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Design Studies and Optimization of Phase-Contrast Mammography

X-ray phase-contrast imaging holds great promise for revolutionizing breast imaging and diagnostic radiology, and has now reached the frontier of feasibility for clinical implementation. Although most previous studies of X-ray phase-contrast imaging have employed synchrotron sources or microfocus X-ray tubes that are not suitable for clinical usage, Konica Minolta now markets a phase-contrast mammography system that is being employed and evaluated clinically. Preliminary reader studies have established that phase-contrast mammograms can improve the detection of both microcalcifications and masses as compared to conventional absorption-based mammography. These results are truly significant because they confirm some of the advantages of phase-contrast mammography that have been promised by the Physics community for years. Moreover, it has established a proof-of-principle of the technology with consideration of imaging geometries and image acquisition times that satisfy the constraints of clinical mammography. Although these recent advancements are exciting, there remains a great need to further develop and optimize phase-contrast mammography. Several powerful and distinctive features of X-ray phase-contrast imaging remain unexploited by the Konica Minolta system. Because X-ray phase-contrast imaging utilizes a contrast mechanism based on the refractive index values of tissue, they can permit visualization of object features that present little or no absorption contrast. Consequently, it can operate effectively at higher X-ray energies than conventional mammography, resulting in a dramatic reduction of the radiation dose. The Konica Minolta system utilizes a Molybdenum X-ray anode, similar to conventional mammography systems, and therefore still relies strongly on absorption contrast and does not exploit the dose-reducing capability of phase-contrast imaging. Because it is a screening modality, the ability to dramatically reduce the dose in mammography would be of tremendous significance. Another distinctive feature of X-ray phase-contrast imaging is that the recorded radiographs typically reflect a mixture of the absorption and refractive (i.e., “phase”) properties of the object. This results in a radiograph with an edge-enhanced appearance that has been shown to be diagnostically useful. However, by use of computational algorithms and certain data-acquisition protocols, it may be possible to reconstruct images that separately depict the absorption and refractive distributions, which represent two distinct physical properties of the breast tissue. This may result in an improved ability to reliably differentiate tissue structures in certain imaging studies.

The broad objective of this proposal is to investigate how much X-ray phase-contrast mammography can be improved via a task-based optimization of the imaging system design and associated computational algorithms. Our research methodology is highly innovative and will bring the distinctive features of phase-contrast imaging mentioned above to the realm of clinical imaging. For example, we will investigate the use of a tungsten anode for low-dose phase-contrast mammography, and demonstrate that the low absorption contrast typically associated with the use of tungsten anodes in conventional mammography is circumvented. The geometry of the imaging system will be systematically optimized in conjunction with the X-

ray source size and spectrum. Nonconventional imaging systems will be investigated and implemented that employ polycapillary optics and other types of X-ray optics to collimate the incident X-ray beam, thereby resulting in improved beam coherence properties or decreased image acquisition times. Robust numerical algorithms will be developed and implemented for reconstructing images that depict the absorption and refractive properties of breast tissue. Our system and algorithm designs will be developed in parallel, and task-based measures of image quality derived from numerical and human observers will guide our optimization studies.

The specific aims of the project are:

- (1) To identify optimal imaging geometries and X-ray source properties for X-ray phase-contrast mammography
- (2) To investigate the use of polycapillary optics to improve beam coherence or reduce image acquisition times
- (3) To develop and investigate robust methods for quantitative phase-retrieval
- (4) To objective assess image quality in phase-contrast mammography using expert reader studies