Design of phantoms and software for automatic image analysis applied to
digital radiographic equipments

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\textbf{Abstract.} In a quality control of the radiographic equipment, the quality of the obtained image is very useful to characterize the physical properties of the image radiographic chain. In the radiographic technique it is necessary that the evaluation of the image can guarantee the constancy of its quality to carry out a suitable diagnosis. The use of digital systems allows the automatic analysis of the obtained radiographic images, increasing the objectivity in the evaluation of the image.

In this work we have designed some radiographic phantoms for different radiographic digital devices, as dental, conventional, equipments with computed radiography (phosphor plate) and direct radiography (sensor) technology. Additionally, we have developed a software to analyse the image obtained by the radiographic equipment with digital processing techniques as edge detector, morphological operators, statistical test for the detected combinations. The images have been acquired in DICOM, tiff, format and they can be analysed with objective parameters as an image quality index and the contrast detail curve.

The design of these phantoms let the evaluation of a wide range of operating conditions of voltage, current and time of the digital equipments. Moreover, the image quality analysis by the automatic software let study it with objective parameters and the functioning of the image chain of the digital system.

\textbf{KEYWORDS:} radiographic phantoms, quality control, digital image

\section{1. Introduction}

Digital radiography equipments with computerized digital radiography (phosphor plate) and direct digital radiography (sensor), are replacing the conventional radiographic equipments in medical applications. In a quality control of the equipment, the quality of the obtained image is very useful to characterize the physical properties of the imaging chain for the evaluation of the image.

The development of specific phantoms to study the image obtained by digital radiographic equipments is an important task to analyse physical aspects of the imaging chain related to the evaluation of the image and the quality control of radiographic equipments in normal operating conditions [1].

The development of specific phantoms to study the obtained image of computerized and direct digital radiographic equipments is the objective of this work to characterize the constancy of the imaging chain. These phantoms have specific characteristics for these systems, as different test zones for the analysis of the image quality. The test zones that are in these phantoms are low contrast objects, varying in diameter and size, for the threshold contrast resolution of the system, high resolution test for the limiting spatial resolution, dynamic step wedge for the dynamic range of greys of the system, homogeneity zone and alignment marks for position and size of radiation field.

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2. Materials and Methods

2.1 Constancy X-Ray developed phantoms

In this work we have developed specific phantoms applied to acceptance and constancy test to analyse the image obtained by digital radiographic equipment. This phantom has been designed with different test objects recommended by international and national associations (IEC-61223-2-9, RD 1976-1999) [1, 2], as low contrast objects varying in diameter and size for the threshold contrast resolution, high resolution test for the limiting spatial resolution, dynamic step wedge for the dynamic range of the system, homogeneity zone and alignment marks for position and size of radiation field. Additionally, we have developed a software to analyse the phantom images obtained with digital processing techniques based on mathematical algorithms applied to each test of the developed phantoms. This type of phantom covers all range of resolution and contrast of radiographic digital systems.

One of these developed phantoms is a constancy phantom named RACON that a sketch of it is shown in Figure 1. The features of the developed constancy phantom RACON to acceptance and constancy test of size 325x325x10 mm are that it is made of plexiglas with test objects embedded in it (recommended by international and national associations (IEC-61223-2-9, RD 1976-1999) that are:

1. Low contrast objects varying in diameter and size for the threshold contrast resolution. This test zone is a block of aluminium that has specific objects of contrast-detail combinations that are cylindrical holes of determined diameter related with resolution, in a range from 0.3 to 1.6 mm and in depth related with contrast, in range from 0.14 to 1.28 mm.
2. High resolution test for the spatial resolution which varies from 0.5 pl/mm to 10 pl/mm 45º rotated.
3. Dynamic copper step wedge with different step thickness from 0.3 to 2.3 mm for the evaluation of the dynamic range of the imaging system
4. Homogeneity zone the grey level related with the type of exposition and alignment marks for position and size of radiation field for different format sizes 180x240, 260x260 and 300x300 mm.

This type of phantom is very useful to analyse different test zones and could be applied to detect abnormal functioning of the radiographic equipment because this phantom could be applied to obtain images in different working conditions of the radiographic equipments as conventional, hemodynamic. The operating conditions of these X ray equipments based on the parameters voltage, current and time are the following:
- Voltage of functioning of the x ray tube: 50-150 kv,
- Current of the x ray tube: 5-1000 mA,
- Operating time: 20-1000 ms.

![Figure 1: Sketch of the developed constancy phantom](image)

So this phantom let the evaluation of the sensitivity of the acquired image of the phantom designed based on variations of the voltage (kv), working load (mAs), clinical use distance (normally 1 meter) and concordance of the radiation field (orthogonality of the beam). With this phantom we pretend to characterize parameters of the image adequate of the radiographic images.
Also we have developed a phantom applied to analyze the image obtained by dental radiographic equipments, named RADEN. It has specific test objects of contrast-detail combinations that are cylindrical holes of determined diameter in a range from 0.3 to 1.6 mm and in depth from 0.14 to 1.28 mm designed by the resolution of the dental digital systems and the contrast attenuation curves of the X-radiation. The phantom consists in a block of aluminium of 10 mm which has a lodge for the sensor of the digital dental system below of the contrast-detail combinations that is fixed to the phantom by an elastic system [3, 4]. In Figure 2 we can see a sketch of this phantom.

**Figure 2:** (a) Developed dental phantom. (b) Sketch of the dental phantom.

2.2 Evaluation of the digital phantom images

Additionally we have developed specific software to analyze the phantom images obtained by the developed phantoms in this work RACON and RADEN by digital radiographic equipment with digital processing techniques based on mathematical algorithms applied to each test zone of the phantom [5, 6] This automatical software applied to each type of phantom is based on image processing techniques, as image masks for detection of objects, morphological operators, statistical tests.. and they are programmed with commercial software MATLAB 7.0.

The software developed for each phantom pretends the evaluation of the image in an objective way. Concretely the software developed to analyze the image of RACON phantom is based on that the program firstly searches the representative geometrical marks in the image and after these marks have been found, the program applies some specific algorithms to each test zone. These specific algorithms are based on different techniques as filters for noise removal, pattern recognition, thresholding and morphological operators. After that we can obtain specific parameters for each test object as contrast with its background, geometrical features and exactly location [5].

**Figure 3:** Acquisition of the constancy phantom image by the radiographic conventional equipment.
In addition we have developed a software to analyse in an automatic way the image quality obtained of the dental developed phantom RADEN. It is based on digital processing techniques as edge detector, morphological operators, statistical test for the detected combinations. The images have been acquired in DICOM, tiff.. format and they can be analysed with objective parameters as an image quality index (IQFinv) and the contrast detail curve [5,7].

The techniques of the developed software in this work are applied in several steps: First of all, the algorithm determines the border of the dental phantom with four corner control marks that are very thin holes; then the software resolve the position and the centre of the contrast-detail combinations by Hough mask transformations. After that, it is determined the mean and standard deviation of the background and the mean and standard deviation of the spot that is the projection of the disk in each contrast detail combination. The programme tests with a statistical method if the average contrast-detail is greater than the average background, to consider the combination as detected. After that, it is applied a score correction taking into account the nearest neighbours of the combination under evaluation.

**Figure 4:** Acquisition of the dental phantom image by the radiographic dental equipment.

The reason to develop these software applied to the RACON and RADEN phantoms is to avoid the subjectiveness and accelerate the task of the evaluation of the digital image based on the detection of contrast detail combinations. These procedure to evaluate the image could be a routinely task to evaluate the image chain of the digital system in an automatic way.

### 3. Results

#### 3.1 Constancy phantom RACON results

The design of this phantom let the evaluation of a wide range of operating conditions of voltage (kv), current (mA) and time (s) of the radiographic equipment. We have acquired some images of the phantom in DICOM format varying the working conditions of the digital radiographic equipments. Then the images have been analysed with the automatic software developed for this phantom. We can see from the results obtained that the test objects of the phantom are enough sensitive to the variation of the working conditions of the equipment.

In Figure 5 it is shown the graphical representation of detected tests of the constancy phantom obtained by the software after the application of automatic algorithms. In Figure 5 (a) it is represented the wedge step test zone with different thickness of copper to simulate different attenuations of material, in Figure 5 (b) it is shown the detected grid and in Figure 5 (c) it is detected the test constancy resolution zone.

**Figure 5:** Developed software for the constancy phantom. (a) Dynamic Wedge Step (b) Detected grid constancy phantom (c) Detected resolution test constancy phantom
3.2 Dental phantom RADEN results.

We have acquired different images in DICOM format of the dental phantom varying the operating conditions of the dental radiographic equipment to evaluate the sensitivity of this designed phantom. In addition, we have study different technology of the dental radiographic equipments using computerized radiographic technology (phosphor plates) and direct digital radiography (RVG sensor). These images have been study applying the developed software adapted to the dental phantom and analysing the contrast detail combinations detected in its image so they can be analysed with objective parameters as an image quality index ($IQF_{inv}$) and the contrast detail curve. In Figure 6 we can see which is the functioning of this automatic software for the evaluation of the image.

**Figure 6**: Detection of contrast detail zones in the dental phantom images with the automatic software.
In the following table there are shown the obtained results for different images in different exposure conditions and technology, computerized (CR) and direct radiography (DR), for dental equipments. The image quality index shows a variation as the exposure conditions are varying too, so this index is sensitive to the operating conditions of the dental radiographic equipments.

Table 1: Results obtained for different images of the dental developed phantom.

<table>
<thead>
<tr>
<th>Image</th>
<th>Digital technology</th>
<th>IQF&lt;sub&gt;inv&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>65kv , 7.5mA, 100ms</td>
<td>Indirect (phosphor)</td>
<td>51.38</td>
</tr>
<tr>
<td>70kv, 8 mA, 200ms</td>
<td>Indirect (phosphor)</td>
<td>55.06</td>
</tr>
<tr>
<td>70kv, 8 mA, 320ms</td>
<td>Indirect (phosphor)</td>
<td>65.62</td>
</tr>
<tr>
<td>65kv, 8mA, 110 ms</td>
<td>Direct (sensor)</td>
<td>90.96</td>
</tr>
<tr>
<td>65kv, 8mA, 200 ms</td>
<td>Direct (sensor)</td>
<td>95.95</td>
</tr>
</tbody>
</table>

4. Conclusions

As we can see from the results in the section above, the developed constancy phantoms RACON and RADEN are designed to evaluate different digital technologies of the radiographic equipments, as conventional radiographic or radiography equipments for the RACON phantom and dental radiographic equipment for RADEN phantom. These two phantoms are enough sensible to detect variations in the operating conditions of the equipment because of the designed test objects inside of them, varying its detection with the variable conditions of voltage kV, current mA and time ms. In addition the developed software to detect the test objects automatically for each of both phantoms to evaluate the image let perform an objective analysis of the digital image carrying information about objective parameters as image quality index, that is useful to determine the quality of the system image chain to obtain the digital image.

The developed constancy phantom RACON evaluates the uniformity and analyses the image quality obtained for different digital radiographic equipments with different constancy tests based on test objects of low contrast, high contrast resolution, geometric distortion to measure the concordance of the radiation field. The development of a software that let the automatical analysis of the objects in the image using objective parameters to study it. The developed phantom in this work evaluates the characteristics of the digital system, as contrast threshold and detail detectability to evaluate the global state of the imaging system to certificate the image quality of the digital system in a wide range of operating conditions of voltage (kv), current (mA) and time (s) of the equipment. The image quality analysis by the automatic software let study it in an objective way and the functioning of the image chain of the digital system analysing the evolution of the image quality parameters.

The results obtained show that the dental phantom is enough sensitive to evaluate the obtained image quality in different digital dental radiographic equipments. The best obtained image quality is for the direct or RVG sensor systems because under similar operating conditions of the equipment the number of contrast detail combinations are bigger than in the indirect or phosphor systems. In this work the

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IQF_{inv} = \frac{1}{\sum_{i=1}^{n} C_{i} \cdot D_{i,th}} \cdot 100
\]
developed software to analyse the image quality of the dental phantom let the automatical detection that are in the phantom image, based on border identification with image processing operators, mask application and statistical corrections to determine the contrast detail combinations. After this, the software let the analysis of the image quality with the contrast detail curve and the image quality index IQF, which evaluates the image quality with the dose radiation exposure in the radiographic exploration. So the developed dental phantom RADEN is a kind of phantom evaluates the characteristics of the digital system, particularly contrast threshold and detail detectability to evaluate the global state of the imaging system to certificate the image quality of the digital system. The image quality analysis by the automatic software let study it in an objective way and the functioning of the image chain of the dental digital system.

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