Project title: Implications of Medical Low Dose Radiation Exposure

Grant Agreement Number: 755523

Call identifier: NFRP-2016-2017

Topic: NFRP-9

Deliverable 2.21

Software tool (CT-IQURAD) module on image quality

Lead partner:	IPC in cooperation with OvGU
Author(s):	Christoph Hoeschen, Zahra Passand, Graciano Paulo
Work Package:	2
Estimated delivery:	31.05.2021
Actual delivery:	31.10.2021
Type:	Report
Dissemination level:	Public

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 755523.

Table of contents

List of figures 1
List of tables 1
Abbreviations 1
1. Introduction 2
2. Content 3
2.1 Study on subjective image quality 3
2.2 Correlation of subjective image quality ratings and objective image quality metrics derived on simple parameters 3
2.3 Evaluation of a new metrics 5
2.4 Prototype software for objective image quality assessment. 6
2.5 Web based software tool 7
3. Conclusion 10
4. References 11

List of figures

Figure 1: chest CT part, of an image rated as good image quality

Figure 2: PS/MTF curve for image section from figure 1

Figure 3: chest CT part, of an image rated as bad image quality

Figure 4: PS/MTF curve for image section from figure 3

Figure 5: GUI of the first software prototype for image quality evaluation.

Figure 6: web-based tool for evaluating image quality GUI after running an example evaluation.

List of tables

Table 1: Different features in the images labeled as "good quality"

Table 2: Different features in the images labeled as "bad quality"

Abbreviations

AUC_{MTF}	Area under the MTF curve
AUC_{NPS}	Area under the NPS curve
AUC_{PS}	Area under the PS curve
MTF	Modulation transfer function
NPS	Noise power spectrum
PS	Power spectrum
ROI	Region of interest

1. Introduction

The overall objective of task 2.1. of the MEDIRAD project is to develop an optimisation strategy for CT imaging of the chest region. This optimisation needs to take into account the exposure of the patient as well as the achievable image quality.

The ultimate goal of imaging applications in medicine is to perform a reliable diagnosis. Achievable diagnostic performance is, nevertheless very difficult to predict. It is depending on the image quality influenced by the patient characteristics, the image acquisition parameters and the reconstruction set-up. Therefore, it is of uttermost importance for the optimisation process, to evaluate the image quality of such clinical investigations.

The first question which needs to be addressed in this context is: how image quality should be defined for this purpose?

Regarding the optimisation that is intended as an outcome of MEDIRAD, the exposure for the patient should be reduced as much as possible, while the diagnostic accuracy must be maintained.

The diagnostic accuracy depends on the visibility of pathological structures. However, such pathological structures are very different and dependent on the clinical indication and are not present in all patients. Therefore, the image quality assessment needs to be performed on normal anatomical structures and in structure free regions (ie: regions where no structure can be identified compared to the background).

As described in deliverable 2.12 there are also ways to describe image quality by means of physics based “objective” image quality parameters. It was already described that there are limitations when looking at physics-based image quality descriptors derived from phantom images. Therefore, it had been the idea of task 2.1.1 in the MEDIRAD project to develop a methodology which allows the correlation of objective physics-based image quality parameters and subjective image quality evaluations.

The main idea behind this concept was to

- Identify relevant clinical indications, especially those for chest CT imaging not using contrast media
- Identify the relevant structures within such CT images which allow a suitable subjective image quality evaluation
- Develop physics-based image quality descriptors and corresponding evaluation methods within the clinical images, preferably even on the same structures
- Compare the subjective and the objective image quality parameters as determined on clinical chest CT images

In task 2.1.3 the main objective was then to develop a tool accessible as a web-based software tool to determine image quality in patient images as well as relevant dose parameters for the same investigations.

The principal was to provide a tool for optimisation of chest CT imaging with respect to radiation exposure of patients while maintaining an appropriate image quality, for diagnostic purpose.

2. Content

The work of subtasks 2.1.1 and 2.1.3 which are the basis of this deliverable has been performed according to the description of actions (DoA) with a slight delay due to Covid-19 pandemic implications on the availability of the radiologists for subjective image quality (IQ) determination and evaluation of the software tool.

Based on the results presented in the deliverable regarding the correlation of subjective and objective image quality (D2.12), the missing steps for the development and validation of the software tool for image quality assessment have been performed.

2.1 Study on subjective image quality

The study described in deliverable 2.12 has been performed. To do so, over 300 chest CTs have been collected in the contributing hospitals.

From those, 300 had been chosen to allow a statistically significant number of investigations per clinical indication (3 indications meaning approximately 100 cases per indication collected in 5 hospitals, which have slightly different imaging protocols), and 9 out of 10 radiologists finalised the image scoring using the ViewDex program as well as the criteria and definitions stated in the previous report. The number of images as well as the number of readers had been chosen based on previous studies e.g. conducted on chest X-ray images for example. The achievable power of the study was estimated in advance during the preparation phase of the project. It will be evaluated again from the final data and being documented in the intended publication (see next paragraph).

From analysing the different imaging parameters, (eg. kV, mAs, tube current modulation, slice thickness, etc) when available, it turned out that there are quite some differences in the imaging procedures between European hospitals but also even within the same hospital. This was quite helpful as it showed also differences in subjective IQ determination including some images where the overall IQ was rated “bad” or partly even “unacceptable”. A peer reviewed publication regarding the subjective image quality evaluation is under preparation.

Besides this overall study, some radiologists also provided feedback for a subset of 30 “good” and 30 “bad” images where they judged certain parameters like anatomical structures and noise (in which slice and at which points).

This was used to perform the resolution evaluation based on objective IQ assessment, as described in the earlier report. We have implemented the methodology, as described earlier, but now on patient images, to determine the noise power spectrum (NPS) deriving structure-free patches to evaluate the NPS.

2.2 Correlation of subjective image quality ratings and objective image quality metrics derived on simple parameters

We evaluated the objective IQ parameters derived in the 60 images mentioned above (we choose to use these 60 images since we had the information on where to do the evaluation for those and an early definition of which of those images were rated “good” or “bad” to allow progressing with correlating the IQ subjectively with the physics based objective parameters. In addition, using all 300 examples could maybe have resulted in a bias, since the majority of the cases had been rated as “good”.

In the following tables there are a few summarized parameters for some of the cases, actually we present here the results of the first 11 cases that had been annotated by radiaologists as “good” or “bad” images. We did use for the first cases the major fissure of the left lung as the structure we evaluated. The radiologists marked areas to evaluate for that and then regions of 18 by 18 pixel (ROIs) were evaluated as described in deliverable 2.12. Documented are the areas under the different curves as well as the variances determined in the ROIs:

	Area containing anatomical structure			Background area	
Patient No	**AUC_{MTF}**	**Variance**	**AUC_{PS}**	**Variance**	**AUC_{NPS}**
10	0.29	4700	3200	1950	1930
11	0.35	2900	3990	1960	1360
12	0.29	16600	33100	3540	1800
19	0.31	4530	7300	1010	1050
20	0.34	21700	35700	4160	3570
Mean	**0.32**	**10086**	**16658**	**2524**	**1942**
Std	**0.03**	**8498**	**16295**	**1289**	**975**

Table 1: Different features in example images labeled as “good quality”

	Area containing anatomical structure			Background area	
Patient No	**AUC_{MTF}**	**Variance**	**AUC_{PS}**	**Variance**	**AUC_{NPS}**
13	0.28	13140	16190	12830	9720
14	0.19	67600	65900	7530	4490
15	0.21	101000	195000	3150	1690
16	0.21	96800	172500	1760	2230
17	0.29	26900	16400	3160	2360
18	0.25	59300	127800	7620	8450
Mean	**0.24**	**60790**	**98965**	**6008**	**4823**
Std	**0.04**	**35725**	**77748**	**4142**	**3460**

Table 2: Different features in example images labeled as “bad quality”

As it can be easily seen, on average, the area under the curve of the Modulation Transfer Function (**AUC_{MTF}**) is higher for images rated as “good quality” than as for those depicted as “bad quality”. On the other hand, the area under the curve of the NPS (**AUC_{NPS}**) for the images rated as “good” is lower than for those rated as “bad”. The values show in principle results as they had been hoped for: Bad images are showing lower resolution properties for image structures and / or higher noise. However, looking to this example for the image of patient number 17 the **AUC_{MTF}** is pretty high, but the noise is not, meaning this patient image could have been classified wrongly just by using the parameters mentioned above.

Therefore, we decided to look more deeply into the data of the objective IQ evaluation and the original images. Together with the involved radiologists we saw that rather not only the resolution or the noise alone determines the impression of a clearly visible structure but the relation between noise and structure sharpness in various detail sizes seemed to be relevant.

2.3 Evaluation of a new metrics

We decided to develop a completely new metric for evaluating the images based on the finding described above. We evaluated the power spectrum (PS) of the region in which we determined the MTF. We herewith determined the power in the structure and the noise in that area.

Since this function would always determine the power over the frequency, the effect of the noise might overwhelm the structure components at least for higher frequencies and make the shape of the curve less prominent. Thus, to avoid this effect, we divided the PS by the MTF.

Doing so, we found a very interesting behavior of the images depending on their classification:

For images rated as "good images" the curve of the metric PS value divided by MTF value at the same frequency is staying larger than the starting value for up to quite high frequencies (depending on the type of structure and the size of the evaluated region of interest (ROI).

The same values drop much faster for images that had been marked as "bad quality". For example, for the major fissure of the left lung using ROIs of 18 by 18 pixels, the curve drops below 80 % (for most cases even below 60%) for frequencies below 0.5 mm^{-1}. This can be appreciated in two examples shown in figures 1 to 4. The first image shows a "good quality" image of which the curve for PS/MTF is represented in figure 2.

In the same way figure 3 shows an example for the same structure in a "bad quality" image with the corresponding PS/MTF curve shown in figure 4.

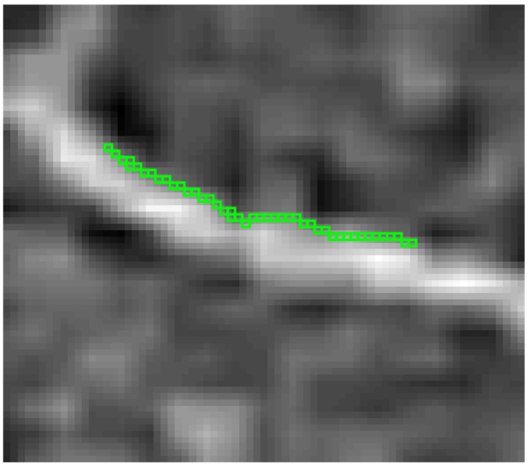


Figure 1: chest CT part, of an image rated as good image quality

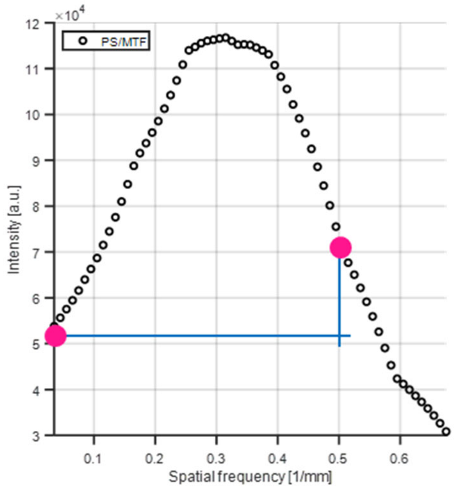


Figure 2: PS/MTF curve for image section from figure 1

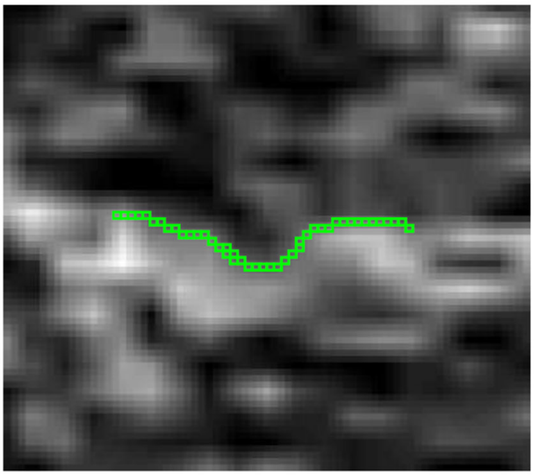


Figure 3: chest CT part, of an image rated as bad image quality

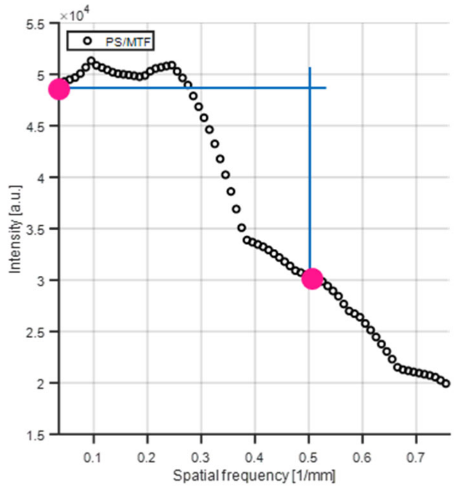


Figure 4: PS/MTF curve for image section from figure 3

Combining all classifications, we are able to achieve a 100% separation in our test set. We will evaluate also the rest of the images from the subjective IQ assessment study. However, due to the achieved results we were able to build up a web-based software tool for the objective image quality evaluation. The corresponding results will be published in the next few months as a major outcome of the tasks 2.1.1 and 2.1.3 of the MEDIRAD project. The corresponding publication manuscript is currently prepared. It will refer to more data sets as well as more examples of the values but also the interesting separating figures.

2.4 Prototype software for objective image quality assessment.

In figure 5 an image of the first prototype GUI for the image quality assessment is shown.

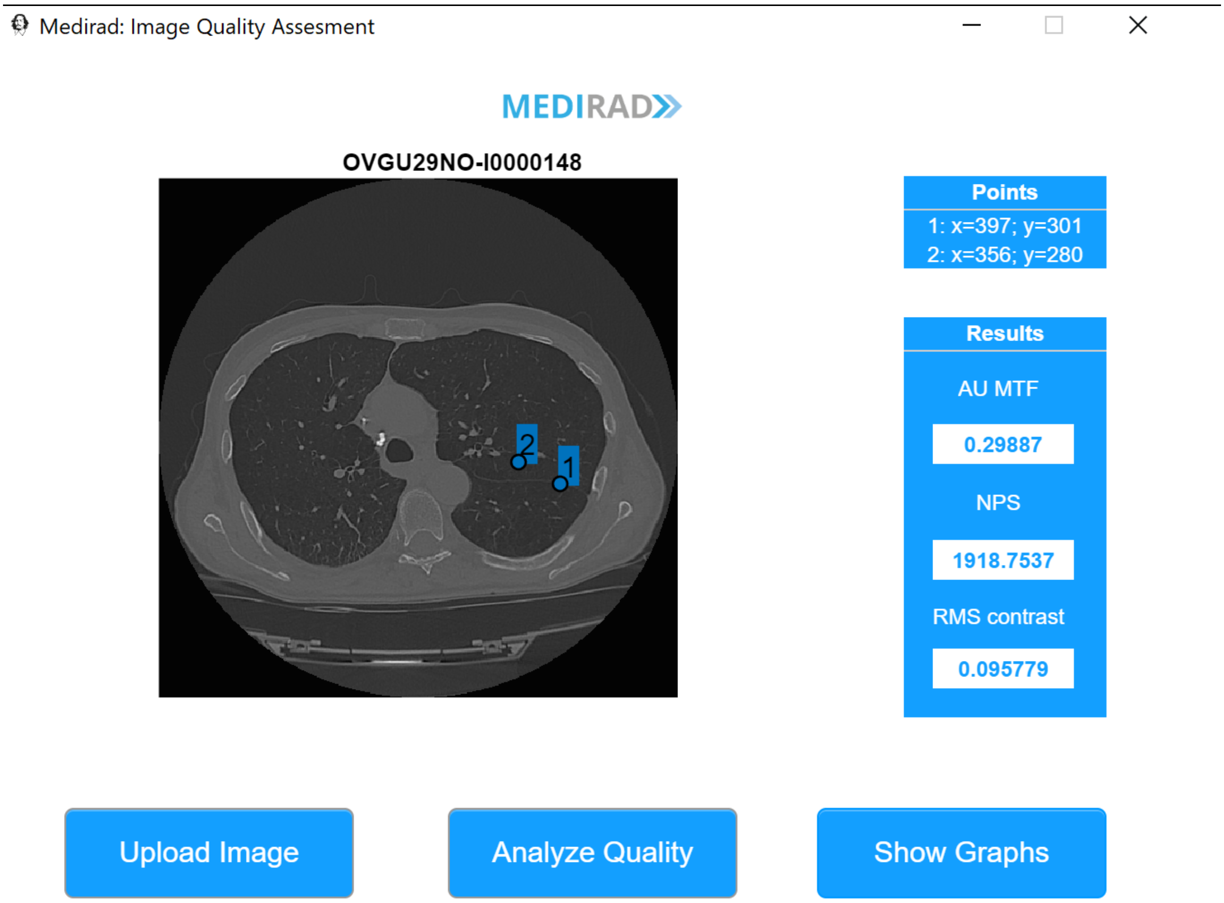
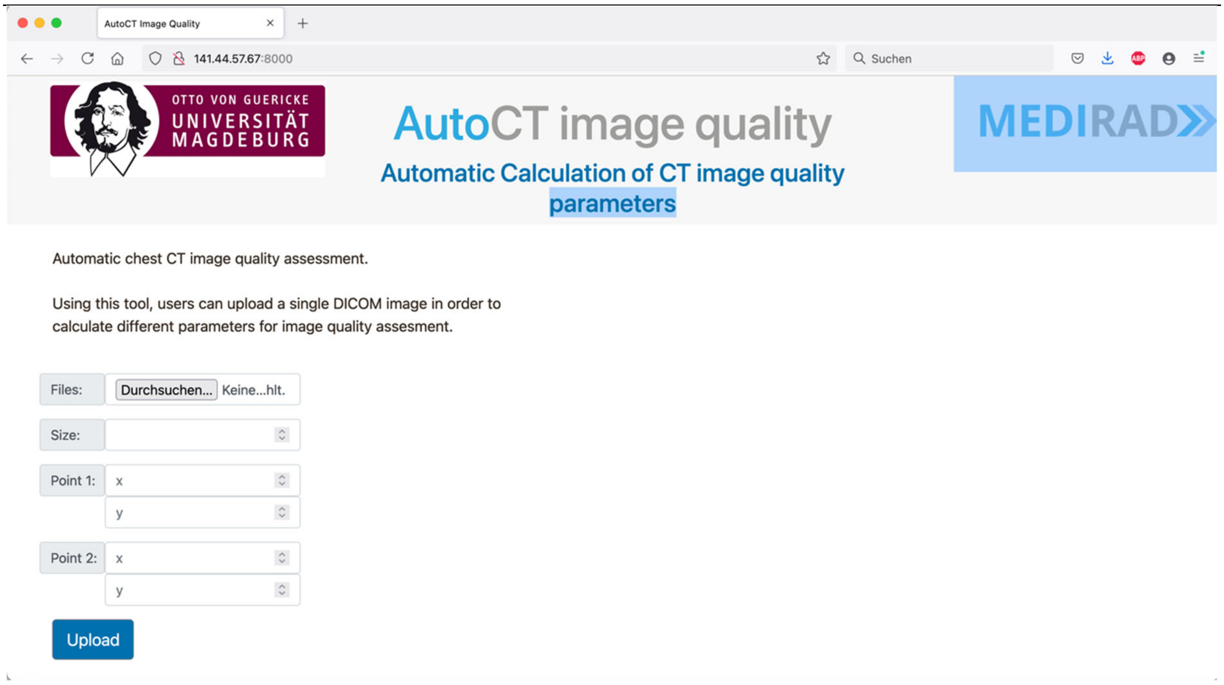


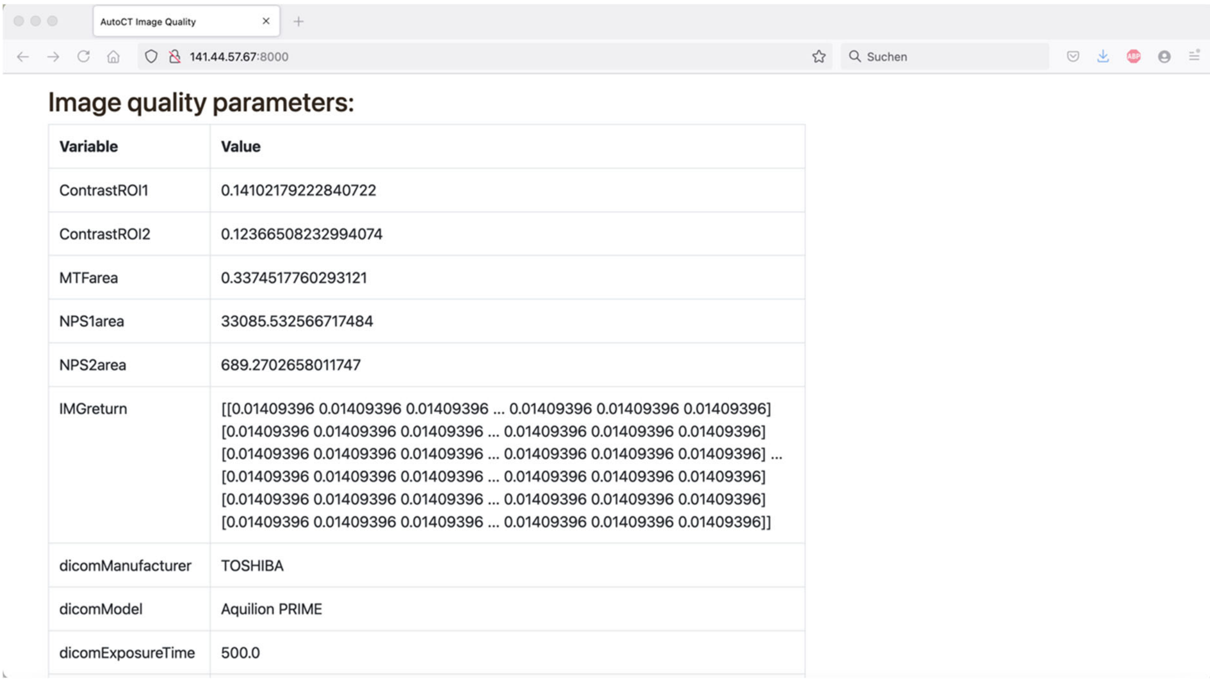
Figure 5: GUI of the first software prototype for image quality evaluation.

This was discussed between the OvGU and the IPC group to optimise for daily clinical use. There were a number of suggestions that should be implemented to make the application more user friendly. This was done in the next step.

2.5 Web based software tool

Figure 6 shows the GUI of the new web-based tool for objective IQ assessment for chest CT imaging during the IQ analysis of a test image of a real patient from the 300 patient image data sets collected in MEDIRAD. The program can be used with single slices or full data sets. The graphs shown represent the case when the slice is determined or uploaded.





Variable	Value
ContrastROI1	0.14102179222840722
ContrastROI2	0.12366508232994074
MTFarea	0.3374517760293121
NPS1area	33085.532566717484
NPS2area	689.2702658011747
IMGreturn	[[0.01409396 0.01409396 0.01409396 ... 0.01409396 0.01409396 0.01409396] [0.01409396 0.01409396 0.01409396 ... 0.01409396 0.01409396 0.01409396] [0.01409396 0.01409396 0.01409396 ... 0.01409396 0.01409396 0.01409396] ... [0.01409396 0.01409396 0.01409396 ... 0.01409396 0.01409396 0.01409396] [0.01409396 0.01409396 0.01409396 ... 0.01409396 0.01409396 0.01409396] [0.01409396 0.01409396 0.01409396 ... 0.01409396 0.01409396 0.01409396]]
dicomManufacturer	TOSHIBA
dicomModel	Aquilion PRIME
dicomExposureTime	500.0

Figure 6: web-based tool for evaluating image quality GUI after running an example evaluation.

Area 1 is the area containing the structure, area 2 is that area where there should not be a structure inside as used for the NPS measurement. Both ROIs (here named as area1 and area 2) have a size of 18 by 18 pixels which is the default value but can be changed. The contrast values in the output are determined by using the RMS contrast method (2). The value indicated as MTF_{area} is the area under the curve of the MTF. The value indicated as $NPS1_{area}$ is the area under the curve of the power spectrum in the area 1 containing also the structure. The name will be changed to PS_{area}. It was named like it was to show it determined the PS in the same area as the MTF determination. The value indicated as $NPS2_{area}$ is the area under the curve of the noise power spectrum in the area 2. In the block IMGreturn, the original CT slice values scaled to a range 0 to 1 are given to allow a display of the image once more.

As the next step we will color-code the values as well as an overall rating to indicate whether the image quality is sufficient or not. A professional version will also provide the graphs behind the values for download. The graphs will be the MTF, the NPS as well as the PS/MTF curves. However, this option would require higher knowledge, so it will be provided after attending corresponding training courses.

This tool is currently available on a server of the OvGU. It will be accessible in a first step beginning next month through a link on the MEDIRAD platform to all MEDIRAD partners. In a second step, it will be made available to the public (health care providers and hospitals) based on registration. The registration system and the open use access is currently being organized by OvGU. Then there will also be a short manual available as well as an online help function for the major features.

The public use will be established by the end of the project, so that potential bugs can be detected by project partners in advance and can be resolved. OvGU will be hosting the web-based program, but it will be linked through the MEDIRAD webpage. This is the software tool (CT-IQURAD) module on image quality as it had been proposed in the MEDIRAD project proposal. Together with the software tool (CT-IQURAD) module on dose evaluation as developed by the group of UoC it generates a unique tool for optimising chest CT imaging with respect to optimised image parameters and their corresponding image quality.

3. Conclusion

As it has been described in the proposal for the MEDIRAD project based on a correlation between a subjective IQ assessment study and a set of parameters for objective IQ assessment as developed in the project. MEDIRAD will provide a general optimisation tool for chest CT imaging in a web-based approach. The tool presented here allows determination of image quality on relevant structures in chest CT and can be used together with a similar to use module on dose evaluation for optimising purposes. The image quality module alone can also be used for verifying that the images acquired provide a sufficient image quality for the diagnostic purpose.

This gives unique opportunities for harmonisation of practises, a standardized quality assurance and a meaningful optimisation in terms of radiation protection of the patient. The approach will be linked by EUROSAFE imaging to a concept of appropriate image quality. A corresponding publication is in preparation. It seems more than helpful to elaborate and adopt the same concept for other body regions.

The promised achievements could be gained although some conditions were more difficult than expected due to the Covid-19 pandemic situation.

4. References

(1) Medirad Deliverable D2.12 report
(2) https://en.wikipedia.org/wiki/Contrast_(vision), looked up on 26th of October 2021