An Alternative Approach to Measuring Volumetric Mammographic Breast Density

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Abstract. The effect on the measurement of volumetric breast density of variations in physical and chemical properties of adipose and fibroglandular tissue reported in a number of studies is investigated using the authors' model of mammographic image formation. This model is developed specifically for the measurement of breast density. The effect of varying stromal composition, a popular histopathological explanation of mammographic density, is also discussed. Given the uncertainties in tissue attenuation highlighted by this study, as well as noise, and acquisition model error, the validity of this measurement is discussed, together with alternative measurement scales. Several issues are considered, including the effect of beam quality on normalisation accuracy, and the measurement failure which can occur when clinical data falls outside the limited range defined by 100% adipose to 100% fibroglandular tissue.

1 Introduction

The correlation between radiological features of the breast and the likelihood of the breast containing, or subsequently developing, a malignant lesion, is termed breast density. Work in this area was pioneered by Wolfe in 1969 [1] who proposed a four category classification for assessing mammographic parenchymal patterns: in particular this considered the prominence of ductal patterns and the occurrence of connective tissue hyperplasia. Wolfe presented findings showing that each of the four groups, from lowest to highest density, had an incidence of developing breast cancer of 0.1, 0.4, 1.7 and 2.2 [2]. Boyd et al [3] defined a six category classification (SCC) system which focuses on mammographic hyperplasia. Both these measures suffer from reader subjectivity, which caused Byng et al [4] to develop a interactive thresholding technique to segment, and thereby quantify, mammographic hyperplasia. Such measures are termed "area measurements" since they ignore the third dimension, and treat the projected image as entirely representative.

To take account of the three-dimensional breast, "volumetric measurements" of breast density have been developed. Such measures approximate the quantities of fibroglandular and adipose tissue present in the cone between a detector pixel, and the x-ray focal spot, using the likely x-ray attenuation coefficients of these tissues.

In 1996 Highnam and Brady proposed [5] the h_{int} representation which measures volumetric density. They developed a model of image formation considering the path of x-ray photons from point of emission in the x-ray tube, to absorption at the detector.

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Several alternative techniques of measurement have been subsequently proposed, for example Kaufhold et al [6], which approximates a transfer function describing imaging formation gleaned from tissue equivalent phantom images.

Inspired by Highnam and Brady's work [7], a second generation of their model has been developed [8]. The extra power made available by modern computers has enabled the removal of many of their simplifying assumptions. Features of the enhanced model include: a ray tracing architecture, removing the parallel beam approximation; consideration of self-filtration within the tube target to model spatial inhomogenity of the x-ray beam; a theoretical scatter model removing the need for interpolation from empirical data; and an enhanced detector calibration procedure. Our findings are presented here, using our enhanced model, concerning the significant impact on density readings of the likely variation in x-ray attenuation of fibroglandular and adipose tissues within the population, and also consider the impact of the various sources of error present within the model.

2 The Histopathology of Mammographic Density

The most common form of breast cancer is a carcinoma, a tumour arising from epithelial malignancies. It has therefore been suggested that epithelial hyperplasia results in high mammographic density. In this case, a large number of cells exist, increasing the likelihood of mutation, and hence risk. Several studies however, including that of Alowami et al [9], have found no correlation between density of ductal units and areas of high mammographic density. Alowami et al did however report that such areas showed significantly higher collagen density and extent of fibrosis within the stroma. The stroma is a major tissue fraction, orders of magnitude larger than that of the epithelium, and so its composition is likely to have a discernable effect on the x-ray attenuation of the breast. The key question concerns the link, should it exist, between cancer development and stromal composition.

3 The Difficulty of Measuring Tissue Composition

The ratio of fibroglandular to adipose tissue may be approximately measured using a model of image formation by varying the tissue ratio in the modelled breast at each pixel until such a value is reached that the simulated pixel intensity matches that in the acquired image. Errors in the model, both systematic and random, will inevitably result in the incorrect ratio of tissues being calculated. Consideration in this paper is given to two such sources of uncertainty. The first is that which arises from inconsistencies between the various components of the image formation model, and their counterparts in reality. A certain level of uncertainty is expected due to effects such as stochastic noise and engineering tolerances in the manufacture of components. Whilst every effort may be made to limit the resulting errors, perfection will never be achieved, and a compromise has to be struck at a acceptable level of uncertainty. Inaccuracies within the model of image formation are dependant on a number of factors, such as beam quality; thickness of the item under investigation; exposure time; and the portion of the image receptor transfer characteristics in which the image is