Letter to the Editor

Is it time to retire the CTDI for CT quality assurance and dose optimization?

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To the Editor,

Ultimately, computed tomography quality assurance[1] and dose optimization[2] (CT QA/DO) have the goal of reducing, as far as practical, radiation-induced cancer risks in the examined population. In turn, these cancer risks are determined by the organ doses to which individuals are exposed. Thus it is logical for the quantities measured in CT QA/DO to bear as direct relationships to organ doses as is reasonably practical. As discussed here, the dose descriptors currently used[1,2] for CT QA/DO, the CT dose index[3–5] (CTDI) and its subsequent modifications,[2,6] bear an increasingly distant relationship to organ doses.[7–9] The technology does now exist, however, to directly and routinely measure organ doses from helical CT scans in realistic anthropomorphic phantoms, and it is thus suggested here that such measurements now represent a more logical basis for CT QA/DO than do CTDI measurements.

Historically, because of the unique pattern of dose delivery inherent in CT scans, a variety of CT-specific dose descriptors have been developed, based on the concept of the CTDI.[2,6] The CTDI descriptor was pragmatic in origin,[3–5] and not intended as a surrogate of risk, but rather was designed to measure, in a homogeneous phantom, an average central dose associated with a multiple contiguous fixed-current axial-mode scan.[3–5] The CTDI was necessarily based on single-slice dose measurements, having been formulated at a time when CT scanners were slow and with limited anode heat capacity for multislice measurements. While the CTDI has not failed in its original, quite limited, goal, as CT technology has advanced—for example to multislice variable pitch helical scanning—modified CTDI indices have been required, such as $CTDI_{14T}$, $CTDI_{100}$, $CTDI_{w}$, $CTDI_{vol}$, and dose length product (DLP).[2,6]

While the CTDI was not originally intended as a surrogate of organ dose or risk,[3–5] these modifications to the CTDI concept are, in part, motivated by a desire to use the CTDI in this way.[10–15] As CT technology develops, still more modifications to the CTDI concept are and will be needed. For example, as multislice scanners utilize increasingly broad beams, the 100-mm ion chamber now used in CTDI measurements will no longer collect all the scatter from a single-slice profile.[7–9] Another recent development is the advent of continuous automated tube current modulation along the z direction (i.e., continuous current modulation to compensate for changes in attenuation by different organs along the patient axis);[16] in this situation, individual organ doses will no longer be scalable from the overall mean mAs.

The use of the single-slice CTDI for CT QA/DO was entirely appropriate at the inception of the multislice CT era.[3–5] However, as CT technology continues to develop, rather than continuing to make *ad hoc* modifications to the CTDI, it is argued here that it may make sense to altogether replace the CTDI as a dose index, instead adopting quantities that are direct surrogates of cancer risk—specifically, measured organ doses in realistic anthropomorphic phantoms. The argument is that, given that the goal of CT QA/DO is to minimize unnecessary cancer risks to patients and exposed populations, and given that it is now quite practical to measure direct surrogates for cancer risk, namely organ doses in realistic phantoms, with about the same amount of technical effort as is required to measure CTDI, it makes sense to use these more direct measurements as the basis for CT QA/DO.

In fact, direct thermoluminescent dosimeter (TLD) measurements of organ doses at specific locations in heterogeneous anthropomorphic phantoms have been reported,[13–15,17] though largely to check the accuracy of CTDI→organ dose conversion factors, rather than as a replacement for CTDI measurements. TLDs are rather laborious for multiple routine measurements,[13] and the recent advent of metal-oxide-semiconductor field-effect transistor (MOSFET) solid-state dosimeters[18–20] suggests another practical alternative. MOSFET dosimeters are small (active volume 0.2×0.2 mm), sensitive at doses of a few milliGrays,[20] have a linear response at these doses,[18,20] have immediate readout, and are convenient for simultaneous multidetector use.

Specifically then, given (1) the problems in maintaining CTDI as a relevant dose index, (2) the availability of MOSFET (or TLD, if preferred) dosimeters that are very small, sensitive, and convenient to use, and (3) the commercial availability of heterogeneous whole-body anthropomorphic phantoms such as the ATOM® phantoms[21,22] and the Alderson radiation therapy phantoms,[23,24] perhaps it is time to consider retiring (with honor) the CTDI-inhomogeneous-phantoms approach to CT QA/DO. One might envisage CTDI measurements being replaced by direct simultaneous MOSFET or TLD measurements of doses at locations in appropriate organs of a full-body anthropomorphic phantom, perhaps appropriate subsets of stomach, colon, breast, lung, gonads, thyroid, bladder, esophagus, liver, brain, and relevant bone marrow.[25] A typical such measurement at 20 (simultaneously measured) locations should take about 30 min, including setup.

Of course, there would be practical and technical issues to consider: Full-body heterogeneous anthropomorphic phantoms are not inexpensive, currently costing about $20 000,

but that is less than 2% of the cost of a single modern CT scanner. One might also wish to utilize a pair of anthropomorphic phantoms, one adult and one pediatric.[22,26] On the technical side, the energy dependence of the MOSFET or TLD dosimeters would need to be considered—as is also the case for a CTDI ion chamber. It would also be desirable to establish a benchmark system for extrapolating direct dosimetric measurements to different, but similar, scanner settings; by analogy with current techniques,[10,11] one could envisage this being done based on standardized sets of Monte Carlo simulations in voxelized computational versions of the physical phantoms.

In conclusion, there is no argument that CTDI, and related quantities, can be used to compare outputs of different CT scanners and different CT models. However, CTDI was never intended to provide a surrogate for organ dose or cancer risk, and subsequent attempts to base such estimates on CTDI are running into increasing difficulties. Given that the goal of CT QA/DO is to minimize unnecessary cancer risks to patients and exposed populations, and given that it is now quite practical to measure direct surrogates for cancer risk, with no more technical effort than required to measure CTDI, it makes sense to use these more direct measurements as the basis for CT quality assurance and dose optimization.

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