POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Colin G. Orton, Professor Emeritus, Wayne State University, Detroit: ortonc@comcast.net. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

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

David J. Brenner, Ph.D., DSc
Center for Radiological Research, Columbia University Medical Center, New York, New York 10032 (Tel: 212-305-9930, E-mail: djb3@columbia.edu)

Cynthia H. McCollough, Ph.D., DABR
Mayo Clinic College of Medicine, Department of Radiology, Rochester, Minnesota 55905 (Tel: 507-266-0631, E-mail: mccollough.cynthia@mayo.edu)

Colin G. Orton, Ph.D., Moderator

(Received 19 January 2006; accepted for publication 21 January 2006; published 12 April 2006)

[DOI: 10.1118/1.2173933]

OVERVIEW

The computed tomography dose index (CTDI) was introduced over a quarter century ago for optimization of patient protection in CT.[1] 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.[2] 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.

Arguing for the Proposition is David J. Brenner, Ph.D. Dr. Brenner is Professor of Radiation Oncology and Public Health at the Columbia University Medical Center. He focuses on developing models for the carcinogenic effects of ionizing radiation on living systems at the chromosomal, cellular, tissue, and organism levels. He divides his research time roughly equally between the effects of high doses of ionizing radiation (related to radiation therapy), and the effects of low doses of radiation (related to radiological, environmental, and occupational 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.

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,[3] bear an increasingly distant relationship to

 0094-2405/2006/33(5)/1189/3/$23.00

organ doses and thus to risk.[4] The technology now exists to directly, routinely and rapidly measure organ doses from helical 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 represent 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,[4] 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[7] and the Alderson radiation therapy phantoms,[8] it is time to consider retiring the CTDI/homogeneous phantom approach to CT QA/DO. One might envisage CTDI measurements being 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 unnecessary cancer risks to patients, there is a need for a quantity that is a surrogate of risk, and neither CTDI nor its modifications 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 upheld the validity of extending the CTDI construct to spiral CT.[9,10] The larger problem, both for spiral or sequential acquisitions, 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.[11] Hence a fixed integration length of 100 mm, which purposely matched the active length of the well-established CTDI "pencil" chamber, was adopted in Europe[12] and in International CT Safety standards.[13] This resulted in a CT dose *index* that is easily and reproducibly measured,[3] and that captures the majority of the scatter tails for even wide x-ray beam widths.[14]

Recently, the pitch-normalized metric $CTDI_{vol}$ was required by international standards to be displayed on the user interface prior to scan initiation.[13] The radiology community, through extensive educational efforts, is becoming "calibrated" to typical $CTDI_{vol}$ values for common examinations, thereby allowing users to note scan prescriptions that deliver radiation levels outside of the typical range. Users can use $CTDI_{vol}$ 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.[15] $CTDI_{vol}$ is a valuable and necessary tool for this task, primarily because it is so well established and uniformly 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 manner. So too, does dose optimization. Knowing the dose to my liver or your liver is not the issue in clinical dose optimization. Rather, one must know that a $CTDI_{vol}$ of 18–22 mGy is typical for an average adult abdominal CT. That way, if a wrong parameter is selected leading to a $CTDI_{vol}$ of 59 mGy, the user has a clear indication that something is wrong. Besides avoiding unnecessarily high dose CT exams, the display of a universal, easily- and reproducibly-measured metric 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 the sole object of the exercise is to compare and confirm outputs from CT machines, as they are used in 2006, then the $CTDI_{vol}$ 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.[3] For example, as multislice scanners feature increasingly broad beams, the 100 mm ion chamber will no longer characterize enough of the scatter from a single-slice profile.[4,16] 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 attenuation by different organs along the patient axis,[17] CTDI measurements 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 $CTDI_{100}$ would be more complicated than needed. In fact, still more complicated, spatially-averaged versions of the $CTDI_{100}$, like $CTDI_w$ and $CTDI_{vol}$, 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 $CTDI_{vol}$.
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 published Monte Carlo coefficients[18,19] or Monte Carlo code modified for this task.[20,21] Using "virtual phantoms" from actual patient CT scans, dose optimization can easily be performed for patients of varying age, gender, and habitus for countless perturbations of scan parameters.[22] The time, effort, and cost associated with "brute force" measurements of organ doses for the innumerable combinations of detector configurations, pitch values, kVp and mAs settings, beam shaping filters, and multiple child and adult physical phantoms—per scanner model—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 dosimeter 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.

[1]R. Jucius and G. Kambic, "Radiation dosimetry in computed tomography CT," Proc. SPIE **127**, 286–295 (1977).
[2]D. J. Brenner, "Is it time to retire the CTDI for CT quality assurance and dose optimization?," Med. Phys. **32**, 3225–3226 (2005).
[3]M. F. McNitt-Gray, "AAPM/RSNA Physics Tutorial for Residents: Topics in CT. Radiation dose in CT," Radiographics **22**, 1541–1553 (2002).
[4]R. L. Dixon, "A new look at CT dose measurement: beyond CTDI," Med. Phys. **30**, 1272–1280 (2003).
[5]M. W. Bower and D. E. Hintenlang, "The characterization of a commercial MOSFET dosimeter system for use in diagnostic x ray," Health Phys. **75**, 197–204 (1998).
[6]D. J. Peet and M. D. Pryor, "Evaluation of a MOSFET radiation sensor for the measurement of entrance surface dose in diagnostic radiology," Br. J. Radiol. **72**, 562–568 (1999).
[7]V. Varchenya, D. Gubatova, V. Sidorin, and S. Kalnitsky, "Children's heterogeneous phantoms and their application in röntgenology," Radiat. Prot. Dosim. **49**, 77–78 (1993).
[8]S. W. Alderson, L. H. Lanzl, M. Rollins, and J. Spira, "An instrumented phantom system for analog computation of treatment plans," Am. J. Roentgenol., Radium Ther. Nucl. Med. **87**, 185–195 (1962).
[9]M. F. McNitt-Gray *et al.*, "Radiation dose in Spiral CT: The relative effects of collimation and pitch," Med. Phys. **26**(3), 409–414 (1999).
[10]W. A. Kalender and A. Polacin, "Physical performance characteristics of spiral CT scanning," Med. Phys. **18**(5), 910–915 (1991).
[11]American Association of Physicists in Medicine, Report No. 31, "Standardized Methods for Measuring Diagnostic X-ray Exposures," 1990.
[12]European guidelines for quality criteria for computed tomography (European Commission, Luxembourg, 2000).
[13]International Electrotechnical Commission, Medical Electrical Equipment. Part 2-44: Particular requirements for the safety of x-ray equipment for computed tomography. IEC publication No. 60601-2-44. Ed. 2.1. IEC Central Office: Geneva, Switzerland, 2002.
[14]C. H. McCollough, F. E. Zink, and R. L. Morin, "Radiation dosimetry for electron beam CT," Radiology **192**, 637–643 (1994).
[15]D. Hart *et al.*, "Doses to patients from medical x-ray examinations in the UK–1995 review," Health Protection Agency, Chilton, UK: NRPB-R289 (1996).
[16]S. Mori, M. Endo, K. Nishizawa, T. Tsunoo, T. Aoyama, H. Fujiwara, and K. Murase, "Enlarged longitudinal dose profiles in cone-beam CT and the need for modified dosimetry," Med. Phys. **32**, 1061–1969 (2005).
[17]M. K. Kalra, M. M. Maher, T. L. Toth, B. Schmidt, B. L. Westerman, H. T. Morgan, and S. Saini, "Techniques and applications of automatic tube current modulation for CT," Radiology **233**, 649–657 (2004).
[18]D. G. Jones and P. C. Shrimpton, Report No. NRPB-SR250, Health Protection Agency, Chilton, UK (1993).
[19]M. Zankl, W. Panzer, and G. Drexler, "The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods Part VI: Organ doses from computed tomographic examinations," GSF-Bericht 30/91. Neuherberg, Germany: Gesellschaft für Strahlen- und Umweltforschung (1991).
[20]W. A. Kalender *et al.*, "A PC program for estimating organ dose and effective dose values in computed tomography," Eur. Radiol. **9** (3), 555 (1999).
[21]J. J. DeMarco *et al.*, "A Monte Carlo based method to estimate radiation dose from multidetector CT (MDCT).: cylindrical and anthropomorphic phantoms," Phys. Med. Biol. **50** (17), 3989 (2005).
[22]N. Petoussi-Henss *et al.*, "The GSF family of voxel phantoms," Phys. Med. Biol. **47** (1), 89 (2002).