Saudi Journal of Radiology
February 2023
Proceeding of the 13th Radiological Society of Saudi Arabia (RSSA)

# NEW ADVANCES IN CT DOSIMETRY: THE PLANAR AVERAGE EQUILIBRIUM DOSE

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## ABSTRACT

**Background:** The conventional way of measuring CT dosimetric performance using the computer tomography dose index (CTDI) is no longer compatible with modern CT scanners due to their advanced features such as helical scanning modes, dosage modulation, array detectors, multiple slice planes, or cone-beam irradiation geometries. Recognizing the limitations of the CTDI methods, the AAPM TG 111 study proposed a new approach that utilizes a short ion chamber instead of a pencil chamber and better characterizes the dose profile from modern CT scanners.

**Materials and Methods:** An in-house phantom design was constructed and characterized using clinical scan sequences of three different anatomical regions, including the head, chest, and abdomen. The phantom's equilibrium dose was measured to determine if the beam attenuation was similar to that of the CTDI phantom. The results were compared to CTDI dose estimates obtained using a conventional pencil chamber.

**Results:** The new method proposed in the study enabled the evaluation of both the equilibrium and cumulative doses for any clinical scan length, which was not possible with the conventional CTDI method. In comparison, the CTDI method can underestimate the dose by 25% to 35%, as per the results obtained using the revised methodology in the study.

**Conclusion:** The efficacy of CTDI measurements is being questioned as they are found to be inadequate in determining the actual dose delivered, with a tendency to underestimate it.

**Keywords:** CTDI, CT scanner, Dose equilibrium, Pencil ion chamber

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**eISSN:** 1658-8959

## 1. INTRODUCTION

CT scanners are the biggest source of medical radiation exposure. CT tests are performed annually in the United States at a rate of about 80 million exams [1]. For all medical radi-

ation exposure in US, CT exams account for 50% of the total [2, 3]; thus, a precise dosage estimation is needed for both pediatric and adult patients.

CT dosimetry relies on the Computed Tomography Dose Index (CTDI), which measures the radiation dose from one rotation of the X-ray tube in a CTDI phantom. The CTDI is a foundational element in determining the amount of radiation a patient receives during a CT scan. A pencil ionization chamber known as the CTDI 100, measuring 100mm long, is used to measure the CTDI. This chamber is placed inside a cylindrical phantom made of PMMA, which represents both the head and body. CTDI is not a suitable measure for modern CT scanners that use advanced features such as helical scanning modes, dose modulation, array detectors, and cone-beam irradiation geometries with multiple slice planes [4, 5]. The 100 mm pencil ionization chamber is too limited to measure the tails of the scattered dose distribution accurately [6]. The CTDI phantoms are only 14 cm long, which is considerably shorter than an average adult torso. Due to this limitation, these phantoms cannot accurately replicate the scattered radiation that would typically occur in an adult patient [7]. These two limitations are the main drawbacks of the CTDI method. A new method of measurement that would account for the scatter of modern CT scanners was presented in Task Group Report No. 111 (AAPM TG111) [8] of the American Association of Physicists in Medicine. They suggested employing an ion chamber with a tiny volume and a phantom length that permits dosage equilibrium close to the chamber [8]. Therefore, we aimed to construct and evaluate a phantom based on the American Association of Physicists in Medicine's (AAPM) TG 111 report, and to measure the accumulated and equilibrium doses using a Farmer chamber. Our argument is that the dose equilibrium (DEq) approach accurately calculates the real patient dosage.

## 2. MATERIALS

### 2.1 Dose Equilibrium and CTDI Phantom

A DEq phantom was created at NUI Galway (Figure 1). The phantom was 50 cm long with a 32 cm diameter. A central hole and four peripheral holes comprised the structure of the DEq phantom. When not in use, the holes were stuffed with blanks. The phantom was intended to be brought empty to the experimental setting, and once set down on the couch, it could be easily emptied or filled using a little pump connected to the sink in the room. The size of the phantom was selected to mimic the absorption and attenuation properties of an adult body of average size. The phantom's composition was based on IAEA TRS 277 [9, 10].

West Physics produced the commercial CTDI phantom. This phantom's body and head were both constructed of PMMA and had diameters of 320 mm and 160 mm, respectively. The cylinders have a length of 140mm each and contain holes large enough to accommodate a pencil chamber. When not in use, the holes are covered with Perspex blanks.

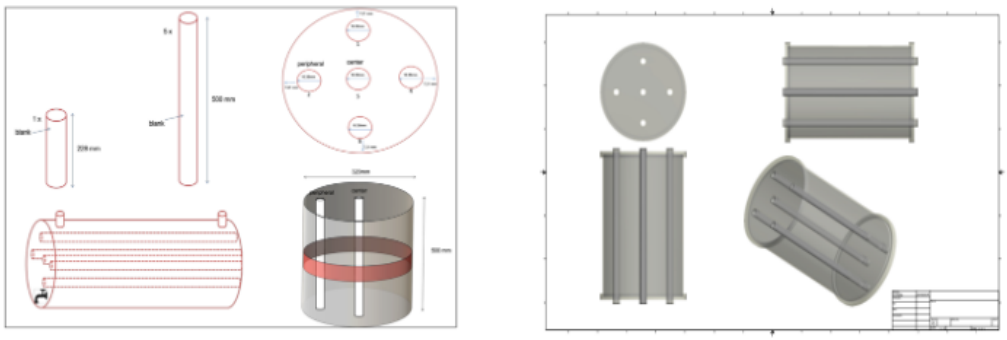

**Figure 1** Diagram of the DEq phantom.

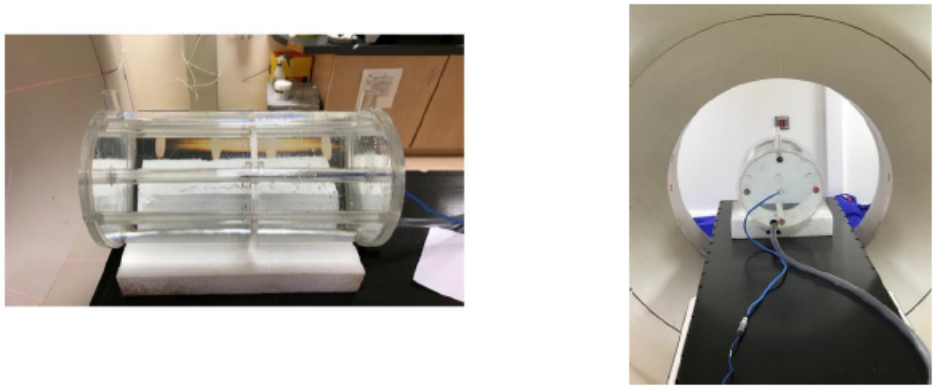

**Figure 2** DEq phantom with an integrated ion chamber in the middle.

## 2.2 Computed Tomography (CT) Scan and Ionization Chambers

CT scans were conducted using a Philips AcQsim CT. A PTW 30013 Farmer chamber (Figure 2) and a pencil chamber (Unfors XiTM) were used to measure the dose. Both chambers rely on ionization.

The Farmer chamber had a size of 0.6 cm3. The German Institute for Standardization performed the calibration of the Farmer chamber. Sun Nuclear provided a PC electrometer for the Farmer chamber. Unfors RaySafe calibrated the 10-cm-long pencil chamber.

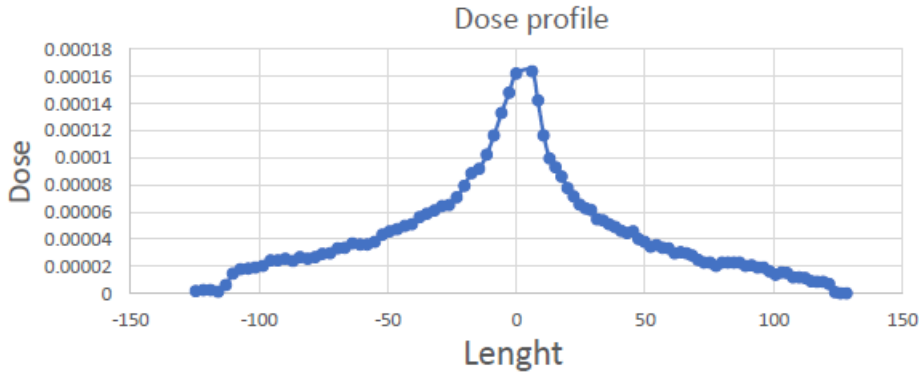


**Figure 3** Single-slice dosage profile in the middle of the scan length.

## 3. METHODS

### 3.1 Farmer Ionization Chamber

An accumulated dose is produced when a DEq phantom is scanned through a rotating X-ray while moving along the z-axis [11]. The accumulated dose can be visualized as the radiation dose accumulated by overlaying stationary, longitudinally displaced single-scan dose profiles. The upper limiting value utilized to establish the equilibrium dose is derived from the relationship between the cumulative dosage and the scanning length [12]. As the scanning length (L) gets longer, the cumulative dose at a particular point (z=0) also increases. This is due to increasing contributions from the peripheral scan sections (scatter tails), which eventually reach an upper limit where the scatter radiation source contributes minimally to the dose. For the three protocols (Table 1), the equilibrium dose was calculated for the center and periphery. The planar average equilibrium dose [8, 13, 14] was calculated using Equation (1) [15] and compared to the CTDI volume [8]

$$D_{Eq} = \frac{1}{2}D_{eq,\ center} + \frac{1}{2}D_{eq,\ peripheral} \quad (1)$$

**Table 1** Sequence of the protocols used Pencil Ionization Chamber.

| Protocol | Protocol 1 Head | Protocol 2 Chest | Protocol 3 Abdomen |
|---|---|---|---|
| Scanning mode | Axial | Axial | Axial |
| kVp | 120 | 130 | 120 |
| mA | 100 | 100 | 100 |
| Collimation | 4 | 4 | 4 |
| Rotation time | 1s | 1s | 1s |
| Spiral pitch | 1 | 1 | 1 |

Using the Perspex phantom, On the central and periphery axes of the three protocols, the CTDI 100 was determined (Table 1) [16, 17]. CTDI volume calculation and comparison to planar average equilibrium dose [18, 19].

## 4. RESULTS

### 4.1 Planar Average (DEq) Measurements and Comparison with CTDI Volume

Equation (1) was used to calculate the planar average DEq. For the three protocols, the center and periphery were measured to determine the DEq. In order to compare the CTDI volume to the DEq for the head, chest, and abdomen, the CTDI volume was determined using a Perspex phantom for each procedure, yielding in underestimations of 27%, 35%, and 25% for each of the three protocols, respectively. The results are presented in Table 2. Furthermore, according to the single-slice dosage profile close to the middle of a DEq phantom (Figure 3), the 100mm scan length was inadequate to measure the entirety of the scattered dosage distribution's tails. Additionally, the result revealed that the CTDI index is no longer a suitable measure of the dosage delivered during an exam.

**Table 2** CTDI volume compared to the DEq.

| Protocols | DEq (mGy) | CTDI volume (mGy) | Variation |
|---|---|---|---|
| Head | 24.314 | 19.1 | 27% |
| Chest | 14.01 | 10.4 | 35% |
| Abdomen | 11.15 | 8.9 | 25% |

## 5. CONCLUSION

The organ dosage and cumulative dose were calculated using CTDI, which was proven to underestimate the dose. Table 4.4 shows that the real dose was between 25% and 35% higher than what was determined by the 10 cm chamber measurement.

The limiting DEq was underestimated for scan lengths greater than 100 mm, because the size of the 100 mm pencil chamber was inadequate. Hence, the CTDI determined organ dose does not accurately reflect the radiation dosage that the organs actually absorb.

On the other hand, using a shorter ion chamber and a phantom long enough to determine the DEq will result in a dosage estimate that is more precise. In addition, instead of measuring only an accumulated dose at the center of the scan length, the measurement of an accumulated dose can be made anywhere in the phantom. Hence, the DEq approach is more flexible and takes less time than the current method, which employs a lengthy cham-

ber.

## CONFLICT OF INTEREST

All authors declare no conflict

## ACKNOWLEDGEMENT

Non

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