

Quantitative CT characterization of body fluids with spectral ρZ projection method

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Abstract — We have performed a clinical study on the characterization of body fluids with the spectral ρZ projection algorithm. It converts dual-energy CT scans into density ρ and atomic number Z information. We provide data on a total of 56 samples of 6 different classes. Blood, gall, pus and urine, as well as mixtures of blood + pus and blood + ethylenediaminetetraacetate (EDTA, a blood anti-coagulant) have been investigated. For standard measurements with 80 kV and 140 kV tube voltages we encounter larger overlaps of the HU attenuation values. Gall fluid and pus are the only distinguishable substances. For the ρZ projected image data, we find blood, pus and the blood + pus mixtures to be clearly distinguishable in the two-dimensional ρZ plane. Gall fluid shows a small overlap to pus. The density and the atomic number values have standard deviations in the order of $\Delta\rho = 10 \text{ mg / cm}^3$ and $\Delta Z = 0.1$. The theoretical density and atomic number values for blood and water are reproduced with very small deviations in the range of $\Delta\rho = -20 \text{ mg / cm}^3$ and $\Delta Z = 0.02$.

I. INTRODUCTION

COMPUTED Tomography (CT) is one of the most important non-invasive diagnostic imaging modalities. It provides three-dimensional representations of the X-ray attenuation coefficient $\mu(r)$ with a resolution down to the sub-millimeter range. However, it is limited in soft tissue contrast resolution. Various types of soft tissue and lesions differ only slightly in density and chemical composition and thus their measured X-ray attenuation coefficients are very similar.

In 1976, Alvarez and Macovski [1,2] proposed dual-energy CT as a method to further increase the contrast resolution. Their basic idea is to independently determine the coefficients of photoelectric absorption and Compton scatter attenuation by two CT measurements with different tube voltages. They also proposed the base-material decomposition which uses alternate sets of base functions, e.g. the attenuation functions of water and bone material. Phelps et al. [3] used the method to obtain clinical identification data on various body tissues. Weaver et al [4] investigated the stability of the base material compared to the original decomposition into Photo absorption and Compton scatter. Stonestrom et al [5] and Vetter et al [6] proposed corrections for scattered radiation and beam-

hardening effects. Kalender et al. [7] implemented the base material decomposition into a commercial product (Siemens Somatom DR, 1983 - 1987).

A major problem in the latter practical application of the base material decomposition was its limited noise performance. Like examined more thoroughly in [8] the base material decomposition increases the statistical errors by a factor of 3 to 5 and is not capable to measure small contributions of one base material. As a consequence body tissue characterization seems to be limited at reasonable dose rates.

In this paper we quantitatively characterize body fluids with the ρZ projection algorithm [9] as an alternative method. It converts dual-energy scans to effective density and atomic number information. The attenuation spectra of the chemical elements are used as base functions; see the revision of the algorithm in the theoretical section. We present the results of a measurement series on ex-vivo body fluid samples.

II. THEORY

The ρZ projection inverts a dual-energy CT measurement into an effective density ρ and atomic number Z . The basic idea is to use the attenuation functions $\kappa(E, \rho, Z)$ of the chemical elements as base functions (see [9]). Consider measuring two μ_1, μ_2 with two different spectral weightings w_1, w_2 . Using the standard Radon approximation the measurements are described by

$$\begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} = \rho \cdot \begin{pmatrix} \int w_1(E) \left(\frac{\kappa}{\rho} \right) (E, Z) dE \\ \int w_2(E) \left(\frac{\kappa}{\rho} \right) (E, Z) dE \end{pmatrix} = \rho \begin{pmatrix} f_1(Z) \\ f_2(Z) \end{pmatrix} \quad (1)$$

Here the spectral attenuation coefficient is factorized into the density ρ and the specific spectral attenuation function $(\kappa/\rho)(E)$. The central idea of the ρZ projection is to invert (1) for the density and atomic number:

$$\begin{pmatrix} \mu_1(\rho, Z) \\ \mu_2(\rho, Z) \end{pmatrix} \rightarrow \begin{pmatrix} \rho(\mu_1, \mu_2) \\ Z(\mu_1, \mu_2) \end{pmatrix}. \quad (2)$$

As the numerical solution we obtain [9]

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$$Z = F^{-1}\left(\frac{\mu_1}{\mu_2}\right), \quad \rho = \frac{\mu_1}{f_1(Z)} \quad (3a,b)$$

with the pre-calculated functions

$$f_i(Z) = \int w_i(E) \left(\frac{\kappa}{\rho}\right) (E, Z) dE, \quad F(Z) = \frac{f_1(Z)}{f_2(Z)} \quad (4a,b)$$

III. EXPERIMENT

A total of 56 samples of body fluids from diagnostic and therapeutic punctures were collected after informed consent of the adult patients was obtained. The samples comprise 9 samples of blood, 13 samples of a blood + ethylenediaminetetra acetate (EDTA) mixture, 13 samples of gall, 5 samples of pus, 9 samples of a pus + blood mixture and 7 urine samples.

Each sample was scanned with a dual sequence scan:

1. Scan: Tube voltage $U_1 = 80$ kV with 0.6mm titanium (Ti) pre-filtering and a tube current-time product of 300 mAs
2. Scan: Tube voltage $U_2 = 140$ kV with 1.2mm Ti pre-filtering and a tube current-time product of 300 mAs.

For all samples we took the corresponding image data of the 80 kV and 140 kV measurements as input for the ρZ projection method. The resulting density and atomic number images were evaluated by extracting pixel values. From each sample an average over 150 to 200 pixels of the fluid depicted in the images was taken for analysis.

IV. RESULTS AND DISCUSSION

Fig. 1 shows the initial 80 kV and 140 kV HU ranges of the fluid samples. The HU values are generally overlapping for both tube voltages and most of the sample types. Only gall and pus can be separated whereas the rest of the samples exhibit significant overlaps. In particular, the urine sample values possess a large spread.

Fig. 2 graphically shows the ρZ -projection results of the clinically interesting blood, pus, blood + pus and gall fluids. The samples of pus have a higher Z than blood, whereas this is reversed for the density. The samples of the blood and pus mixture consequently take up intermediate values. Gall values tend to be close to the pus data. The blood + EDTA values coincide with the pus + blood values and have been omitted from Fig. 2 for sense of clarity.

V. REFERENCES

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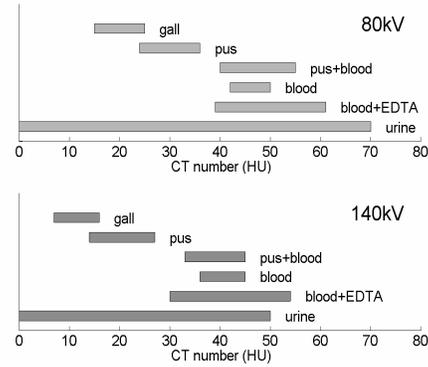


Fig. 1. Body fluid HU intervals obtained in the 80 kV and 140 kV dual-energy measurements. Gall and pus are mostly distinguishable whereas the attenuation values of the rest of the samples are indistinguishable due to overlaps.

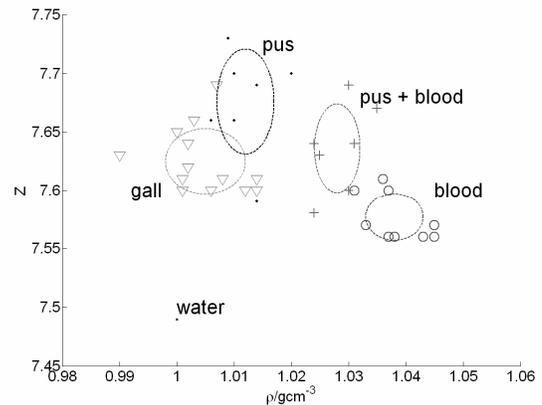


Fig. 2. The ρZ diagram of the sample types gall, pus, blood and pus + blood shows a clustering of the samples. The ellipses represent the average values as the center and the 1σ standard deviations as their axis length. Pus and blood can be clearly distinguished, while gall and pus partly overlap. The mixture of blood + pus has intermediate values. It can be differentiated from the blood samples. This is not possible using the attenuation values alone (s. Fig. 3). We can explain this by the monotonic increasing dependency of the attenuation coefficient on ρ and Z . Different combinations of ρ and Z may generate the same attenuation measurement in a standard CT procedure.