Volumetric Breast Density Estimation on Mammograms Using Breast Tissue Equivalent Phantoms – An Update

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Abstract. Methods for improving the accuracy of a technique for estimating volumetric breast density are described. A breast tissue-equivalent phantom encompassing a range of thicknesses and compositions of tissue is used to evaluate the sources of error in the technique. The image acquisition parameters that can affect the accuracy of calibration are considered, and sensitivity to these factors is evaluated. The robustness of the technique was tested by obtaining calibration images on 24 mammography machines, at 18 different sites, over a period of 3 years. The ability to use a single calibration on all machines of a given model type was assessed by comparing effective linear attenuation coefficients of fat and fibroglandular tissues, derived from the calibration phantom images obtained from various machines.

1 Introduction

Mammographic density has been proven to be strongly associated with breast cancer risk. Various quantitative methods for measuring breast density have been developed, based on the assessment of the fractional area of the breast occupied by fibroglandular tissue [1], [2]. These methods are subjective and results may vary, depending on the imaging conditions (tube potential, tube current and anode/filter materials) as well as the type film used. Furthermore, the effect of breast thickness may confound the determination of tissue composition. A more accurate and relevant measure of the amount of dense breast tissue is likely to be achieved using volumetric quantification of breast density. Highnam and Brady [3] approached this problem by estimating the primary energy at the receptor by mathematically removing the scattered radiation and glare. Their method is limited by the accuracy of the reported attenuation coefficients from the literature, variability of the film response to exposure and the uncertainty in breast thickness estimation [4].

Our volumetric technique involves the direct calibration of mammography units using a plastic step phantom composed of breast tissue equivalent materials [5].

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2 Method

Calibration was accomplished by imaging a plastic phantom composed of steps providing 8 different thickness and 5 different breast tissue-equivalent compositions ranging from 100% fat to 100% fibroglandular tissue. Calibration images were obtained for all possible kV and anode-filter combinations that are used clinically. An aluminum step wedge, placed at the distal corner of the image receptor was imaged at the same time as the calibration phantom, and also as part of every clinical mammogram.

The aluminum step wedge was placed to track any subsequent variations in optical density that might be caused by variations in the mAs, film-processing, film-emulsion, as well as by scattering, beam hardening and reciprocity law failure of the film-screen systems. X-ray field non-uniformities were corrected by obtaining images of a plastic annular spherical phantom. Optical sensitometry data were used to convert the image pixel intensities to log relative exposure (LRE) values, which is a representation of the transmitted x-ray intensity plus contributions from scatter and glare. A surface relating the percent density, total thickness, and LRE was then constructed from the plastic step phantom for each kV and anode-filter combination and each image receptor size of the mammography unit used clinically. A ‘useful thickness range’ was selected for each tissue type calibration curve taken from the step phantom. This is where the signal values fall on the ‘straight line’ part of the sensitometric curve. The very short dynamic range of the film-screen systems made the polyenergetic approximation of the calibration surface almost impossible and, therefore, a monoenergetic approximation was made in the useful thickness range for each exposure technique. A ‘linearised’ three-dimensional surface relating the log relative exposure, breast composition and thickness was then generated.

From the exposure parameters for the mammogram, the compressed breast thickness and the image signal value at each pixel location, the fraction of the path through the breast that is composed of fibroglandular tissue can be extrapolated from the calibration surface, obtained for the same kV and anode-filter combination on the same machine and image receptor size. The total breast volume and the volume of fibroglandular tissue in the entire breast can also be calculated to yield the volumetric breast density (VBD).

The robustness of the VBD technique was tested by obtaining calibration images at six-month intervals from 24 mammography machines at 18 different sites over a period of 3 years. Calibration images included a set of slab phantoms made of breast tissue equivalent material on which the VBD measurements were calculated. The processed films were digitized using a Lumisys 85 digital laser film scanner, at 12 bits and a pixel size of 260 μm. Optical sensitometry was performed using the same mammographic film and processing employed for clinical use from each site on the same day as calibration images were obtained. The resulting calibration curves were then compared to test the ability of the aluminum step wedge to capture all of the inherent variations. The various parameters that could affect the accuracy of VBD values were studied during this period of time, including a) design of the aluminum stepwedge, b) variations in exposure, c) variations in film processing and film-screen combinations, d) shift in the kVp and tube replacement, and e) beam hardening and scatter.