Optimization of diagnostic procedures protocols

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Purpose

With the improvement of technologies and methods available in the medical field, in recent years has gone increasingly spreading the installation and use of imaging equipment, more precise, fast and complex that can provide a substantial amount of information. Most of the instruments aimed at diagnostic imaging is characterized by equipment using ionizing radiation, raising the value of average dose of exposure of the patient and operator.

The purpose of this investigation was to development a cross-analysis techniques of objective and subjective quality image (QI) related to dose, in order to optimize biomedical Computed Tomography protocols and to reduce the exposure risk to ionizing radiation for patients, ensuring an acceptable quality image.
Methods and Materials

A set of 5 PMMA simplified geometry phantoms was realized to study QI and absorbed dose. The set consisted of 5 devices variables in diameter, in particular: 60, 100, 160, 240 and 320 mm. Each phantom was characterized by a specific modular structure, which made it suitable for both dose of image quality assessment; in particular, each containing a central hole of diameter 54 mm for both the inclusion of dosimetric modules than those relating to image quality evaluation (Figure 1).

Fig. 1: Central hole of diameter 54 mm for both the inclusion of dosimetric modules than those relating to image quality evaluation.

References: Fondazione Toscana â€œG. Monasterioâ€#, Imaging Departement, Heart Hospital - /

In order to avoid module position changes within the phantom during the various dose and quality assessments, a series of "thorns" was developed, in addition to the modules. Each thorn was made with complementary structures in their respective quarries in adjacent modules. The alignment of phantom with the longitudinal CT axis scanner is guaranteed by the presence of two square plates (side size equal to the diameter of the device) attached to the phantom from holes placed peripherally to the plates. Dosimetric modules were characterized by 5 blind holes, one of which was in the central position and 4 in peripheral, arranged radially and offset each other by 90° (Figure 2). In every hole (47 mm long) was inserted 4 thermoluminescent sensors (TLD). This configuration made it possible to assess the CTDI (Computed Tomography Dose Index).
In addition for estimation of absorbed dose were built on the outskirts of shells (diameter 100, 160, 240, 320 mm), 4 holes in length equal to those found in central dosimetry controls described above. Each hole was placed at a distance from the edge of the phantom equal to 10 mm. This distance was used to ensure build up thickness required to achieve balance. The parameters analyzed in order to assess the diagnostic equipment in terms of image quality have included: uniformity, contrast, high-contrast resolution, low-contrast resolution. For the determination and analysis of a specific parameter of quality 4 different modules were made. We also developed a module for morphoscopic resolution for subjective QI assessment. The module for the uniformity assessment was made of Plexiglass and was designed as an integral part of the shell-phantom so as to guarantee the minimum number of interfaces between the form and the shell. The aim was to assess the consistency of CT number in a homogeneous material. The module for the contrast evaluation (figure 3_A) consisted of 4 hole of 15 mm diameter, containing the following materials: teflon, air, low density polyethylene (LDPE) and acrylic. This module, in addition to testing the linearity of CT number, allowed the noise assessment in different materials. The module for the high-contrast resolution evaluation (figure 3_B)
contained along the periphery a series of holes diameter: 5 mm, 4 mm, 3 mm, 2 mm, 1 mm, 0.8 mm, 0.7 mm, 0.6 mm, 0.5 mm, 0.4 mm, 0.3 mm, 0.2 mm. Also in the fourth quadrant were 6 pairs of holes of 1 mm in diameter distant respectively 2.5, 2, 1.5, 1, 0.5, 0.25 mm; the purpose was to resolve fine details adjacent to various distances and locate the “boundary distance” which was the minimum distance that must be two objects to be identified as yours. The module for low contrast resolution evaluation (figure 3_C) was made of 5 holes along 5 spokes off each other at 72°. The diameter of these holes were equal to 5 mm, 4 mm, 3 mm, 2 mm, 1 mm. Each group of holes present along the radius was filled with different materials (acrylic, low-density, HDPE, POM, HDPE). This module allowed the identification of the number of details distinguishable from the fund; the diameter of the smallest circular object solved provided the detection limit low-contrast. The morphoscopic module (figure 3_D) was characterized by the presence of different geometric shapes and was aimed at assessing the ability of discriminating feature. All shapes (circle, square and triangle) of different dimension were created from a series of variable diameter holes (from 0.2 to 0.5 mm) and were positioned according to a logic that unknown to the observer. The geometric shapes have been selected to understand the visual ability of the physician to identify various injuries. Then, subjective and objective QI evaluations were performed.
Fig. 3: A-D, Contrast module (A), high contrast resolution module (B), low contrast resolution module (C), morphoscopic module (D).

References: Fondazione Toscana â€œG. Monasterioâ€œ, Imaging Departement, Heart Hospital - /

Objective quality was evaluated with automatic algorithms taking account of the most qualified scientific and technical regulations. Automatic processing of images includes two phases: extraction phase signal (average of CT numbers and standard deviation SD) from regions of interest automatically identified on images and their storage database; extraction parameters of image quality by using the specific queries on data previously storaged in database tables.

Extracting signals from regions of interest (ROI) provided:

-by uniformity, extracting a central circular region of interest (ROI) and 4 peripheral circular ROI distant 1 cm from the edge of the phantom with radius of up to 1/7 the diameter of the phantom.

-by modules of contrast and low contrast, extracting signals from circular ROI on different materials with radius of up to 50% of the radius of the insert.
by high contrast, the extraction of signals from both regions of interest in the form of circular area centered on peripheral holes arranged radially and circonferenzialmente in the "L"-shaped geometry (figure 4) and both ROI focused on pairs of holes made to variable distance.

Fig. 4: Regions of interest in the form of circular area centered on peripheral holes arranged radially and circonferenzialmente in the "L"-shaped geometry

The measure of uniformity was achieved comparing the value of the average number CT of central ROI with the peripheral one. The maximum value of the difference represented image uniformity. The noise amplitude was given by the standard deviation of the circular central ROI in the uniform material.

The contrast is evaluated for each material-specific insert, comparing the average gray level of ROI centered in the insert with a ROI in the background of same size.

The Contrast to noise ratio (CNR) was a significant parameter because it take into account both the contrast and the noise. In fact the same contrast detail will be less visible in an image with high noise and more visible in an image with low noise.

High contrast module was used for the evaluation of spatial resolution system, either through the analysis of L-shaped inserts and through pairs of holes made to variable distance.

The images were analyzed by different radiologists, getting an assessment by a perceived quality visual scale. For achieving a viable subjective assessment of scanned images, was developed a special questionnaire to be submitted to a group of physicians.
The questions were developed in order to understand the influence of various parameters on the diagnostic evaluation and the predominance of a factor compared to other perceptual capabilities, for quality assessment. The subjects tested did not possess any kind of objective information, to avoid possible influences on personal evaluation. A timer allowed control weather, presenting images automatically to the minutes. The default time was necessary to avoid disturbances on the perceptive ability of the operators and to make possible a reliable comparison. For the test were selected certain images on the basis of appropriate objective parameter values. The images were presented in digital. Each observer was asked to express a qualitative judgement on them, giving a quality score in terms of uniformity, noise, CNR. As regards the images related to morphoscopic resolution module, made specifically for studying the quality parameters that affect medical perception, were asked to specify the visibility or less than a certain detail. The images were also analyzed by a neural network ables to predict the perceived image quality, acting as support for the physician clinical decisions. Starting from objective metrics of image, it aimed to establish how each individual radiologist perceived the same and the information content associated, by analyzing the process of visual learning in expert medical. Such approach by-passes the problems encountered in the use of indices of correlation between objective and subjective evaluation, which were not able to faithfully reproduce the judgement of the operator. The developed neural architecture received inbound objective values image and put out the associated image perception in terms of noise, contrast, resolution, uniformity. Thus, the final scores provided by network (quality scores) could serve as support for the subjective assessments of operators, and to be used, in later stages, for finding optimal protocols.

To optimize acquisition protocols depending on the absorbed dose were realized different dose measure: in phantom and in the operator. Dose analyses were performed with thermoluminescent dosimeters (TLD). These dosimeters, although did not permit a real-time measurement of absorbed dose, had some advantages in vivo dosimetry ; thanks to their small size, they could be apply to patient and operator during the radiological procedure.

The set of CT phantom described above had provided both central that peripheral holes for the CTDI\textsubscript{w} calculation as described in the standard EUR 16262 EU.

As regards radiation operator protection was necessary to determine the equivalent dose to the thyroid, crystalline, extremities (especially hands, wrists and forearms, lower legs below the bottom edge of the leaded shirts). The study on dosimetry operators was evaluated relative to external factors that act on radiation level like: the position in relation to the source, the duration of exposure and the shielding type used.

The statistical analysis for the evaluation of experimental data was achieved through linear regression models in order to evaluate the correlation between different device parameters and values of objective image quality and absorbed dose.
Results

Through this procedure, it was possible to obtain a biomedical device performance evaluation aimed at the selection of optimal protocols in terms of image quality/dose. In addition, there was high degree of correlation between neural networks quality indices and those perceived by the radiologist ($R^2 = 0.92$), demonstrating how networks were able to predict perceived image quality, with specific scanning and morphological parameters associated.
Conclusion

The results collected were used for the production of technical documentation in order to contribute to the formulation of new protocols characterized by a reduction of exposure to ionizing radiation, consistent with the need to meet the quality of images and therapeutic treatment planning. Upon completion of this testing were drawn up documents of Health Technology Assessment (HTA) containing proposals for a "proper and appropriate" use of CT equipment aimed at better protection of the right to health of patients and operators.
References

"Radiation Dose and Image Quality in Pediatric CT: Effect of Technical Factors and Phantom Size and Shape" Marilyn J. Siegel et al.