Determination of Total Breast Volume and Breast Density Using FSE 3 Point Dixon Sequence

M. C. Masiker[1], N. B. Konyer[1], S. Chavez[1], M. J. Bronskill[1]

[1]Medical Imaging, Sunnybrook and Women's College Health Sciences Centre, Toronto, ON, Canada

Introduction:
There is a known relationship between the ratio of parenchyma to fat tissue in the breast and the risk of breast cancer. [1] While this ratio is usually determined by processing mammograms, x-ray mammography is inappropriate for the assessment of breast density in young women. In the breast, parenchyma is responsible for the water content measured by MRI. Relative water content of breast tissue determined by MRI has a strong positive correlation with mammographic density. [2] The FSE 3pt Dixon technique provides a rapid measurement of both total breast volume and breast density (percent water content) which can be used to evaluate breast composition in individuals for whom mammography is contraindicated. In preparation for a large cohort study of mothers and daughters to investigate the etiology of breast cancer, we have optimized and calibrated the use of the FSE 3pt Dixon sequence for the determination of both total breast volume and breast density.

Methods:
All experiments were performed on a General Electric (Waukesha WI) 1.5T Signa CVi MR scanner using a Medical Advances breast coil. The GE FSE Dixon product sequence (OS Version 11) was used. The sequence was adjusted from the default asymmetric offset of the phase of fat relative to water ($-\pi/6$, $\pi/2$, $7\pi/6$) to the symmetric values 0, π and 2π. Breast images were collected in the sagittal plane. A 28-cm, square field-of-view was used with a 256x192 acquisition matrix. The slice thickness was 6-mm interleaved. TE = 14.8 ms, ETL=10 TR = 2500. The no-phase-wrap option was selected to eliminate aliasing which required 2 NEX. The total imaging time was <11 minutes per breast. Offline segmentation, phase unwrapping, and reconstruction was done using an in-house, semi-automated program based on IDL to produce separate water and fat images and a water + fat image in which the breast tissue could be segmented from the chest wall and air background (see Fig A). The water and fat content per voxel were summed to provide the total volume (cc) of water and fat per segmented slice and the totals for each segmented slice were summed to determine the total breast volume. Informed consent was obtained from all research subjects prior to imaging.

In order to assess the capability to separate fat and water contributions to individual voxels (a partial volume issue), homogeneous phantoms were constructed using mixtures of mineral oil and water emulsified under pressure in the presence of lecithin. $MnCl_2$ was used to adjust the T1 of the mixtures close to that of water in the breast. The mixtures ranged nominally from 10 to 80 percent oil, representative of the range of fat content likely to be found in breast tissue. The mixtures were decanted into 50 ml plastic tubes, remaining homogeneous below the voxel level for many weeks. The actual phantom percent water and fat were accurately calibrated using proton NMR spectroscopy. Volumetric accuracy was tested using balloons filled with water adjusted with NaCl and $MnCl_2$ to adjust T1 and conductivity to that of water found in breast tissue. The balloons were weighed before and after scanning; density was assumed to be 1gm /cc at laboratory temperature. Balloons were measured which ranged in volume between 350cc and 1200cc, representative of the range of breast volumes observed in preliminary work.

Results:
Figure A shows a segmented water image and Figure B shows the corresponding fat image. The automated snaking routine routinely segmented the breast/chest wall interface and the breast/air interface. Some intervention (based on radiologists' criteria) was used to define the superior and inferior limits of the breast, using interactive computer tools. Breasts of all sizes and shapes could be reliably segmented and there were no problems with the phase unwrapping method implemented in our program. Figure C shows the calibration for the oil and water mixtures plotted as the water content (%) determined by the 3pt Dixon and spectrometer methods. . The error bars represent the standard deviation from 2 to 4 repeated measurements and the line represents the least squares fit.

The slice represented in figures A and B is 6 mm thick with a total segmented volume of 42.3 cc. The total water was 19.2 cc and the total fat was 23.1 cc. The total volume for the breast from which this slice was taken was 477 cc. The corresponding fat and water volumes were 267 cc and 209 cc respectively. Balloon volumes determined by the Dixon method [3] were in agreement with the volumes determined by weight to within 2%.

Discussion:
The 3-pt FSE Dixon method with offline segmentation and reconstruction has been developed to determine fat and water content of phantoms accurately even when the oil and water mixture is homogeneous below the voxel level. In addition, volumes determined by the Dixon method agree with water volumes determined by weight. The image processing method is independent of breast coil B1 inhomogeneity patterns. Currently over twenty minutes of imaging time is required per research subject but this can probably be reduced by scanning both breasts simultaneously and by using coarser spatial resolution.

Conclusion:
The GE 3-pt Dixon technique with offline segmentation and reconstruction provides a rapid, noninvasive method for the determination of total volume and quantitative water content and fat content in the breast. This method is being applied to investigate breast density in young women for whom mammography is contraindicated.

References:
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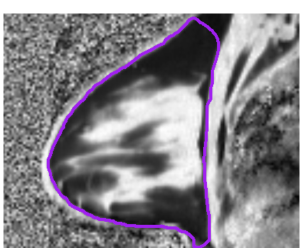
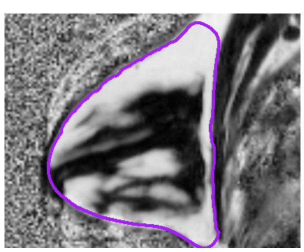
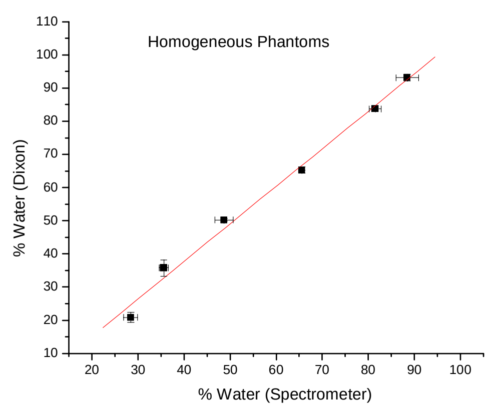


A



B



C

Figure A shows segmented percent water image. Figure B shows segmented percent fat image. Figure C shows calibration curve for oil and water phantoms.