Which Spiral CTDI is an Alternative to Axial CTDI?

Purpose or Learning Objective

The computed tomography dose index (CTDI) is the standard metric for characterizing radiation output in CT. Traditionally, CTDI is measured using an axial acquisition without table motion (axial CTDI, aCTDI). However, modern clinical CT is dominated by spiral (helical) acquisition modes, and on most clinical scanners, axial protocols equivalent to clinical spiral protocols are unavailable except in service mode or are difficult to configure. This limits the practicality and representativeness of aCTDI-measurements for quality assurance and dose comparison.

Several studies have proposed measuring CTDI directly during spiral acquisition (spiral CTDI, sCTDI), showing good reproducibility and agreement with axial measurements [1-5]. Nevertheless, uncertainties remain regarding the influence of pitch, collimation, scan length, and longitudinal scatter, particularly for systems with larger longitudinal coverage.

The purpose of this work is to systematically compare axial and spiral CTDI measurement approaches under clinically relevant conditions, to evaluate the reproducibility of spiral CTDI, and to assess whether extended spiral CTDI concepts provide a more suitable alternative to axial CTDI for modern CT scanners.

Methods or Background

Measurements were performed using a standard 32 cm polymethylmethacrylate (PMMA) CTDI body phantom with one central and four peripheral measurement positions. A 100 mm pencil ionization chamber (PTW Nomex, PTW, Freiburg, Germany) was placed sequentially in the central and a peripheral position. All scans were acquired at 120 kV and 100 mAs with automatic exposure control disabled.

Two clinical CT systems were investigated: a Siemens Somatom Definition Flash and a Siemens Naeotom Alpha.Peak. For spiral CTDI measurements, the phantom was positioned at isocenter and acquisitions were performed using a spiral protocol intended for abdominal imaging. All CTDI measurements were repeated five times for each scan configuration. Mean values and standard deviations were calculated to assess measurement reproducibility.

We follow the literature and define a spiral CTDI (sCTDI) covering a scan length of 100 mm, matching the active length of the pencil ionization chamber [5]. This approach mirrors the traditional axial CTDI methodology but is expected to underestimate CTDI for modern scanners as longitudinal scatter radiation extends beyond the 100 mm integration length.

To investigate the influence of longitudinal scatter tails, extended spiral CTDI variants were defined with increasing scan lengths:

- eCTDI (150 mm): scan length covering the full phantom length. This variant is expected to capture a larger fraction of scatter originating within the phantom while remaining close to the conventional CTDI concept.

- oCTDI (150 mm ± 50 mm): scan length covering the phantom plus overscan regions in air. This approach is expected to further reduce underestimation by including scatter contributions generated near the phantom boundaries.
- xCTDI (450 mm): scan length covering three longitudinally stacked CTDI phantoms, with the chamber positioned in the central phantom. Only this configuration fully integrates the longitudinal dose profile, including extended scatter tails, and therefore overestimate CTDI relative to conventional definitions.

For all spiral measurements, each configuration was repeated five times to assess reproducibility. The weighted CTDI was calculated as

$$CTDI_w = 1/3 \times CTDI_{center} + 2/3 \times CTDI_{peripheral}$$

For axial CTDI (aCTDI) measurements, acquisitions without table motion were performed where an appropriate protocol was available. On the Definition Flash scanner, a clinically available axial protocol (38.4 mm collimation) was used as the closest approximation. As for any CTDI measurement with a 100 mm pencil ionization chamber, the longitudinal scatter tails of the dose profile can extend beyond the 100 mm integration length and are therefore not fully captured. On the Alpha.Peak scanner, no suitable axial protocol was available, and aCTDI could not be measured.

Multiple pitch values were selected to investigate the influence of tube start-angle effects on spiral CTDI measurements. For a given scan length and beam collimation, the pitch determines the number of gantry rotations that cover the 100 mm ionization chamber. This number may be an integer or a non-integer multiple of rotations with respect to the collimation width.

If the ionization chamber is irradiated by an integer number of rotations, the angular distribution of the x-ray tube is expected to be uniform over the chamber length. In this case, the tube start angle has no systematic influence, and low measurement variability is expected.

In contrast, if the chamber is covered by a non-integer number of rotations, the angular irradiation becomes uneven. Depending on the tube start angle, different regions of the ionization chamber receive different exposure contributions. This effect is most pronounced for peripheral measurement positions and is expected to be strongest for half-integer coverage, where the imbalance between opposing tube angles is maximal.

Accordingly, pitch values were chosen to produce integer, near-integer, and non-integer numbers of rotations covering the 100 mm chamber length for each scanner and collimation. This allowed systematic evaluation of start-angle-related variability while keeping all other scan parameters constant. Accordingly, highest variability is expected for non-integer coverage.

Results or Findings

For the Definition Flash system, axial CTDI (aCTDI) yielded a value of 6.45 mGy and served as the primary experimental reference. Note that scatter distributions are only partially captured using this CTDI variant, given that that scatter tails extend beyond the length of the ionization chamber. Spiral CTDI (sCTDI), measured over a 100 mm scan length, ranged from 6.17 to 6.42 mGy depending on pitch, corresponding to approximately −1% to −4% relative to aCTDI.

Extending the spiral scan length increased the measured CTDI as expected from progressive inclusion of longitudinal scatter tails. On the Flash, eCTDI (150 mm) increased to 6.67 to 6.77 mGy, approximately +3% to +5% compared to aCTDI, and oCTDI (150 mm ± 50 mm) to 6.80 to 6.82 mGy, approximately +5% to +6% compared to aCTDI. In contrast, xCTDI (450 mm, three stacked CTDI phantoms) exceeded aCTDI by 15 to 20%, reflecting integration of a much larger portion of the longitudinal dose profile, including extended scatter tails well beyond the region conventionally associated with CTDI. For the Definition Flash, the vendor-reported CTDI (vCTDI) for the spiral protocol was 6.75 mGy. Compared with the measured aCTDI value of 6.45 mGy, vCTDI was higher by approximately 4%. This relationship between measured aCTDI and reported vCTDI provides a reference for interpreting CTDI values on systems where aCTDI cannot be obtained.

For the Naeotom Alpha, no suitable axial protocol was available and aCTDI could not be measured. Vendor-reported CTDI (vCTDI) was therefore used as the reference and was 7.90 mGy. Spiral CTDI (sCTDI), measured over a 100 mm scan length, ranged from 6.98 to 7.39 mGy, corresponding to deviations of approximately −12% to −7% relative to vCTDI, depending on pitch. With increased spiral scan length, CTDI values increased: eCTDI (150 mm) ranged from 7.34 to 7.47 mGy, approximately −7% to −6% relative to vCTDI, and oCTDI (150 mm ± 50 mm) ranged from 7.40 to 7.54 mGy, approximately −6% to −5%. xCTDI (450 mm) yielded substantially higher values, ranging from 8.97 to 9.59 mGy, corresponding to deviations of approximately +13% to +19% relative to vCTDI.

Across both systems, reproducibility was high for all spiral CTDI variants. The standard deviation of repeated measurements was small compared with the systematic differences observed between the various spiral CTDI definitions, which were dominated by differences in longitudinal scan length and increased integration of scatter tails.

Conclusion

Spiral CTDI measurements have the potential to provide a robust and reproducible alternative to conventional axial CTDI on modern CT scanners, particularly when axial protocols equivalent to clinical spiral acquisitions are unavailable. Where both quantities could be assessed, measured aCTDI and vendor-reported CTDI (vCTDI) showed close agreement, indicating that vCTDI represents a suitable practical reference on systems lacking axial measurement capability. Among the spiral CTDI variants, eCTDI and oCTDI yielded values close to aCTDI and vCTDI, while systematically exceeding sCTDI, reflecting increased longitudinal integration of the longitudinal dose profile. All CTDI variants resulted in substantially lower values than xCTDI, which integrates nearly the entire longitudinal dose profile and may therefore be considered closest to the "true" CTDI. However, xCTDI requires two to three stacked CTDI phantoms and is slighly less practical for routine clinical use. In contrast, sCTDI, eCTDI, and oCTDI can be implemented with standard equipment and may serve as practical substitutes for aCTDI on scanners where axial CTDI measurements are not available.

References

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