Near-infrared, Broad-band Spectral Imaging of the Female Breast for Quantitative Oximetry: Applications to Healthy and Cancerous Breasts

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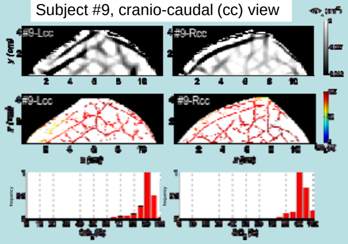
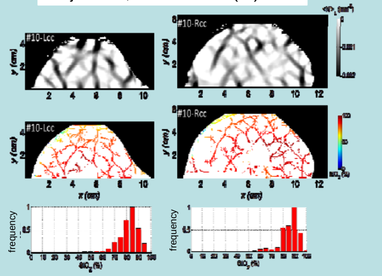
Healthy subjects

Left breast (L) Right breast (R)

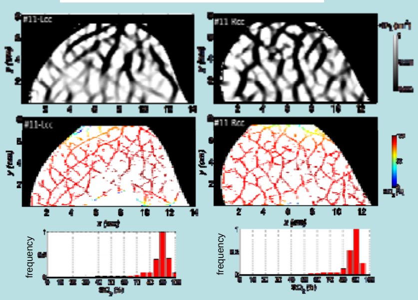
Subject #9, cranio-caudal (cc) view



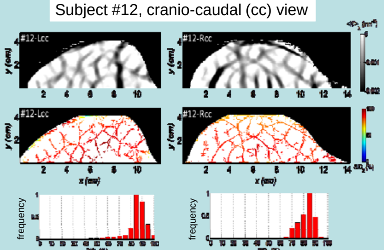
Subject #10, cranio-caudal (cc) view



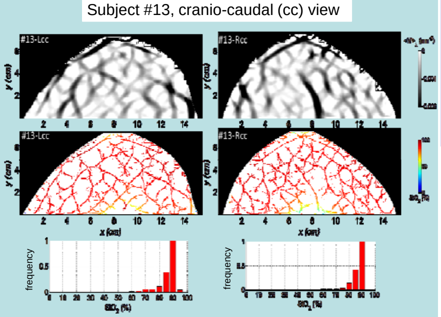
Subject #11, cranio-caudal (cc) view



Subject #12, cranio-caudal (cc) view



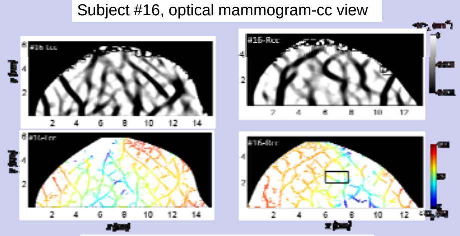
Subject #13, cranio-caudal (cc) view



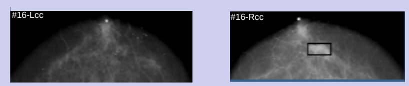
Patients with cancer

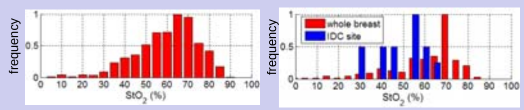
Left breast (L) Right breast (R)

Subject #16, optical mammogram-cc view

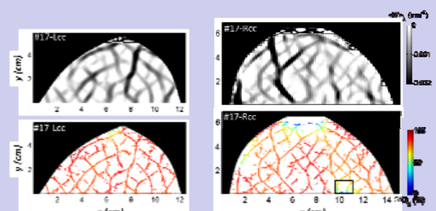


Subject #16, x-ray mammogram-cc view

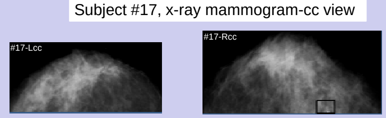


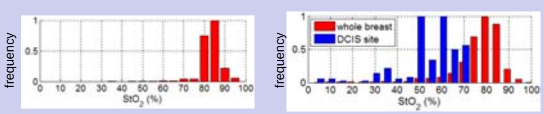


Subject #17, optical mammogram-cc view



Subject #17, x-ray mammogram-cc view



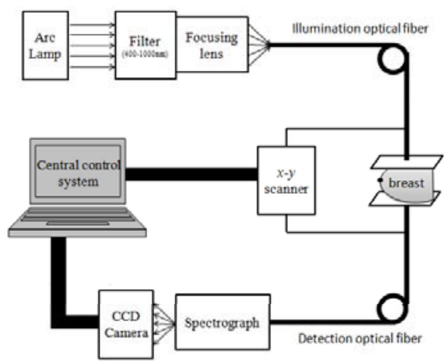


Frequency: Normalized frequency corresponding to the entire 0~100% oxygenation values.
The right breast of #16 and #17 bears invasive ductal carcinoma (IDC) and ductal carcinoma *in situ* (DCIS) respectively. The cancerous region is highlighted in both functional images and x-ray mammograms, and its corresponding oxygenation distribution is plotted in blue bars adjacent to the whole breast oxygenation distribution.
In both cases, spectral oximetry yields lower oxygenation values of the cancer locations compared to the whole breast.

Introduction

Near-infrared (NIR) imaging utilizes light at wavelengths from 600 to 1000 nm, and is capable of revealing both angiogenesis and hypermetabolism, both of which are considered hallmarks of cancer [1-2]. Our group has been focusing on developing a robust way to quantify breast tissue oxygenation to measure the degree of metabolic activities and oxygen supply. Here, we present our NIR imaging system and a preliminary human study.

Instrumentation



CCD: charge coupled device. Breast tissue, gently compressed between two glass plates, is being probed by a single source-detector pair in a transmission geometry. Spectral information is acquired through a combination of spectrograph/CCD system [3], whose photon count is used as the real-time feedback signal to trigger the scanner to next scanning line when the detected photon number is above a threshold. A raw breast image and the most recent spectrum are being displayed in the computer screen concurrently while the scan is being performed, allowing a rough estimate of regions of interest and associated signal-to-noise ratio.

Results

We have examined ten female human subjects, whose ages range between 19 and 68 years old. Of the ten human subjects examined, eight (9-15, 18) are healthy subjects and two (16, 17) are cancer patients with unilateral invasive ductal carcinoma and ductal carcinoma *in situ*, respectively. For each subject, we generate second-derivative images [4] that identify a network of highly absorbing structures in the breast that we assign to blood vessels. A previously developed paired-wavelength spectral method [5] assigns oxygenation values to the absorbing structures displayed in the second-derivative images. The resulting oxygenation images feature average values over the whole breast that are significantly lower in cancerous breasts (69 ± 14%, $n = 2$) than in healthy breasts (85 ± 7%, $n = 18$) ($p < 0.01$). Furthermore, in the two patients with breast cancer, the average oxygenation values in the cancerous regions are also significantly lower than in the remainder of the breast (invasive ductal carcinoma: 49 ± 11% vs 61 ± 16%, $p < 0.01$; ductal carcinoma *in situ*: 58 ± 8% vs 77 ± 11%, $p < 0.01$).

Summary of the results of breast oxygenation mapping on the ten subjects

Subject #	Age (y)	Ethn/Race	Side	Plate separ. (cm)	StO_2 (%) ave +/- std
9	25	NH/Wh	L	6.0	88±9
			R	5.5	91±5
10	24	NH/Wh	L	7.2	83±7
			R	7.2	87±7
11	22	NH/AA	L	5.0	87±11
			R	5.0	86±10
12	20	NH/Wh	L	5.0	87±7
			R	5.0	83±5
13	35	NH/Wh	L	6.0	87 ±6
			R	6.0	86±7
14	19	NH/Wh	L	6.0	83±8
			R	6.0	88±5
15	25	NH/Wh	L	5.5	92±2
			R	5.5	90±2
16*	68	H/Wh	L	4.5	60±14
			R*	4.5	61±17
17*	56	NH/Wh	L	6.5	83±5
			R*	6.4	77±12
18	20	NH/Wh	L	5.5	83±4
			R	5.5	82±4

Ethnicity (Ethn) is either Hispanic (H) or not Hispanic (NH). Race is African American (AA), or White (Wh). The glass plate separation corresponds to the maximum thickness of the imaged breast tissue. L: left breast; R: right breast. The stars next to subject numbers 16 and 17 indicate that these are the two breast cancer patients, both with cancer in their right breast. The StO_2 column reports the average and standard deviation of the distribution of oxygenation values in the image, as illustrated in the oxygenation histograms.

Conclusions

This work represents our efforts toward developing optical mammography as a stand-alone breast imaging modality. The appeal of the method lies on the ability of optical mammography to collect breast images non-invasively and without using ionizing radiation or extrinsic contrast agents, while yielding relevant information about the spatial distribution and oxygen saturation of hemoglobin in breast tissue. A statistically significant lower oxygenation value is found at the cancer locations compared to the remainder of the same breast. We also observe consistent higher average oxygen saturation values in healthy subjects compared to cancerous patients. Furthermore, the more advanced tumor present in patient #16 exhibits a significantly lower oxygen saturation value than the ductal carcinoma *in situ* in patient #17, indicating a potential discriminating power of quantitative oximetry in breast cancer stages.

Acknowledgments

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References

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