Phantoms and the Problem of Quantification in Medical Computed Tomography (CT)

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The quantification of medical CT faces many barriers, both social and technical. Curiously, the relatively slow adoption of more quantitative methods is due, in part, to the success of the existing image-oriented practice. Indeed, I have heard it argued forcefully that improving the accuracy of CT would be a waste of time because the natural variability of the patients exceeds the variation of the machines already.

A compelling case must be made for change. At the risk of being charged for advertizing, please see my forthcoming article in Optics Express which demonstrates that the volume of ellipsoids may be measured with volumetric techniques with ten times less uncertainty than using the standard RECIST method (i.e., Response Evaluation Criteria in Solid Tumors). Perhaps smaller changes in volume may be detected leading to faster cancer diagnosis in clinical practice and research.

One barrier to the acceptance of volumentric techniques is that the amount of data it generates is too high, leading to data storage issues as well as requiring a change in the familiar slice-by-slice analysis of radiologists which dates to the age of film.

On the technical side, one less-appreciated problem is that the Hounsfeld unit or "CT number" does not have a precise definition. Hounsefeld scaled the absorption reported to water, using an offset scale with 0 at water and -1000 at air. The spectrum is not considered, yet the result is spectrum dependent. Moreover, there isn't a clear distinction between scattering and attenuation, even though Compton scattering of x-rays is about five times more likely than photoabsorption. This sort of sloppiness makes people in standards laboratories bang their balding heads against their grey file cabinets! The arrival of dual energy scanners (which makes the absorption spectrum variable) and continuing increase in parallelism (which makes the system more sensitive to scattering) may bring these issues to the fore.

The problem is compounded by the fact that most reconstruction kernels do not have publically available mathematical definitions. Hence, the CT system becomes a black box to be probed.

Phantoms offer the best hope of performing such probes. Phantoms are presently used to calibrate CT systems, typically on a daily basis, although also through multi-year accreditation. The system works well enough for image-oriented analysis, although the variations between manufactureres, models, upgrades, and local machine settings and practices make longitudinal studies and transfers of patients from machine to machine problematical, are not well quantified, and lead to awkward problems such as the difficulty of supplying a single size-independent cut-off value to describe emphyzema. Scanning a carefully-crafted phantom on a per-patient basis, as suggested by a Cornell group a decade ago, offers the best hope to provide the ability to provide uncertainties, permit corrections of reported densities, assess the interaction of spatial position and CT number, and understand the length-scale of the smearing introduced by the measurement and reconstruction process. We need all these things to extend the reach of these already-impressive machines.