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SIMULATION OF NODULE-LIKE PATHOLOGY IN RADIOGRAPHS OF THE LUMBAR SPINE

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Abstract — For image evaluation in clinical routine, techniques like contrast–detail diagrams are commonly used. However, it is difficult to make an interpolation from these test results to real patient images. This problem can be solved by observer studies on the detection of certain pathology, which is often simulated by fixing external objects to healthy volunteers. This approach is relatively simple and rather successful in chest imaging. For lumbar spine images, however, the situation is different because nodule-like tumours in the spine can present themselves being osteosclerotic (producing bony material) or being osteolytic (destroying bone). Such a behaviour is extremely hard to simulate by fixing an external object to the patient. Therefore, this paper presents a computer model for the simulation of nodules in lumbar spine images, which has been applied to digital radiographic data within a study to investigate the influence of MTF and noise power spectra on the diagnostic quality.

INTRODUCTION

There are well-established standards for measuring techniques available for the evaluation of the imaging properties of medical radiographic systems, e.g. ISO 9236 for the measurement of the H/D curve. In a clinical environment, however, corresponding sophisticated measuring equipment is not readily available. Therefore techniques like contrast–detail diagrams or the visual inspection of radiographs of grid pattern with varying contrast and spatial resolution are very commonly used instead for image evaluation in clinical routine. The disadvantage with these techniques is that is difficult to make an interpolation from these test results to real patient images. For a quantitative evaluation of the influence of different radiographic techniques on the diagnostic image quality, measures of the observer performance are necessary. Therefore, observer studies on the detection of certain pathologies are commonly used employing ROC methodology[1,2]. However, the detection of real pathology in a real patient image is the most realistic case compared to the requirements of daily clinical routine. Unfortunately, it is very difficult to obtain a statistically sufficient number of cases for scientific studies. Both patients and typical pathologies show a large variety with respect to their visual presentation in a radiograph. When there is no doubt about the presence of pathology, then its visibility is far from the edge of detectability, and thus the pathology is not suitable in a detection study. Therefore, it is advantageous to employ simulated pathology: the truth is known with respect to location, size and contrast of the pathology, and all these properties can be easily manipulated according to the detection task required.

Principally, there are two different methods to accomplish simulation of pathology: hardware simulation, where solid objects are fixed to phantoms or patients before real radiographs are produced[3–6]; and software simulation, where digital radiographs are manipulated according to a digital model of the pathology[7,8].

In the literature, there are different approaches to simulate nodules for chest images but none for lumbar spine. The simulated nodules presented in this paper were used within a CEC founded research project, which was investigating the influence of MTF and noise power spectra on the diagnostic quality of radiographs with regard of the lumbar spine.

MATERIAL AND METHODS

General procedure

To simulate a certain type of pathology in a computer, a digital model of this pathological object is necessary. For the model presented here, an approach was adopted which was originally proposed by Samei *et al* in 1997 for chest nodules[6]. Samei had demonstrated that subtle lung nodules can be represented by circular Teflon phantoms with a Gaussian thickness profile. Our computer model (achieved by means of the software package IDL™) simulates the effect of such an object by assuming a linear absorption of radiation. Contrast and lateral size can be adjusted independently. To simulate the limited spatial resolution of a radiographic image, the model includes digital filtering with the modulation transfer function (MTF) of a conventional screen–film system. Such a nodule is finally represented by a two-dimensional array of logarithmic kerma values. The lumbar spine radiograph to which this two dimensional array is added, has been produced from a conventional clinical film radiograph of a real patient which was digitised using a calibrated CCD scanner (Vexcel, Graz, Austria; Type: ULTRASCAN 5000, with 40 μm spatial resolution and 16 bit dynamic resolution). The digital image data was interpreted in terms of kerma by making use of the H/D curve of the screen–film system used for the original radiograph. The corresponding data were measured at the Institute of Applied Radiation Physics at the University of Lausanne according to ISO 9236[9] (beam quality III), together with the MTF according to DIN 6867[10]. The advantage of performing the manipulation in the kerma domain instead of the density domain is that the nodule contrast in terms of optical density is automatically adjusted according to the H/D curve: e.g. added to an anatomical background with an optical density of about 0.5, the nodule contrast is about $\Delta D = 0.06$, and at a background of $D = 1.8$ the same object produces a contrast of more than $\Delta D = 0.14$, caused by the increase of the film gradient.

After the addition of the nodule, the digital data is transferred to an 8 bit representation calibrated in terms of optical density for being printed back to film by means of a medical laser imager (Manufacturer: Agfa Gevaert; Type: SCOPIX LR 5200).

Special features

The procedure described so far results in a patient image with a nodule which could have been obtained alternatively by fixing a Teflon nodule to the patient — according to Samei's procedure — and then taking a radiograph. The nodule appears as a blurred circular spot with decreased optical density due to the simulated increased X ray absorption (sclerotic type of nodule). The computer model, however, offers the possibility not only to add but also to subtract the nodule. The subtraction corresponds to a type of disease which destroys the bony structures in the spine and decreases the X ray absorption (osteolytic type of nodule). Consequently, the nodule appears as a blurred circular spot with increased optical density on the film. As an example, a schematic representation of such a nodule with a size of 6 mm and a contrast ΔD of 0.13 is given in Figure 1. It must be emphasised that such a lesion cannot be simulated by fixing objects externally to a patient.

The destruction of certain anatomical details like the pedicle cortex is an important characteristic feature which a radiologist uses for diagnosing malignant disease in the spine. Therefore a special routine of the computer program simulated the destruction of the cortex line when osteolytic lesions were located within the vertebral bodies. In the region where the nodule was going to be placed, the cortex line was detected and filled like a channel using a digital erosion/dilation procedure of directed and weighted type applied to the gray scale image[11]. The intensity values of the nodule were used as weighting factors for this procedure: the smaller the distance between the cortex and the centre of the nodules, the larger was the destruction of the cortex. An example is presented in Figure 2, showing a detail of a vertebral body without and with the osteolytic nodule. Again, such a behaviour cannot be simulated by, for example, taking radiographs of objects externally fixed to patients or phantoms.

Based on one digitised radiograph of the lumbar spine, fifty images were produced by adding the nodules at different locations. From one image to another, the positions and the total number of nodules were varied randomly. The contrast of the nodules was varied until the edge of detectability was reached.

The total number of lesions per set was

(i) in the spine with a diameter of 10 mm: 200 destructive and 84 sclerotic lesions (1–10 per image);
(ii) in the pelvis with a diameter of 6 mm: 191 destructive and 82 sclerotic lesions (1–10 per image).

The film prints were presented to seven board certified radiologists for nodule detection according to a free-response forced error experiment (FFE)[12]: the radiologists had the task to mark, in order of decreasing confidence, those regions in the image which they thought to contain a nodule.

RESULTS AND CONCLUSIONS

The evaluation of the corresponding observer study[13] revealed, that 49% of the 10 mm nodules were correctly detected before the first false positive decision was made. In the case of the 6 mm nodules, the corresponding figure was 66%. In other words, the contrast of the nodules was subtle enough so that it was neither

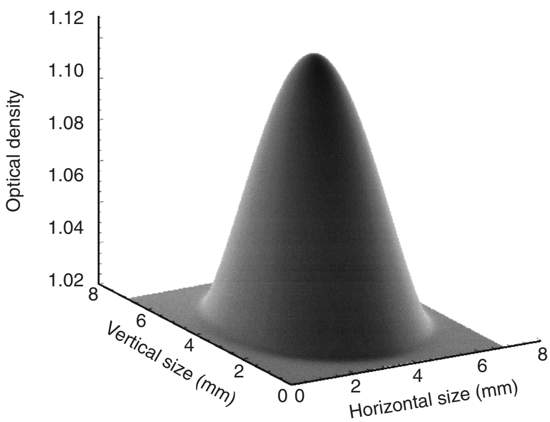

Figure 1. Schematic representation of an osteolytic (destructive) lumbar spine nodule with a diameter of 6 mm and a density contrast of 0.13 at a background density level of 1.0.

too easy (→ 100% detection rate) nor too difficult (→ 0% detection rate) to detect the nodules. Therefore it can be concluded that the simulated nodules were appropriate for a further investigation of the influence of different levels of image quality on the observer performance[13].

Figure 2 demonstrates that the circular shape of the nodules is obscured due to the details of the anatomical background. This is mainly true for the nodules located in the spine. In the iliac bone, however, the anatomical background is much more homogenous and consequently, even in case of low contrast nodules the circular shape of the model is more visible. Therefore, it is planned to improve the model by varying and randomising the basic geometric shape of the nodule, resulting in the creation of more irregularly shaped objects.

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Figure 2. Detail of a vertebral body without (left hand side) and with an osteolytic nodule destroying the cortex line (right hand side).

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