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Towards patient dose optimization in digital radiography

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ABSTRACT

Digital radiographic imaging systems cover a wide range of clinical applications and can produce adequate image quality using a broad span of exposure levels. Over exposure may generate higher dose levels without an affective increasing of the images quality; thus experimental data analysis is an ongoing process useful to provide information about adequacy of radiation exposure. The main purpose of this work is the assessment of quality performance of digital radiographic systems by using objective image quality tests. To this aim, the influence of radiographic parameters has been investigated in order to reduce radiation dose to patients by assuring a good quality of the images.

1. Introduction

Medical imaging systems are widely used in radiological diagnosis. Their main benefits are more accurate and faster exams, elimination of exploratory surgery, availability of post processing and computed aided detection, immediate images availability, and ability to store and/or transmit the images electronically [1,2]. Opposite, the potential risk of associated ionization radiation exposure from medical imaging, such as Computed Tomography and digital radiography [3,4] must be considered in risk to benefit ratio assessment.

Growing concern expressed by Radiology Community about the increasing exposure to ionizing radiation [5–7], has led to investigate and develop suitable strategies able to deliver the lowest dose necessary to provide sufficient image quality required to extract the desiderate details and diagnostic information.

Many studies have been proposed about the performance comparison of an imaging system with another "reference" system to define the amount of possible maximum radiation dose reduction without affecting the reference image quality. Using this approach, it is possible to optimize the system performance by means of an appropriate selection of technical parameters [8–11]. Moreover, to assure a correct use of digital X-ray devices in clinical practice, it is necessary to regularly perform standardized quality control tests by using suitable patient equivalent phantom developed both to detect possible image quality degradation and to allow corrective actions on the analyzed device [12]. They are acrylic and aluminum phantoms specifically designed to conform to the AAPM recommendations [13]. These devices are mainly used to perform only quality image tests with standard values of X-ray parameters and without any evaluation of the impact of the radiation dose.

In this work, the use of standard image quality tests was proposed to investigate the effects of X-ray parameters variations on the different image quality indexes (such as the Contrast to Noise Ratio for both high and low contrast details, and resolution limit) by identifying the index more sensitive to different operating conditions.

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Then in order to evaluate the optimal radiographic parameters, the correlation between image quality and radiation dose has been investigated. For this aim real measurements of absorbed dose have been performed by using a calibrated dosimeter device instead to consider the exposure index value provided by X-ray device which gives only an approximated and low accurate estimate of radiation dose.

2. Image quality in diagnostic radiology

In digital radiographic systems three main parameters affect the image quality: (i) the *tube voltage* representing the penetration energy of the photon in X-ray tube, (ii) the *tube current* linked to the quantity of photons generated in the tube, (iii) the *exposure time* expressing the emission time of the radiation beam (i.e. an increase in time provides higher exposure) [14,15].

The suitable setting of these parameters directly affects the diagnostic results. There is a wide variety of approaches in the assessment of radiological image quality [9,16–18]. The most applied techniques are based on the use of *Test Objects,* consisting on a set of standard objects able to provide objective information about the capability of imaging system under test and to distinguish details at different contrast and resolution values under specific conditions [11,12,16].

Alternative methods for image quality evaluation use anthropomorphic phantoms based on suitable model for simulating the tissue composition of human body [19,20]. Their aim should be to reproduce as closely as possible the behavior of X-ray energy after passing through structures of standard sized patients. These phantoms are complex and expensive systems and are unlikely available in all departments of radiology.

The identification of an objective measurement index for image quality assessment is a very crucial issue which has led many researchers to develop and propose different quality metrics whose effectiveness depends on image characteristics and specific applications. In radiological diagnosis the image contrast is a very important factor which allows to distinguish the anatomical structures of interest from their surrounding and then it is of very basic importance for the correctness of the medical exams.

Another important factor is the resolution including the capability to distinguish different adjacent structures.

For these reasons the quality indexes taking into account resolution and contrast are mainly used in the radiological quality assessment.

3. Materials and method

In the proposed study, Test Objects were applied to evaluate the performance of a digital radiographic system; particularly, the KODAK DIRECTVIEW DR 7500 (tube voltage ranging in 40–150 kV, tube current ranging in 25–500 mA, dynamic range 14 bit) [21] device, used for routine radiographies in Hospital ‘‘Casa Sollievo della Sofferenza” (San Giovanni Rotondo, Italy) is been used in the tests. The tested device is equipped with an *Automatic Exposure Control* device (*AEC*) [22], which automatically sets the X-ray parameters as function of the selected beam potential so in order to keep approximately constant the exposure value. It has antiscatter grid placed close to the entrance surface of an image receptor to reduce the amount of scattered radiation reaching the receptor, according to the European Guidelines for quality assurance in X-ray diagnosis [23].

3.1. X-ray device analysis

As first step, the characterization of analyzed radiographic device has been carried out. In particular, the X-ray output intensity expressed as absorbed dose to air K_{air} (*Air-Kerma*) [16] was evaluated as function of the tube voltage (V), of the tube current and of the exposure time product, often referred as the *tube loading* (Q).

Several studies have proved that K_{air} is linearly dependent on the tube loading and approximately proportional on the square of the tube voltage [14,15].

For this aim several experimental tests have been carried to measure the *Air-Kerma* at a focus-to-detector distance of 2 m by using a RTI Piranha dosimeter [24] and by varying the values of X-ray parameters in the range normally used in clinical practice. For measurements traceability the dosimeter used in the tests has been suitably calibrated; really, the device was calibrated in June 2013 and the manufacturer recommends a calibration interval of 2 years.

Several values of *Air-Kerma* were measured by varying the tube voltage and the tube loading in the range 60–135 kV and 0.5–20 mA s, respectively, which represent the typical values adopted in practice X-ray analysis.

The obtained results shown that the K_{air} is linearly dependent on tube loading (as shown in Fig. 1) and that the coefficients of the linear regression vary with the tube voltage values according to the following equation:

$$K_{air} = c_{1_{Vi}} \cdot Q + c_{2_{Vi}} \tag{1}$$

Unfortunately, these coefficients (listed in Table 1) can change over time and with the continuous use of the X-ray device, so it is recommended to periodically verify the stability of the system performance.

The obtained relative mean root square fitting error is resulted to be lower than 5.4% for all tube voltage values considered.

Moreover, for a fixed tube loading value, K_{air} can be expressed as quadratic function of tube voltage (as shown in Fig. 2) by providing a relative suitable mean root square fitting algorithm, whose error is resulted to be lower than 4.0%. These results confirm the good fitting of the proposed models assuring both the reliable of the X-ray device and the validity of the tests.

$$K_{air} = k_{1_{Qi}} \cdot V^2 + k_{2_{Qi}} \cdot V + k_{3_{Qi}} \tag{2}$$

3.2. Phantom TOR CDR

After the modelling phase was completed the performance assessment of radiographic systems was carried out by means of TOR CDR (Leed Test Object) [25].