Short Thesis for the degree of doctor of philosophy (PhD)

Investigation of dose and body shape estimation methods based on a single CT slice

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Debrecen, 2025

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The PhD Defense takes place at the Lecture Hall of Building A, Department of Internal Medicine, Faculty of Medicine, University of Debrecen, at 1 pm, 16th December 2025.

1. Background and objectives of the doctoral thesis

Computed cross-sectional tomography (CT) scans are routinely used in medical practice primarily for pathology diagnosis, lesion characterisation, tumour monitoring, radiotherapy planning and histological sampling, but they also provide a range of other highly relevant and useful information.

However, despite the outstanding diagnostic sensitivity of CT, the dose to which patients are exposed must always be taken into account. Half of the patient doses in medical imaging examinations involving ionizing radiation are generated by CT scans. Although technological advances by manufacturers have reduced the single, individual doses received by patients, the steady increase in the number of CT scanners and the corresponding increase in the diagnostic needs of tumor patients are contributing to an increase in cumulative doses. During examinations involving X-ray radiation, it is necessary to measure or estimate the radiation exposure to patients in some way. Radiology institutions with the appropriate professional background can develop their own programs for dose monitoring, but many manufacturers also offer software systems for this purpose. Typical absorbed dose measures used in CT diagnostics are the dose length product (DLP) and the size-specific dose estimate (SSDE), as well as the effective dose (ED), which also indicates the risk of developing cancer. Of these, SSDE is currently considered the most advantageous in recommendations, as the SSDE value also takes into account the individual size of the patient being examined, while ED is only an estimate for an average patient size based on phantom measurements. In recent years, however, the concept of "size-specific effective dose" (SED) has also emerged, but little data is available on its estimation based on CT scans. Although

optimizing patient dose and image quality appears to be a technical problem, it has become the subject of active research due to its global impact on diagnostic quality.

A special but very important application of CT is the differentiation and segmentation of different tissues. For example, CT images of the abdominal region can be used to monitor the amount of different fatty and muscle tissues and changes in these, and their values can be examined in correlation with clinical conditions. Furthermore, it is also useful data in research related to body size or body mass index (BMI). It is also obvious that it is not possible to determine the total body fat and muscle tissue content from a given CT scan, so it has become a general practice in the literature to make an estimate based on a single axial slice. However, there is no consensus in the literature on the optimal anatomical position of the slice, and the specific Hounsfield (HU) values for segmentation are also not uniform.

Our research findings, which form the basis of this dissertation, focused on two major areas related to CT examinations. First, we compared and examined in detail the capabilities of our dose monitoring system (DE-DMS), developed at the Department of Radiology at the University of Debrecen, and GE's DoseWatch program. We included DLP, SSDE, and ED dose data from CT scans performed over the past few years in the analysis. A separate objective was to analyze the relationships between SED, ED, and SSDE dose parameters and to examine whether SED can be estimated based on a specific CT scan. The comparison of the values estimated by the two programs contributed to the validation and further development of DE-DMS. In the other research question, we analyzed the CT-based adipose tissue segmentation method by selecting different HU threshold values and different anatomical regions to obtain data on the sensitivity of the technique. We also examined the question of whether a single abdominal CT slice is sufficient to estimate the patient's shape.

Objectives

In recent years, the number of computed tomography examinations has increased significantly worldwide, including in Hungary. This is primarily due to advances in diagnostic imaging, increased demand for methods that provide rapid and detailed anatomical information, easier access, and the prominent role played in emergency and oncological care. Parallel to the spread of CT examinations, increasing attention is also being focused on special CT issues. On the one hand, the justification and optimization of procedures involving ionizing radiation are the subject of special research, and on the other hand, the segmentation of tissues/organs and the examination of the clinical relevance of the data obtained from them.

Accordingly, the basic objectives of the doctoral thesis were as follows:

1. We wanted to find out how closely the dose data calculated by our dose monitoring system, developed at the Radiology Clinic of the University of Debrecen, corresponded to the results of the widely used DoseWatch program. We included the DLP, SSDE, and ED dose metrics in the analysis. Another specific goal was to characterize any discrepancies as accurately as possible.
2. We also wanted to examine the properties of size-specific effective dose, which has been introduced in the literature in recent years. Our question was whether the SED parameter, which is fundamentally defined by Monte Carlo calculation, can be estimated from actual CT examinations.
3. In a further research question, we wanted to analyze the CT-based fat tissue segmentation method. We wanted to find out to what extent the segmentation result depends on the pre-selected HU range and the axial position of the anatomical region.

4. Finally, we also wanted to examine the question of how sufficient a single abdominal CT slice is for estimating the patient's adipose tissue distribution and body shape.

2. Materials and methods

2.1 Patient dose assessment using DoseWatch and DE-DMS

We included the dose data of all CT examinations performed between June 2020 and December 2023 at the Radiology Clinic of the University of Debrecen Clinical Center in our research, which were performed on GE Revolution HD and Revolution EVO devices (hereinafter referred to as CT1 and CT2). The devices were directly connected to the locally developed DE-DMS and DW applications. After the initial data collection, the data was further selected according to strict criteria. Finally, a total of 79,383 CT examinations were included in our retrospective analysis. In the present study, we filtered the relevant dose data from the two systems and combined them into a single MS Access database, after which all evaluations and processing were performed in MATLAB™ software. To calculate the ED, the two dose monitoring systems used slightly different f factors. The effective dose values calculated by DW were marked with ED_{DW}, while the values calculated by the DMS system with and without weight correction were marked with SED_{DMS} and ED_{DMS}, respectively. To determine the SED_{DMS} value, we used a previously published weight-dependent factor wkg. The following specific formula was used to calculate wkg, where w denotes the patient's body weight expressed in kg:

$$\mathrm{wkg} = 1{,}73 - 1{,}33 \cdot 10^{-2}\mathrm{w} + 4{,}04 \cdot 10^{-5}\mathrm{w}^2$$

In the case of DMS, SSDE was determined in the middle slice based on the effective diameter of the patient (Deff), CTDIvol,

and the formula recommended by the AAPM. For CT series where the middle slice fell in the chest region, we also determined the SSDE using the water equivalent diameter (Dwater), which we denoted with the symbol SSDE(Dwater).

The examinations were classified into five and six anatomical regions according to two nomenclatures (based on series and study), which were as follows: head, neck, chest, abdomen, pelvis, and trunk; and head, neck, chest, abdomen, and pelvis. This resulted in a total of 79,383 studies and 93,259 series.

Finally, the size-specific effective dose (SED) was calculated based on a previously published method. In the publication [31], several digital human phantoms of different sizes were created using Monte Carlo simulation, and then all relevant dose data for the CT examination were calculated using a validated Monte Carlo-based CT simulation program: DLP, CTDI, and SED values.

2.2. Segmentation of adipose tissue

A total of 98 human CT examinations were randomly selected between March 2012 and September 2013 from examinations performed on a Philips 64 TF PETCT camera. The patient population was selected from outpatients suffering from various diseases. During the CT examination, a standard dose optimization algorithm was used to ensure signal-to-noise ratio stability, in which the intensity of X-ray radiation increased proportionally with body weight in both CT protocols. In Protocol I, we used a higher mAs range (100–200 mAs) for better image quality, while in Protocol II, the X-ray radiation was approximately half of that. The tube voltage was 120 kV in all cases.

We selected three axial slices at the level of the L.1 vertebra and the right and left renal hilum. Two ROIs (regions of interest) were manually drawn on each selected slice on a diagnostic

monitor using MATLAB software. The larger ROI was placed on the body contour and the smaller one on the abdominal cavity.

In our study, we performed fat tissue segmentation based on three different Hounsfield ranges [window median/window width] in HU: [-190/-30], [-150/-40] and [-195/-45]. Thus, SAT and VAT values were calculated using three different HU ranges. In addition, we obtained three different SAT (SATi, i=1,2,3) and three different VAT (VATi, i=1,2,3) estimates for the three different anatomical position. In each case, we also calculated the body mass index (BMI) using the following standard formula:

$$BMI = \frac{body\_mass}{body\_heigth^2}\left[\frac{kg}{m^2}\right]$$

The data from the reconstructed images allowed estimation of BMI using the following formula:

$$BMIest\ male = 2.069 + (0.037 * SQA) - (0.05 * age) + (0{,}984 * BTD) - (2.647 * L1APD)$$

$$BMIest\ female = 9.163 + (0.252 * BC) + (10.621 * \frac{SQA}{BA}) - (0.08 * age) + (0.597 * BAPD).$$

These formulas required the horizontal and anteroposterior diameters of the body (BTD, BAPD), the vertebral body diameter (L1APD), the body circumference (BC), the total body area (BA), the subcutaneous fat area, and the patient's age from each axial section.

We thought that the original BMI estimation formula for both sexes was too complicated, so we tried to propose and create simpler ones. BMIest depends on 4-5 data points, which are different for both sexes. Furthermore, it is questionable whether the individual constants depend on the specific CT settings. In our study, we proposed nine new models based on the original and current models, which we labeled I through IX.

We used nonlinear regression to calculate the coefficients of the nine equations, minimizing the following weight function in each case:

$$h(a,b,c,d,e) = \sum_{k=1}^{n} (BMI_k - BMImodell((a,b,c,d,e))_k)^2$$

We performed hypothesis tests on paired data sets to compare values from different axial slices and regions. We evaluated the distribution of the data using the Anderson-Darling normality test. We then selected the appropriate hypothesis test: a paired t-test for normally distributed data and a Wilcoxon signed-rank test in other cases. We considered the data sets to be significantly different if the p-value was less than 0.05.

All data evaluation and processing was performed using commercially available Microsoft Office Excel and MATLAB software.

3. New scientific results of the thesis

We have shown that the dose monitoring system developed by our working group at the Radiology Clinic of the University of Debrecen enables accurate estimation of the most important patient dose data (DLP, SSDE, and ED) for CT examinations, which correlate very well with the corresponding data from the DW dose monitor application. Although DW is a widely used solution in international practice, we have identified a number of its disadvantages. When determining ED, problems arise in the case of DW due to incorrect identification of the body region in the given series. And since the calculation of ED depends on the values of DLP and the weight factor depending on the anatomical region, the ED value will also be distorted. Furthermore, in the case of cranial CT, the calculation of SSDE may also be incorrect in the DW application because the

algorithm does not properly handle images taken with the CT gantry tilted. We have analyzed and demonstrated in detail that the size-specific effective dose (SED), recently introduced in the literature and based on complex Monte Carlo simulation, can be estimated from the SSDE values of actual CT examinations. This is based on the use of an analytical formula dependent on the patient's weight, which can be used to derive SED from ED data. SED can be very useful for the acceptable calculation of cumulative patient doses, the scientific need for which has become increasingly important in recent years.

In relation to CT-based adipose tissue segmentation, we observed that the specific measurements of both SAT and VAT correlated well with each other when we performed the segmentation using three different HU ranges that are frequently used in the literature. It was also observed that although the VAT and SAT adipose tissue areas correlated with each other, there was no directly proportional relationship between the ranges. The position of the slice selected for segmentation did not have a significant effect on the correlations, but the absolute values of SAT and VAT were statistically different. CT image data acquired with a higher tube current resulted in better correlations between SAT, VAT, and BMI. For the 98 patients, we determined and compared model-based and actual BMI values. We simplified the model-based BMI estimation, and our results show that a complex, multivariate model is not necessary for CT-based BMI calculation.

In summary, we identified a remarkable parallel between the two research areas studied: just as SSDE calculated from a single slice accurately characterizes the absorbed radiation dose for the entire body, the fat mass estimated from a single slice also shows a close correlation with the total body fat mass. This analogy supports the effectiveness of single-slice CT analyses in both dose estimation and body composition analysis.

4. Summary

It can be concluded that in most cases, the ED estimates of our locally developed dose monitoring program do not show significant deviations from the values estimated by DW. The small deviation is caused by the conversion factors used. In cases where the deviation is significant, it is caused by DW identifying the wrong region. When comparing SSDE values, a significant deviation can be observed in the skull region, which is caused by DW's incorrect identification of the middle CT slice, which is caused by the CT's tilted gantry. We have analyzed and demonstrated in detail that the size-specific effective dose (SED) can be estimated from the SSDE values of actual CT examinations. This is based on the use of an analytical formula dependent on the patient's weight, which can be used to derive the SED from the ED data.

During fat tissue segmentation, we found a good correlation between the SAT and VAT areas when the segmentation was based on three different HU ranges. The anatomical level chosen for segmentation significantly influences VAT and SAT values. We determined and compared model-based and actual BMI in 98 patients. We simplified the model-based BMI estimation and showed that CT-based BMI calculations do not require a complex multivariate model.

5. Publications on which the thesis is based

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Registry number: DEENK/444/2025.PL
Subject: PhD Publication List

Candidate: Lilla Szatmáriné Egeresi
Doctoral School: Doctoral School of Molecular Medicine

List of publications related to the dissertation

1. **Egeresi, L.**, Urbán, L., Dankó, Z., Balázs, E., Berényi, E., Marosi, M., Kiss, J., Bágyi, P., Képes, Z., Emri, M., Balkay, L.: Relationship Between Effective Dose, Alternative Metrics, and SSDE: experiences with Two CT Dose-Monitoring Systems.
   Diagnostics. 15 (13), 1-15, 2025.
   DOI: http://dx.doi.org/10.3390/diagnostics15131654
   IF: 3.3 (2024)
2. **Egeresi, L.**, Székely, A., Kallos-Balogh, P., Trón, L., Garai, I., Balkay, L.: Effect of Single-Slice CT Segmentation Methods on Fat Volume and Body Shape Estimation.
   Acta Polytech. Hung. 20 (8), 89-109, 2023.
   DOI: http://dx.doi.org/10.12700/APH.20.8.2023.8.6
   IF: 1.4

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List of other publications

3. Esze, R., Balkay, L., Barna, S., **Egeresi, L.**, Emri, M., Páll, D., Paragh, G., Rajnai, L., Somodi, S., Képes, Z., Garai, I., Káplár, M.: Impact of Fat Distribution and Metabolic Diseases on Cerebral Microcirculation: a Multimodal Study on Type 2 Diabetic and Obese Patients.
   J Clin Med. *13* (10), 1-14, 2024.
   DOI: http://dx.doi.org/10.3390/jcm13102900
   IF: 2.9
4. Kallos-Balogh, P., Vas, N. F., Tóth, Z., Szakáll, S., Szabó, P., Garai, I., Képes, Z., Forgács, A., **Egeresi, L.**, Dahlbom, M., Balkay, L.: Multicentric study on the reproducibility and robustness of PET-based radiomics features with a realistic activity painting phantom.
   PLoS One. *19* (10), 1-24, 2024.
   DOI: http://dx.doi.org/10.1371/journal.pone.0309540
   IF: 2.6

Total IF of journals (all publications): 10,2
Total IF of journals (publications related to the dissertation): 4,7

The Candidate's publication data submitted to the Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

08 July, 2025