Validation of a paediatric thyroid phantom using different multidetector computed tomography models

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Abstract. The aim of this study was to compare the attenuation values of a fabricated paediatric thyroid phantom material using different MDCT models. A paediatric thyroid phantom was designed to mimic the shape and size of a paediatric patient with an age of 9 years using high-density Polyethylene as the phantom material. The fabricated phantom was scanned using two different multidetector CT scanners (16- and 128-row detectors). The CT numbers were evaluated and the mass attenuation coefficients (μ/ρ) of the phantom material were obtained at each applied energy from each scanner. The results were compared with the tables of the National Institute of Standards and Technology (NIST). The CTs of 16- and 128-row detectors showed that the obtained attenuation values are very similar to the NIST's values. However, the CT of the 128-row detectors showed a slightly much closer match to the NIST's values. This refers to the type and quality of the electronic connections between the detectors. Furthermore, the type and number of detectors (16- and 128-detectors) could affect the details and quality of the output images. The results show that different multidetector CTs can be used to validate the phantom and determine the mass attenuation coefficients of its material.

1. Introduction

In the early 1990s, the spiral CT was introduced and the usage of a wider array of detectors had improved, thus speeding up the scanning procedure. Sequentially, the manufacturing of wider detectors increased and rose with up to 320 rows. This increase of row detectors is known as Multidetector Computed Tomography (MDCT). It has a shorter scanning time as well as lesser artefacts in the output images and higher contrast resolution [1–3].

The improvement of the CT scanners focused on two major things, namely the number and size of detectors along the patient table or the z-axis directions, as well as the connection between these detectors that produce a set of multi-projection data in each gantry rotation around the desired organ. The design of detectors and the electronic connection of these detectors strongly rely on the scanner model and manufacturer [4]. As a result, the improvement of MDCT enhanced the CT number values. The CT numbers depend mainly on the linear attenuation coefficients of the scanned material. Few studies have been conducted to evaluate the difference in CT numbers between different scanner models.

The ultimate goal of this study was to validate a fabricated paediatric thyroid phantom using different MDCT and to investigate the effect of a number of row detectors on the obtaining mass attenuation coefficients of the phantom material.

2. Theoretical background

The material of the CT detectors is so sensitive to radiation and has a high detection efficiency to match the high speed of the gantry rotation [5]. The linear attenuation coefficient of the phantom material that can be used to obtain the CT numbers (measured by Hounsfield Unit, HU), is affected strongly by the energy of penetrated photons and the detection efficiency of the detectors. By using the known linear attenuation coefficient of water (μ_w) at any applied energy and the calculated linear attenuation coefficient of the material (μ_m), the CT number is computed [6,7].

$$CT\ number = \left(\frac{\mu_m - \mu_w}{\mu_w} \right) \times 1000 \tag{1}$$

Essentially, two types of multidetector scanners were introduced to the market, namely the Uniform and Non-uniform detectors. The Uniform design, also called Matrix or Fixed detectors, was invented and first manufactured by GE Healthcare, which the detectors are divided into equal elements. Whereas, the elements are divided by the Non-uniform design (also known as Variable or Adaptive detectors) into different sizes. Such designs were used by several manufacturers such as Siemens (Germany) and Philips (Netherlands) in their CT scanners [4,5]. Furthermore, another type invented by Toshiba (Japan) called Hybrid detectors in which a combination of two different dimensions of detector elements are used in the same row.

Recent studies found considerable variations of measured CT numbers from different CT models and different detector numbers, but still have useful clinical information for physicians [7,8]. In one of the interesting studies done by Grosjean *et al.* 2013 which is related to the scanning of human renal stones using different CT manufacturers, the evaluation of CT numbers showed substantial variation from four different models. It was found that at least one scanner model gave poor details to recognize the attenuation values of the human renal stones, whilst the others show very similar match of CT numbers [8].

In principle, data is provided by 16 detectors for 16 slices, with a thickness as small as 1.25 mm for each slice from the 16 rows. It is assumed that each row contains 1000 detectors and a typical scanner can achieve 1000 views per single rotation whilst 16 million measurements from the 16-row detectors in the z-direction could be made per single rotation [9]. The 128 rows of detectors will give 128 million measurements for the same number of views and number of detectors per one rotation.

3. Methods

In this study, the 128 detectors CT (Somatom Definition; Siemens AG, Wittelsbacherplatz Muenchen, Germany) and the 16 detectors CT (GE Healthcare, Waukesha, WI) were used to scan a fabricated paediatric thyroid phantom. The phantom consists of three parts that can be combined together as one unit as demonstrated in figure 1. The Neck and Trachea are made of Polymethylmethacrylate (PMMA) while the thyroid is made of high-density Polyethylene. The average size of each part of the phantom were taken for the same age (9 years) of female and male children. A diameter of 10 cm for the neck part and 1 cm for the trachea part were selected. Meanwhile, the thyroid part had a width of 2.4 cm and height of 2.5 cm [10–14].

Four voltages (80, 100, 120 and 140 kV) were applied to scan the phantom using both CT machines (the 16- and 128-detectors) to produce single images for each applied kV.

The current (mAs) was set automatically using CARE Dose 4D in the 128 Siemens CT and SMART mA in the 16 GE CT. The slice width was also set automatically to 1.5 mm and 5 mm for the 128 Siemens CT and 16 GE CT respectively.

Weasis Medical Viewer Free Software v.1.2.7 was used to read and analyse the output images from both machines in DICOM format. The CT numbers of each image were evaluated for each applied voltage and the average was taken from both CT scanners, where the mass attenuation coefficients (μ_p/ρ) of the thyroid phantom material were then calculated. The obtained results from both machines were compared with the tables of the National Institute of Standards and Technology (NIST).

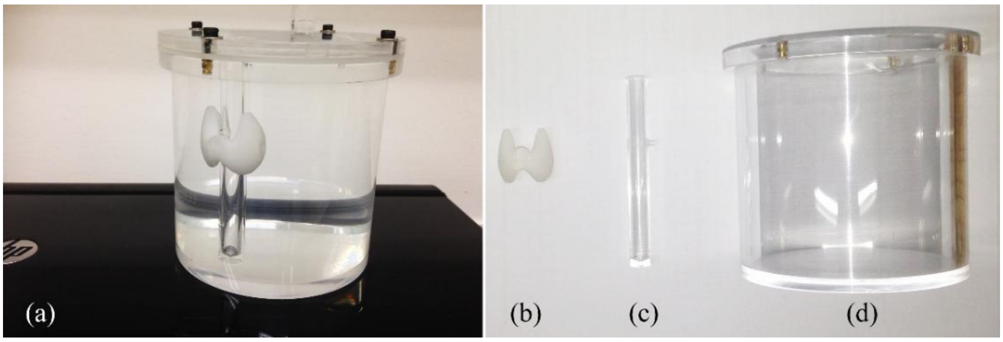

Figure 1. (a) The fabricated paediatric thyroid phantom consists of (b) thyroid phantom, (c) trachea phantom and (d) neck phantom.

4. Results and discussion

The area of the thyroid phantom was selected in each output image and the CT numbers were evaluated by Weasis software. Table 1 summarizes the results of the evaluated CT numbers of the phantom at each applied energy from both scanner models. The average difference in readings of CT numbers from both machines was -1.87 (2.42%), which showed insignificant difference between the CT numbers from the 16- and 128-row detectors CT scanners.

Table 1. The evaluated CT numbers from 16- and 128-detectors CTs.

	128 Detectors CT		16 Detectors CT		Difference in reading
kV	CT No. (HU)	STD (±)	CT No. (HU)	STD (±)	
80	-90.73	11.57	-93.38	7.87	-2.65
100	-76.44	9.52	-78.14	6.56	-1.70
120	-66.33	8.95	-68.84	6.16	-2.51
140	-60.22	7.36	-60.85	5.13	-0.63

Figure 2 shows a close match between the readings in CT numbers of the fabricated thyroid phantom from both scanner models. The SMART mA is used by GE, instead of the CARE Dose 4D in Siemens. However, it is noticeable that current has no effect on the measured CT numbers, where the current in this study varied from 84 mAs to 39.2 mAs in the 16 detectors GE and from 106 mAs to 133 mAs in the 128 detectors Siemens at different applied voltages.

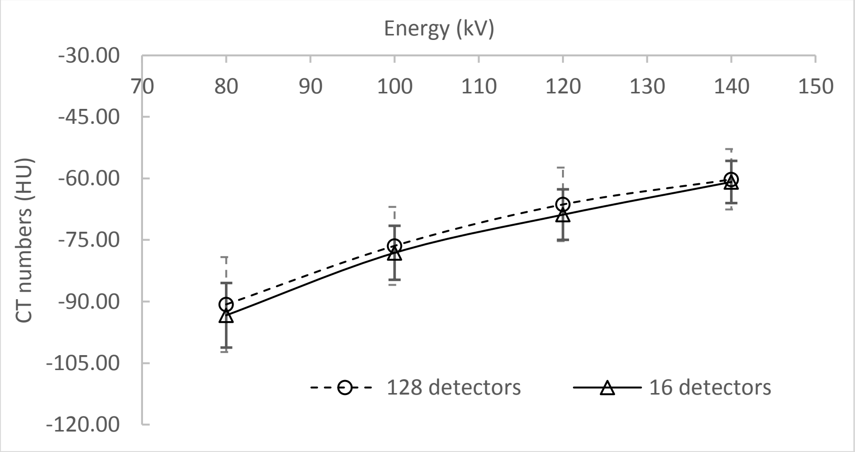

Figure 2. The CT numbers from 16- and 128-row detectors CTs scanners at different applied energies.

The calculated linear attenuation coefficients were used and divided by the density (ρ) of the thyroid phantom material (Polyethylene ≅ 0.92 g/cm^2) [15] to obtain the mass attenuation coefficients of Polyethylene (μ_p/ρ) for each applied energy in both machines. Table 2 shows the obtained (μ_p/ρ) and the percentage difference between each attenuation value at certain voltage with the values listed in the NIST's tables. The average percentage difference between the (μ_p/ρ) and the values of NIST were -0.02 % for the 128 Siemens and 0.18 % for the 16 GE, which showed no significant different between the two machines and can be ignored. The average of the mean percentage difference was also found to be very small (0.08 %).

Table 2. The mass attenuation coefficients from 16- and 128-row detectors CTs compared with the values of NIST.

kV	128 Detectors		16 Detectors			NIST
	μ_p/ρ	% Difference	μ_p/ρ	% Difference	Mean % Difference	μ/ρ
80	0.1816	0.41	0.1810	0.70	0.55	0.1823
100	0.1714	0.31	0.1710	0.50	0.41	0.1719
120	0.1650	-0.33	0.1646	-0.06	-0.19	0.1645
140	0.1579	-0.49	0.1578	-0.42	-0.45	0.1571

The results of the obtained mass attenuation coefficients of the phantom material from the 128 multidetector CT was expected to have a closer match to the values of NIST with the increase in the number of multidetector rows. On the contrary, the results from both CT scanners showed a very good match with the reference tables of NIST as illustrated in figure 3. However, the 128-row detectors CT showed a slightly much closer match to the values in NIST's tables. This refers to the type and quality of the electronic connections between the detectors. Furthermore, the type and number of detectors (16- and 128-detectors) could affect the quality of the output images since the number of output measurements from the 128-row detectors, which could be made per single rotation in the z-direction, is higher than the 16-row detectors.

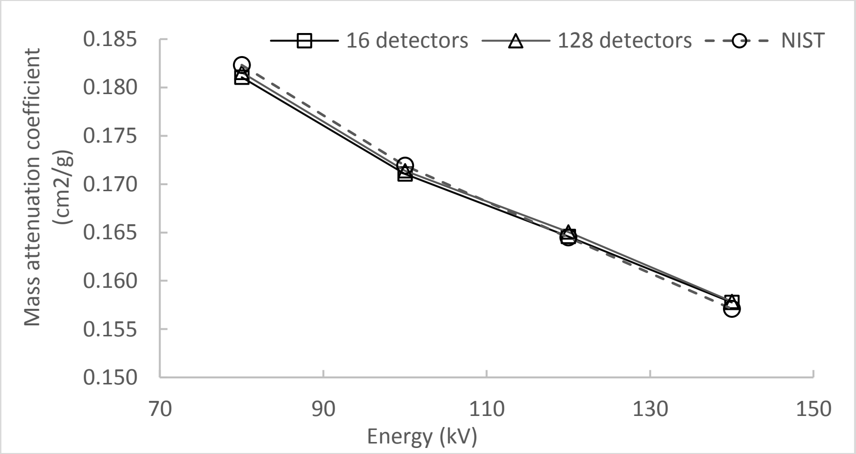

Figure 3. The obtained mass attenuation coefficient from 16 GE and 128 Siemens compared with the values of NIST at different applied energies.

For further comparison between the different multidetector CT models, the t-test for two-tails was used. All p-values showed insignificant difference (P-value > 0.05) between the results from the 16- and 128-row detectors, where the p-values between the mass attenuation coefficients from the 16- and 128-row detectors with the NIST's values were equal to 0.96 and 0.99 respectively, and 0.85 between the CT numbers from both scanner models.

5. Conclusion

As this study was performed using only two different CT models (Siemens and GE) with different numbers of multidetector rows, the results can vary when using other scanner models. Siemens CT and GE show very similar CT number readings and can be used to determine the mass attenuation coefficients of the phantom material, as they show a perfect match with the values of NIST. Therefore, the multidetector CT can be used to validate the fabricated paediatric thyroid phantom material.

A slightly better reading is obtained with the increase in the number of detectors. However, readings are varied from one manufacturer model to another due to the image reconstruction method, the number of electronic connections, the number of row detectors, the type and size of the detector elements as well as the scanner model.

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