/pubmed/15344497
sup181_bb08	Spherical Deconvolution	A method to estimate the distribution of fiber orientations by deconvolution of the diffusion-weighted signal attenuation measured over the surface of a sphere expressed as the convolution over the sphere of a response function.	Tournier J-D, Calamante F, Gadian DG, Connelly A. Direct estimation of the fiber orientation density function from diffusion-weighted MRI data using spherical deconvolution. NeuroImage. 2004 Nov;23(3):1176–85. "https://www.researchgate.net/profile/Alan_Connelly/publication/8192

			772_Direct_estimation_of_the_fiber_orientation_density_function_from_diffusion-weighted_MRI_data_using_spherical_deconvolution/links/5452dc230cf26d5090a37c8a.pdf".
...	...	...	...

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DICOM PS 3.17: Explanatory Information

Item: Add the following Section

XX Diffusion Tractography Storage Encoding Example (Informative)

This section illustrates the usage of the MR Diffusion Tractography Module (PS 3.3 C.X.1) in the context of the MR Diffusion Tractography Storage IOD.

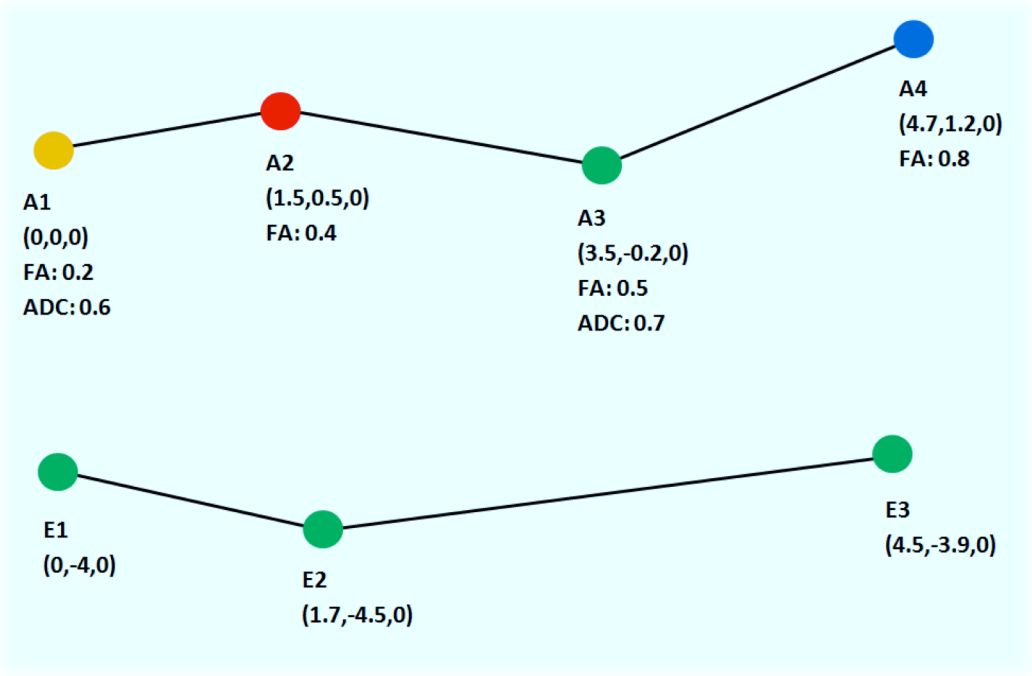

Figure XX-1. Example Track Set with two Tracks

Figure XX-1 shows an example track set. The example track set consists of:

- Two tracks “A” and “E”
- Track “E” consists of
  - 3 points
  - Single colored
  - No additional values
- Track “A” consists of
  - 4 points
  - Different color for each point
  - Fractional anisotropy for each point
  - Apparent diffusion coefficient for point 1 and 3

The table XX-1 shows the encoding of the Diffusion Tractography module for the example above. In addition to this example track set the table XX-1 also encodes the following information:

- The mean fractional anisotropy value for track “E”.

- The maximum fractional anisotropy value for the whole track set.
  Note: Track "A" doesn't have any fractional anisotropy values associated with.
- Diffusion acquisition, model and tracking algorithm information.
- Image instance references used to define the tractography instance.

Table XX-1. Example of the Diffusion Tractography Module

Name	Tag	Value	Comment
Instance Number	(0020,0013)	1	
Content Label	(0070,0080)	TRACKSET	
Content Description	(0070,0081)	Sample Trackset	
Content Creator's Name	(0070,0084)	<empty>	*Type 2 Attribute*
Content Date	(0008,0023)	20150113	
Content Time	(0008,0033)	161216.572000	
Track Set Sequence	(gggg,eee1)		
>Track Set Number	(gggg,eee5)	1	
>Track Set Label	(gggg,eee6)	Adam and Eve	
>Track Set Anatomical Type Code Sequence	(gggg,eee8)		
>>Code Sequence Macro Values	(0008,0102) (0008,0100) (0008,0104)	SRT, T-A0095, White matter of brain and spinal cord	*CID cp1407_SSS*
>Track Set Anatomical Type Modifier Code Sequence	(gggg,eee9)		
>>Code Sequence Macro Values	…	SRT, G-A100, Right	*CID 244*
>Track Sequence	(gggg,eee2)		
Item 1 (First Track)			
>>Point Coordinates Data	(0066,0016)	**0, 0, 0** **1.5, 0.5, 0** **3.5, -0.2, 0** **4.7, 1.2, 0**	
>>Track Point Values Sequence	(gggg,0021)		
Item 1			
>>>Track Point Value Type Code Sequence	(gggg,0022)		
>>>>Code Sequence Macro Values	…	DCM, 110808, Fractional Anisotropy	*CID XXX4*
>>>Measurement Units Code Sequence	(0040,08EA)		
>>>>Code Sequence Macro Values		UCUM, 1, no units	*CID 82*
>>>Floating Point Values	(gggg,0025)	**0.2, 0.4, 0.5, 0.8**	

		Item 2			
		>>>Track Point Value Type Code Sequence	(gggg,0022)		
		>>>>Code Sequence Macro Values	…	DCM, 113041, Apparent Diffusion Coefficient	*CID XXX4*
		>>>Measurement Units Code Sequence	(0040,08EA)		
		>>>>Code Sequence Macro Values		UCUM, 1, no units	
		>>>Coordinate Value Pairs Sequence	(gggg,0026)		
			Item 1		
			>>>>Point Index	(gggg,0029)	1
			>>>>Floating Point Value	(0040,A161)	**0.6**
			Item 2		
			>>>>Point Index	(gggg,0029)	3
			>>>>Floating Point Value	(0040,A161)	**0.7**
	>>Summary Statistics Sequence			(gggg,0024)		*Statistical Values derived from the values of this track*
	>>>Value Summarized Type Code Sequence			(gggg,0027)		
	>>>>Code Sequence Macro Values			…	DCM, 110808, Fractional Anisotropy	*CID XXX4*
	>>>Summary Statistic Type Code Sequence			(gggg,0028)		
	>>>>Code Sequence Macro Values			…	SRT,R-00317,Mean	*CID 3488 (part of CID 7464)*
	>>>Measurement Units Code Sequence			(0040,08EA)		
	>>>>Code Sequence Macro Values				UCUM, 1, no units	*CID 82*
	>>>Numeric Value			(0040,A30A)	0.475	
	>>Recommended Display CIELab Value List			(gggg,eee3)	**47270/40385/52501/ 34751/53214/49924/ 57318/11632/54042 22077/53113/5901/**	
	Item 2 (Second Track)					
	>>Point Coordinates Data			(0066,0016)	**0, -4, 0 1.7, -4.5, 0 4.5, -3.9, 0**	
	>>Recommended Display CIELab Value			(0062,000D)	**57318/11632/54042**	

>Summary Statistics Sequence	(gggg,0024)		*Statistical Values derived from the values of the whole track set*
>>Value Summarized Type Code Sequence	(gggg,0027)		
>>>Code Sequence Macro Values	…	DCM, 110808, Fractional Anisotropy	*CID XXX4*
>>Summary Statistic Type Code Sequence	(gggg,0028)		
>>>Code Sequence Macro Values	…	SRT,G-A437,Maximum	*CID 3488 (part of CID 7464)*
>>Measurement Units Code Sequence	(0040,08EA)		
>>>Code Sequence Macro Values		UCUM, 1, no units	*CID 82*
>>Numeric Value	(0040,A30A)	0.8	
>Diffusion Acquisition Sequence	(gggg,eee5)		
>>Code Sequence Macro Values	…	DCM, sup181_aa03, DTI	*CID XXX1*
>Diffusion Model Sequence	(gggg,eee6)		
>>Code Sequence Macro Values	…	DCM, sup181_bb01, Single Tensor	*CID XXX2*
>Tracking Algorithm Identification Sequence	(gggg,eee4)		
>>Algorithm Family Code Sequence	(0066,002F)		
>>>Code Sequence Macro Values	…	DCM, sup181_ee01, Deterministic	*CID XXX3*
>>Algorithm Name	(0066,0036)	Example	
>>Algorithm Version	(0066,0031)	1.0	
Referenced Instance Sequence	(0008,114A)		
Item 1			
>Referenced SOP Class UID		1.2.840.10008.5.1.4.1.1.4	*MR Image Storage*
>Referenced SOP Instance UID		1.2.3.4.1	
Item 2			
>Referenced SOP Class UID		1.2.840.10008.5.1.4.1.1.4	*MR Image Storage*
>Referenced SOP Instance UID		1.2.3.4.2	
…			
Item n			
>Referenced SOP Class UID		1.2.840.10008.5.1.4.1.1.4	*MR Image Storage*
>Referenced SOP Instance UID		1.5.6.1	

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