Supplement 1

SPP Radiomics – List of extracted step terms

A SPP Radiomics Workflow Definition Supplement

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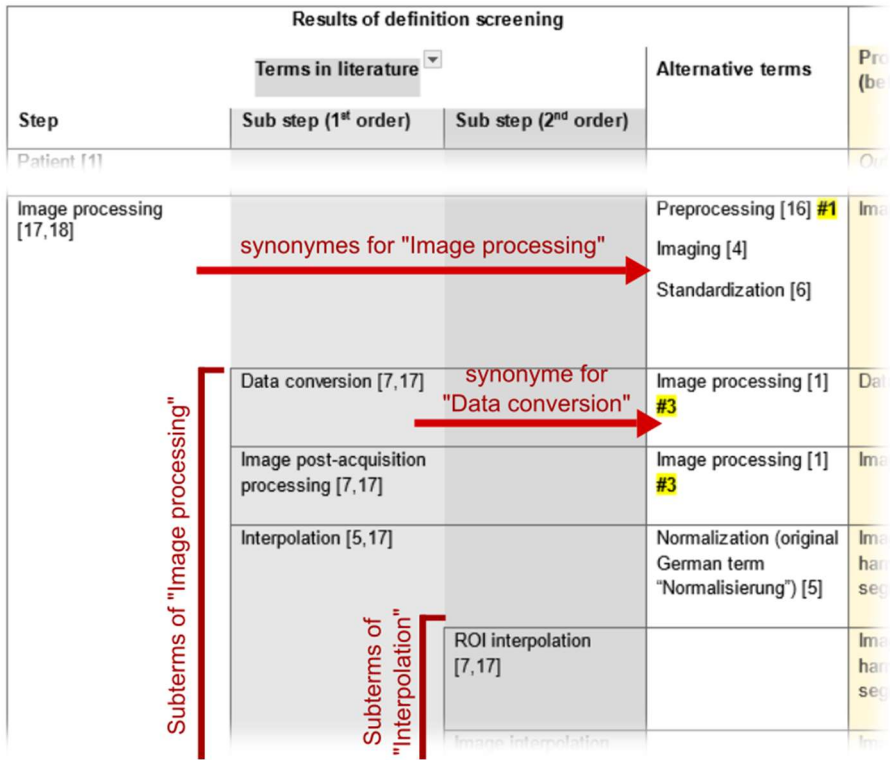
Scope: This is a supplement for the publication “Radiomics Workflow Definitions and Challenges of Implementation in Clinics: a Delphi-based Interdisciplinary Consensus” by the Scientific Priority Program Radiomics (DFG SPP2177) by the Germany Research Foundation. The supplement contains the list of step terms extracted from analyzed literature and used for compiling the baseline for the Delphi process described in the publication.

Table of content

Table instructions

Purpose of the provided table is to illustrate the terms, found in the analyzed literature, and their relation. Further this table documents which term was used to represent a certain definition for the Delphi process and the consensus term that was finally chosen for a definition.

How to read the table



The first four columns (heading “Results of definition screening”) are containing terms extracted from the analyzed literature. The first three columns (heading “Terms in literature”) are needed to depict the identified hierarchies between the terms. A cell of a higher order column can span over multiple rows of the lower order column (e.g. column 1 over column 2). This indicates that all rows of the lower order column contain sub terms. E.g. the “Image processing” cell spans over multiple rows of the 2nd column which indicates that e.g. “Data conversion” and “Interpolation” are sub terms of “Image processing” (see figure on the left). In the same way it is indicated that “ROI interpolation” is a sub term of “Interpolation” (whose cell spans over the “ROI interpolation” row). The fourth column (heading “Alternative terms”) contains all found synonyms for the term on the left side of the same row (e.g. “Preprocessing” is one found synonym for “Image processing”; see figure on the left).

The last two columns (heading “Delphi process”) indicate which terms were used in the therapy process after the analyzes. The fifth column (heading “Proposal (before Delphi)”) shows the terms that are used at the beginning of the process. The sixth column (heading “Workflow consensus (after Delphi)”) shows the respective consensus terms after the Delphi process.

Remark 1: The rows are ordered according to the analysis process that constructed the tree of step terms. Therefore, the order of the last column (“Workflow consensus (after Delphi)”) does not represent the structure/organization (phases and their aspects) of the consensus definition.

Remark 2: There is no dedicated meaning for the selection of which terms should be in the first three columns and which terms are declared their respective synonyms, as all synonymous terms are equivalent.

Table of step terms

Results of definition screening				Delphi process	
	Terms in literature		Alternative terms	**Proposal (before Delphi)**	**Workflow Consensus (after Delphi)**
Step	**Sub step (1st order)**	**Sub step (2nd order)**			
Patient [1]				*Out of scope*	*Out of scope*
Data selection [2]			Creation of a dataset with appropriate clinical and radiological data [3] **#3**	Data selection	Study design *(Merged into)*
	Choice of imaging protocol [2] **#3**			Choice of imaging protocol	Choice of imaging data
	Choice of prediction target [2]			Choice of prediction target	Choice of prediction target
	Choice of volume of interest [2]		ROI definition [4] #1	Choice of volume of interest	Choice of region of interest

Data acquisition (original German term “Datenakquisition”) [5]			Creation of a dataset with appropriate clinical and radiological data [3] **#3** Medical imaging [2] MR Image acquisition with a standardization [6] Medical imaging acquisition [7] Image acquisition [3,7–12]	Data acquisition	Data acquisition
	Standardization [4,6]			Choice of imaging protocol	Choice of imaging data
	Imaging at multiple time points [2]		Test-retest repeatability [1]	Test-retest imaging	Test-retest imaging
	Image acquisition [1,2,13–15]			Image acquisition	Image acquisition
	Reconstruction [1,13,15]			Reconstruction	Reconstruction
	Phantom studies [2]			Phantom studies	Phantom studies
Data management (original German term “Datenmanagmement”) [5]				Data management	Data management

	Export of DICOM images from PACS to the computer software that will be used to perform the radiomics analysis [3] **#3**			PACS export	Export of Imaging Data
Image processing [17,18]			Preprocessing [16] **#1** Imaging [4] Standardization [6] Computation of radiomics features [7] #3 Data preprocessing (original German term “Datenvorverarbeitung”) [5]	Image processing	Image processing and segmentation *(Merged into)*
	Data conversion [7,17]		Image processing [1] **#3**	Data conversion	Data conversion
	Image post-acquisition processing [7,17]		Image processing [1] **#3**	Image filtering	Image filtering
	Interpolation [5,17]		Normalization (original German term “Normalisierung”) [5]	Image geometry harmonization (pre segmentation)	Image geometry harmonization and resampling *(Merged into / unified as)*

		ROI interpolation [7,17]		Image geometry harmonization (post segmentation)	Image geometry harmonization and resampling *(Merged into / unified as)*
		Image interpolation [7,17]		Image geometry harmonization (post segmentation)	Image geometry harmonization and resampling *(Merged into / unified as)*
	Analysis of outliers (original German term “Analyse von Ausreißern”) [5]			Outlier analysis	Image quality assessment
Segmentation [1,2,4,8,9,11–13,17]			Image segmentation [3,18–20] Nodule volume segmentation [10] Segmentation (original German term “Segmentierung”) [5] ROI Extraction (original German term “Extraktion der ROI”) [5] **#1** Region of interest segmentation [15,16] Tumor labeling [6] Specification of ROIs [14] ROI segmentation [7]	Segmentation	Segmentation/ annotation *(Merged into Image processing and segmentation as)*

			ROI definition [6] **#1** Computation of radiomics features [7] #3		
	Re-segmentation [17]		ROI resegmentation [7]	Re-segmentation	Quality control of segmentation

Feature extraction [2,3,6,9–14,16,18,20]			Feature extraction and quantification [15] Feature selection and extraction [8] Radiomics feature extraction [19] Calculation of the radiomics characteristics (original German term “Berrechnung der Radiomics-Merkmale”) [5] Computation of image biomarker [1] Generation of radiomics features [4] Computation of radiomics features [7] #3	Feature extraction	Feature extraction
	Feature calculation [17]				Feature calculation
	ROI extraction [7,17] **#1**			ROI extraction	ROI extraction
	Intensity discretization [17]		Discretisation [7]	Intensity discretization	Intensity discretization
	Preprocessing [12,13] **#1**			Preprocessing	Preprocessing

Development of database [4]			Data handling [16]	Multimodal data integration	Multi disciplinary data curation and integration *(+ moved to Data management)*
Modeling [1,2,21]			Statistical analysis and machine learning [7] Analysis [10,11,13,16] Model building [9] **#2** Building predictive and prognostic models [15] Statistical analysis [6,16] Machine learning for building radiomics classifiers [9] Analysis of database [4]	Modeling	Modeling
	Feature harmonization [22]			Feature harmonization	Feature harmonization

Feature selection [2,3,9,11,12,14,15,18, 22]		Feature selection and extraction [8] Radiomic feature selection [19] Selection of radiomics characteristics (original German term “Auswahl von Radiomics-Merkmalen”) [5] Radiomics signature modeling [20]	Feature selection	Feature selection
	Dimensionality reduction [22]	Dimension reduction [18]	Dimensionality Reduction	Dimensionality Reduction
	Exploratory analysis [2]		Exploratory analysis	Exploratory analysis
Choice of modeling methodology [2]			Choice of modeling methodology	*Splitted into* Definition of the analysis and modeling strategy *and* Adaption of the analysis and modeling strategy

Model building [12,14,19] **#2**		Creation and application of the radiomics model (original German term “Erstellung und Anwendung des Radiomics-Modells”) [5] Model development (original German term “Modellentwicklung”) [5] Model construction [22] Model training [18] Radiomics signature modeling [20] Multivariate Analysis and Model Building [6]	Model building	Model building
	Classification [15,22]		Classification	*Merged into* Modeling *as it is just one of several specific task types (e.g. also detection)*
Validation [2,3,9,12,16,22]		Model analysis [20] Performance evaluation [12]	Validation	Testing *(renamed as validation in ML normally means the optimization of the architectural model/hyperparameter and Testing is semantically covering*

					what the publication wanted to express)
		MVI Prediction Model Evaluation [19]		Validation	Testing
		Nomogram Construction and Evaluation [19]		Validation	Testing
Reporting open-access scientific data [2]				Reporting	Reporting
Clinical application of radiomics [7]			Deployment (original German term “Bereitstellung”) [5]	*Out of scope*	*Out of scope*
	Prospective evaluation of model [7]			*Out of scope*	*Out of scope*
	Personalized treatment [7]			*Out of scope*	*Out of scope*
Radiomics signature [4]				*Out of scope*	*Out of scope*

Legend:

(x): Reference to the publication using that term

#1: Term involved in a conflict of type “Homonym”

#2: Term involved in a conflict of type “Hierarchy conflict”

#3: Term involved in a conflict of type “Semantic ambiguity”

Terminology conflicts

Explanation of all conflicts found while screening the workflow definitions in literature.

Synonyms: This type of conflict is indicated if a cell in column “Alternative names in literature” is not empty; each alternative term, not indicated as another type of conflict, is a synonym. The cell then contains all found synonyms for the respective term in the same row (e.g. term “Choice of volume of interest” has the synonymous term “ROI definition”). Remark: Synonyms are regarded as conflicts in this context, as it makes the “interoperability” between different publications harder as the reader has to translate between different terms.

Occurrences: 55 (including 9 synonymous usages that are also involved in other conflicts)

Homonyms: Homonyms were found when identically named steps were defined differently. This type of conflict is indicated by a term being present in multiple rows of the first 4 columns (“Result definition screening” columns).

Occurrences:

1. ROI Extraction: Used as synonym for “Segmentation” [5] and as its own term [1].
2. Preprocessing: Used as synonym for “Image processing” [16] and as its own term [12, 13] as a sub step of “Feature extraction”.
3. ROI Definition: Used as synonym for “Choice of volume of interest” [4] and as synonym for “Segmentation” [6].

Hierarchy conflicts: This type of conflict is a subclass of Homonyms. They occurred when a step was mentioned as a step in one publication, while it was a sub step in another publication. It is indicated by the same term occurring on multiple levels (nth order sub steps) of the same step term.

Occurrences:

1. Model building: Used as synonym for “Modelling” [9] and as its sub step [12,14,19].

Semantic ambiguity: Semantic ambiguities occurred where definitions of a publication could not be clearly assigned to one step, but to multiple main steps.

Occurrences:

1. Choice of imaging protocol [2]: Could be partly a sub step of “Data selection” (planning part) and partly of “Data acquisition” (execution).
2. Image processing [1]: Could be partly sub step “Data conversion” [17] or sub step “Image post-acquisition processing” [17].

3. Export of DICOM Images from PACS [3]: Could be partly a sub step of “Development of database” [4] or sub step of “Data management” [5].
4. Creation of a dataset with appropriate clinical and radiological data [3]: Could partly be “Data selection” [2] or partly “Data acquisition” [5].
5. Computation of radiomics features [7]: Could partly be “Image Processing” [17], partly “Segmentation” [1] and partly “Feature Extraction” [2].

Literature

List of literature that was analyzed in the definition screening.

1. Zwanenburg A. Radiomics in nuclear medicine: Robustness, reproducibility, standardization, and how to avoid data analysis traps and replication crisis. Eur J Nucl Med Mol Imaging. 2019;46(13):2638. doi: 10.1007/s00259-019-04391-8

2. Lambin P, Leijenaar RTH, Deist TM, et al. Radiomics: The bridge between medical imaging and personalized medicine. Nat Rev Clin Oncol. 2017;14(12):749. doi: 10.1038/nrclinonc.2017.141

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5. Murray JM, Kaissis G, Braren R, Kleesiek J. Wie funktioniert radiomics. Radiologe. 2020;60(1):32. doi: 10.1007/s00117-019-00617-w

6. Chaddad A, Kucharczyk MJ, Daniel P, et al. Radiomics in glioblastoma: Current status and challenges facing clinical implementation. Front Oncol. 2019;9:374. doi: 10.3389/fonc.2019.00374

7. Vallières M, Zwanenburg A, Badic B, Cheze Le Rest C, Visvikis D, Hatt M. Responsible radiomics research for faster clinical translation. J Nucl Med. 2018;59(2):189. doi: 10.2967/jnumed.117.200501

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9. Avanzo M, Stancanello J, El Naqa I. Beyond imaging: The promise of radiomics. Phys Med. 2017;38:122. doi: 10.1016/j.ejmp.2017.05.071

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12. Ibrahim A, Vallières M, Woodruff H, et al. Radiomics analysis for clinical decision support in nuclear medicine. Semin Nucl Med. 2019;49(5):438. doi: 10.1053/j.semnuclmed.2019.06.005

13. Fornacon-Wood I, Faivre-Finn C, O'Connor JPB, Price GJ. Radiomics as a personalized medicine tool in lung cancer: Separating the hope from the hype. Lung Cancer. 2020;146:197. doi: 10.1016/j.lungcan.2020.05.028

14. Lee S-H, Park H, Ko ES. Radiomics in breast imaging from techniques to clinical applications: A review. Korean J Radiol. 2020;21(7):779. doi: 10.3348/kjr.2019.0855

15. Thawani R, McLane M, Beig N, et al. Radiomics and radiogenomics in lung cancer: A review for the clinician Lung Cancer. 2018;115:34. doi: 10.1016/j.lungcan.2017.10.015

16. Machicado JD, Koay EJ, Krishna SG. Radiomics for the diagnosis and differentiation of pancreatic cystic lesions. Diagnostics (Basel). 2020;10(7):505. doi: 10.3390/diagnostics10070505

17. Zwanenburg A, Vallières M, Abdalah M, et al. The image biomarker standardization initiative: Standardized quantitative radiomics for high-throughput image-based phenotyping. Radiology. 2020;295(2):328. doi: 10.1148/radiol.2020191145

18. van Timmeren JEs, Cester D, Tanadini-Lang S, Alkadhi H, Baessler B. Radiomics in medical imaging—“how-to” guide and critical reflection. Insights Imaging. 2020;11(1):91. doi: 10.1186/s13244-020-00887-2

19. Yang L, Gu D, Wei J, et al. A radiomics nomogram for preoperative prediction of microvascular invasion in hepatocellular carcinoma. Liver Cancer. 2019;8(5):373. doi: 10.1159/000494099

20. Gu D, Hu Y, Ding H, et al. CT radiomics may predict the grade of pancreatic neuroendocrine tumors: A multicenter study. Eur Radiol. 2019;29(12):6880. doi: 10.1007/s00330-019-06176-x

21. Moons KGM, Altman DG, Reitsma JB, et al. Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD): Explanation and elaboration. Ann Intern Med. 2015;162(1):W1. doi: 10.7326/M14-0698

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