Radiographic Contrast-Enhancement Masks in Digital Radiography

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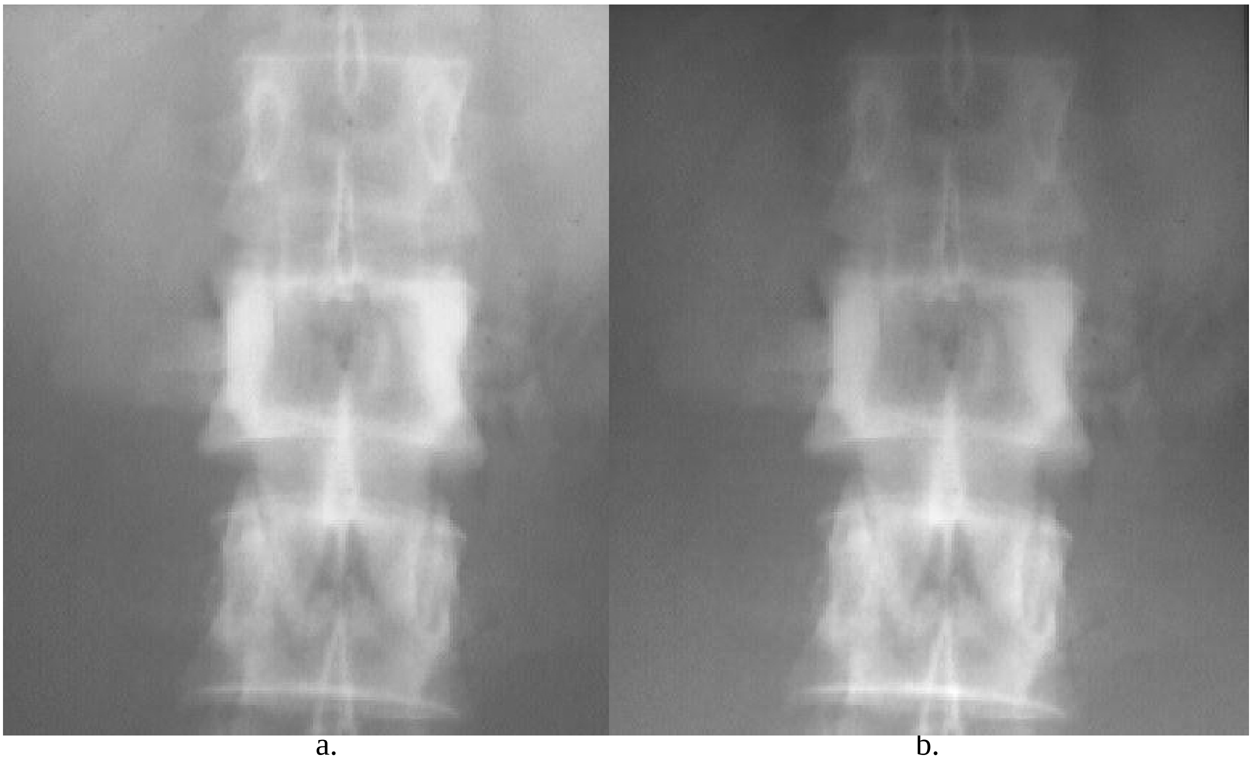
There is nothing worse than a sharp image of a fuzzy concept.

Ansel Adams – photographer (1902 - 1984)



a. b.

The first application of a radiographic contrast-enhancement mask (RCM).

The original image (a) has had a digital wedge RCM applied. The result of the application of the RCM to the original image is seen on the right (b). Image brightness and contrast are altered in a non-uniform manner in image (b). The changes in image brightness and contrast can be seen as decreased brightness at the top compared to the original image, similar brightness in the middle and increased brightness at the bottom of the image compared to the original image.

Abstract

Radiographic film/screen (F/S) images have a narrow latitude or dynamic range. The film's ability to record and view all the anatomy within the x-ray field is limited by this narrow dynamic range. The advent of digital radiographic means of storing and displaying radiographic images has improved the ability to record and visualise all of the anatomy. The problem still exists in digital radiography (DR) when radiographic examinations of certain anatomical regions are undertaken.

In this work, the value of anatomically shaped radiographic contrast-enhancement masks (RCMs) in improving image contrast and reducing the dynamic range of images in DR was examined. Radiographic contrast-enhancement masks are digital masks that alter the radiographic contrast in DR images. The shape of these masks can be altered by the user.

Anatomically shaped RCMs have been modelled on tissue compensation filters (TCFs) commonly used in F/S radiographic examinations. The prime purpose of a TCF is to reduce the dynamic range of photons reaching the image receptor and hence improve radiographic contrast in the resultant image. RCMs affect the dynamic range of the image rather than the energy source of the image, that of the x-ray photons.

The research consisted of three distinct phases. The first phase was to examine physical TCFs and their effects on F/S radiographic images. Physical TCFs are used in radiographic F/S examinations to attenuate the x-ray beam to compensate for varying patient tissue thicknesses and/or densities. The effect of the TCF is to reduce resultant radiographic optical density variations in the image, allowing the viewer to observe a range of densities within the image which would otherwise not be visualised.

Physical TCFs are commonly aluminium- or lead-based materials that attenuate the x-ray beam. A TCF has varying physical thickness to differentially attenuate the

beam and is shaped for specific anatomical situations. During this project, various commonly used physical TCFs were examined. Measurements of size and thickness were made. Characteristics of linear attenuation coefficients and half-value thicknesses were delineated for various TCF materials and at various energies.

The second phase of the research was to model the physical TCFs in a digital environment and apply the RCMs to DR images. The digital RCMs were created with similar characteristics to mimic the shapes to the physical TCFs. The RCM characteristics can be adjusted by the viewer of the image to suit the anatomy being imaged.

Anatomically shaped RCMs were designed to assist in overcoming a limitation when viewing digital radiographic images, that of the dynamic range of the image. Anatomically shaped RCMs differ from other means of controlling the dynamic range of a digital radiographic image. It has been shown that RCMs can reduce the range of optical densities within images with a large dynamic range, to facilitate visualisation of all anatomy within the image.

Physical TCFs are used within a specific range of radiographic F/S examinations. Digital radiographic images from this range of examinations were collected from various clinical radiological centres. Anatomically shaped RCMs were applied to the images to improve radiographic contrast of the images.

The third phase of the research was to ascertain the benefits of the use of RCMs. Various other methods are currently in use to reduce the dynamic range of digital radiographic images. It is generally accepted that these methods also introduce noise into the image and hence reduce image quality. Quantitative comparisons of noise within the image were undertaken. The anatomically shaped RCMs introduced less noise than current methods designed to reduce the dynamic range of digital radiographic images. It was shown that RCM methods do not affect image quality.

Radiographers make subjective assessment of digital radiographic image quality as part of their professional practice. To assess the subjective quality of images enhanced with anatomically shaped RCMs, a survey of radiographers and other

qualified people was undertaken to ascertain any improvement in RCM-modified images compared to the original images. Participants were provided with eight pairs of image to compare. Questions were asked in the survey as to which image had the better range of optical densities; in which image the anatomy was easiest to visualise; which image had the simplest contrast and density manipulation for optimal visualisation; and which image had the overall highest image quality.

Responses from 123 participants were received and analysed. The statistical analysis showed a higher preference by radiographers for the digital radiographic images in which the RCMs had been applied. Comparisons were made between anatomical regions and between patient-related factors of size, age and whether pathology was present in the image or not.

The conclusion was drawn that digital RCMs correctly applied to digital radiographic images decrease the dynamic range of the image, allowing the entire anatomy to be visualised in one image. Radiographic contrast in the image can be maximised whilst maintaining image quality.

Using RCMs in some digital radiographic examinations, radiographers will be able to present optimised images to referring clinicians. It is envisaged that correctly applied RCMs in certain radiographic examinations will enhance radiographic image quality and possibly lead to improved diagnosis from these images.

Contents

Note: An electronic version of this thesis is supplied on the enclosed CD ROM. Some image quality has been lost in the printing of this thesis. Readers may prefer to view the images, which form an integral part of the thesis, on a computer monitor. This can be done from within the relevant chapter in the Word® documents on the CD ROM.

STATEMENT OF AUTHORSHIP

Except where reference is made in the text of this thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or be awarded another degree or diploma.

No other person's work has been used without due and correct acknowledgement in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

Signed:…………………………………………….

Robert Davidson

Date:…………………………………..

Acknowledgements

Undertaking a doctoral research project is a journey. Mine began over 9 years ago when I was given the task of teaching digital image processing to medical imaging students. This is where a deep interest in digital imaging and digital image processing began. About 6 years ago the fusion of ideas from the physical to digital worlds allowed the original masters project to become a doctoral project. The journey still continues and I do not think it will stop with the completion of this project. Along the journey, three main groups of people have supported me.

The first group is my family and friends. Debbie and my children, Sarah and Michael, have understood my desire to undertake such a project and have allowed me time that could have been spent with them. Debbie has been a source of encouragement, even though she may not always think she is. Mum and Dad have always wanted another "doctor" in the family. Sorry Dad, I'm not as medically inclined as you were! Other family and friends have listened to me ramble on about the project but have continued to provide encouragement despite this. Another group that needs mentioning is the umpires. Umpiring Aussie Rules football has allowed a physical outlet and the ability to completely clear my mind from study and work and maintain a health perspective on life.

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Glossary of Terms

added filtration – the addition of material, other than that inherent material in the x-ray tube, in the path of the x-ray beam. The prime purpose is to reduce the number of low energy photon in the beam and hence patient dose. Aluminium is typically the material used in general radiography for this purpose

absorbed dose – the ionising radiation dose that is absorbed in the irradiated material or patient's anatomy. Typically measured in milliGray (mGy)

artefact – an appearance in a radiographic image not related to the patient

attenuation – the reduction in intensity of the x-ray beam that results from photon interaction with matter

Bremsstrahlung – a process of x-ray production through the interaction of accelerated electron having an interaction with an atom that causes deceleration of the electron. From German meaning breaking radiation

characteristic curve or H&D curve – a plot of the logarithm of exposure incident on a film and the resultant optical density of the film

collimator – a device placed between the x-ray tube and the patient which uses high attenuation material, typically lead, to control the size of the x-ray field

Compton scatter – a type of scattered radiation that result from the incident x-ray photon and an interaction with an outer shell electron of the atom

Compton spectrometer – a device, coupled to an x-ray detector and multi-channel analyser, used to deconvolve or determine the energies within a polyenergetic x-ray beam

computed radiography (CR) - a type of digital radiography that uses photostimulable phosphors (PSPs) to capture a latent image on the imaging plate

digital radiography (DR) – a form of general radiography that is captured and displayed by digital means. Computed radiography is an example of DR

dynamic range – the range of x-ray photons intensities in the primary beam or in the beam as it exists the patient. Also known as latitude

dynamic range control – a method used to overcome problems associated with a large dynamic range electromagnetic (EM) radiation – a type of radiation that consists of electric and magnetic fields at 90° to each. X-ray, light and radio waves are examples of EM radiation

exit intensity of the x-ray beam – the number of unattenuated photons per unit area that exit the anatomy. Can be considered as a function of the probability that an x-ray photon will have an attenuating event on its path through the anatomy

exposure time – the time duration that x-ray photons are emitted from the x-ray tube

film latitude – the linear response range of a film/screen radiographic system to ionising radiation

film/screen (F/S) radiography – a type of general radiography where fluorescent screen are used to amplify the effects of the x-ray photons and expose the film to light. Film is used to capture a latent image

filtration – the removal of x-ray photons from the beam by attenuation when the beam is passed through a medium

focal-film distance (FFD) – the distance between the x-ray focus or focal spot and the film or image receptor. Also known as source to image distance (SID)

focal spot – the area on the anode of the x-ray tube where x-ray photons are produced

fog – unwanted exposure to a film that results in an increase in optical density on the film

general radiography – single projection radiographic images. Film/screen and computed radiography are types of general radiography

half value thickness (HVT) – a measurement of the effective energy of the x ray beam

image resize – a function in digital imaging to reduce or enlarge the actual or displayed image size

imaging plate (IP) – the computed radiographic system's image receptor that captures a latent image

inherent filtration – the material in the x-ray tube that is in the path of the x-ray beam prior to exit of the beam from the x-ray tube

intensity (photon) – number of photons per unit area

ionising radiation – EM radiation that is on sufficient energy to remove an electron from an atom

K-edge – a point of sudden increase in attenuation of the x-ray photons as photon energy is increased in a given matter. Associated with the K binding energy of the electron to the nucleus of the atom

latent image – a potential image prior to some form of processing that will enable the visualisation of the image

latitude – the range of x-ray photons intensities in the primary beam or in the beam as it exists the patient. Also known as dynamic range

look-up function – a table of results of a function that is performed on all possible inputs to the function. Used as a short-cut means to reduce calculation time typical of those in large digital data set such as digital images

monoenergetic x-ray beam – an x-ray beam that is comprised of photons of all the same energy

multi-channel analyser (MCA) – a device that enables the measurement of multiple ranges of photon energies. Use in conjunction with an x-ray detector

multi-scale approach – a digital image processing technique used to alter spatial frequencies in the image. This approach alters multiple (more than 2) groups of frequencies within the image. Typically uses a frequency based method

multi-scale image contrast amplification (MUSICA) – a frequency based set of digital image processing functions that may be used to alter the dynamic range of the image. An Agfa-Gevaert product.

optical density – a logarithmic measure of the opacity or “blackness” of a film

phantom (radiographic) – a device that mimics radiographic characteristics of human anatomy. Typically used to evaluate radiographic systems without exposure of ionising radiation to humans

photon – a bundle of energy of EM radiation that describes its particular nature

polyenergetic x-ray beam – an x-ray beam that is comprised of photons of many different energies

quantum mottle – an appearance of noise in a radiographic image due to low signal-to-noise ratio of the exit intensity of the x-ray beam

radiation dose – an amount of ionising radiation that is received in an object or anatomical region. Absorbed dose is a specific measure of radiation dose

radiographer – a qualified person who is responsible for undertaking a radiographic examination radiographic examination – an investigative procedure, such as a general radiographic examination, that uses x-ray radiation as its energy source

radiographic contrast – the difference of optical densities between areas in the radiographic image

radiographic image – an image, typically of a patient's anatomy, that uses x-ray radiation as the energy source

ripple factor – a measure of the voltage variations from the peak voltage during an alternating wave cycle. A measure of the efficiency of the x-ray generator

sampling frequency – the number of times the measurement of the objects intensities are made within the imaging system

signal-to-noise ratio (SNR) – a ratio of the amount of signal to the amount of noise in a system

spatial frequency – a measure of the rate of change in density of an object as a function of its spatial dimensions

spatial resolution – the ability of an imaging system to accurately represent small objects

subject contrast – the differences in exit intensities between areas of the x-ray beam that results from differing properties within the anatomy

target or x-ray target – the anode of the x-ray tube where the electrons accelerated across the x-ray tube interact with atoms that results in characteristic or Bremsstrahlung radiation

tissue compensation filters (TCF) (physical) – attenuating material that is shaped with differing thicknesses to attenuate the x-ray beam at differing amounts. Designed to suit a specific anatomical region

unsharp mask – an image enhancement technique that alters spatial detail in an image

window width (WW) and window level (WL) – a specific type of look-up function typically used to alter displayed contrast and brightness of an image

x-ray detector – a devices that is able to detect x-ray radiation

x-ray tube – the device that is used to generate an x-ray beam. It requires a high voltage, a current, a means of decelerating the electrons and a vacuum to achieve the production of x-ray photons x-ray tube voltage (kVp) – the voltage or electrical potential difference that is applied between the cathode and the anode of the x-ray tube. It is applied for the acceleration of the electrons between the cathode and the anode to generate x-ray radiation. Measured in peak kilo-Volts

x-ray tube current (mA) – the number of electrons or current that flow between the cathode and the anode when a x-ray tube voltage is applied to the x-ray tube. Measured in milli-Amperes