# Supplementary material

**dcmqi: an open source library for standardized communication of quantitative image analysis results using DICOM**

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The material included below has also been added to the *dcmqi* Frequently Asked Questions (FAQ) section and is publicly available at: <https://qiicr.gitbooks.io/dcmqi-guide/content/user_guide/faq.html>.

## Motivation for the development of *dcmqi*

The goal of *dcmqi* is to help imaging researchers use DICOM for storing the results of quantitative image analysis.

The use of DICOM helps improve interoperability of your data, enhances the ability to automatically find and use the data by the computational tools, as well as supports reuse of your data by individuals. These goals are widely recognized as important in the scientific community (1).

To highlight some of the specific advantages of using DICOM for storing analysis data, below we annotate the FAIR (Findable, Accessible, Interoperable, Reusable) Guiding Principles (1) formalized by FORCE11[[1]](#footnote-0), as applied to quantitative image analysis, describing how research formats help meet the FAIR requirements, and contrasting those with the functionality provided by DICOM.

While speaking of "research formats", we refer primarily to the formats commonly used by researchers developing quantitative image analysis tools. Examples include NRRD (2), MetaImage (3), NIfTI (4), and Analyze (5).

A notable example of a domain-specific solution is Brain Imaging Data Structure (BIDS) (6) being developed for neuroimaging applications. We are not aware of a domain-specific solution developed for cancer imaging.

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| **FAIR Guiding principle** | **Research formats** | **DICOM** |
| ***To be Findable:*** |  |  |
| *F1. (meta)data are assigned a globally unique and persistent identifier* | usually not assigned | each object has a unique identifier |
| *F2. data are described with rich metadata (defined by R1 below)* | minimal metadata sufficient to solve specific task (e.g., image resolution and orientation) | metadata is stored in standardized attributes describing versatile aspects of the data (the subject being imaged, processing details, references to related objects, etc.) |
| *F3. metadata clearly and explicitly include the identifier of the data it describes* | metadata describing the subject may be stored separately from the analysis result, and cross-linked by means of file name or similar mechanism, creating opportunity for inconsistencies and errors | metadata is stored in the same object as the processing result |
| *F4. (meta)data are registered or indexed in a searchable resource* | problem-specific solutions | general-purpose search and indexing of DICOM data is supported by every Picture Archival and Communications System (PACS) using DICOM Query and Retrieve protocol, or using REST-based DICOMWeb protocol |
| ***To be Accessible:*** |  |  |
| *A1. (meta)data are retrievable, by their identifier using a standardized communication protocol* | problem-specific solutions | general-purpose retrieval of DICOM data is supported by every Picture Archival and Communications System (PACS) using DICOM Query and Retrieve protocol, or using REST-based DICOMWeb protocol |
| *A1.1. the protocol is open, free, and universally implementable* | no comparable protocols have been proposed and implemented in widely accessible solutions | yes |
| *A1.2. the protocol allows for an authentication and authorization procedure, where necessary* | no comparable protocols have been proposed and implemented in widely accessible solutions | DICOMWeb can be integrated with existing authentication protocols defined by other standards |
| *A2. metadata is accessible, even when the data is no longer available* | no | not applicable, since metadata is stored alongside the data in the same object |
| *To be Interoperable:* |  |  |
| *I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation* | domain-specific solutions | DICOM is a formal, accessible, shared and broadly used standard |
| *I2. (meta)data use vocabularies that follow FAIR principles* | domain-specific solutions | can reuse vocabularies defined elsewhere, relying often on the terminology defined by [SNOMED-CT](http://searchhealthit.techtarget.com/definition/SNOMED-CT), [UCUM](http://unitsofmeasure.org/trac), [NCIt](https://ncit.nci.nih.gov/ncitbrowser/), [FMA](https://bioportal.bioontology.org/ontologies/FMA), and allows for integration with other vocabularies, including those defined by the user |
| *I3. (meta)data includes qualified references to other (meta)data* | usually, no | derived objects can include pointers to the datasets used in the derivation, including the purpose of reference |
| ***To be Reusable:*** |  |  |
| *R1. (meta)data are richly described with a plurality of accurate and relevant attributes* | usually, no | data attributes that need to be included for a specific object are defined by the standard, as a result of the community discussion and consensus process; the process of amending the standard is formalized and open |
| *R2. (meta)data are released with a clear and accessible data usage license* | not applicable; data usage license is selected by the data provider | not applicable; data usage license is selected by the data provider; the DICOM standard itself is available free of charge, and its implementation is not restricted by any licenses |
| *R1.2. (meta)data are associated with detailed provenance* | usually, no | composite context is preserved across imaging and derived datasets describing patient and acquisition details; provenance-related attributes are included, depending on the specific object type |
| *R1.3. (meta)data meet domain-relevant community standards* | domain-specific solutions | DICOM is the main standard in the medical imaging domain |

# Research formats supported by *dcmqi*

The research formats supported are specific to the type of the object being converted, as summarized in the table below.

|  |  |  |
| --- | --- | --- |
| **Object type** | **Supported research formats** | **DICOM object** |
| Segmentation image | All research volumetric image formats supported by the Insight Toolkit (ITK) (7): NRRD (2), MetaImage (3), NIfTI (4), Analyze (5); extra metadata is communicated using JSON (8) and constrained by JSON-Schema (9). | DICOM Segmentation Image (10) |
| Parametric map image | All research volumetric image formats supported by the Insight Toolkit (ITK) (7): NRRD (2), MetaImage (3), NIfTI (4), Analyze (5); extra metadata is communicated using JSON (8) and constrained by JSON-Schema (9). | DICOM Parametric map (11) |
| Volumetric measurements | Both measurements and associated metadata should be described using JSON (8) and constrained by JSON-Schema (9). We are are planning to add support for CSV as input format in the future. | DICOM TID1500 Structured Report (12) |

## Relationship of *dcmqi* to related developments in the community

Discussion of the relationship of *dcmqi* to some of the other tools used in the community is provided below. We note that this list is not exhaustive, and is a snapshot of our understanding of the most relevant packages as of the submission time.

* Insight Toolkit (13) - does not provide tools for conversion of DICOM objects supported by *dcmqi*. *dcmqi* uses ITK as a lower-level component for reading and writing research formats, and for image data operations.
* DCMTK (14) and GDCM (15) - DICOM toolkits that provide attribute- and SR tree-level C++ API for interacting with DICOM data; provide general-purpose command line tools for converting DICOM objects into human-readable list of attribute; do not provide tools for generating DICOM objects from research formats. *dcmqi* is using DCMTK as the lower-level component to operate on DICOM data.
* PixelMed Toolkit (16) - provides attribute- and module-level Java API for interacting with DICOM objects; does not provide conversion tools for generating DICOM Segmentation image objects, Parametric maps, or volumetric measurements reports from research formats
* dicom3tools (17) - provides attribute-level C API for interacting with DICOM objects; does not provide conversion tools for generating DICOM Segmentation image objects, Parametric maps, or volumetric measurements reports from research formats
* pydicom (18) - provides attribute-level Python API for interacting with DICOM objects; does not provide conversion tools for generating DICOM Segmentation image objects, Parametric maps, or volumetric measurements reports from research formats
* 3D Slicer (19) - provides interactive application to load and process DICOM data; includes *dcmqi* as an extension; uses dcmqi to perform conversion of the objects *dcmqi* supports.
* ePAD (20) - provides interactive application to visualize and annotate DICOM data; by design, does not provide conversion tools; uses dcmqi to perform conversion of DICOM TID1500 SR objects supports; uses attribute-level API of PixelMed to implement support of DICOM Segmentation objects and DICOM Parametric maps.
* CERR (21) - a software platform for developing and sharing research results in radiation therapy treatment planning. Supports DICOM RT-STRUCT annotation format (planar contours defining segmented region). Does not support DICOM Segmentation image, Parametric map, or volumetric measurements.

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