Development of software helping in optimising computed tomography protocols: initial results

Poster No.: C-1653
Congress: ECR 2015
Type: Scientific Exhibit
Authors: F. Gardavaud, H. Pasquier, A. Rahmouni, A. Luciani; Creteil/FR
Keywords: Radioprotection / Radiation dose, Computer applications, CT, Radiation safety, Computer Applications-General
DOI: 10.1594/ecr2015/C-1653

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method ist strictly prohibited.

You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Aims and objectives

Because of broader indications of CT, its use is increasing around the world. In 2012, the French Institute for Radiological Protection and Nuclear Safety (Institut de Radioprotection et de Sûreté Nucléaire, IRSN) estimated that 71% of the medical exposure in France was due to Computed Tomography (CT) [1]; a 22% increase of the dose was noted over the past five years mainly due to CT as the number of standard X-ray examinations is decreasing at a rate of 2% per year. Radiologists and health professionals are aware of this problem and dose optimization of CT is a major concern for patient care [2, 3]: recent works [4, 5, 6] show a higher risk of leukemia and glioma in patients who underwent a CT scan during childhood. In addition, some studies [7] show that beyond the organ-specific radio-sensitivity, there is also a genetic individual radio-sensitivity. Malfunctions of DNA repair capabilities even for low exposure (about 1 mGy) doses can now be identified thanks to advances in biology [8].

The best patient protection firstly requires ensuring the relevance of each exam as mentioned in the EURATOM 2013/59 Directive (Justification principle). Thus, to meet this requirement, the French Society of Radiology, in conjunction with the Nuclear Safety Authority, the High Authority of Health and the French Society of Nuclear Medicine have published a recently updated guide to good usage of medical imaging examinations [9]. This is a comprehensive data repository to guide physicians looking for the best imaging test to answer to the clinical symptoms or diseases of their patient.

Decrease of CT doses is also a challenge for the R & D section of manufacturers developing new detectors or new reconstruction algorithms for this purpose. Therefore, radiation protection based on the "As Low As Reasonably Achievable" principle (ALARA) [10] applies more and more in Medical Imaging: the examinations should be made by delivering the minimum dose required to ensure the proper diagnosis.

Current CT's offer new reducing dose technologies, such as iterative reconstruction or automatic exposure control. However, these techniques need to be properly configured to be useful [11]. In addition, changes in primary acquisition parameters influence both dose and Image Quality (IQ) [12, 13]. To our knowledge there is no practical guide to optimize the new techniques mentioned above. Indeed, several tools for monitoring patient dose (Dose Archiving and Communication System, DACS) have been recently proposed by the manufacturers. These systems archive cumulative patient dose from any x-ray modality. They allow the detection of poor acquisition practices. Nevertheless, none of them offers a support to radiological teams in order to correct wrong CT protocols settings.

Objectives
To develop a simulation tool enabling the visualization of optimized CT protocols in terms of resulting IQ and radiation exposure in order to help radiologists and medical physicists to optimize CT protocols.
Methods and materials

Reference Protocols database and quality image options

A database of reference CT protocols, adapted to the Discovery CT750 HD (GE Healthcare, Wisconsin, USA), for the most encountered clinical indications in CT was established by collecting CT protocols from the American Association of Physicists in Medicine (AAPM) and from optimized and clinically validated protocols in multicentric radiological departments. We defined the reference CT protocols by rejecting values which were not consistent with the CT optimization physical principles and by meaning the previous data.

For each reference protocol, three different IQ levels (low dose, optimized, high quality) were defined, by adjusting the tube current modulation in term of noise index (fig. 1).

Acquisition on an anthropomorphomeric phantom

For each reference protocol and each IQ level, CT images were acquired on an anthropomorphic phantom (PBU-60®, KYOTO KAGAKU, fig. 2). This phantom has a thin morphology, equal to the mean Japanese morphology, with a Body Mass Index (BMI) of 18.4. There is no possibility to inject contrast medium in this object. For each sequence, the volume Computed Tomography Dose Index (CTDIvol) and the Dose Length Product (DLP) were collected from the CT acquisition console. Beforehand, the medical physicist controlled the CT to ensure that the displayed CTDIvol and DLP were physically robust.

Software for CT optimization: ProtoEnhance

The authors developed a software, named ProtoEnhance, to help to optimize CT protocols by displaying the anthropomorphic images with the associated CTDIvol and DLP. The software was coded in Java language and can be used in the most common operating systems (Windows®, OS X® and most common Linux distributions).

The user imports his own protocol database from an USB device. Then, ProtoEnhance recognizes all the user protocols (except protocols which used kVp fast-switching acquisition for the moment) and proposes to select a protocol to optimize. The user has to match the chosen protocol with the corresponding reference protocol. Then, ProtoEnhance displays the three IQ levels sequences with the associated CTDIvol and DLP. ProtoEnhance includes a DICOM viewer allowing to scroll through the axial images and to select a windowing. Thus, Radiologists are able to qualify as a routine examination,
the three proposed optimizations and make a choice according to their clinical needs. Once the user selected the IQ level he preferred, ProtoEnhance generates CT system files that are automatically implemented from the USB device into the acquisition console without generating human errors due to manual data entry.

Clinical validation

Anthropomorphic images were acquired using our clinically used hepatic helical acquisition without contrast medium and then compared to the images of the corresponding optimized IQ level acquisition proposed in ProtoEnhance (fig. 3, 4). A senior radiologist qualitatively validated the anthropomorphic images of the optimized IQ level offered in ProtoEnhance. Also, we have extended this comparison by acquiring the two previous sequences on a patient with a BMI comparable to the phantom and on another patient with higher BMI than the phantom.

For each sequence, phantom and patient images included, we determined the CTDIvol only for the analyzed slices thanks to data in the DICOM fields. For these same slices, we measured the average Signal-Noise Ratio (SNR) in liver, noted SNR\textsubscript{liver}, using the following formula:

\[
\text{SNR}_{\text{liver}} = \frac{\text{Gray level}}{\text{Gray Standard Deviation}}
\]

Where Gray level corresponds to the mean value of the four Region of Interest (ROI) in the liver for axial image and Gray Standard Deviation corresponds to the mean standard deviation of the gray level for the same previous ROIs.

Then, we measured the average Contrast-Noise Ratio (CNR) between liver and air, noted CNR\textsubscript{liver/air}, by making ROIs at the same position between sequences using the following formula:

\[
\text{CNR}_{\text{liver/air}} = \frac{(\text{Gray level}_{\text{liver}} - \text{Gray level}_{\text{air}})}{\text{Gray Standard Deviation}_{\text{air}}}
\]

Where Gray level corresponds to the mean value of the associated element and Gray Standard Deviation\textsubscript{air} corresponds to the standard deviation of the gray level for the ROI in the air.
To achieve those measurements, we designed four ROIs uniformly placed in the liver to achieve a good average and one in the air as illustrated in Figure 5. We calculated the variation of these measurements between the clinically used protocol and the ProtoEnhance protocol for both phantom and patients images.
Fig. 1: Proposed IQ levels and impact on the resulting radiation exposure. Text in red means an increase of dose: i.e. CTDIvol. Text in green means a decrease of dose: i.e. CTDIvol.

© Imagerie Médicale, Hôpital Henri Mondor - Creteil/FR

Fig. 2: Photography of the PBU-60 anthropomorphic phantom.

© KYOTO KAGAKU
Fig. 3: The three IQ levels proposed in ProtoEnhance software with the associated CTDIvol (mentioned as IDSV in the figure) and DLP (mentioned as PDL in the figure). "Basse Dose", "Standard", Haute Qualité d'Image" referred to the low dose, optimized and high quality IQ levels respectively.

© Imagerie Médicale, Hôpital Henri Mondor - Creteil/FR
Fig. 4: Visualization of one slice of our clinically used hepatic helical acquisition without contrast medium acquired on the PBU-60 anthropomorphic phantom. The liver with veins can be assimilated to a good representation of a patient anatomy.

© Imagerie Médicale, Hôpital Henri Mondor - Creteil/FR
**Fig. 5:** Positioning of the ROIs in a slice for liver protocols analyzed; 4 ROIs were positioned at different parts of the liver to have a good overview; 1 ROI was positioned in the air. All the ROIs had the same area and were duplicated computationally between the different slices.

© Imagerie Médicale, Hôpital Henri Mondor - Creteil/FR
Results

Evaluation of acquisition protocols before and after optimization on the anthropomorphic phantom

As shown in Table 1, on the anthropomorphic phantom, optimized IQ ProtoEnhance acquisition was able to save 26.8 % of delivered dose without significantly observable impact on IQ by the senior radiologist. Indeed, the higher ratio was only 1.2 for the average CNR between liver and air. Furthermore, radiologists could validate qualitatively this new sequence in ProtoEnhance DICOM viewer before implementing it in clinical routine.

Evaluation of acquisition protocols before and after optimization on a patient with similar BMI than the anthropomorphic phantom

As shown in table 2, on a patient with similar BMI than the anthropomorphic phantom, optimized IQ ProtoEnhance acquisition was able to save 21.2 % of delivered dose without significantly observable impact on IQ by the senior radiologist. Indeed, the higher ratio was only 1.2.

If we compare results in table 1 and 2, variations between CTDIvol, the average SNR in liver and the average CNR between liver and air for this patient and the anthropomorphic phantom were at most 8.3 %. So, the anthropomorphic phantom could be assimilated to this patient for this anatomic region regarding the delivered dose and IQ.

Evaluation of acquisition protocols before and after optimization on a patient with higher BMI than the anthropomorphic phantom

As shown in table 3, on a patient with higher BMI than the anthropomorphic phantom, optimized IQ ProtoEnhance acquisition was able to save 6.3 % of delivered dose without significantly observable impact on IQ by the senior radiologist. Indeed, the higher ratio was only 1.1.

If we compared results in table 1 and 3, variations between CTDIvol, the average SNR in liver and the average CNR between liver and air for this patient and the anthropomorphic phantom were at most 21.4 %. So, the anthropomorphic phantom could not be assimilated to this patient for this anatomic region regarding the delivered dose and IQ.
For the authors, the explanation of this mismatch could be due to tube current modulation technic. Indeed, noise index needs to be adjusted to the body habitus to ensure dose efficiency as demonstrated by Schindera et al. [14].
Table 1: Comparison of the CTDIvol, the average SNR in the liver, noted Average SNR\textsubscript{Liver}, the average CNR between liver and air, noted CNR\textsubscript{Liver/air}, before and after optimization on the anthropomorphic phantom. Ratios of these previous parameters before and after optimization were evaluated. The anthropomorphic phantom BMI was equal to 18.4. With optimized IQ ProtoEnhance protocol, CTDI\textsubscript{vol} was reduced by 26.8\% without significantly altering the resulting IQ. Furthermore, radiologists can qualitatively validate in ProtoEnhance the proposed acquisition before applying it in clinical routine. The term "before optimization" referred to the clinically used hepatic helical acquisition. The term "after optimization" referred to the optimized IQ level acquisition proposed in ProtoEnhance.

Table 2: Comparison of the CTDI\textsubscript{vol}, the average SNR in the liver, noted Average SNR\textsubscript{Liver}, the average CNR between liver and air, noted CNR\textsubscript{Liver/air}, before and after optimization on a patient with similar BMI than anthropomorphic phantom. Ratios of these previous parameters before and after optimization were evaluated. The BMI patient was equal to 19.3. With optimized IQ ProtoEnhance protocol, CTDI\textsubscript{vol} was reduced by 21.2\% without significantly altering the resulting IQ. The term "before optimization" referred to the clinically used hepatic helical acquisition. The term "after optimization" referred to the optimized IQ level acquisition proposed in ProtoEnhance.
Table 3: Comparison of the CTDIvol, the average SNR in the liver, noted Average SNR\textsubscript{liver}, and the average CNR between liver and air, noted CNR\textsubscript{liver/air}, before and after optimization on a patient with higher BMI than anthropomorphic phantom. Ratios of these previous parameters before and after optimization were evaluated. The patient's BMI was equal to 27.5. With optimized IQ ProtoEnhance protocol, CTDI\textsubscript{vol} was only saved by 6.3 % without significantly changing the resulting IQ. The term "before optimization" referred to the clinically used hepatic helical acquisition. The term "after optimization" referred to the optimized IQ level acquisition proposed in ProtoEnhance.

<table>
<thead>
<tr>
<th></th>
<th>Before Optimization</th>
<th>After Optimization</th>
<th>Ratio Before / after optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTDI\textsubscript{vol} (mGy)</td>
<td>12.8</td>
<td>12.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Average SNR\textsubscript{liver}</td>
<td>3.1</td>
<td>3.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Average CNR\textsubscript{liver/air}</td>
<td>84.1</td>
<td>84.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Conclusion

In this study, we developed a software, named ProtoEnhance, to help radiologists and medical physicists to create as well as possible, optimized CT protocols for patients. ProtoEnhance offered the possibility to prospectively design, without any patient exposition but only on an anthropomorphic phantom, new protocols. Indeed, radiologists could evaluate the resulting protocols IQ and radiation exposure and could achieve their needs in term of patient care. Moreover, radiologists and medical physicists no longer needed to use the console acquisition because ProtoEnhance offered direct protocol implementation also removing human input errors. They could save their patients examinations number while leading an optimization policy thanks to ProtoEnhance.

We directly showed that the anthropomorphic phantom, which was used for this study, could be assimilated to patient with similar BMI for the hepatic region.

Limitations

There are some limitations on this study. First, ProtoEnhance was not a simulator and users had to match their CT protocols with ProtoEnhance CT protocols database. However, we built ProtoEnhance with an adaptive structure to easily implement additional CT protocols to fit with user’s clinical practice. Second, ProtoEnhance allows user to screen through images in the only axial plane. Third, even if tube current modulation was activated, anthropomorphic phantom IQ did not reflect the one of patient with higher BMI. Nearly, we prospect to implement additional pads on the anthropomorphic phantom to increase phantom BMI to a level of European standard BMI. Last, in this study, only one patient per BMI range was included in this study.

As far as we know, there is no similar solution to drive radiologists and medical physicists in their optimization.
Personal information

François Gardavaud, M.Sc.
AP-HP, Hôpitaux Universitaires Henri Mondor, Imagerie Médicale, Creteil, F-94010, France.
francois.gardavaud@sat.aphp.fr

Hugo Pasquier, M.Sc.
AP-HP, Hôpitaux Universitaires Henri Mondor, Imagerie Médicale, Creteil, F-94010, France.
Université Paris Est Creteil, Faculté de Médecine, Creteil, F-94010, France
hugo.pasq@gmail.com

A. Rahmouni, M.D, PhD.
AP-HP, Hôpitaux Universitaires Henri Mondor, Imagerie Médicale, Creteil, F-94010, France.
Université Paris Est Creteil, Faculté de Médecine, Creteil, F-94010, France
alain.rahmouni@hmn.aphp.fr

A. Luciani, M.D, PhD.
AP-HP, Hôpitaux Universitaires Henri Mondor, Imagerie Médicale, Creteil, F-94010, France.
Université Paris Est Creteil, Faculté de Médecine, Creteil, F-94010, France
INSERM Unite U 955, Equipe 18, Creteil, F-94010, France
alain.luciani@hmn.aphp.fr
References


2. E. Castellano, "CT Dose calculations for individual patients - what you should know," CT Users group meeting, 2010.


7. N. Foray, C. Colin and M. Bourguignon, "100 years of individual radiosensitivity: how we have forgotten the evidence," Radiology, vol. 264, pp. 627-631, 2012.


