Session 1: Screening & Clinical Interpretation

Breast compression parameters among women imaged with full field digital mammography and breast tomosynthesis in BreastScreen Norway

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Abstract Text: Breast compression is used in mammography to improve image quality and reduce radiation dose. However, the compression may lead to discomfort or pain for the women. Breast compression time lasts longer for digital breast tomosynthesis (DBT) than for full field digital mammography (FFDM). We aimed to explore breast compression parameters with FFDM and DBT. We included information from 16,832 women participating in the Bergen Tomosynthesis Trial between January 2016 and April 2017. We compared mean values of applied compression force (N), compression pressure (kPa) and compressed breast thickness (mm), for FFDM and DBT, by view (craniocaudal, CC, and mediolateral-oblique, MLO). Two-sample t-tests were used to test statistical significance. Number of women screened with FFDM or DBT were similar (DM: n= 8354 and DBT: n= 8478). Mean compression force was statistically significantly higher for FFDM compared to DBT for CC and MLO view (CC: 108.6 N versus 102.7 N; MLO: 122.4 N versus 120.8 N, p <0.01). Mean compression pressure was higher for FFDM compared to DBT for CC view (13.9 kPa versus 13.0 kPa, p<0.01). For MLO view, no difference in compression pressure was observed (DM and DBT: 9.7 kPa, p= 0.55). Mean compressed breast thickness did not differ statistically significantly for FFDM compared to DBT (CC: 58.7 mm N versus 58.6 mm, p= 0.72; MLO: 60.1 mm versus 59.9 mm, p= 0.23). Radiographers applied statistically significantly less breast compression with DBT compared to FFDM. However, the observed differences were negligible. Further research should investigate the clinical implications of the differences, such as image quality.

Can radiologists improve their breast cancer detection in mammography when using a deep learning-based computer system as decision support?

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Abstract Text: For more than a decade, radiologists have used traditional computer aided detection systems to read mammograms, but mainly because of a low computer specificity may not improve their screening performance, according to several studies. The breakthrough in deep learning techniques has boosted the performance of machine learning algorithms, also for breast cancer detection in mammography. The objective of this study was to determine whether radiologists improve their breast cancer detection performance when they concurrently use a deep learning-based computer system for decision support, compared to when they read mammography unaided. A retrospective, fully-crossed, multi-reader multi-case (MRMC) study was designed to compare this. The employed decision support system was Transpara™ (Screenpoint Medical, Nijmegen, ehe Netherlands). Radiologists interact by clicking an area on the mammogram, for which the computer system displays its cancer likelihood score (1-100). In total, 240 cases (100 cancers, 40 false positive recalls, 100 normals) acquired with two different mammography systems were retrospectively collected. Seven radiologists scored each case once with, and once without the use of decision support, providing a forced BI-RADS® score and a level of suspiciousness (1-100). MRMC analysis of variance of the area under the receiver operating characteristic curves (AUC), and specificity and sensitivity were computed. When using decision support, the AUC increased from 0.87 to 0.89 (P=0.043) and specificity increased from 73% to 78% (P=0.030), while sensitivity did not significantly increment (84% to 87%, P=0.180). In conclusion, radiologists significantly improved their performance when using a deep learning-based computer system as decision support.

Detection of the abnormal gist in the prior mammograms even with no overt sign of breast cancer

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Abstract Text: Can radiologists distinguish prior mammograms with no overt signs of cancer from women who were later diagnosed with breast cancer from the prior mammograms of women reported as normal and subsequently confirmed to be cancer-free? Twenty-three radiologists and breast physicians viewed 200 craniocaudial mammograms for a half-second and rated whether the woman would be recalled on a scale of 0 (clearly normal) to 100 (clearly abnormal). The dataset included five categories of mammograms, with each category containing 40 cases. The categories were Cancer (current cancer-containing mammograms), Prior-Vis (prior mammograms with visible cancer signs), Contra (current 'normal' mammograms contralateral to the cancer), Prior-Invis (priors without visible cancer signs), and Normal (priors of normal cases). For each radiologist, four pairs of analyses were performed to evaluate whether the radiologists could distinguish mammograms in each category from the normal mammograms: Cancer vs Normal, Prior-Vis vs Normal, Contra vs Normal, and Prior-Invis vs Normal. The Area under Receiver Operating Characteristic curves (AUC) was calculated for each paired grouping and each radiologist. Wilcoxon Signed Rank test showed the AUC values were above- chance for all comparisons: Cancer ($z=4.20$, $P<0.001$); Prior-Vis ($z=4.11$, $P<0.001$); Contra ($z=4.17$, $P<0.001$); Prior-Invis ($z=3.71$, $P<0.001$). The results suggest that radiologists can distinguish patients who were diagnosed with cancer from individuals without breast cancer at an above-chance level based on a half-second glimpse of mammogram even before the lesion becomes apparently visible (Prior-Invis). Apparently, something about the breast parenchyma can look abnormal before the appearance of a localized lesion.

Session 2: Deep Learning: Lesion Detection & Classification

Automated lesion detection and segmentation in digital mammography using a u-net deep learning network

Full Author List: T. de Moor, A. Rodriguez-Ruiz, R. Mann M.D., A.G. Merida, J. Teuwen, Radboud University Medical Center (Netherlands)

Abstract Text: Computer-aided detection or decision support systems aim to improve breast cancer screening programs by helping radiologists to evaluate digital mammography (DM) exams. Commonly such methods proceed in two steps: selection of candidate regions for malignancy, and later classification as either malignant or not. In this study, we present a candidate detection method based on deep learning to automatically detect and additionally segment soft tissue lesions in DM. A database of DM exams (mostly bilateral and two views) was collected from our institutional archive. In total, 7196 DM exams (28294 DM images) acquired with systems from three different vendors (General Electric, Siemens, Hologic) were collected, of which 2883 contained malignant lesions verified with histopathology. Data was randomly split on an exam level into training (50%), validation (10%) and testing (40%) of deep neural network with u-net architecture. The u-net classifies the image but also provides lesion segmentation. Free receiver operating characteristic (FROC) analysis was used to evaluate the model, on an image and on an exam level. On an image level, a maximum sensitivity of 0.94 at 7.93 false positives (FP) per image was achieved. Similarly, per exam a maximum sensitivity of 0.98 at 7.81 FP per image was achieved. No significant differences were observed across images from different systems. In conclusion, the method could be used as a candidate selection model with high accuracy and with the additional information of lesion segmentation.

Deep learning in computer-aided diagnosis incorporating mammographic characteristics of both tumor and parenchyma stroma

Full Author List: H. Li, D. Sheth, K. Mendel, L. Lan, M. L. Giger, University of Chicago (United States)

Abstract Text: We investigated the additive role of breast parenchyma stroma in the computer-aided diagnosis (CADx) of tumors on full-field digital mammograms (FFDM) by combining images of the tumor and contralateral normal parenchyma information via deep learning. The study included 182 breast lesions in which 106 were malignant and 76 were benign. All FFDM images were acquired using a GE 2000D Senographe system and retrospectively collected under an IRB-approved, HIPAA-compliant protocol. Convolutional neutral networks (CNN) with transfer learning were used to extract image-based characteristics of lesions and of parenchymal patterns (on the contralateral breast) directly from the FFDM images. Classification performance was evaluated and compared between analysis of only tumors and that of combined tumor and parenchymal patterns in the task of distinguishing between malignant and benign cases with the area under the Receiver Operating Characteristic (ROC) curve (AUC) used as the figure of merit. Using only lesion image data, the transfer learning method yielded an AUC value of 0.871 (SE=0.025) and using combined information from both lesion and parenchyma

analyses, an AUC value of 0.911 (SE=0.021) was observed. This improvement was statistically significant (p-value=0.0362). Thus, we conclude that using CNNs with transfer learning to combine extracted image information of both tumor and parenchyma may improve breast cancer diagnosis.

Comparing the performance of various deep networks for binary classification of breast tumours

Full Author List: A. Hamidinekoo, Z. Suhail, Aberystwyth University (United Kingdom); E. Denton, Norfolk & Norwich University Hospital (United Kingdom); R. Zwiggelaar, Aberystwyth University (United Kingdom)

Abstract Text: Breast cancer is considered to have a high incidence and mortality rate among women worldwide. Recent development in biomedical image analysis using deep learning based neural networks have motivated researches to enhance the performance of Computer Aided Diagnosis (CAD) systems. In this paper, the performance of four different deep neural networks was compared for malignant/benign classification of mammographic mass abnormalities. For this aim, different annotated mammography repositories were introduced and the classification performance of four deep Convolutional Neural Networks (CNNs) on each dataset and on their combination was investigated. Moreover, the robustness to over-fitting regarding the size of data and the approach of transfer learning were compared. Our quantitative results indicated the importance of training samples regardless of acquisition methods when training with various deep CNN models. We achieved an average accuracy of 85% and an average AUC of 0.83 in our best result on the combination of all datasets. However, we concluded that several runs with different samples are needed to understand the variation in the results, especially the case for smaller datasets.

Improving the Automated Detection of Calcifications by combining Deep Cascades and Deep Convolutional Nets

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Abstract Text: Recently, both Deep Cascade classifiers and Convolutional Neural Networks (CNNs) have achieved state-of-the-art microcalcification (MC) detection performance in digital mammography. Deep Cascades consist in long sequences of weak classifiers designed to effectively learn from heavily unbalanced data as in the case of MCs (~ 1 MC every 10,000 non-MC samples). CNNs are powerful models that achieve impressive results for image classification thanks to the ability to automatically extract general-purpose features from the data, but require balanced classes. In this work, we introduce a two-stage classification scheme that combines the benefits of both systems. Firstly, Deep Cascades are trained by requiring a very high sensitivity (99.5%) throughout the sequence of classifiers. As a result, while the number of MC samples remains practically unchanged, the number of non-MC samples is greatly reduced. The remaining data, approximately balanced, are used to train an additional stage of classification with a CNN. We evaluated the proposed approach on a database of 1,066 digital mammograms. MC detection results of the combined classification were statistically significantly higher than Deep Cascade and CNN alone, yielding an average improvement in mean sensitivity of 3.19% and 2.45%, respectively. Remarkably, the proposed system also yielded a faster per-mammogram processing time (2.0s) compared to Deep Cascade (2.5s) and CNN (5.7s).

Retrieval of reference images of breast masses on mammograms by similarity space modeling

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Abstract Text: Presentation of reference images that are similar to a query image can be helpful in medical image diagnosis and treatment planning. The purpose of this study is to investigate a method for retrieving relevant images as a diagnostic reference for breast masses on mammograms. In our previous studies, subjective similarities for pairs of masses were obtained from experienced radiologists and used as the gold standard for retrieving visually similar images. By use of multidimensional scaling, a subjective similarity space was spanned so that masses that were placed close to a query image can be retrieved as reference images. In this study, we modelled this similarity space using convolutional neural network. The result was compared with that using conventional hand-crafted features and that by direct estimation of similarity index.

Interactive Poster Session 1

A deep learning framework for micro-calcification detection in 2D mammography and C-view

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Abstract Text: The aim of this paper is to propose a deep learning framework for micro-calcification detection in 2D mammography and in 2D synthetic mammography (C-view) from digital breast tomosynthesis (DBT). The dataset used for 2D mammograms is the INbreast dataset that consists of 410 digital images with annotated micro-calcifications. For the synthetic views in DBT, we used a private dataset of 199 images, where micro-calcifications were validated by an experienced radiologist. The network is trained in a patch based fashion, where micro-calcifications are considered positive samples, while patches containing other breast tissues are considered negative. In addition, sliding window method was used to compare new patches within an image with those from the trained model. Preliminary results for the 2D mammography shown a testing accuracy of 0.9981 and an area under the curve (AUC) of 0.9971 for 100 epochs. Preliminary results for the C-View, considering a sub-dataset, showed a testing accuracy of 0.9977 and an AUC of 0.9985. For the final version of the manuscript, C-view analysis will be extended and the number of cases increased.

Multi-scale morphological feature extraction for the classification of micro-calcifications

Full Author List: Z. Akram, Aberystwyth University (United Kingdom); E. R. Denton, Norfolk and Norwich University Hospitals NHS Foundation Trust, Department of Radiology (United Kingdom); R. Zwiggelaar, Aberystwyth University (United Kingdom)

Abstract Text: Mammography is considered the most appropriate method to defeat breast cancer in population screening. Although mammography is used for the detection of micro-calcifications, the benign/malignant classification relies on subsequent histology assessment. We describe a novel method for the automatic classification of benign and malignant micro-calcifications directly from mammographic images, which uses the morphology as well as the distribution aspects of micro-calcifications and is directly associated with the BIRADS categorisation of micro-calcifications. The developed approach is building on Iwanowski's morphology work, but is adding class-extractors and multi-scale aspects. Translation to other application areas is discussed and evaluation based on the MIAS and DDSM datasets show results in line with state-of-the-art micro-calcifications classification approaches.

Transfer deep learning mammography diagnostic model from public datasets to clinical practice: a comparison of model performance and mammography datasets

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Abstract Text: Literature has showed that deep learning models can detect a breast cancer with high diagnostic accuracy in the publicly available mammography datasets. The objective of this study is to examine whether the high performance (accuracy) of a deep learning model, trained by the public mammography dataset, can be transferred into the clinic practice by applying it to a new mammography dataset obtained in an academic breast center. An end-to-end CNN architecture was trained on DDSM dataset and transferred to INbreast dataset and the in-house collected dataset. The model achieved validation AUC of 0.82 on DDSM dataset and 0.93 on INbreast dataset. However, it only achieved 0.70 when applied to the in-house dataset. Reviewing the images revealed that the in-house dataset is more challenging to classify. The mean subtlety score for DDSM dataset is 3.64 and median is 4. For in- house dataset, the mean and median scores are 2.65 and 2, respectively. In addition, the in-house dataset has more co-existing benign abnormalities as more patients with benign biopsy or prior surgery return for mammography. These observations are in line with other institutes' finding that the relative percentage of early stage cancer cases from mammography diagnosis has more than tripled since 2002. This indicates that currently available public open datasets may be inadequate to represent the mammography seen in today's clinical practice. It is necessary to build an updated mammography database that contains sufficient pathological heterogeneity of breast cancer and co-existing benign abnormalities that reflect the cases seen in current practice.

Radiation dose reduction in digital breast tomosynthesis (DBT) by means of neural network convolution (NNC) deep learning

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Abstract Text: To reduce cumulative radiation exposure and lifetime risks for radiation-induced cancer from breast cancer screening, we developed neural network convolution (NNC) deep learning for radiation dose reduction in digital breast tomosynthesis (DBT). Our NNC deep learning employed patched-based neural network regression in a convolutional manner to convert lower-dose (LD) to higher-dose (HD) tomosynthesis images. We trained our NNC with quarter-dose (25% of the standard dose: 12 mAs at 32 kVp) raw- projection images and corresponding "teaching" higher-dose (HD) images (200% of the standard dose: 99 mAs at 32 kVp) of a breast cadaver phantom acquired with a DBT system (Selenia Dimensions, Hologic, CA). Once trained, NNC no longer requires HD images. It converts new LD images to images that look like HD images; thus the term "virtual" HD (VHD) images. We reconstructed tomosynthesis slices on a research DBT system. To determine a dose reduction rate, we acquired 4 studies of another test phantom at 4 different radiation doses (1.35, 2.7, 4.04, and 5.39 mGy entrance dose). Structural SIMilarity (SSIM) index was used to evaluate the image quality. Our cadaver phantom experiment demonstrated up to 79% dose reduction. For further testing, we collected half- dose (50% of the standard dose: 32±14 mAs at 33±5 kVp) and full-dose (100% of the standard dose: 68±23 mAs at 33±5 kvp) images of 51 clinical cases with the DBT system at University of Iowa Hospitals & Clinics. Our NNC converted half-dose DBT images of the 51 clinical cases to VHD DBT images that were equivalent to full-dose DBT images, according our observer rating study of 10 breast radiologists. Thus, we achieved 50% dose reduction without sacrificing the image quality.

Metastatic breast cancer: characterization of axillary sentinel lymph node (SLN) on the preoperative spectral CT

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Abstract Text: Axillary lymph node (ALN) status is a prognostic factor for patients with breast cancer. Metastasis of sentinel lymph node (SLN) indicates ALN involvement. In this study, our purpose is to develop a quantitative approach in characterizing the metastasis of ALN on spectral CT using the largest SLN (LSLN) as the surrogate. With IRB approval, a data set of 185 patients with breast cancer was retrospectively collected at Sun Yat-Sen Memorial Hospital in Guangzhou, China. Each patient underwent a preoperative spectral CT scan. A chest and axillary dual-phasic contrast media enhanced scan were acquired with a GE Discovery CT750HD CT scanner while the patient was in supine position. The LSLN was manually identified by radiologists for quantitative image analysis. We used a total of 6 sets of dual-phasic scans including 40 keV monochromatic images, 70 keV monochromatic images, and gemstone spectral images obtained at arterial and venous phases. 82 patients were positive to biopsy-proven cancer metastasis and the remaining 103 were negative. A deep convolutional neural network (DCNN) was used to extract quantitative image features as the image representation of SLN. To assess the efficacy of quantitative image features in characterization of SLN, three machine learning classifiers including KNN, SVM, and random forest were compared. Ten-fold cross validation was used for model selection. Results indicated that the AUCs on the 6 CT images for classification of LSLN metastasis ranged from 0.71-0.78 in which the best classification were observed on 70 keV monochromatic images at arterial phase. The overall classifications in arterial phase were better than those in venous phase for low (40 keV) and mixture energy setting while the findings were reversed for high (70 keV) energy setting. Future work is underway to assess our quantitative measures in axillary staging.

Automatic classification of clustered microcalcifications in digitized mammogram using ensemble learning

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Abstract Text: Microcalcifications (MC) are small deposits of calcium, which are associated with early signs of breast cancer. In this paper, a novel approach is presented to develop a computer-aided diagnosis (CADx) system for automatic differentiation between benign and malignant MC clusters based on their morphology, texture, and the distribution of individual and global features using an ensemble classifier. The images were enhanced, segmented and the feature extraction and selection phase were carried out to generate the feature space which is later fed into an ensemble classifier to classify the MC clusters. The validity of the proposed method was investigated by using two well-known digitized datasets that contain biopsy proven results for MC clusters: MIAS (24 images: 12 benign, 12 malignant) and DDSM (280 images: 148 benign and 132 malignant). A high classification accuracies (100% for MIAS and 91.39% for DDSM) and good ROC results (area under

the ROC curve equal to 1 for MIAS and 0.91 for DDSM) were achieved. A full comparison with related publications is provided. The results indicate that the proposed approach is outperforming the current state-of-the-art methods.

Creation of new artificial calcification shadows for breast cancer and verification of effectiveness of CAD development technique that uses no actual cases

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Abstract Text: To compensate for an insufficiency of the case images needed in the development of CAD (Computer-Aided Diagnosis), work is underway to create artificial case images by embedding tumors and other such lesions into lesion-free images. Previously, the authors have demonstrated the effectiveness of creating artificial case images for hepatic and breast tumors and utilizing them in CAD development. Thus far, however, when training data comprising 50% or more artificial cases is used in CAD development, the resulting discrimination performance on test data has tended to be somewhat inferior compared to when training data comprises only actual cases. With the objectives of applying artificial case images to a greater range of sites and of using exclusively artificial cases to develop a high-performance discriminator, in this study, effectiveness verification was conducted that focused on breast cancer calcifications as a new target. Because the characteristics of calcification shadows differ substantially from those of the hepatic and breast cancer tumor shadows studied thus far, a new artificial image creation technique was developed. Artificial cases created using this technique were applied to CAD development. As a result, a discriminator trained with 100% artificial cases obtained detection performance equal to that of a discriminator trained with entirely actual cases.

Fully automated pectoral muscle identification on MLO-view mammograms with deep convolutional neural network

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Abstract Text: Accurate segmentation of breast region is an essential step for quantitative analysis of breast parenchyma on mammograms. Pectoral muscle identification on mediolateral oblique (MLO) view mammograms remains a challenging problem. In this study, our purpose is to develop a supervised deep learning approach for automated identification of the pectoral muscle on MLO- view mammograms. With IRB approval, 756 MLO-view mammograms including 656 digitized film mammograms (DFM) and 100 full field digital mammograms (DM) were retrospectively collected. The film mammograms were digitized at a pixel size of 50 μm × 50 μm and the DMs were acquired with a GE Senographe system with a pixel size of 100 μm × 100 μm. All mammograms were subsampled to 800 μm × 800 μm before the pectoral muscle analysis. An experienced radiologist manually segmented the pectoral muscle boundary as the reference standard. We constructed a U-Net-like deep convolutional neural network (DCNN) to identify the boundary of the pectoral muscle. The DCNN consisted of a contracting path to capture multi-resolution image context and a symmetric expanding path for prediction of the pectoral muscle region. A total of 15 million parameters in DCNN were trained with a mini- batched gradient decent algorithm by minimizing a binary cross-entropy cost function. Ten-fold cross-validation was used in training and evaluating the performance of our model. The DCNN-segmented pectoral muscle was compared to the reference standard with three criteria: 1) the percent overlap area (POA), 2) the Hausdorff distance (Hdist) and 3) the average Euclidean distance (AvgDist). We found that the mean POA, the mean Hdist, and the mean AvgDist were 96.0±5.3%, 2.14±1.50 mm, and 0.77± 0.97 mm, respectively. Further study is underway to evaluate its effect on quantitative analysis of mammograms.

First results with a deep learning (feed-forward CNN) approach for daily quality control in digital breast tomosynthesis

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Abstract Text: Digital breast tomosynthesis (DBT) is a relatively new breast imaging technique that generates 3D information on the breast anatomy. A large number of parameters influence system performance and the requirement to achieve high quality images every day suggest the implementation of a daily quality control (DQC) procedure. In 2D digital mammography, daily QC is typically performed with homogenous plates and a minimal amount of technical inserts for assessment of signal to noise, uniformity, defective pixels and other artefacts. This work proposes an alternative means of performing DQC in DBT with a 3D structured phantom that also includes a constancy test of reconstruction stability in the analysis. The aim of the study was to explore deep learning techniques to automatically track deviations from the normal or

baseline operating point. As a first test case, changes in dose were investigated. Feed-forward convolutional neural networks (CNN) have been successfully applied in the medical imaging domain and this study uses such a network to track deviations in a structured DBT test object. A 15 layer CNN model was constructed to extract features for image classification. A structured phantom was scanned on a Siemens inspiration DBT system (Siemens AG Healthcare, Erlangen, Germany) at three dose levels: normal dose, half this dose and double. After training the CNN on 36 DBT acquisitions (511488 image segments), newly acquired test images were categorized by the algorithm into the dose categories with an accuracy of 98.1%. This result indicates the potential for further use of deep learning algorithms for DQC.

Bag of visual words based approach for the classification of benign and malignant mass in mammograms using voting-based features encoding

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Abstract Text: Classification of benign and malignant masses in mammograms is one of the challenging problem for the development of Computer Aided Diagnosis (CAD) systems. Due to the risk associated with segmenting the mass region, focus is shifting from selecting the features from the mass area to the whole Region of Interest (RoI) containing the mass. Bag of Visual Words (BoVW) techniques are gaining considerable attention for classification tasks in medical imaging by considering RoI as a set of local features. In general BoVW aims to construct global descriptor based on the extracted local features. In this work, we investigated the effect of using BoVW methodology for the classification of benign and malignant mammographic masses. Several features has been explored to construct the local features and building the codebook. Subsequently a voting-based approach is used to encode the features. The proposed method is evaluated on a subset of DDSM dataset. Initial results reveals good classification performance Classification Accuracy (CA) = 87% and Area Under the curve=0.93 that are comparable to the state-of-the-art approaches developed for the classification of benign and malignant mass in mammograms.

Classification of mammographic microcalcification clusters with machine learning confidence levels

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Abstract Text: This paper presents a novel investigation of machine learning performance by examining probability outputs in conjunction with classification accuracy (CA) and area under the curve (AUC). One of the main issues in the deployment of computer- aided detection/diagnosis (CAD) systems is lack of `trust' of clinicians in the CAD system, increasing the possibility of the system not being used. Whilst most authors evaluated the performance of their breast CAD systems based on CA and AUC, we study the use of confidence level to indicate the reliability of a computer system. Experimental results suggest that although most classifiers produced similar results in terms of CA and AUC, their performances are significantly different when considering confidence level.

A novel nipple detection algorithm on Digital Mammography (DM)

Full Author List: J. Jiang, Y. Lu, Sun Yat-Sen University (China); Y. Guo, Department of Computer Science University of Illinois Springfield (United States)

Abstract Text: Previous studies found that multiple view techniques improved the accuracy of lesion detection on mammograms. One of the key components in multiple view techniques was the detection of nipple location, which is the only reliable landmark on mammograms. In this study, our purpose was to develop a novel nipple detection scheme by using geometric and radiomic information extracted on digital mammography (DM). We first extracted a region of interest (ROI) to limit the region of nipple detection by using breast area and the chest wall orientation. The geometric information along the breast boundary was used to categorize the nipples into obvious and subtle types. A top hat transform was used to identify the location of obvious nipples. For subtle type, the radiomic feature matrix was calculated on straightened ROIs along the normal direction of breast boundary. A random forest classifier was trained to combine the radiomic features and to predict the location of subtle nipples. Seven hundred and twenty one DMs were collected for evaluation of our algorithm. A radiologist manually identified the location of nipples as the reference standard. It was found that the average Euclidean distances between the computer and the reference standard were 0.93±5.0 mm for obvious nipples, and 2.74±5.0 mm for subtle nipples, respectively. Future work is underway to evaluate the automated nipples on the registration of abnormalities on multiple view mammograms.

Deep learning methods aid in predicting risk of interval cancer

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Abstract Text: The purpose of this study was to apply a neural net to a dataset of women who later experienced either screening detected or interval cancers and determine if it aids in classifying risk of interval cancer compared to using BI-RADS density. Full-field digital screening mammograms acquired in our clinics were reviewed from 2006-2015 and patients were identified that were later diagnosed with screen detected and interval cancers. A deep learning architecture (ResNet50) was trained on this dataset with the goal to classify between interval and screen detected cancers. Initial weights were initialized from ImageNet training and the final fully connected layers were retrained. Prediction loss and accuracy were calculated using this deep learning architecture and compared to predictions from conditional logistic regression using BI-RADS density. 182 interval and 173 screening-detected cancers were found in our study group. The prediction accuracy went from 0.63 using only BI-RADS density to 0.69 using ResNet50 and retraining the fully connected layer. We conclude that deep learning methods may be useful in identifying individuals at risk of interval cancer and that these methods can provide additional risk information not contained in breast density alone.

Deep learning and color variability in breast cancer histopathological images: a preliminary study

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Abstract Text: Variability in the color appearance in H&E stained histopathological images are typically observed. Color normalization has been found useful in standardizing the color appearance of H&E stained histopathological images prior to quantitative analysis with machine learning (using handcrafted features). However, its usefulness has not been previously studied when deep convolutional neural networks (CNNs) are used in classifying H&E stained breast cancer histopathological images. In this paper, we have adopted a representative CNN for classifying breast cancer histopathological images and evaluated the benefit/necessity of color normalisation using the Macenko, Khan and Reinhard color normalization methods. The representative CNN was implemented in-house and was verified. The BreaKHis dataset was used to train and test the CNN model. The results did not show significant superiority in the CNN performance when color normalization was used to standardize the color appearance of histopathological image. Furthermore, the classification performance of a magnification-independent CNN is comparable to that of magnification- specific CNNs with an additional benefit of a simpler classification scheme and training for only one CNN models (rather than multiple magnification-specific models). It may also have an advantage in clinical practice when the magnification factor of a histopathological image is not known.

Mass detection in mammograms using pre-trained deep learning models

Full Author List: R. Agarwal, O. Diaz, X. llado, R. Marti, Universitat de Girona (Spain)

Abstract Text: Mammography is a gold standard imaging modality and is widely used for breast cancer screening. With recent advances in the field of deep learning, the use of deep convolution neural networks (CNNs) in medical image analysis has become very encouraging. The aim of this study is to exploit to use of CNNs for mass detection in mammograms using pre-trained networks. In particular, we use the resnet-50 CNN architecture pre-trained with the ImageNet dataset to perform mass detection via patch classification on two publicly available image datasets: CBIS-DDSM and INbreast. Using CBIS-DDSM database, we demonstrate that the CNN model pre-trained using natural image database (ImageNet) can be effectively finetuned to yield better results, compared to randomly initialized models. The performance of pre-trained resnet-50 on INbreast is also analyzed. Further, the benefit of using transfer learning on a smaller dataset is demonstrated by using the best model obtained from CBIS-DDSM training to finetune on the INbreast dataset. We analyzed the adaptability of the CNN's Fully Connected (FC) layer and the Fully Convolutional (FCN) layers to detect masses. The results showed a testing accuracy of 0.78 and AUC of 0.87 for model finetuned on FCN layers, while testing accuracy of 0.79 and AUC=0.87 when the model is trained only on the FC layer.

Automatic estimation of glandular tissue loss due to limited reconstruction voxel size in tomographic images of the breast

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Abstract Text: An accurate measurement of the breast glandular fraction, or glandularity, is important in many research and clinical applications, such as breast cancer risk assessment, radiation dose evaluation and improvement of patient-based phantoms generated from data with finite pixel/voxel size. In light of this, we propose a method to estimate the loss of glandular tissue detail due to the limited voxel size in tomographic images of the breast. From CT images of a breast tissue

sample acquired using a synchrotron x-ray source (single-photon-counting CdTe detector with a nominal pixel size of 60μm) and reconstructed at seven different voxel dimensions, we extracted five groups of Regions of Interest (ROIs) with different glandularity amounts and patterns. Each group of ROIs contains the same portion of the sample image reconstructed at a different voxel size. Glandular tissue was segmented and the glandularity calculated from each ROI. For the five groups of ROIs the respective glandularity values were plotted as a function of the reconstruction voxel size. A machine learning algorithm was then trained on these data. After the training was completed, the algorithm was able to estimate, given a tomographic breast image reconstructed at a given voxel size with a certain glandularity, the increase (or decrease) of glandularity if the same image were reconstructed with a smaller (or larger) voxel dimension. The algorithm was tested on five additional groups of ROIs, resulting in an average standard error between the calculated and estimated glandularity of 0.21%±0.11%.

Deep radiogenomics for predicting clinical phenotypes in invasive breast cancer

Full Author List: H. Yoon, A. Ramanathan, F. Alamudun, G. Tourassi, Oak Ridge National Lab (United States)

Abstract Text: Integration of heterogeneous data from different modalities such as genomics and radiomics is a growing area of research expected to lead to better prediction of clinical outcomes than single modality approaches. To date radiogenomics studies have mainly focused on investigating correlations between genomic and radiomic features, or selecting salient features to determine clinical tumor phenotypes. In this study, we designed deep neural networks that combine both radiomic and genomic features to predict pathological stage and molecular receptor status of invasive breast cancer patients. Based on imaging data from The Cancer Imaging Archive (TCIA) and gene expression data from The Cancer Genome Atlas (TCGA), we evaluated the predictive power of Convolutional Neural Networks (CNN). Overall, results suggest superior performance for CNNs leveraging radiogenomics than CNNs relying on single modality data sources.

Changes in breast density over time using automatic density measures: preliminary analysis

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Abstract Text: Breast density is an important risk factor for the development of breast cancer. During the women lifetime, the breast glandularity varies due to hormonal changes. In particular, around menopause, the glandular tissue tends to decrease. The aim of this paper is to evaluate temporal breast density changes using density maps, provided by the commercial software Volpara. The dataset is composed of 563 mammograms from 55 patients (aged between 24 and 75 years old). The time frame between two acquisitions varies from less than one year to 4 years. Pairs of mammograms are registered using the morphons registration algorithm, in order to evaluate the structural similarity of the parenchymal distribution between the two acquisitions. To provide a fair comparison, the results are divided considering the patient age during the first mammographic acquisition and the time between the two studies. To evaluate the changes in breast density, local and global measures, such as the rate of change of the volumetric breast density, the histogram intersection between two density maps and the normalized cross-correlation after the registration, are considered. The results show significant differences in the statistics, mainly focused on patients younger than 30 years old and ranged between 56 and 65 years old with respect to those in the adulthood (between 30 and 55 years old). Similarly, the time between the two mammographic acquisitions shows a significant difference for patients older than 56 years old considering one and two year of difference between the two studies.

Proposal of algorithms for evaluation of geometric distortion and ghosting artefacts in digital breast tomosynthesis

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Abstract Text: Tomosynthesis devices are expensive and they need to be operated by professionals who know all their functions, to prevent damage and optimize your use in terms of image quality and radiation doses to the patient. A proper operation assists in the identification of defects presented by the equipment in routine mammography, enabling immediate corrections and preventing major damages. Therefore, special attention should be given to quality assurance programs for such equipment. The objective of this study was to evaluate the geometric distortion and ghosting artefacts in digital breast tomosynthesis images using algorithms (computational codes) developed by our group and to compare our results with results of the literature, based on the *European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis* (EUREF). Geometric distortion is the incoherent representation of the size or shape of a structure in the radiographic image. Exaggerated distortion makes radiography unacceptable for diagnosis. For the analyses, images were initially obtained with a 5 mm thick rectangular phantom composed of polymethylmethacrylate containing 1 mm diameter aluminium spherules. The reconstructed images for the geometric distortion and ghosting artefact tests were obtained with a phantom positioned at 25, 35 and 45 mm distance from the top of the breast support table. The digital mammography and tomosynthesis equipment

used were Hologic, GE and Siemens and they are installed in radiological clinics in several States of Brazil. ImageJ software was used for image evaluation via algorithms. The height of the plane in focus, the accuracy of the positioning in the plane in focus and the appearance of the aluminium spherules in the adjacent focus planes were analyzed. The planes in focus represent the planes where the spherules appear most clearly in the images. The images were also analyzed by a code described in the EUREF protocol (NCCPM_Tools). The algorithms developed in this study allow data on geometric distortion and dispersion of artefacts similar to the computational tool used in the European protocol (EUREF), with the advantage that the user can access all the information about the logic used in the analyses.

One size doesn't fit all: impact of object variability on iterative image reconstruction for DBT

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Abstract Text: In digital breast tomosynthesis (DBT), the image volume is reconstructed from a set of projection views acquired over a limited angle. Many research groups have successfully developed iterative image reconstruction algorithms for this problem. Compared to analytic reconstruction algorithms based on filtered backprojection, there is larger number of parameters involved in iterative reconstruction, that strongly affect the quality and appearance of the reconstructed images. In filtered backprojection, the main driving parameter is the apodization filter width, which affects the resolution of the resulting image. For iterative reconstruction parameters, there is, in general, no such clear relation between a given parameter and the image property that it will be affecting. The lack of these relationships makes it difficult to optimize reconstruction parameters for varying objects. The variability of the breast in terms of density and overall volume generally requires different algorithm parameters (or, different algorithms) to achieve similar quality and appearance across a patient population, which hinders the translation of iterative reconstruction algorithms into clinical practice. The purpose of this work is to demonstrate the impact of breast variability on tomosynthesis images reconstructed with iterative algorithms, and to propose a novel generalized algorithm that is less affected by breast variability. When reconstructed with a fixed algorithm (global parameter settings), the reconstructed thick breast is less noisy than the thin breast. When using an algorithm incorporating object-specific parameters, sharpness and noise texture is matched across the parameter range.

Characterization of a prototype high-energy X-ray inline phase sensitive digital breast tomosynthesis system for Phase I human imaging evaluations

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Abstract Text: A high-energy in-line (propagation-based) prototype phase sensitive imaging system was developed and tested to improve efficacy and reduce radiation dose in 2D and 3D breast imaging. Characterization and image quality measurements were performed to optimize SID, SOD, ODD, magnification factor (M) and angular geometry for 2D and 3D imaging while maintaining low mean glandular dose (D-g), including: micro-focus x-ray source spectral/beam quality; objective indices of spatial resolution, MTF, and CNR; and evaluations of 3D imaging parameters (limited angle acquisition and number of projection images). We compared the prototype 2D/3D phase imaging system to a clinical breast tomosynthesis (DBT) system, using contrast-detail test objects within homogeneous and heterogeneous modular breast phantoms of varying adipose-glandular compositions. A phase retrieval algorithm based on the phase-attenuation duality was applied to each projection view, and a modified Feldkamp-Davis-Kress algorithm was used to reconstruct the phase sensitive DBT slices. Simulated tumor margins were rated as more conspicuous and better visualized for phase sensitive acquisition geometries versus conventional DBT imaging, particularly for heterogeneous background images. CD curves and CNR figure-of-merit (FOM) values confirmed improvement in both contrast and spatial resolutions. The CNR improvements provided by the phase sensitive DBT prototype were sufficient to offset the attenuation-contrast loss with use of high tube voltages. The prototype for human imaging includes the following specifications: a hybrid microfocus xray tube (5-50 μ variable focal spot) that will operate at 40.6 mR/mAs at 120kVp; 70μ pixel (FOV of 3328 x 4096; 23.3cm x 28.5cm) amorphous selenium detector; SID of 156cm and ODD of 85cm (M= 2.2); acquisition angle of 15 degrees acquiring 9 projection images over 35 sec using "step and shoot" technique. Phase 1 human breast imaging will be performed at 120 kVp, 6.75 mAs, with D-g of 1.5 mGy to a 4.2cm average (50%glandular/50% adipose) breast.

Session 3: Breast Density

Volumetric breast density measurement for personalized screening: accuracy, reproducibility, and agreement with visual assessment

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Abstract Text: Assessment of breast density at the point of mammographic examination could lead to optimized breast cancer screening pathways. The onsite breast density information may offer guidance when to recommend supplemental imaging for women in a screening program. In this work, performance evaluation of a new software for fast onsite quantification of volumetric breast density is presented. Accuracy of volumetric measurement is evaluated using breast tissue equivalent phantom experiments. Reproducibility of measurement results is analyzed using 8150 4-view mammography exams. Furthermore, agreement between breast density categories computed by the software with those determined visually by radiologists is examined. The results of the performance evaluation demonstrate that the software delivers accurate and reproducible measurements that agree well with the visual assessment of breast density by radiologists.

Mammogram breast density classification using mean-elliptical local binary patterns

Full Author List: M. George, Aberystwyth University (United Kingdom); E. Denton, Norfolk and Norwich University Hospital (United Kingdom); R. Zwigelaar, Aberystwyth University (United Kingdom)

Abstract Text: This paper presents a novel variant of Local Binary Patterns (LBP) so called Mean-Elliptical Local Binary Patterns (M-ELBP) for breast density classification. The basic idea of (E)LBP is that an image texture consists of micropatterns and the histogram of these micropatterns could give information about the local features in an image. To include intensity based information along with texture features, we improve the ELBP descriptor by including the mean intensity around the central pixel. We use multiple orientations which facilitates capturing sufficient micropattern features from the mammographic images. The M-ELBP is computed for the fibroglandular disk area instead of the whole breast region. A Bayesian network classifier was used for performing mammogram density classification and a stratified ten-fold cross-validation scheme was used for performance evaluation of the proposed method. The proposed method achieved an accuracy of 74% which is comparable with other methods in the literature using the same dataset.

Mammographic breast density over time among women who have participated in BreastScreen Norway

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Abstract Text: Using information from an automated method for breast density assessment, we examined the consistency in absolute and percent MD among women who attended BreastScreen Norway by age, body mass index (BMI) and use of hormonal therapy (HT). We used information from 33,711 women aged 50-69 who had two-five screening full field digital examinations in Rogaland or Hordaland counties, 2007-2015. BMI and HT-use was obtained from a self-administered questionnaire, given to women together with the invitation to screening. BMI was categorized into < 21.0; 21.0-24.9; ≥ 25.0 kg/m2, while use of HT was defined as “ever used” or “never used”. The automated software produced measurements of fibroglandular volume (cm3), breast volume (cm3) and volumetric breast density (%) for each screening examination. We applied mixed-effects linear models to estimate the association of age, fibroglandular volume, breast volume and volumetric breast density over time including data on BMI and HT. Volumetric breast density decreased by age regardless of BMI and HT. The results of the mixed-effects models indicated that age was associated with decrease in fibroglandular volume and volumetric breast density, and increase in breast volume. BMI <21 kg/m2 was associated with higher volumetric breast density, but lower fibroglandular and breast volume. Contrary, BMI ≥25 kg/m2 was associated with lower volumetric breast density and higher fibroglandular and breast volumes. Variation in volumetric breast density and fibroglandular volume within women was rather subtle: this variance either exceed 10% for volumetric breast density, fibroglandular volume or breast volume. Absolute and percent MD changed with a maximum of 10% over time, from first to last screening examination in our study including two to five subsequent screening examinations. MD estimated as volumetric breast density and fibroglandular volume by the automated software decreased with age among women screened in BreastScreen Norway.

Using a convolutional neural network to predict readers' estimates of mammographic density for breast cancer risk assessment

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Abstract Text: Mammographic density is an important risk factor for breast cancer. In a recent study, density assessed visually by readers using Visual Analogue Scales (VAS scores) showed stronger prediction of risk than existing automated density measures, suggesting readers may recognise relevant image features not yet captured by automated methods. By training a deep convolutional neural network (CNN) to predict VAS scores, we aim to learn these features and ultimately create an automated method that achieves at least human performance for risk assessment. We have built CNNs to predict VAS scores from full-field digital mammograms. The CNNs are trained using whole mammograms, each labelled with the average of two VAS scores, as assessed independently by two readers. The CNNs learn a mapping between mammographic appearance and VAS scores, so that at test time, they can predict a VAS score for an unseen image. The networks were trained using 72692 mammogram images from 18246 women, and tested on an independent set of 73128 images from 18360 women. Pearsons correlation coeffcient between readers' and predicted VAS was 0.74 per mammogram and 0.82 per woman (averaging over all mammographic views). VAS scores were significantly different between normal cases and cancers ($p<0.01$ for both readers' and predicted scores). We achieve good performance predicting VAS scores. We will extend our method by directly predicting cancer risk, using the pre-trained weights from our current CNNs, and testing on data from a case control study matched by age, menopausal status, parity, HRT and BMI.

Masking risk predictors in screening mammography

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Abstract Text: High mammographic density reduces the diagnostic accuracy of mammography by masking tumors, leading to interval cancers and late stage diagnosis. In this study, various models to predict masking risk are computed on a cohort of 91 interval or undiagnosed ("masked") invasive cancers and 192 screen-detected invasive cancers, based on biometric (age and BMI) and image- based parameters (BI-RADS density, volumetric breast density (VBD) and detectability). Univariate logistic regressions were computed to predict masked cancers, and the accuracy of the regressions was evaluated using the area under receiver operator characteristic curve (AUC). The univariate AUC for BMI, age, BI-RADS density, VBD and mean detectability were 0.63 [0.57-0.71], 0.64 [0.57-0.72], 0.67 [0.61–0.73], 0.70 [0.63-0.76] and 0.73 [0.66-0.79] respectively (95% confidence intervals are noted in the brackets). The models were applied to a set of 245 mammography exams from cancer-free women of the same population. A stratified screening model was tested by computing the fraction of disease-free women identified as masked (the recruitment rate) as a function of the fraction of masked cancers that were correctly identified. For BI-RADS densities 3 or 4 (4th edition), up to 59% of interval cancers could potentially be detected by supplemental tests, requiring 42% of women to be recruited for extra screening. Selecting by mean detectability would require a 36% recruitment rate for the same potential capture. Future work to develop multivariate masking risk predictors could yield more efficient stratified screening approaches for breast cancer detection.

Session 4: Intersection of Clinical Imaging Sources

Simulation of sequential pathology images for the rad-path virtual clinical trials

Full Author List: P. R. Bakic, Univ of Pennsylvania Health System (United States); D. Pokrajac, Delaware State University (United States); M. Feldman, A. D. Maidment, University of Pennsylvania Health System (United States)

Abstract Text: Virtual Clinical Trials have been used for preclinical evaluation of novel breast imaging systems, based upon the computer simulation of breast anatomy, imaging modalities, and image interpretation. Most VCTs today are focused on the evaluation of imaging systems at the "radiological" spatial scale, by simulating anatomical structures which are seen in clinical radiological images (e.g., breast outline, skin, tissue compartments containing adipose or dense tissue, and fibrous ligaments which septate adipose tissue compartments). This paper extends this simulation to the smaller (i.e., "pathological") spatial scale, to allow for radiology-pathology ("rad-path") correlation in the simulation. Previously, we developed a preliminary simulations of adipose and dense tissue regions in pathology images, corresponding to a small region selected

within a breast phantom simulated at the radiological scale. This paper formalizes the procedure to simulate dense tissue fibers and fibroblasts by employing an analogy with the electrostatic field. Our approach is aimed at modeling volumetric cell distributions, which allows the simulation of sequential pathology images at clinical inter-slice distances. The proposed simulation method has been evaluated by clinical pathologists. The effect on the visual appearance by the components of the rad-path simulation (including the number of points at which the analogue electrostatic field is calculated, and the functional form to model fibrous bundles) have been evaluated. Future work would include quantitative evaluation by comparing statistical descriptors of cellular morphology and distribution estimated in clinical and phantom images, and designing a proof-of-concept rad-path VCT.

Developing imaging biomarkers for mammographically-occult cancer in dense breasts using a radiologist's progress rating on cancer development: a preliminary analysis

Full Author List: J. Lee, University of Pittsburgh (United States); S. Song, Korea University Anam Hospital (Korea, Republic of); R. M. Nishikawa, University of Pittsburgh (United States)

Abstract Text: We developed imaging biomarkers for mammographically-occult (MO) cancer in women with dense breasts using a radiologist's progress rating on cancer development. MO cancer is a cancer that is occluded by dense breast tissue, or visually subtle that radiologists fail to recognize the cancer. We used screening mammograms of 246 normal women (half training) with dense breasts and 116 women (66 training and 50 testing) with dense breasts who had ipsilateral MO cancer, i.e., negative consecutive mammograms followed by a diagnosis of cancer. With full cancer diagnosis information of the cancer-diagnosed in the current year's mammogram, an experienced breast radiologist reviewed 1 – 3 prior consecutive mammograms in the training set and rated the progress score on cancer development over prior mammograms, using a [0 100] scale. We segmented a dense area in those mammograms and extracted 42 image features (5 histogram, 16 texture, and 21 bilateral asymmetries). We conducted a Pearson's correlation analysis between image features and the radiologist's cancer development ratings. We found 23 features correlated with the radiologist's ratings (p-values < 0.05). We used the top five correlated image features (p-values = [0.0002 – 0.0041]) with the radiologist's ratings to develop a classifier to identify women with MO cancer. The features included three histogram and two bilateral histogram asymmetry features. Using training and testing sets, we trained and tested a logistic regression classifier. The mean and 95 confidence interval of the area under the receiver-operating characteristic curve (AUC) of the classifier was 0.78 [0.693, 0.852].

Effect of biopsy on the MRI radiomics classification of benign lesions and luminal A cancers

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Abstract Text: Radiomic features extracted from breast magnetic resonance (MR) images have been shown to contribute to diagnosis and prognosis of breast cancer cases. However, presentation of cancer on MRI may be affected by a biopsy event. Thus, we investigated the difference in radiomic features and the area under the receiver operating curve (AUC) for the task of classification of the lesions as benign or luminal A, relative to biopsy condition. Dynamic contrast-enhanced (DCE) MR images were acquired retrospectively under IRB/HIPAA compliance. The 361-case dataset included 92 benign and 30 luminal A lesions imaged pre-biopsy, and 40 benign and 199 luminal A lesions imaged post-biopsy. Radiomic feature values for each group of lesions, by biopsy condition, were compared using the Kolmogorov-Smirnov test to determine if the two groups were drawn from the same patient distribution. P-values were corrected for multiple comparisons by the Holm-Bonferroni method; features were significantly different when corrected p-value < 0.05. AUC was calculated using the conventional binormal model. Using 500 bootstrap iterations, the mean of the AUC and the 95% confidence interval of the difference in AUC was determined for each feature by biopsy condition. AUC performance for a feature was considered significantly different when corrected p < 0.05. While, as expected, the morphology feature of irregularity was significantly different (p < 0.0001) for benign lesions due to how biopsy events increased irregularity of benign lesions, most features were robust between biopsy conditions. All features failed to demonstrate significance in terms of difference in AUC between biopsy conditions.

Session 5: Image Quality: Dose & Motion

Diagnostic radiation dose after the implementation of digital breast tomosynthesis screening

Full Author List: B. Barufaldi, E. McDonald, E. Conant, A. Maidment, University of Pennsylvania

Abstract Text: Our clinical practice transitioned from digital mammography (DM) to DM/DBT screening in 2011. This study analyzes the radiation dose of diagnostic exams in two cohorts, before (I) and after (II) the transition with four Hologic

Selenia Dimensions DM/DBT systems. We considered different imaging modes: DM, magnification DM, and the 2D and 3D components of DBT. Diagnostic exams were screening recalls and classified into four groups based on recalled finding: asymmetry, architectural distortion, masses, and calcifications. The study set consisted of 7,409 images from 1,857 women (mean age 55.3±10 yrs.) acquired at two time periods (2010-11, cohort I; 2011-13, cohort II). The average glandular dose (AGD) for the population was computed from the sum of all exposures and analyzed by finding type. The AGD, breast thickness, and exposure settings were obtained using an automated dose-reporting software that stores DICOM metadata in a database for real-time data exploration. The average AGD per patient was 5.82 mGy for cohort I (4.95, 5.40, 6.01 and 8.96 mGy for masses, asymmetry, architectural distortion and calcifications, respectively) and 7.15 mGy for cohort II (6.23, 7.19, 7.61 and 9.03 mGy, respectively). While the AGD for calcifications remained the same after the transition, a net increase of 19% was found due to the addition of 3D imaging for the other findings. The implementation of DBT in the screening and diagnostic setting results in increased radiation dose to the individual woman.

Dose reduction in breast CT by spectrum switching

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Abstract Text: To evaluate whether combining a polychromatic reconstruction algorithm for breast CT with projection data acquired using alternating high and low energy spectra allows a significant dose reduction while maintaining image quality. A breast phantom was scanned on a clinical breast CT scanner using the automatic exposure setting at the regular spectrum with a tube voltage of 49kV and a 1.576mm aluminum filter and with a second, higher energy spectrum created by adding a 0.254mm copper filter. An acquisition with spectrum switching was simulated by interleaving projections from the standard and high energy datasets, and a previously developed polychromatic reconstruction algorithm was modified to reconstruct the breast CT images. Image quality was assessed using the signal difference-to-noise ratio (SDNR) of high and low contrast targets in the phantom. A Monte Carlo simulation was performed to determine the mean glandular dose (MGD) of each scan. Acquisition of the simulated scan with spectrum switching would result in an MGD of 1.71mGy, compared to the standard acquisition MGD of 2.72mGy, a reduction of 37%. At the same time, measured SDNR of the mixed spectrum reconstructions was slightly higher than that of the standard acquisition, with an increases in SDNR of 6.6% ($p<0.01$) and 5.3% ($p=0.12$) for the high and low contrast targets, respectively. Our approach combining a polychromatic reconstruction algorithm for breast CT with an advanced acquisition protocol using alternating high and low energy spectra can lower dose by at least a third without loss of target SDNR.

Development of an automated detection algorithm for patient motion blur in digital mammograms

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Abstract Text: The purpose is to develop and validate an automated method for detecting image unsharpness caused by patient motion blur in digital mammograms. The goal is that such a tool would facilitate immediate re-taking of blurred images, which has the potential to reduce the number of recalled examinations, and to ensure that sharp, high-quality mammograms are presented for reading. To meet this goal, an automated method was developed based on interpretation of the normalized image Wiener Spectrum. A preliminary algorithm was developed using 25 cases acquired using a single vendor system, read by two expert readers identifying the presence of blur, location, and severity. A predictive blur severity score was established using multivariate modeling, which had a coefficient of determination, $R2=0.58$, for linear regression against the average reader blur severity, and up to $R2=0.69$ for regression against the scores of the second reader alone. A heatmap of the relative blur magnitude showed good correspondence with reader sketches of blur location, with a Spearman rank correlation of 0.70 between the algorithm-estimated area fraction with blur and the maximum of the blur area fraction categories of the two readers. Given these promising results, the algorithm-estimated blur severity score and heatmap are proposed to be used to aid observer interpretation. The use of this automated blur analysis approach, ideally with feedback during an exam, could lead to a reduction in repeat appointments for technical reasons, saving time, cost, potential anxiety, and improving image quality for accurate diagnosis.

Measuring breast motion at multiple DBT compression levels using ultrasound speckle-tracking techniques

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M.D., George Washington University (United States); T. Ahmed M.D., Vetarans Affairs Medical Center (United States); R. Kaczmarek, K. J. Myers, US Food and Drug Administration (United States)

Abstract Text: The goal of this study is to investigate whether reduced breast compression in digital breast tomosynthesis (DBT) exams causes larger internal breast motion that would adversely affect DBT image quality. We designed an experiment to collect real- time breast motion data of patients using ultrasound under three levels of DBT compression (full, medium and half). The ultrasound RF data had a pixel size of 21.5 m and 150 m in the axial and lateral directions of the probe, allowing the tracking of very fine movement of internal structure. We have successfully collected data from six human subjects and continue to recruit patients. The data were analyzed using speckle-tracking techniques to extract internal tissue movement trajectories pixel by pixel at multiple locations. Initial data analysis showed that internal breast tissue movement highly correlated with breathing. Based on the first four patient datasets we have processed, the internal motion magnitudes on average were smaller than 1 mm under the full and reduced compression levels. The statistical distributions of the motion magnitudes among the three compression levels were similar, indicating that the internal breast motion may not necessarily increase with reduced compression up to the half compression level being tested in our study. However, more data will be collected to strengthen this study for more solid conclusions.

Interactive Poster session 2

Lesion assessment and radiation dose in contrast-enhanced digital breast tomosynthesis

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Abstract Text: Contrast-Enhanced Digital Breast Tomosynthesis (CEDBT) provides a three-dimensional (3D) contrast-enhancement map with co-registered anatomical information from low-energy DBT. It combines the benefits from Contrast-Enhanced Digital Mammography (CEDM) and Digital Breast Tomosynthesis (DBT), and may improve breast cancer detection and assessment of lesion morphology. We investigate the efficacy of CEDBT in the assessment of lesion contrast enhancement and margin identification, and evaluate the dose efficiency. We generate synthetic CEDM images from CEDBT data, similar to synthesis of 2D mammograms from DBT data, which may facilitate overall lesion assessment without additional radiation dose. Preliminary results from a patient study show that CEDBT depicts lesion margins better compared to CEDM, while the contrast-enhancement level for in-plane slice is not as high as in CEDM. CEDBT delivers less radiation dose compared to CEDM + DBT. Synthetic CEDM is able to provide lesion contrast- enhancement level comparable to CEDM.

Development of energy resolved photon-counting mammography with a cadmium telluride series detector to reduce radiation exposure and increase contrast-to-noise ratio using high-energy x-rays

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Abstract Text: A new energy resolved photon-counting mammography (ERPCM) device with a cadmium telluride (CdTe) series detector (JOB Corporation, Japan) is currently being developed. The CdTe series detector can detect higher-energy photons with high sensitivity, enabling the use of high-energy X-rays for imaging. Our previous research, in which we compared ERPCM using high- energy X-rays (tube voltage 50 kV) with general mammography using low-energy X-rays (tube voltage about 30 kV), reported that ERPCM had a higher CNR (contrast-to-noise ratio) than general mammography. The purpose of this study was to examine the magnitude of the CNR using a simulation and ERPCM; especially we would like to examine the CNR when the tube voltage of higher than 50 kV was adopted. Using the simulation and ERPCM, we compared the CNR between images taken at 50 kV and 75 kV under a constant average glandular dose. The simulation phantom was composed of 50% mammary gland and 50% adipose tissue, and contained tumor regions. The thickness of the simulation phantom was varied. We put an acrylic plate (1 mm thickness) on an RMI- 156 phantom. Furthermore, we placed the thicker acrylic plate (10, 20, 30, 40 mm) on the 156 phantom and 1 mm-thick acrylic plate to simulate thicker breast. Based on the simulation results, it was suggested that there was an advantage in taking an image at 75 kV when the breast thickness was approximately 80 mm. The advantage of the image taken at 75 kV for the thicker breast was also confirmed in ERPCM.

Breast Tomosynthesis reconstruction using software tool TIGRE

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Abstract Text: In this article the open source Tomographic Iterative GPU-based Reconstruction (TIGRE) Toolbox for cone-beam x- ray computed tomography (CBCT) has been used to reconstruct images from a Digital Breast Tomosynthesis (DBT) system. We present reconstructed images of commercial breast phantoms CIRS models 013 and 073; acquired by a Hologic Selenia Dimensions system. Initial results have shown the ability of TIGRE to reconstruct images using both two reconstruction algorithms (FDK and OSSART), although a wider variety of iterative algorithms are available. For the first time, the reconstruction tool TIGRE is used in DBT geometries, opening new possibilities for free, fast and reliable reconstruction algorithms to other research groups.

Digital breast tomosynthesis: impact of a new beam quality on dose to patients

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Abstract Text: In this study we analyze the impact of a new beam spectra on the mean glandular doses (MGD) delivered by a digital breast tomosynthesis system. The new spectra is generated with a rhodium (Rh) target and a 30 m silver (Ag) filter. To evaluate the influence of the new spectra on patient doses, we compare the MGD values with those delivered with a regular Rh/Rh target/filter combination. Individual glandularity (%) of the patients in the study was estimated using the commercial software Volpara. Median of MGD values for CC and MLO views are around 38% and 46% lower with the Rh/Ag combination than with the Rh/Rh combination. Results suggest that the new spectra, with reduced dose properties, could be very useful in breast cancer screening programs.

Independent images: a requirement for phantom-based image quality assessment using model observers?

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Abstract Text: The use of model observers for image quality assessment in digital mammography is currently being considered. Model observers assign decision variables to signal present and signal absent images which, if they are independent, can be used as a measure of performance. In this study, the impact of different dependencies at pixel level between the signal present and signal absent images were studied for the detection of 0.25 mm and 2.5 mm disk-shaped objects. Clinical images were acquired on an Amulet Innovality (FujiFilm, Tokio, Japan) mammography unit and modified multiple times to appear as acquired at 75% of the original dose level, to simulate different noise realizations. From these modified images, regions of interest (ROIs), with and without an embedded signal were obtained. Subsequently, detection experiments were created for which the images with and without embedded signals had: 1) exactly the same background structures, 2) the same background structures but different quantum noise realizations, and 3) completely different background structures. The ROIs were evaluated using a channelized Hotelling observer (CHO) with dense difference of Gaussian channels. It was found that if the background structures within the ROIs with and without signal are dependent, the CHO decision variables also show strong dependencies. However, the performance measurement of the CHO yield values that were not affected. This finding is important for future developments of phantom-based image quality analysis in mammography using model observers and a single or limited number of anthropomorphic phantoms.

Preliminary experiences of DBT (digital breast tomosynthesis) and hybrid 18F-FDG-PET/MRI for neoadjuvant chemotherapy (NAC) cases in breast cancer

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Abstract Text: To assess clinical findings of new diagnostic modalities of DBT (Digital Breast Tomosynthesis) and 18F–FDG-PET/MRI for evaluations of loco-regional staging and treatment response of NAC in comparison with pathological findings. In this study, primary 16 patients with 17 invasive breast cancers (IDC: =15, ILC: n=1, and Metaplastic Ca: n=1), that NAC was preoperatively underwent, were enrolled. The average age was 48±12.25 y.o.. Clinical stage was cT2-4 N0 (IIA: n=3) or cT1-4 N1-3 (IIA: n=1, IIB: n=6, and IIIC: n=6). 2DMMG+DBT, US, and PET/MRI were obtained before and after NAC.As whole-body scans, a hybrid system of PET and 3.0T MR was obtained after intravenous injection of 18F–FDG followed by a resting period of 60 min in a supine position as early phase and T1WI and T2WI without fat suppression of MR images were obtained. In addition, breast MR images were conducted with a dedicated bilateral 8-channel breast

radiofrequency coil in a prone position. As well as breast MR, breast PET images as late phase 80 min after injection were obtained in a prone position. MR imaging protocol were consisted of T2WI with fat suppression, DWI, and a four phases of dynamic contrast enhanced T1WI sequences (30, 90,180, and 270 seconds) with fat suppression were obtained. The breast PET and MR images were evaluated independently and the fusion images of early phase (90 seconds) of dynamic contrast enhanced T1WI and the PET images at late phase were also evaluated. For determining cN-stage, numb and location of suspicious lymph nodes were assessed on MRI and FDG uptake. Pathological diagnosis of primary lesion and LNs were confirmed by US-guided biopsy before NAC.NAC response was evaluated the primary lesion as increased FDG uptake compared to the surrounding breast tissue by PET and the enhanced area by MRI. Regarding DBT, the images were acquired by MLO and CC views with the rotation angle of ±25°and reconstructed into 2 mm thick slices having 1mm overlap with high in-plane resolution of 0.085 mm × 0.085 mm. NAC response was evaluated by the diameter and the residual density of the lesion. The clinical response to chemotherapy was classified into the following categories, based on the "response evaluation criteria in solid tumors" (RECIST), using the measurements obtained with the different imaging methods: 1) Responders: a) Complete Response (CR): no clinical evidence of residual tumor or b): Partial Response, (PR), reduction in size of the tumor by more than 30%; 2) Non-Responders : a: Stable disease (SD): reduction in size of the tumor by less than 30% or b: Progressive disease (PD): increase in size of tumor or presence of new lesions. Pathological response to NAC was classified into four categories: 1) Grade 0: (no response), 2) Grade 1a (mild response): Mild changes are seen in less than one-third of cancer cells, 3) Grade 1b (moderate response): Marked changes in one-thirds or more of invasive cancer cells, Grade 2 (marked response) 2a (marked response) Marked changes in two-thirds or more of invasive cancer cells,2b (extremely marked response) Less than a few clusters of invasive cancer cells remaining, and Grade 3 (complete response) Necrosis or disappearance of all invasive cancer cells; replacement in accordance with the criteria by Japanese Breast Cancer Society (JBCS). Before NAC, PETMR detected primary lesions and LN metastasis as enhanced and enlarged lesions with MR and FDG uptake with PET by 100%.The mean±SD of SUV of the primary lesion and LN were 9.95±5.90 and 8.52±5.95. Pathological responses of the lesions to NAC were Grade 0 (n=1), Grade 1a (n=2), Grade 1B (n=4), Grade 2 (n=5), and Grade 3 (n=5). Among the cases of pathological Grade 3 (n=5), 2D+DBT demonstrated the lesions as no residual mass lesion with or without microcalcificatons as CR (4/5:80.0%) or reduced mass with or without microcalcifications as PR (1/5:20%). Shrinkage pattern of the lesion was concentric pattern with 2D+DBT. PETMRI demonstrated the lesions as reduced enhanced mass lesion by MRI as PR (n=3) and no residual mass lesion (n=2) as CR. FDG uptake was positive before NAC and negative after NAC in all of the cases. Regarding the Grades 1b-2 lesions (n=9), 7 lesions were detected as reduced masses with or without microcalcifications as PR (7/9: 77.8%). Shrinkage pattern of the lesion were concentric pattern (4/7: 57.1%) and honeycomb pattern (3/7:42.9%).Two lesions were detected as no residual mass lesion with or without microcalcificatons as CR (2/9: 22.2%) by 2D+DBT. PETMRI demonstrated the lesions as reduced enhanced mass lesion by MRI as PR (8/9:88.9%) and no residual mass lesion (1/9: 11.1%) as CR. After NAC, FDG uptake was positive in 3 lesions (3/9: 33.3%) and negative in 6 lesions (6/9: 66.7%).

Towards clinic-friendly solutions for a patient trial in breast cancer phase-contrast tomography

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Abstract Text: Phase-contrast imaging of the breast is expected to deliver significantly improved image quality and diagnostic value at a reduced radiation dose compared to present-day 2D X-ray mammography, digital breast tomosynthesis (DBT) and computed tomography (CT) and become a viable method for early diagnosis of breast cancer in women. This paper builds upon the evaluation of a novel protocol to evaluate 3D mammographic phase contrast imaging for the detection of breast cancer undertaken with a purpose designed phantom and selected breast cancer specimens. Following evaluation, propagation-based phase contrast imaging was demonstrated to have high contrast to noise ratio alongside an important reduction in radiation dose. The challenge now is to shift the focus of research to real clinic solutions, with the world-first demonstration of X-ray in-line full field phase-contrast mammographic tomography (PCT) with cancer patient and cancer-free volunteers through an international collaboration of a multi- disciplinary team.

Clinical performance of the tomosynthesis guided breast biopsy

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Abstract Text: To evaluate the clinical performance of tomosynthesis guided vacuum assisted breast biopsy (TVAB) and compare it to conventional stereotactic vacuum assisted biopsy (SVAB). From June 2013 to May 2017, all women who underwent breast biopsy were included in this retrospective study. Between June 2013 and April 2015, lesions were biopsied with SVAB. Since June 2015, all biopsies were performed with DVAB. Patient demographics, rates of aborted procedures, causes of abortions, as well as the radiologic and pathologic properties of lesions were compared between these two groups.

The significance level was accepted as $p<0.05$. From June 2013 to May 2017, 336 patients with 352 lesions (mean age 56.05±10.54) underwent SVAB and 516 patients with 555 lesions (mean age 56.05±10.27) underwent DVAB. 5.4% of SVAB and 4.1% of DVAB were cancelled due to non-visualization or difficult lesion location. Eight patients underwent DVAB had self-limiting vasovagal reaction; none reported in SVAB group. The rates of high-contrast lesions with calcifications were 83% in SVAB and 74% in DVAB while the rates of low-contrast lesions without calcifications were 17% and 26% in SVAB and DVAB, respectively ($p=0.002$). No statistically significant differences were found between the two groups with respect to histological results of lesions ($p=0.074$). Invasive breast cancers mostly presented as low contrast lesions while ductal carcinoma in situ (DCIS) as high contrast lesions ($p<0.001$). DVAB has a better clinical performance compared to SVAB because it can successfully biopsy not only the high contrast lesions detected on mammography but also the low contrast lesions only visualized on tomosynthesis. While high contrast lesions have more DCIS, low contrast lesions are often associated with a high rate of invasive breast cancer. DVAB can replace SVAB in routine clinic practice but at a cost of low rate of vasovagal reaction.

The effect of scan angle and slice thickness on the in-plane spatial resolution of calcifications in digital breast tomosynthesis

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Abstract Text: Digital breast tomosynthesis (DBT) is a three-dimensional X-ray imaging modality that allows the breast to be viewed in a 3-D format, minimizing the effect of overlapping breast tissue. DBT is commonly known for its high in-plane spatial resolution allowing to detect very small structures inside the breast which makes it a powerful tool in the clinical environment. However, since DBT is a limited angle tomography, artifacts are inevitable. In this paper, we investigate the influence of the angular scanning range as well as the thickness of the reconstructed slices on the resolution of calcification and present an analytic model to describe the imaging process. For validation, we used 54 datasets with varying calcification diameter, slice thickness, and angular scanning range, and compared the derived model to a Matlab simulation. It could be shown that the overall absolute mean error between the analytic model and the Matlab generated ground truth is very minimal and thus can be considered as a numerical error. The results indicate that both investigated parameters affect the in-plane spatial resolution in a non-linear way which yields that they have to be considered in a cascaded system analysis.

Nature sounds as a pain and anxiety reducing strategy in patients undergoing breast core biopsy: a randomized study

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Abstract Text: Higher patient anxiety is associated with greater pain during core-needle biopsies (CNB) and possibly lower adherence to biopsy recommendation. For this reason, we are proposing a novel intervention to reduce patient's anxiety during CNB of the breast by playing nature sounds (NS) in the background, in an attempt to synchronously lower experienced levels of pain. We test the physiologic and psychologic response of the patients during the biopsy and also of the technologist who is assisting during the CNB. Total of 100 women undergoing a stereotactic (ST) or ultrasound (US) guided breast biopsy will be included in this HIPAA compliant study. Pilot data from 4 patients have been acquired so far. Patients will be randomly assigned to one of two groups: the group exposed to NS, or standard care group exposed to supportive dialogue. 6 electrodes will be placed over the chest wall depending on the location of the biopsy to record the parameters of the autonomic nervous system. Bio-harness chest strap will be worn by technologist during the procedure which calculates the cardiac parameters. 5 time points are considered as triggers and marked during the biopsies: (1) baseline (2) injection of superficial lidocaine (3) firing of the 1st core (4) placement of the clip. High frequency heart rate variability (HF-HRV) and heart rate will be measured during these time points. Subjective analysis associated with CNB will be assessed by patients and technologists in both cohorts completing a short questionnaire before and after CNB with questions taken from the short form Spielberger State-Trait Anxiety Scale. 4 patients exposed to NS were analyzed (mean age= 63 yrs) who underwent US guided biopsy (3/4) and ST biopsy (1/4). Average HR of participants (n=4) in the first three minutes of the procedure was 79.08 bpm, and 81.45 bpm during the last three minutes. HF-HRV during the first three minutes was 4.83, versus 3.94 during the last three minutes. The average score on the STAI short form was one point lower post-procedure. According to participant self-report, average satisfaction in regards to the calming effects of the nature sounds was rated as a 2.75 (2 being "slightly" and 3 being "somewhat". The additional time needed for the study was approximately 8 mins. Our preliminary data supports that; NS can be helpful in reducing feelings of pain, and anxiety as well as dampening the physiological stress response during CNB. And, we want to expand our engagement and performance by understanding which patients will benefit from such intervention.

How does wide-angle breast tomosynthesis depict calcifications in comparison to digital mammography? A retrospective observer study

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Abstract Text: Digital breast tomosynthesis (DBT) provides superior breast cancer detection performance compared to digital mammography (DM), but it is unclear whether DBT alone is sufficient to accurately visualize lesions with calcifications, or supplemental DM is needed. In this work, we performed a retrospective observer study to assess and compare the depiction of calcifications on DM, DBT, and synthetic mammography (SM). Eighty views from 40 lesions with calcifications in 39 patients acquired with a wide-angle DBT system were included (two views per case - craniocaudal and mediolateral oblique). Four experienced researchers (3, 10, 11, 21 years) in breast imaging scored the images. For each case, the regions-of-interest containing calcifications in DM, DBT and SM were shown simultaneously. The readers ranked (ties allowed) the three modalities for the depiction of calcifications and assessed if more blurring was present in DM or DBT. DM was ranked as the best modality to depict calcification lesions in 84% of the cases, DBT in 22%, and SM in 7% ($P<0.001$). Similarly, for 86% of the views, DBT had more blurring of the calcifications than DM. In some cases, DBT showed higher contrast of calcifications providing better visualization, but worse characterization due to signal blurring. For cases with subtle calcifications, the higher noise of DBT images deteriorated their visualization. SM was preferred over DBT for large clusters, while it failed in some cases to display any calcifications. In conclusion, our results show the current limitations of DBT and its derived SM to depict calcifications in comparison to DM.

Developing populations of software breast phantoms for virtual clinical trials

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Abstract Text: Virtual Clinical Trials (VCTs) have been used as preclinical tool to evaluate novel breast imaging systems by computer simulations of breast anatomy, image acquisition and interpretation. VCTs offer significant advantages over clinical trials in terms of cost, duration, and radiation risk. The performance of VCTs depends on the selection of simulated breasts to represent a population of interest. We have developed a method for selecting a population of software phantoms to match the clinical distribution of compressed thickness, compression force, and percent density. Average clinical values and standard deviations can be used to develop phantom populations, assuming a normal distribution. Alternatively, characteristic clinical sub-populations may be identified (using supervised or unsupervised clustering algorithms), and represented separately by software phantoms. For this paper, we extracted the thickness and force information from anonymized DICOM headers of mammography images from 12,610 women. Percent density was estimated using an open source software tool. The average values and standard deviations were calculated and used to design software phantoms. Desired number of phantoms (determined by the power-analysis of the specific VCT) can be generated by random variations of the internal phantom composition. This paper illustrates the phantom population selection as integrated in the open-source VCT pipeline, previously developed in our lab. In the final paper, we will explore identifying characteristic clinical sub-populations. Future work may include the comparison of phantom populations selected using various clustering methods based and/or different descriptive features (e.g., age, hormonal status, parenchymal descriptors, or risk/disease history).

Impact of angular range of digital breast tomosynthesis on mass detection in dense breasts

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Abstract Text: The detection of cancerous mass lesions using digital breast tomosynthesis (DBT) has been shown to be limited in patients with dense breasts. Detection may potentially be improved by increasing the DBT angular range (AR), which reduces breast structural noise and increases object contrast in the reconstructed slice. We investigate the impact of DBT AR on the detection of masses in a simulation study using a cascaded linear system model (CLSM) for DBT. We compare the mass conspicuity between wide- and narrow-AR DBT system in a clinical pilot study. The simulation results show reduced in-plane breast structural noise and increased in-plane detectability of masses with increasing AR. The clinical results show that masses are more conspicuous in wide- AR DBT than narrow-AR DBT. Our study indicates that the detection of mass lesions in dense breasts can be improved by increasing DBT AR.

Ultrasound transducer tracking system for correlation of masses in combined breast ultrasound and X-ray imaging

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Abstract Text: Breast ultrasound is used in the USA primarily as an adjunct to projection x-ray (traditionally mammography) or DBT in breast cancer diagnosis. Ultrasound is employed internationally, and increasingly in the USA, to detect breast cancers in dense breasts. Time is consumed and errors made in finding corresponding masses in the two modalities. The most critical of such errors is delay in diagnosis of a cancer. When breast ultrasound is performed through a special mammographic paddle in the same or slightly reduced compression as the x-ray exam, such correlation errors should be reduced. With tracking of the position of the ultrasound image through the projection or tomosynthesis x-ray(s), time and errors in identification of the mass in the second modality should be reduced further. In order to allow ultrasound visualization of breast masses from any position and orientation through the paddle, we utilized Kinect™ (Microsoft, Redmond, WA) for tracking position, and a 6-axis sensor for tracking orientation of the hand-held ultrasound transducer. The Kinect module was mounted to a fixed location relative to the paddle while the 6-axis sensor was attached to the transducer body to send the acceleration and angular velocity information at a frequency of 100 Hz. This information allows display of the expected location of a DBT-identified mass or possible locations of a mammographic mass, in, or relative to, the real-time ultrasound image. Similarly, the expected location of an ultrasound identified mass can be displayed on a previous DBT. With help from the sensor information, this location in ultrasound can be marked on a previous mammogram if the ultrasound beam through the lesion is oriented parallel to the x-ray path. So far, the whole system can achieve a frame rate near 5 Hz and mean position error of 3.4 mm. Improved position tracking would allow creation of spliced 3D volumes and precise, multimodality image fusion.

Optimized simulation of breast anatomy for Virtual Clinical Trials

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Abstract Text: Virtual clinical trials (VCTs), computer simulations of clinical trials, can take many forms. In the field of breast imaging, VCTs are often involve simulations of breast anatomy, which are used to produce simulated images of the breast with or without lesions. Our anatomic model consists of an array of voxels labeled to denote specific tissue types; the voxel labels are arrayed spatially so as to simulation various anatomic structures. Our most recent breast model includes numerous innovations in the anatomy simulation and data representation. The breast model has been revised in size and shape to better reflect the range of women seen clinically; the breast has be divided into three breast regions (subcutaneous, interior, and posterior) with different rules to guide tissue arrangement; and tissue microstructure has been added to reflect a hierarchy of Cooper's ligaments. The lesion simulation has been enhanced to support lesion with various shapes (e.g., spherical lesions with tapered periphery, circumscribed non-spherical lesions, and single or clustered microcalcifications) and lesion placement which follows the clinical prevalence. Finally, the data representation has been formalized to support large VCTs using the VCT pipeline previously developed in our lab. These innovations have resulted in breast phantoms that are more realistic and more widely applicable, without negatively affecting the processing time. Currently, we can create phantoms with 100 µm voxels in approximately 10 s using a Dell T7610 computer workstation with a 16GB NVidia P5000 GPU.

Optimization of acquisition parameters for the detection of secondary breast lesions applying temporal contrast enhanced digital mammography

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Abstract Text: Temporal contrast enhanced digital mammography (CEDM) is an image technique that might improve detection of secondary breast lesions (multicentric and multifocal breast cancer), as an alternative to breast MRI. This works refers to its implementation using a commercial mammography unit and reports preliminary clinical results. Image acquisition parameters (beam quality and other radiological settings) were optimized to maximize iodine contrast to noise ratio in subtracted images acquired under single- and dual-energy techniques, limited to 2.4 mGy average glandular dose. An analytical formalism is presented to assess how optimization results are affected by breast thickness. Weighting factors were determined using a new method and a single value was proposed for each pair of beam qualities, regardless of breast thickness or dose distribution. Twenty six patients with suspected multicentric breast cancer have been studied with temporal

CEDM and MRI, followed by biopsy of suspicious lesions, following results from this formalism. Preliminary results show that both procedures have a similar sensitivity to detect malignancy (90% and 89%). Additionally, the effect of compression on iodine uptake has been investigated, observing a significant increase in iodine when compression force was reduced from 40 N to 20 N (3.6 mg/cm2 vs. 1.6 mg/cm2, p=0.0004).

Identification of breast tissue using the x-ray image measured with an energy-resolved cadmium telluride series detector based on photon-counting technique

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Abstract Text: We have been developing a new mammography device with a cadmium-telluride series energy-resolved photon- counting X-ray detector. Using a photon-counting technique, we examined the sensitivity of the system for identifying breast tissue and detecting breast tumors. To identify breast tissues, we prepared surgically resected specimens fixed in formalin, consisting of adipose, mammary-gland, and tumor tissues. In order to obtain the values of certain effective atomic numbers, we prepared phantoms with 0%, 50% and 100% simulated mammary-gland tissue. In our imaging system, the X-ray spectrum penetrating the object was measured using three energy bins, and the products of linear attenuation coefficients and thicknesses for the three bins were calculated. These linear attenuation coefficients were properly corrected for beam hardening and normalized, to ignore the thickness. These calculations were applied for each pixel, and the gravity point per ROI (region of interest) was plotted on scatterplots to examine their distribution. Adipose-tissue values were similar to known values; however, mammary-gland values were distant from expected values. In most specimens, the tumor points were focused; however, in some specimens, it was difficult to distinguish between tumor and mammary-gland tissues given their close linear attenuation coefficients. Mammary-gland tissues may have been influenced by formalin, given its tubular structure.

Comparison of screening full-field digital mammography and digital breast tomosynthesis technical recalls

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Abstract Text: The Enhancing Quality Using the Inspection Program (EQUIP) augments the FDA/MQSA program to ensure image quality review and implementation of corrective processes. In our screening program, we compared technical recalls between digital breast tomosynthesis (DBT) and 2D full-field digital mammography (FFDM). This HIPAA-compliant study was exempt from IRB review. In consecutive screening mammograms (October 2013 through December 2017), prospectively recorded technical recalls were compared for imaging modality (FFDM, DBT+FFDM, DBT+synthesized mammography (SynM)), images requested, and indication(s) for technical recall (motion, positioning, technical/artifact). Chi-squared tests evaluated statistical significance between proportions. Of 48,324 screening mammograms, 277 (0.57%) patients were recalled for 360 indications with 371 repeated views. There were significantly less recalls among DBT exams compared to FFDM (X2 = 25.239; p=0<0.001). Overall 98 (27.2%) of technical recalls were for motion, 192 (53.3%) positioning, and 70 (19.4%) technique/artifacts. Of these, 91 (31.1%) FFDM indications were for motion, 138 (47.1%) positioning, and 64 (21.8%) technique/artifacts. For DBT+FFDM there were 7 (15.6%) for motion, 35(77.8%) positioning, and 3(6.7%) technique/artifacts, compared to DBT+SynM with 0 (0%) indications for motion, 19 (86.4%) positioning, and 3(13.6%) technique/artifacts. There were significant differences in the indications for technical recall prior to and after implementing DBT+SynM (X2 = 18.719; p<0.001). Technical recalls declined significantly with the inclusion of DBT (SynM/FFDM) as compared to FFDM alone. The detection of motion on DBT+SynM had the greatest decrease. Positioning remains a dominant factor for technical recall regardless of modality, supporting the opportunity for continued education in positioning to decrease technical recalls.

An anthropomorphic model observer for spiculated masses

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Abstract Text: Compared to micro-calcifications in breast tissue, spiculated masses (SpMs) are larger and include more details that are critical to their detection. Therefore, the model observers designed for small and simple micro-calcifications, such as channelized hoteling observers, cannot be used for SpMs. We propose gauging the visibility of a SpM to a human observer by the visibility of its components, namely the edges (hence, the approach is sound even in the absence of a dense central mass). To this end, we adapt Barten's model for visibility of sinusoidal patterns to calculate the perceived strength for single frequency Marr-Hildreth edges (i.e., zero crossings after Laplacian of Gaussian band-pass filtering). Unlike the popular edge detector Canny, the proposed anthropomorphic edge maps are desirably sensitive to contrast and robust to noise.

Several single frequency perceptual edge maps may be combined to cover the full range of spatial frequencies that human observers are sensitive to, for example, using the principal component analysis or the maximum rule. We form an anthropomorphic double-ended model observer based on the comparison of the perceptual edge maps for the given and the reference radiographs. Our early results indicate that one can predict if a SpM in an input image is less (or more) visible with respect to the reference, when changing the contrast of the input image.

Increasing display luminance as a means to enhance interpretation accuracy and efficiency when reducing full-field digital mammography dose

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Abstract Text: FFFDM reduces radiation dose, but risks associated with dose is a concern. Reducing dose increases noise impacting image quality. Noise can be dealt with at the display level. Increasing display luminance can maintain acceptable levels of target detection performance when dose is reduced. Two CDMAM images were obtained at the same voltage (26 kV) and distance between detectors, but at 45 and 50 mAs resulting in entrance surface doses of 7.093 and 7.880 mGy. They were processed to make average gray level of the background independent of dose level, while maintaining SNR. Eight radiologists viewed the images on a Barco Coronis Uniti in 3 settings: 420 cd/m2, 1000 cd/m2 and SpotViewTM which resulted in an average display luminance of 3138.8 cd/m2. Total Percent correct (Pc) and Pc per dose were compared. Pc for all 3 luminances was higher in high vs low dose condition. In low dose, Pc was highest with SpotView and SpotView and 1000 cd/m2 were significantly higher than 420 cd/m2. In high dose, SpotView Pc was significantly higher than both lower luminances. Average time per image was lower in high dose, and at both doses time decreased as luminance increased, with SpotView have significantly shorter times. Increasing display luminance from 400 cd/m² to 1000 cd/m² significantly increases reading accuracy by approximately 3.0%. SpotView significantly increases reading accuracy by approximately 6.2%. Increasing display luminance from 400 cd/m² to 1000 cd/m² significantly decreases reading time by approximately 6.0%. Use of SpotView significantly decreases reading time with approximately 16.0%.

Computational dose estimative of digital breast tomosynthesis using a female anthropomorphic phantom

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Abstract Text: The digital breast tomosynthesis is the subject of many studies, aiming to investigate highly suitable parameters in order to obtain high quality images, as the radiation doses are kept in the range of digital mammography. The advantage of tomosynthesis, as a new technology in relation to other X ray based mammographic techniques, is its imaging potential with low mammal tissue overlapping effect. In order to determine the impact of the angular variation on the breast dose, and in the remainder organs and tissues of the human body, one important tool is the computational Monte Carlo simulation. To do so, we used a female adult anthropomorphic phantom with a detailed representation of organs, tissues and internal structures. This phantom incorporated in a radiation scenery with a commercial tomosynthesis equipment. The organ doses were determined to tomosynthesis and mammography techniques. The results pointed out that doses from tomosynthesis acquisition mode are quite lower than those from the mammographic mode.

Comparison of registration methods for motion correction in DCE-MRI of the breast

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Abstract Text: Accurate methods for breast cancer diagnosis are of capital importance for disease management. Motion artifacts are a common source of variability that decrease the diagnosis accuracy in dynamic sequenced imaging, and preprocessing steps are required to remove spatial misalignments. Different registration techniques have been developed in the past decades for medical imaging processing, and applied to a variety of magnetic resonance imaging, often focused in brain imaging. In this work we examine the different available solutions to the problem of motion artifacts in dynamic contrast enhancing magnetic resonance imaging (DCE-MRI) of the breast. We evaluate 5 different open-source algorithms based on the paradigms of: symmetric diffeomorphisms (SyN), fast diffeomorphism (DARTEL), optical flow, Demons (simpleITK) and free-form deformations (MIRTK). The evaluation is made in terms of 2 objective measures: contour overlap and volume overlap, obtained by automatic image processing techniques. The breast-diagnosis database from the cancer imaging archive (TCIA) is used for evaluation proposes, providing with a freely available set of 88 DCE-MRI subjects. The evaluation of the registration algorithms allows us to propose recommendations for use in terms of processing time or accuracy.

Session 6: Novel Imaging Technology

The PET/X dedicated breast-PET scanner for optimizing cancer therapy

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Abstract Text: We are currently building the PET/X scanner, which is a breast positron emission tomography (PET) scanner combined with a standard X-ray mammography system. The role for the PET/X scanner is to precisely measure changes in radiotracer uptake after an initial test dose of adjuvant or neoadjuvant therapy. The system performance target is that a measured 20% change in tracer uptake in 5 mm diameter lesions with standardized uptake value (SUV) of 5 should correspond to at least 95% specificity (<5% false positive rate for detecting a true change in uptake). Simulations indicate that this performance can be achieved with a 3-minute scan of a 370-MBq (10-mCi) injection of 18F-FDG or other radiotracers. The PET scanner consisted of 4 planar detectors, forming a rectangular system with complete azimuthal angular sampling (around the z-axis). The panels are formed of detector blocks each using a 20x20 array of LYSO scintillation crystals (2x2x10mm3) coupled to a 12x12 array of 3x3 mm2 pixel silicon photomultipliers (SiPMs). The overall system size is 24cm wide (6 blocks) by 16cm deep (4 blocks axially) by 4-to-12cm adjustable height. The PET system mounts on a mammography scanner by swapping out the standard 'bucky' unit. Patients are scanned in both mammography and PET modes without movement to allow co-registration of the two image sets. Here, we review the system design, construction, and initial performance measures.

Acquisition parameters for dual-energy contrast-enhanced digital mammography using a micelle-based all-in-one nanoparticle (AION) contrast agent: a phantom study

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Abstract Text: The objective of our study is to optimize the acquisition parameters for imaging Ag2S nanoparticles using contrast- enhanced digital mammography (CE-DM) by varying parameters such as kV, mAs, and filtration. The efficacies of three different contrast materials (Ag2S nanoparticles, silver nanoparticles, and iodine) were assessed using a contrast-embedded gradient phantom. The phantom was constructed using tissue-equivalent materials and varied continuously in composition from 100% glandular tissue to 100% adipose tissue. Each contrast agent was prepared at six different concentrations (1, 2, 5, 10, 15, and 25 mg/mL). Holes were bored through the phantom in the direction of varying glandularity, and tubes of contrast agents were inserted into the holes. Phantoms were imaged at four different energies (26 kV, 32 kV, 45 kV, and 49 kV); 5 energy pairs were considered in this study. Our results demonstrate that for a given contrast agent, the contrast-noise-ratio is linearly proportional to concentration, and its magnitude is dependent on the energy of the low-energy (LE) image. In our study, it was shown that the LE images at 26 kV are better suited for imaging silver-based nanoparticles, and the LE images at 32 kV are better suited for imaging iodine contrast. Thus, the energy of the LE image should be chosen so that it is as close as possible to the K-edge of the contrast material. Preliminary results from CE-DM imaging indicate that silver contrast has a significantly higher signal than iodine contrast when imaging at lower energies, thus demonstrating the feasibility of using silver-based nanoparticles in breast imaging.

Multisource x-ray system for artifact reduction in dedicated breast CT

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Abstract Text: This study examines the potential of a multisource x-ray system to reduce cone beam artifacts in a dedicated breast CT acquisition geometry. A breast CT scanner (Doheny), built at our institution, was used to demonstrate the potential of multiple x- ray sources in a single x-ray tube housing. Both 3 cathode and 5 cathode thermionic systems were simulated in this study. The x-ray tube is mounted on a vertical actuator on the breast CT system gantry, allowing the single x-ray source to be positioned at different vertical locations in the field of view. Five acquisition geometries were used to acquire raw cone beam CT data with the x-ray source locations placed at 2 cm intervals. Data were collected using a 6-cm and 15-cm tall Defrise phantom. The individual acquisitions of raw CT data were reconstructed using filtered back projection, aligned and summed. The reconstructed CT volume data set using three sources and five sources were compared to that produced from a single source. Both multi-source datasets demonstrated less visible cone beam artifact, and the contrast was clearly improved. In the region of interest, the average contrast between disks was increased by 2.5X using the three-source geometry with the 6-cm Defrise phantom. The average relative contrast between disks increased by 20X with the five-source geometry for the

15-cm Defrise phantom. This physical simulation of a multisource x-ray CT system successfully demonstrated that a reduction in cone beam CT artifacts could be achieved using a multi-source x-ray tube on a breast CT scanner.

Session 7: Imaging Phantoms

Breast phantom validation of a mammographic image modification method

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Abstract Text: A previously developed method to modify mammographic images so that they appear as if acquired with different radiographic factors would be useful in virtual clinical trials. The methodology was validated using a custom-made 3D printed breast phantom. The radiographic output, 1st half value layer, noise coefficients, grid factor and glare and scatter-to-primary ratio were measured on a Senographe Essential digital mammography system. Three images of the breast phantom at each of four dose levels were acquired with a Mo/Mo 26 kV spectrum using the same digital mammography system. In addition, three images were also acquired at each of 24 kV and 28 kV. The original high dose images at 26 kV were modified to simulate the images acquired at a lower dose, and at the lower and higher tube voltage. The signal level was changed to account for different dose level, scatter, grid attenuation and change of signal across the image. Electronic, quantum and structure noise were then added to the image to match the expected noise for the target image. The power spectra of the target and the simulated images of the breast phantom were calculated and compared. This comparison showed that they match to within an average difference of 4%. Using breast phantom images, it was shown that this method is able to replicate images as if acquired with different radiographic factors. Images modified in this manner could be used for clinical evaluation of image quality or for other types of virtual or human observer studies.

Method for task-based evaluation of clinical FFDM and DBT systems using an anthropomorphic breast phantom

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Abstract Text: Realistic breast phantoms are important tools when evaluating imaging system modifications. Current breast phantoms contain either unrealistic features, uniform backgrounds or are expensive to create. The purpose of this work was to introduce a novel, task-based methodology for evaluating full field digital mammography (FFDM) and digital breast tomosynthesis (DBT) systems using 4 alternative forced choice testing scheme and an anthropomorphic inkjet-printed 3D phantom containing clinically relevant signals. The methodology consists of three components: an anthropomorphic breast phantom and microcalcifications made from two material types. A 4 cm compressed breast phantom was first modeled analytically then physically realized in a slice-by-slice fashion using inkjet printing with iohexol-doped ink. The microcalcifications (MCs) were made by arranging individual specks of varying sizes into regular patterns. One set was made from calcium hydroxyapatite (HA) and another from soda lime coated glass microspheres ranging in diameter from 150 µm to 260 µm. The phantom was imaged on three commercially available FFDM/DBT systems, with typical mammographic beams used according to the AEC for each commercial system. A similar average glandular dose (AGD) was maintained across the systems. A pilot study consisting of a four alternative forced choice (4AFC) analysis with human observers was performed on the acquisitions. The µ of the HA MC was measured to be similar to reference values. A pilot 4AFC study showed the visibility of the microcalcifications ranged from easy to difficult, suggesting a smaller range of task sizes may provide appropriate difficulty for the full study, which will be conducted before the conference presentation. An anthropomorphic breast phantom was created using inexpensive, easily available materials. Task-based assessment was performed on clinical FFDM and DBT systems. This promising phantom generation methodology can be used to objectively evaluate task performance resulting with FFDM and DBT breast imaging systems.

Validation of the textural realism of a 3D anthropomorphic phantom for digital breast tomosynthesis

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Abstract Text: In this paper, texture calculations are used to validate the realism of a physical 3D anthropomorphic phantom for digital breast tomosynthesis. The texture features were compared against clinical data obtained from a large screening

population. Three groups of features (gray-level histogram, co-occurrence, and run-length) were considered. The features were analyzed over a broad range of technique settings (kVp and mAs). These calculations were done in the slice of the reconstruction corresponding to the mid-thickness of the phantom, as well as the synthetic 2D mammogram derived from the reconstruction. For each feature, the clinical data were binned into strata based on the compressed breast thickness. It was demonstrated that the clinical features vary by thickness. To evaluate the realism of the phantom, each feature was compared against clinical data in the same thickness stratum. In the reconstruction, most features in the phantom were found to exhibit realism, as they were not outliers relative to clinical data; specifically, 11 out of 12 gray-level histogram features, four out of seven co-occurrence features, and all seven run-length features. The realism of most features was robust to changes in the technique settings. However, in the synthetic 2D mammogram, more features were outliers relative to clinical data. In conclusion, this paper provides a validation of the textural realism of the phantom in the reconstruction, and shows that there is less realism in the synthetic 2D mammogram. We identify the features that should be considered to refine the design of the phantom in future work.

Development of a physical anthropomorphic breast phantom for objective task-based assessment of dedicated breast CT systems

Full Author List: S. J. Glick, J. Salad, L. C. Ikejimba, A. Makeev, C. G. Graff, B. Ghammraoui, FDA (United States)

Abstract Text: Realistic breast phantoms are important for evaluating system performance in breast CT (bCT). In this work, we present a new methodology for creating physical breast phantoms for use in assessing dedicated bCT systems. We also present a method for modeling microcalcifications (MCs) in the phantom. An uncompressed digital breast phantom was first generated through analytical modeling using a previously described approach. This model represented a breast with 28% fibroglandular density with 13 tissue classes. The breast was binarized to contain only two tissue classes: adipose and fibroglandular/skin tissue. The phantom was then physically realized through inkjet printing using dye ink doped with zinc acetate for the fibroglandular components and baking parchment paper to model the adipose background. Microcalcifications were fabricated from raw calcium hydroxyapatite powder which was pressed under high pressure, crushed, and sieved to obtain specks of specific sizes. The phantom fabrication process was evaluated in terms of material realism and reproducibility using x-ray spectroscopy, a clinical FFDM system, and a benchtop bCT system. The linear attenuation coefficient of the doped ink plus parchment paper and parchment paper alone closely matched those of the fibroglandular and adipose tissues, respectively. Good consistency was found in the printing process, with reproducible results across different prints. A methodology for generating an anthropomorphic, uncompressed breast phantom with accompanied microcalcification clusters was developed using a novel inkjet printing technique. This phantom can be used to objectively assess image quality of dedicated breast CT systems.

Session 8: Image Analysis & Computer-Aided Techniques

Orientation dependent detectability of fiber-like signals in linear iterative image reconstruction for breast tomosynthesis

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Abstract Text: We characterize the detectability of fiber-like signals in digital breast tomosynthesis (DBT) for linear iterative image reconstruction (IIR) algorithms. The detectability is investigated as a function of signal orientation and IIR regularization strength. The detectability is computed with a region-of-interest (ROI) Hotelling observer (HO) and applied to two linear IIR algorithms. Trends in detectability are compared with conspicuity of signals reconstructed in both simulation and real data studies. A common trend is observed with both algorithms in which signals oriented parallel to the detector and the plane containing the source-trajectory have lower detectability than their orthogonal counterparts at low regularization strengths. The orientation dependence is gradually reduced with increasing regularization strength. These trends in detectability are seen to match well with trends in the conspicuity of reconstructed signals in both simulation and real data studies.

A framework for distinguishing benign from malignant breast histopathological images using deep residual networks

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Abstract Text: Studies have shown that there are discrepancies among pathologists in the classification of breast histopathological slides. In this study, we propose a framework for categorizing hematoxylin-eosin stained breast images either as benign or malignant at four magnification factors, and then aggregating the classification results of a patient's

images from different magnification factors to make the ultimate diagnosis for each patient. A publicly available database, containing 7786 images from 81 patients, was used. The images were acquired in four visual magnification factors, namely x40, x100, x200, and x400, with the effective pixel size of 0.49 µm, 0.20 µm, 0.10 µm, and 0.05 µm respectively. In order to mitigate the inconsistencies in the color of images, stain normalization was performed. Next, for each magnification factor, a deep residual network (ResNet) with 152 layers has been trained for classifying patches from the images as benign or malignant. Then, a meta-decision tree was used to combine classification results of a patient's images from different magnification factors to provide a patient-level diagnosis. The ResNets achieved correct classification rates (CCR) of 98.52%, 97.90%, 98.33%, and 97.66% in x40, x100, x200, and x400 magnification factors, respectively. For classification of patients either as benign or malignant, a CCR of 98.77% was obtained. In conclusion, our study showed that the proposed framework can be helpful in the categorization of breast digital slides.

Superpixel pattern graphs for identifying breast mass ROIs in dense background: a preliminary study

Full Author List: S. Sajeev, M. Bajger, G. Lee, Flinders University (Australia)

Abstract Text: Finding mamographic masses located in a dense breast tissue is a challenge even for an experienced radiologist. The difficulty comes from the similarity of intensity between the masses and the overlapped normal dense tissues. In this study, a novel method for classification of masses localized in dense background of breast is proposed. The method can identify meaningful superpixel patterns present in mammograms within mass-like regions. The topology of superpixel patterns, captured by using spatial connectivity graphs, revealed significant differences between cancerous and healthy areas of breasts. Four clinically recognizable features were extracted from the superpixel graphs and used for classification. The proposed approach was evaluated using ninety three dense ROIs selected from the publicly available Digital Database for Screening Mammography (DDSM). All 93 ROIs were localized in dense backgrounds of breasts. Among them, 41 contained malignant masses in dense backgrounds and 52 contained healthy dense breast tissues. The results indicate that the graph features generated from superpixel pattern graphs can produce very effective and efficient feature descriptors of breast masses localized in dense background. Using Fisher Linear Discriminant Analysis (LDA) classifier AUC score of 0.90 was achieved for the four dimensional feature vector.

Mammogram denoising to improve the calcification detection performance of convolutional nets

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Abstract Text: Recently, Convolutional Neural Networks (CNNs) have been successfully used to detect microcalcifications in mammograms. An important step in CNN-based detection is image preprocessing that, in raw mammograms, is usually employed to equalize or remove the intensity-dependent quantum noise. In this work, we show how removing the noise can significantly improve the microcalcification detection performance of a CNN. To this end, we describe the quantum noise with a uniform square-root model. Under this assumption, the generalized Anscombe transformation is applied to the raw mammograms by estimating the noise characteristics from the image at hand. In the Anscombe domain, noise is filtered through an adaptive Wiener filter. The denoised images are recovered with an appropriate inverse transformation and are then used to train the CNN-based detector. Experiments were performed on 1,066 mammograms acquired with GE Senographe systems. MC detection performance of a CNN on noise-free mammograms was statistically significantly higher than on unprocessed mammograms. Results were also superior in comparison with a nonparametric noise-equalizing transformation previously proposed for digital mammograms.

Breast cancer detection using synthetic mammograms from generative adversarial networks in convolutional neural networks

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Abstract Text: The Convolutional Neural Network (CNN) is a promising technique to detect breast cancer based on mammograms. Training the CNN from scratch, however, requires a large amount of labeled data. Such a requirement usually is infeasible for some kinds of medical image data such as mammographic tumor images. Because improvement of the performance of a CNN classifier requires more training data, the creation of new training images -- image augmentation -- is one solution to this problem. In this study, we applied the Generative Adversarial Network (GAN) to generate synthetic mammographic images from the Digital Database for Screening Mammography (DDSM). From the DDSM, we cropped two sets of regions of interest (ROIs) from the images: normal and abnormal (cancer/tumor) Those ROIs were used to train the GAN, and the GAN then generated synthetic images. We used three groups of ROIs (synthetic, real (original), and a mixture of the two) each to train a CNN classifier from scratch. And, we used real ROIs that were not used in training to validate classification outcomes. In the case of synthetic ROIs, the maximum validation accuracy was about 85.4%. This means that the synthetic ROIs could retain the essential features, structure, or patterns of objects from the original ROIs. Also, the

accuracy after training using mixture ROIs was 1.5% higher (in maximum validation accuracy) than using only real data for training. It demonstrates that the GAN is a promising method for generating synthetic mammograms to augment the training data, and to improve CNN's performance for breast cancer detection.

Session 9: Simulation & Virtual Clinical Trials

Performance evaluation of a 3D structured phantom with simulated lesions on breast imaging systems

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Abstract Text: At the introduction of DBT, all phantoms available in routine QA of 2D digital mammography and even in breast imaging research consisted of homogenous test slabs with thin 2D inserts or layers, allowing to test for image contrast and resolution. The development of a 3D structured phantom for breast imaging was deemed necessary to be able to account also for the advantages of DBT, namely the reduction of overlapping normal breast tissue on potential lesions. In our team we have developed a phantom that fulfilled the above requirement of including a 3D background structure. The background structure consists of a mixture of beads in a liquid to produce different realizations of the background structure. The phantom could show advantages and limitations of DBT in comparison to 2D FFDM with a metric close to clinical practice, namely the detection of both calcification like targets and cancerous mass models. The work described here aimed to further investigate the applicability of the 3D structured phantom to study 2D FFDM and DBT systems by performing repeatability studies of target detection and by investigating the effect of dose on target detection in both 2D FFDM and DBT mode. The results may be predictive for the role of other, even more anthropomorphic phantoms in course of development.

A hybrid approach for virtual clinical trials for mammographic imaging

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Abstract Text: Detection of lesions is an essential part of making a diagnosis in mammography and therefore is a main focus in the development of algorithms built for image quality assessment. For those, required ground truth knowledge is often either fully simulated or estimated from phantom data. We propose a hybrid approach with an exact lesion projection model and embedding into clinical images that already contain relevant structures of anatomical noise. Using an algebraic lesion model, lesions with different sizes and contrasts are generated. The projection algorithm incorporates detector subsampling and advanced focal spot sampling to capture blur effects due to system movement and physical extent of the anode. With the lesion embedding, we also consider scatter effects. Signal and background patches are extracted and used to evaluate two types of channelized Hotelling observers. Laguerre- Gauss channels match the algebraic lesion patterns well and we compare it with a rather anthropomorphic set of Gabor channels. A 4AFC study with several medical imaging experts is performed and correlated with the model observers using the same patch data. Currently, this last step is prepared and results will be available in the full abstract.

Phantom-based comparison of microcalcification visibility between digital and synthetic mammography using humans and a deep neural network as observers

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Abstract Text: Most manufacturers have developed a 2D synthetic image (SM) from digital breast tomosynthesis (DBT) reconstructed planes with the aim of reducing breast doses by replacing the conventional mammogram (DM). In this work we analyse the image quality of SM from three different manufacturers for the specific task of detecting microcalcifications (MC), in comparison to DM. A phantom with MC clusters on a uniform background was employed, thus also allowing to explore its feasibility to be used for QC purposes. We have developed a 4-Alternative Forced Choice (4AFC) experiment where four human observers have to select the images with the MC clusters. We also explored the possibility to replace human observers with a virtual observer. For this, we developed a deep learning convolutional neural network for the task of classifying the same images from the 4AFC study, and then compare the results to the human-based study. The results show that for the four readers and all the systems, the percentage of correct answers (PC) was 100% and the visibility was 3 for the largest MC clusters. Also was demonstrated that SM yielded worse detectability and visibility than DM for

microcalcifications with sizes between 180 and 100 µm. The deep neural network yielded similar relative results in terms of the AUC than the 4AFC study performed by four readers. This might encourage the possibility to develop QC procedures based on artificial intelligence image reading, improving reproducibility and reducing costs.