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Technical notes

Quality and dose optimization in hand computed radiography

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ABSTRACT

The objective of the present study was to optimize a radiographic technique for hand examinations using a computed radiography (CR) system and demonstrate the potential for dose reductions compared with clinically established technique. An exposure index was generated from the optimized technique to guide operators when imaging hands. Homogeneous and anthropomorphic phantoms that simulated a patient's hand were imaged using a CR system at various tube voltages and current settings (40–55 kVp, 1.25–2.8 mAs), including those used in clinical routines (50 kVp, 2.0 mAs) to obtain an optimized chart. The homogeneous phantom was used to assess objective parameters that are associated with image quality, including the signal difference-to-noise ratio (SdNR), which is used to define a figure of merit (FOM) in the optimization process. The anthropomorphic phantom was used to subjectively evaluate image quality using Visual Grading Analysis (VGA) that was performed by three experienced radiologists. The technique that had the best VGA score and highest FOM was considered the gold standard (GS) in the present study. Image quality, dose and the exposure index that are currently used in the clinical routine for hand examinations in our institution were compared with the GS technique. The effective dose reduction was 67.0%. Good image quality was obtained for both techniques, although the exposure indices were 1.60 and 2.39 for the GS and clinical routine, respectively.

Introduction

Many disease processes are manifested in the small bones of the hands, wrists, and associated soft tissues [1,2]. Several diagnostic decisions depend on detecting the details and image contrast of interfaces in the hand and wrist. The early detection, diagnosis, and continuous evaluation of disease states are essential for successful treatment [1,2]. Radiography is the first choice for the evaluation of diseases of the hands, and other image techniques are rarely used to establish diagnosis and treatment. Therefore, the image quality of X-ray examinations is essential.

Homogeneous phantoms are widely used in image quality optimization to determine the optimal technique and establish protocols for clinical routines while ensuring maximal image quality with as low as reasonably achievable (ALARA) doses [3,4]. Such phantoms are constructed of tissue-equivalent materials to simulate the absorption and scatter of the X-ray beam in the body. These phantoms are generally made with polymethyl methacrylate (acrylic) and aluminum. Numerous homogeneous phantoms have been constructed for different anatomical regions, such as the chest, abdomen, lumbar spine, skull, and extremities [3–5].

With technical advances from analog to digital systems, techniques that have been traditionally considered optimum for analog systems may no longer be considered optimal for digital systems [6,7]. Operators base their choice of technique on trial and error

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because digital radiography can be manipulated in the display of the image to obtain the desired contrast [8].

Ideally, the objective optimization of digital radiographs is based on the signal difference-to-noise ratio (SdNR) [6]. A digital image with a high SdNR may provide inherently superior image quality compared with a lower SdNR [6]. Measurements of the SdNR are usually performed in a test object, such as a homogeneous phantom, in which the pixel value of a contrast object (signal) is compared with its surrounding area (background). However, the SdNR is of limited importance in optimization experiments unless they are related to patient dose [9]. The SdNR is often used to calculate the figure of merit (FOM) as an endpoint of optimization [6].

These image quality parameters can range widely, and they should be related to clinical evaluations [8]. One can assess image criteria using Visual Grading Analysis (VGA), which characterizes clinical images in a subjective manner [8]. Anthropomorphic phantom image quality can be assessed by VGA, which allows quantitative studies, even for a large number of images [10].

Manufacturers of CR systems provided a numerical indication of the adequacy of exposure that reaches the detector after every exposure event [11]. This method provides feedback to operators of digital radiographic systems in the form of a standard index [7]. Excessive detector exposure may produce high-quality images but at the expense of increasing the patient dose [7]. Therefore, it is necessary to review those indices in CR to check if the correct exposure factors were used in the examination [11]. Thus, it is possible to avoid the phenomenon known as dose creep and to maintain image quality [11]. The name of exposure indices varies between manufacturers. In Kodak it is named Exposure Index (EI), in FujiFilm the S values and in Agfa is called the log mean (lgM) [7,11].

The objective of the present study was to optimize the quality and dose of hand X-ray examinations using CR systems and establish an optimized chart of techniques. An ideal exposure index was also determined to guide operators when imaging hands and to avoid dose creep. We used a homogeneous hand phantom to objectively assess image quality by measuring the FOM. An anthropomorphic phantom was used for subjective assessments by performing VGA.

Material and methods

Phantoms

In the present study, we used a homogeneous phantom of the hand to objectively assess image quality performance of the CR system. The methodology that was used to develop the hand phantom was previously described in studies that quantified the pediatric chest using histogram segmentation methodology [3,12].

The homogeneous phantom was composed of two acrylic slabs of equal thickness with an aluminum layer between them (Fig. 1a). The arrangement of the aluminum and acrylic was based on American Association of Physicists in Medicine recommendations [4]. The homogeneous phantom plates included two acrylic slabs (18.0 cm length × 22.0 cm width × 1.2 cm thickness), simulating soft tissue, and an aluminum layer (18.0 cm length × 11.0 cm width × 0.2 cm thickness) between the acrylic slabs, simulating bone tissue.

The choice of this phantom was based on its homogeneous property, which allowed image quality analysis by determining the SdNR and FOM. Furthermore, the SdNR measurement was made using circular regions of interest (ROIs; 20 mm diameter) to make the measurements less susceptible to noise and exclude larger-scale non-uniformities [6]. The SdNR evaluation was not performed for the anthropomorphic phantom because of small regions of soft tissue that were present in the image. The arrangement of the phantom allowed the evaluation of the SdNR between soft and bone tissues, simulating contrast in hand radiography.

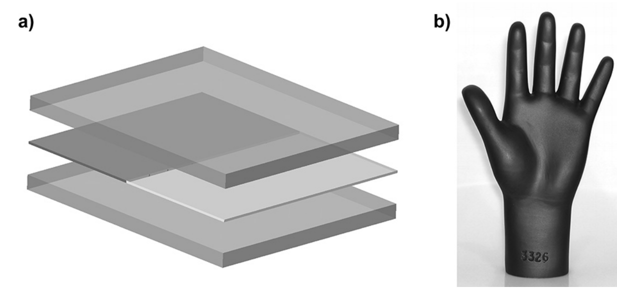

Figure 1. (a) The homogeneous hand phantom that was used for the objective assessment of image quality. The homogeneous phantom was constructed of two acrylic slabs (18.0 cm length × 22.0 cm width × 1.2 cm thickness), simulating soft tissue, and an aluminum layer (18.0 cm length × 11.0 cm width × 0.2 cm thickness), simulating bone tissue. (b) The anthropomorphic phantom that was used to subjectively evaluate image quality.

A homogeneous phantom alone does not allow direct image quality analysis in routine clinical practice [10]. The anthropomorphic phantom (Sectional Hand Phantoms, XA231R, The Phantom Laboratory, New York, NY, USA; Fig. 1b) can be used to directly image anatomical structures that are similar to patients in clinical practice [10]. Therefore, the radiologists subjectively evaluated image quality by performing absolute VGA using the anthropomorphic phantom.

Simulation of images using different techniques

The exposures for both the homogeneous and anthropomorphic phantoms were performed using the image acquisition setup under typical clinical conditions of hand examinations: (*i*) the source-detector distance (SDD) was fixed at 100 cm, (*ii*) the phantoms were positioned on the image plate, and (*iii*) the field of view covered an 18 cm × 24 cm image plate.

The images were acquired using 12-pulse three-phase X-ray equipment (Multix B, Siemens AG Medical Engineering, Erlangen, Germany) and a CR-85X Digitizer (Agfa-Gevaert Group, Mortsel, Belgium) with MD 4.0 general cassette plates (18 cm × 24 cm; effective pixel pitch, 0.1 mm). Image acquisition was performed using only one CR image plate. A delay of 10 min was ensured between exposure and reading the image plate. Recommended quality control tests for the entire set of equipment were performed before the measurements.

Both the homogeneous and anthropomorphic phantoms were imaged over a range of tube voltages and currents that covered the values that are shown in Table 1.

For each kVp value, five images were generated, corresponding to the mAs values. Bold values are the settings used in the clinical routine of our medical school hospital. Equipment limitations did not allow lower kVp and mAs values to be analyzed.

Homogeneous phantom image data were obtained “for processing” prior to the application of image processing in the CR

Table 1
Exposure parameters that were used to simulate different image quality levels. Bold values are the settings used in the clinical routine.

kVp	40	42	44	46	48	**50**	52	55
mAs	1.25		1.6	**2.0**		2.5	2.8	

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