It is time to retire the computed tomography dose index (CTDI) for CT quality assurance and dose optimization

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OVERVIEW

The computed tomography dose index (CTDI) was introduced over a quarter century ago for optimization of patient protection in CT. By means of a single measurement it was possible to determine, to a good approximation, the average dose for a series of scans in lieu of making multiple measurements for each slice. This advance made great sense at the time because of the slow equipment and small anode heat capacities of early CT units, which made multiple measurements difficult. It has recently been suggested that modern technological developments in CT and dosimetry permit patient doses to be determined in a way that better represents the risk to the patient, and that it is now time to retire the use of CTDI for CT quality assurance and dose optimization. However, others argue that measurements of CTDI (or variants thereof) remain adequate for CT quality assurance and dose optimization, and that replacement is unnecessary. This difference of opinion is the topic of this month’s Point/Counterpoint debate.

FOR THE PROPOSITION: David Brenner, Ph.D.

Opening Statement

We have an obligation to reduce, as far as practical, radiation-induced cancer risks in the population who receive computed tomography (CT) examinations. These cancer risks are determined by the organ doses to which individuals are exposed. It is logical for the quantities measured in CT quality assurance and dose optimization (CT QA/DO) to bear as direct a relationship to organ doses as is reasonably practical. The dose descriptors currently used for CT QA/DO, the computed tomography dose index (CTDI) and its subsequent modifications, bear an increasingly distant relationship to exposures). When not involved in radiation matters, he supports Liverpool Football Club.

Arguing against the Proposition is Cynthia H. McCollough, Ph.D. Dr. McCollough is Associate Professor of Radiological Physics at the Mayo Clinic College of Medicine. She oversees the technical support for Mayo’s 22 CT scanners and directs the CT Clinical Innovation Center. Her research interests include CT dosimetry, advanced CT technology, and new clinical applications. She is an NIH-funded investigator, and is active in numerous organizations. She chairs the AAPM’s Task Group on CT Dosimetry and the ACR’s CT Accreditation Physics Subcommittee, and is a member of IEC, ICRU, and NCRP CT committees. Dr. McCollough received her doctorate from the University of Wisconsin in 1991.

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organ doses and thus to risk. The technology now exists to
directly, routinely and rapidly measure organ doses fromhel-
cical CT scans in realistic anthropomorphic phantoms, with
about the same amount of technical effort as that required to
measure CTDI. Thus, I believe that such measurements rep-
resent a more logical basis for CT QA/DO than do CTDI
measurements.

Specifically, given 1) the problems in maintaining CTDI
as a relevant dose index, 2) the availability of MOSFET
(Refs. 5 and 6) (or TLD, if preferred) dosimeters which are
very small, sensitive, quick, and convenient to use, and 3) the
commercial availability of heterogeneous whole-body
anthropomorphic phantoms such as the ATOM phantoms
and the Alderson radiation therapy phantoms, it is time to
consider retiring the CTDI/homogeneous phantom approach
to CT QA/DO. One might envisage CTDI measurements be-
ing replaced by direct simultaneous MOSFET 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. A typical
set of measurements at 20 (simultaneously measured) organ
locations should take about 30 minutes, including setup—
quite comparable to CTDI measurements.

There is no question that CTDI, and its related quantities,
can be used to compare outputs of different CT scanners and
different CT models. But given the goal of minimizing un-
necessary cancer risks to patients, there is a need for a quan-
tity that is a surrogate of risk, and neither CTDI nor its modi-
fications can be forced into this role. 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.

AGAINST THE PROPOSITION: Cynthia McCollough,
Ph.D.

Opening Statement

The advent of spiral CT caused concern about the use of a
discrete axial scan to measure dose for a continuous spiral
acquisition. However, both theory and experimental data up-
held the validity of extending the CTDI construct to spiral
CT. The larger problem, both for spiral or sequential ac-
quisions, was the integration limits established in the early
days of CT: ±7 T, where T was the nominal tomographic
section thickness (in lay person language, the slice width). In
the case of narrow slice widths (which were not considered
in the ‘early days’), the average dose from a series of scans
was underestimated by the ±7 T limits. Hence a fixed in-
tegration length of 100 mm, which purposely matched the
active length of the well-established CTDI ‘pencil’ chamber,
was adopted in Europe and in International CT Safety
standards. This resulted in a CT dose index that is easily
and reproducibly measured, and that captures the majority
of the scatter tails for even wide x-ray beam widths.

Recently, the pitch-normalized metric CTDIvol was re-
quired by international standards to be displayed on the user
interface prior to scan initiation. The radiology community,
through extensive educational efforts, is becoming ‘cali-
brated’ to typical CTDIvol values for common examinations,
thereby allowing users to note scan prescriptions that deliver
radiation levels outside of the typical range. Users can use
CTDIvol to provide a universal index of scanner output that
can be readily compared across scanners worldwide. This
‘apples to apples’ comparison of radiation doses in CT,
where users can check scanner output prior to irradiation
(and hopefully modify techniques that are inappropriately
different from the above reference values), is a practical and
robust method of dose optimization, as the use of reference
values has consistently been shown to reduce average dose
levels and narrow the dose distribution across imaging
practices. CTDIvol is a valuable and necessary tool for this
task, primarily because it is so well established and uni-
formly adopted.

This uniformity in measurement technique makes CTDI
an ideal quality assurance tool, as quality assurance requires
use of the same methods and phantoms in a consistent man-
ner. So too, does dose optimization. Knowing the dose to my
liver or your liver is not the issue in clinical dose optimiza-
tion. Rather, one must know that a CTDIvol of 18–22 mGy is
typical for an average adult abdominal CT. That way, if a
wrong parameter is selected leading to a CTDIvol of 59 mGy,
the user has a clear indication that something is wrong. Be-
sidees avoiding unnecessarily high dose CT exams, the dis-
play of a universal, easily- and reproducibly-measured met-
ric on the user console provides the operator with a practical
tool to reduce dose from CT examinations to appropriate
levels. Thus, I consider it time not to retire the CTDI, but
rather to promote its use in daily CT practice.

Rebuttal: David Brenner, Ph.D.

Professor McCollough cogently makes the point that if
sole object of the exercise is to compare and confirm
outputs from CT machines, as they are used in 2006, then the
CTDIvol dose index is just fine. There are several reasons,
however, why CTDI is not the optimal way forward for CT
QA/DO.

First, if the history of CT dosimetry tells us anything, it is
that the latest version of CTDI will soon need to be modified
due to changes in CT technology. For example, as multi-
slice scanners feature increasingly broad beams, the 100 mm
ion chamber will no longer characterize enough of the scatter
from a single-slice profile. To have to base QA/DO on a
dose index that needs to be modified as CT technology
changes is undesirable. Indeed, there are some imminent
changes in CT technology that are so basic that they cannot
be accommodated by simply tinkering further with CTDI. As
an example, for continuous automated axial tube current
modulation, designed to compensate for changes in attenua-
tion by different organs along the patient axis, CTDI mea-
surements simply will not delineate whether or not the dose
is being delivered appropriately over the length of, say, a
colon scan.
Secondly, Professor McCollough’s central implication is that, in order to check that the scanner is operating correctly, all we need for CT QA/DO is some good index of machine output. But if this were so, even the basic CTDI100 would be more complicated than needed. In fact, still more complicated, spatially-averaged versions of the CTDI100, like CTDIx and CTDIvol, are now the standard.3 Why? Because they are slightly better surrogate indices for organ dose and thus ultimately for organ risk!

In summary, there is a rationale and a desire in CT QA/DO to measure some quantity that will need to be changed, and that is a better surrogate for organ dose/risk than is CTDI. So why not directly measure organ doses in an anthropomorphic phantom?

Thus my arguments in support of the Proposition are:

1. Multiple organ dose measurements in an anthropomorphic phantom with a set of MOSFET detectors, for example, are no harder or slower to make than CTDI measurements.5,6
2. Organ dose measurements provide just as good a check that the machine is working correctly as does CTDIvol.3
3. The CTDI concept needs to be continuously modified as CT technology changes.
4. Organ dose measurements provide direct, rather than crude, surrogates of organ risk—the quantity we ultimately want to control.

Rebuttal: Cynthia McCollough, Ph.D.

In CT, organ doses are determined by the start and end locations of the examination, scanner output and patient anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy. From the anatomy of interest, CTDI and scan protocol, organ doses can be predicted with high precision using an anatomy.

The time, effort, and cost associated with “brute force” measurements of organ doses for the innumerable combinations of detector locations of the examination, scanner output and patient anatomy, is simply not practical. Further, physical anthropomorphic phantoms, which are available in limited sizes, may use less-accurate “geometric” organs, and can vary based on manufacturer or date of purchase. In addition to dosimetry precision and calibration issues, such variations will confound the optimization task, especially between investigators. Silicon-based dosimeters (diodes or MOSFETs) can only be used on phantom surfaces (if placed internally, the wires create problematic gaps). Also, they have spectral dependencies that are not easily addressed in CT, where spectra vary between scanners and across the scan field, and they must be used in high-sensitivity mode for adequate precision, which shortens their lifespan and increases user cost. TLDs, which can be placed inside the phantom, require annealing and removal (to read them) between multiple measurements—a time consuming effort. In contrast, CTDI gives a precise and consistent index of scanner output, can be used to quickly measure output for many combinations of scanner settings, and can be used with Monte Carlo tools for dose optimization. I agree that organ doses are important, but physicists should use their time and talents to work smarter, not harder, towards minimizing radiation risk from CT.