Original

CT Role in the Assessment of Existence of Breast Cancerous Cells

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ABSTRACT

Background: Application of CT- scanning image information and radiation physical characteristics of the biomaterials are two measurable assays for presenting modified cells.

Objective: This study presented that CT number (HU) and linear attenuation coefficient contain useful information which can be determined during usual CT scanning for the prediction of breast cancerous cells existence based on hemoglobin concentration.

Material and Methods: This experimental study used breast phantom containing major and minor vessels with diameters of 10 and 5 mm, respectively. The major vessels are filled by water, fat, hemoglobin (Hb) as a normal and 4× concentration of hemoglobin (4×Hb) as a cancerous breast cells, then scanned by single slice CT (GE, Hi Speed) 120 kVp, 100 mA for the determination of linear attenuation coefficient (μ_L).

Results: The CT numbers were for water (-7 to +7 HU), Hb (22±6 HU) and 4×Hb (80±4 HU). The difference between Hb and 4×Hb was significant (p <0.000). Minimum μ_L was 0.1190±0.00680 cm^{-1} for fat and maximum was 0.1449±0.00794 cm^{-1} for 4×Hb.

Conclusion: The study of CT number and linear attenuation coefficient of different concentration of Hb provides a possibility for early predicting of breast cancerous cells existence (4×Hb).

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Keywords
Tomography, X-Ray Computed; HU Measurements; Blood; Body Fluids

Introduction

The spectrum of X-ray beam contains higher and lower energy portions which is differently absorbed by the object and changes as it passes through it. Current CT systems correct this phenomenon called beam-hardening effective energy shift, using calibration data measured in specific phantoms and calculated with the specific function during the image reconstruction process. If beam-hardening correction is not sufficient, nonlinear artifacts such as shading and dark artifacts occur which might mimic diseases and lead to misdiagnosis [1, 2]. Spectral computed tomography (CT) measurements of X-ray attenuation are used as object additional information and determining its composition as well as discriminating among different materials [3]. CT number (HU) provides a standard scheme for scaling the reconstructed attenuation coefficients in medical CT systems. CT numbers correlate to gray levels or gray shades when the volumetric dataset is rendered into

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images, which are displayed on a monitor (or printed) [4-6].

The probability that a photon would undergo an interaction while passing through a unit thickness of material is defined by the linear attenuation coefficient (μ), which has units of cm^{-1}. The linear attenuation coefficient (μ_L) is dependent on the composition of the attenuating material and the photon energy. The intensity I, the exponential attenuation law states:

$$I = I_0 . \exp^{(-\mu_L x)} \quad (1)$$

Where I_0 is the initial intensity of the incident beam, and x is the thickness of material through which the beam passes.

Different concentrations of hemoglobin of blood can be used for determining the condition of normal or abnormal breast cells. In clinical CT images, blood is characterized and differentiated based on Hounsfield unit (HU) magnitudes and ranges [7-9]. In the Hounsfield scale, the radiodensity of measured materials can change with different amounts of tube current. The radiodensity of blood is known to be in the ranges of 40 and 60 HU, and the exact HU value depends mainly on the cellular content especially the concentration of hemoglobin [10]. Almost all study data referred to about normal hemoglobin but rare data showed concentrated hemoglobin HU in comparison with normal hemoglobin.

CT image data are dependent on the density of tissues and the beam energy, where each image pixel is assigned a Hounsfield unit (HU) [11, 12]. These images are made up of pixels, which has a gray scale value from 1 (black) to 256 (white). This value corresponds to the amount of X-rays passing through the structure, and can be measured and expressed in Hounsfield units (HU). HU is directly related to μ_L at the effective energy of CT (ECT) scanner which are calibrated with reference to water. Accurate CT number measurements are relevant in several clinical applications, which rely on quantitative HU values for diagnosis.

In human body, the low atomic number (Z) composition of the soft tissue causes dominant scattering. Since these factors are related to the density and composition of body tissues, it is crucial to have access to individual attenuation maps to account for the attenuation and scattering effects when high quantitative accuracy is desired. It requires accurate measurement of attenuation. In cancerous breast, changes on the concentration of blood hemoglobin are important signs for early detection.

This study quantifies the CT number (HU) and linear attenuation coefficient (μ_L) of different concentrations of hemoglobin and introduces their usefulness for presenting detailed information for the assessment of different conditions of breast especially prediction of cancerous breast cells.

Material and Methods

Material Selection

In experimental study a wide range of densities of materials which almost exist in breast tissue including water, milk, fat, Oxy or normal hemoglobin (1×hemoglobin) and deoxy or abnormal hemoglobin (4×hemoglobin) were selected. Pomegranate juice (red color) is used for contrast purpose. Different concentrations of hemoglobin are used to simulate the normal and cancerous breast cells.

Phantom Properties

The breast phantom is made up of polyethylene with dimensions $5 \times 18.5 \times 12.5$ cm^3. The phantom contains two major 10 mm and minor 5 mm vessels. All above-mentioned materials were inserted into the main vessels in the breast phantom (Figure 1A).

CT Scanning

General Electric Hi Speed (GE, Hi Speed, USA) diagnostic X-ray CT scanner is used to estimate an average HU value over a number

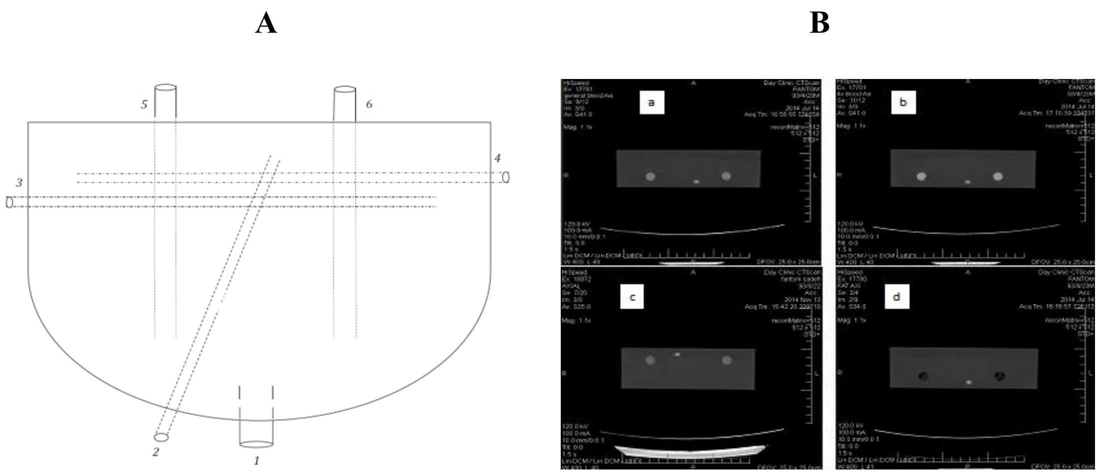

Figure 1: Part A: The breast phantom is made of polyethylene, organized within major and minor vessels as shown from number 2 to 6. Number 1 is nipple, 2, 3 and 4 are minor vessels with 5 mm diameter, 5 and 6 are main vessels with 10 mm diameter. Hb and 4xHb inserted to major vessels. Part B: CT images showed different HU including a: Hb, b: 4×Hb, c: water, d: fat.

of slices at 120 kVp, 150 mAs, 9 slices and one pitch. Spiral and axial scanning mode are used at 10 mm intervals.

One cm^2 of region of interest (ROI) was selected on each image and an HU value determined within each ROI. Linear attenuation coefficients are calculated according to CT number values using standard definition:

$$HU = \frac{(\mu_{material} - \mu_{water})}{(\mu_{water} - \mu_{air}) \times 1000} \quad (2)$$

Where μ_{water} and μ_{air} are the linear attenuation coefficients of water and air, respectively. This definition is for CT scanner calibrated with water reference. A change of one Hounsfield unit (HU) represents a change of 0.1% of the μ of water since the μ of air is nearly zero.

Data were analyzed by SPSS 16 software and compared by T-test statistically based on which a significance level was $p<0.05$.

Results

The CT imaging of breast phantom contains water, fat, Hb and 4×Hb which are inserted into main vessels are shown in Figure 1. Different radiodensity of experimental materials in CT imaging induced to diverse gray level which is displayed as an HU value on the monitor of CT.

The mean μ_L is calculated according to HU as presented in Table 1. The minimum value was for fat (-100 ±10) and maximum was for 4×Hb (80±4). The standard deviation in the HU estimate over the ROI was found to be as low as 10%. A comparison of CT numbers showed that the color of water in pomegranate juice can change the CT number nearly seven times. The concentration of hemoglobin in 4×Hb induces to change CT number nearly four times which is seen in abnormal or cancerous breast cells. The characterization of tumors in soft tissues included CT number in the range of 0 to 100 HU.

The linear attenuation coefficient was calculated for different tube potentials from 75 to 364 keV. As shown in Table 2, the mean CT number of water must be evaluated at

Table 1: CT Number (HU) of experimented materials and SD mean ± and Linear attenuation coefficients (cm^{-1}) are shown.

Materials	CT Number	SD	μ mean
Water	0	7	0.134
Pomegranate water	44	4	0.140
Milk	27	6	0.137
Fat	-100	10	0.119
Hb	22	6	0.137
4×Hb	80	4	0.145
Polyethylene (Phantom material)	-77	10	0.124

Table 2: The relation between linear attenuation coefficient (μ) and energy in the range of 75-364 keV

Energy (Kev)	Water	Pomegranate water	Milk	Fat	Hb	4×Hb	polyethylene
75-80	0.160	0.167	0.164	0.14	0.164	0.172	0.147
140	0.149	0.156	0.153	0.134	0.152	0.161	0.137
160	0.138	0.144	0.141	0.124	0.141	0.149	0.127
167	0.137	0.143	0.14	0.123	0.14	0.148	0.126
170	0.135	0.141	0.139	0.122	0.138	0.146	0.125
245	0.121	0.126	0.124	0.101	0.124	0.131	0.112
364	0.099	0.103	0.102	0.089	0.101	0.107	0.091
Error	0.007	0.008	0.007	0.007	0.008	0.008	0.007

each keV setting that can be selected by the operator. The minimum value of μ_L was for fat (0.1190±0.00680 cm^{-1}) and maximum μ_L was for 4×Hb blood (0.1449±0.00794 cm^{-1}). Relation between CT number and mean linear attenuation coefficient is shown in Figure 2. A linear regression for water, pomegranate juice (red water), milk, fat, Hb and 4×Hb was obtained. According to present data, the difference of μ_L between Hb and 4×Hb was significant (P <0.000). The difference of water and pomegranate juice (red water) μ_L was significant with confidence greater than 95% (P <0.000). Relation between energy (keV) in tube potential of CT and linear attenuation coefficients were also studied (Figure 3). Each energy (keV) and amount of μ_L of water, fat, Hb and 4×Hb showed a good differentiation according to energy range from 75-364 keV.

The energy-response of linear attenuation coefficient relationship over a wide range of energies is presented in Figure 3. The results of a experiment of μ_L of 4×Hb, Hb, water and fat is plotted against the tube potential of CT;

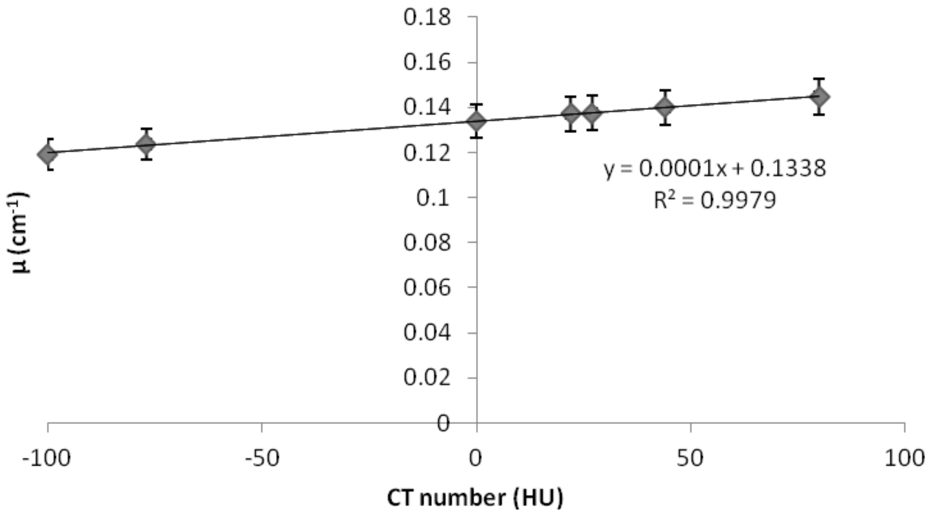

Figure 2: Relation between CT number and mean linear attenuation coefficients of seven materials used in this experiment, y = 0.000x + 0.1338; R^2 = 0.9979.

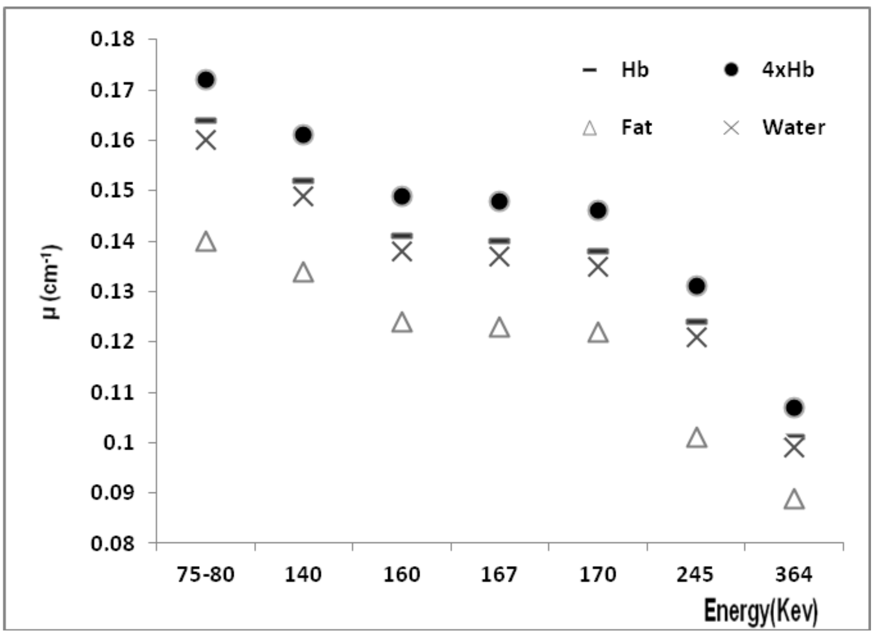

Figure 3: Distribution of linear attenuation coefficients of water, fat, hemoglobin and 4× hemoglobin according to energy range from 75 to 364 keV.

the μ_L of each group decreases when energy increases, which usually occurs between 75 and 160 keV, a further increase did not change μ_L value, but from 170 keV, a rapid decrease of μ_L was observed with further increase in energy.

Discussion

The greatest difference was observed between Hb and 4×Hb which can induce an early detection of breast cancer cells in its early stages. It means if breast cells are going to be abnormal in early stages by this method, Hb and 4×Hb differentiations are possible. The difference of μ_L between Hb and 4×Hb was significant (P <0.000).

The data enable us to assess different conditions of breast especially prediction of blood hemoglobin distribution in normal and cancerous breast cells.

In malignant tumors, hemoglobin concentration is directly related to angiogenesis; this factor is required for tumor growth and metastases [13]. In tumor cells, blood hemoglobin concentration increases to two or four times more than normal blood hemoglobin. HU can be used to assess the CT density of liquid in body.

It has been reported that CT images accurately estimate the attenuation coefficients for soft tissue, blood and milk. Different scaling factors are required for materials with a density higher than that of water because of the increased Compton interactions resulting in more attenuation for lower density materials.

The same relation between μmean and CT number was observed as shown in Table 1. Consequently, a linear regression was performed for mean energy in the relevant range until the best R^2 and linear fit was obtained (Figure 2).

The values of the μ_L are not significant between Hb and milk (P = 0.078) that means this method sensitivity for healthy or normal breast cell is acceptable. The difference of μ_L is significant between 4×Hb and milk (P <0.000). It means this method sensitivity and specificity are acceptable for the comparison of Hb, milk and 4×Hb even in feeding woman.

An average HU value was determined for each of the materials using a 120 kVp X-ray CT scanner [11]. The present study illustrates a comprehensive method in which HU can be derived from the grey levels of any CT machine possessing sufficient linearity. Overall, the corrected Hounsfield numbers in each of the CT acquisitions appear to be within a few percents of the predicted HU and attenuation coefficient for each material into Equation (2) at the effective energy derived by the linear regression of seven reference materials.

In the present research, the CT number of water is expected to be 0±7 HU for images acquired at slice thickness and kVp setting similar to McCollough et al. [14] and CT number for Polyethylene was between -107 and -87 HU which approximates the result (-77 and -100) HU. In a study of Brown et al. [11], Polyethylene was 2±14 HU. This variation of HU is perhaps induced by difference in the tube current.

Additionally, another study on normal/healthy breast bloods showed the range of HU values of the serous fluids was 13-38 HU, but in the non-sediment blood changed to 40-88 HU [15]. In the present study, the ranges of CT number of Hb and 4×Hb were 22±6 HU and 80±4 HU, respectively.

The advantage of this study is the expression of this matter that if CT number analyzing data is added to patient's CT imaging report, it will be unable to provide more information about disease status in chest CT.

Most articles were about water, fat and Hb (normal) but 4×Hb (abnormal) and its comparison with other concentrations and liquids studied in rare cases by CT imaging HU.

In chest diseases i.e. lung and heart, it is possible to analyze different concentrations of hemoglobin and other fluids especially blood according to their differences in CT numbers.

Moreover, the calculation of attenuation coefficient is possible for all. Another suggestion of this study is for breast feeding mothers. In these cases, the assessment of CT number of breast Hb in ductal diseases enables us to predict normal or abnormal breast cells.

Therefore, identification and characterization of HU of hemoglobin and main fluids in chest CT is a useful method, without more charges and radiations for patients in the prediction of cancerous breast cells.

Conclusion

The study of CT number and linear attenuation coefficient of different concentration of Hb provides a possibility for early predicting of breast cancerous cells existence (4×Hb).

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Conflict of Interest

None

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