JACC: CARDIOVASCULAR IMAGING VOL. 3, NO. 5, 2010
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ISSN 1936-878X/$36.00
PUBLISHED BY ELSEVIER INC. DOI:10.1016/j.jcmg.2010.03.004

EDITORIAL VIEWPOINT

Cardiovascular Imaging With Computed Tomography

Responsible Steps to Balancing Diagnostic Yield and Radiation Exposure

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Cardiovascular computed tomography (CT) is at the center of the risk–benefit debate about ionizing radiation exposure to the public from medical procedures. Although the risk has been sensationalized, the cardiovascular CT community has responded to the scrutiny by increasing efforts to ensure the responsible use of this young technology. Efforts to date have primarily included the development of appropriateness criteria and the implementation of dose-lowering techniques. Still needed is the development of standards that incorporate radiation exposure optimization into scan protocol selection. Such standards must consider applied radiation in the context of the clinical indication as well as the characteristics of the patient and provide guidance with regard to specific parameter settings. This editorial viewpoint demonstrates the need for comprehensive, individualized review of the clinical scenario before performing a cardiovascular CT, as well as the need for standards. If cardiovascular CT is the appropriate test and scan parameters are optimized with respect to radiation exposure, benefit should necessarily outweigh potential risk. However, efforts to promote responsible cardiovascular CT imaging must continue to ensure this is true for every patient. (J Am Coll Cardiol Img 2010;3:536–40) © 2010 by the American College of Cardiology Foundation

Based on the ground-breaking work by Sir Hounsfield (1), computed tomography (CT) was introduced into medical imaging in the 1970s. Initially, cardiovascular applications were limited because of the rapid motion of cardiac structures during the cardiac cycle. Complex technical advances synchronizing fast image acquisition to the cardiac cycle finally permitted cardiac imaging with minimal motion artifact on conventional CT systems nearly 3 decades later. Over the last few years, cardiovascular CT has grown exponentially and has developed into a standard clinical test for a wide variety of cardiovascular conditions, complementary to angiography, nuclear imaging, and echocardiography.

The excitement generated by cardiovascular CT has recently been tempered by a string of high-impact publications, raising concern about the increase in radiation exposure to the population from medical procedures (2–4) and the potential cancer risk (5,6). While exposure to ionizing radiation during cardiovascular imaging is not limited to CT—X-ray angiography and nuclear imaging are significant sources of radiation exposure (7)—heightened concern

From *Cardiovascular Imaging, Imaging Institute, †Department of Biomedical Engineering, Lerner Research Institute, and ‡Cardiovascular Imaging, Heart and Vascular Institute, Cleveland Clinic, Cleveland, Ohio. The Cleveland Clinic Imaging Institute receives modest research support from Siemens Medical Solutions and Philips Medical Systems.

Manuscript received March 24, 2010, accepted March 30, 2010.

about the risks of medical radiation exposure during the establishment of CT as an appropriate test for certain cardiovascular indications has led to unparalleled scrutiny of the radiation burden of this relatively new technique.

However, the leap from radiation exposure to the risk of stochastic effects such as cancer is controversial, particularly for individual patients, because of known uncertainties in dose estimates and risk models. The effective dose, expressed in units of millisieverts (mSv), is the dose quantity most commonly used to relate exposures from low doses of ionizing radiation to the probability of detrimental health effects. The effective dose weighs the energy absorbed by all irradiated tissues and organs in the body according to the type of radiation and the sensitivity of the tissue or organ to radiation-induced mutagenic changes. The effective dose represents the amount of whole body irradiation that yields a biological risk equivalent to the irradiation of only a portion of the body (as with cardiovascular CT). Although the effective dose quantity is thought to be the best quantity available for linking radiation dose and health risk, it must be recognized that the effective dose is associated with a level of uncertainty on the order of ±40% when it is used to quantify dose for medical exposures (8). Further, the effective dose is not intended to express absolute patient-specific risk (i.e., risk to specific persons of known age and sex) but rather risk to the general population. These limitations of the effective dose underlie the recommendation to use a different metric, the dose-length product, reported by the CT scanner in units of mGy × cm, to characterize the amount of radiation from a single CT examination in the patient report (9–11) and in research studies.

The calculation of numerical risk from the effective dose estimates is further limited. Cancer risk from the relatively low doses of ionizing radiation used during medical imaging is linearly extrapolated from the radiation risk data of atomic bomb survivors in Japan after World War II. The validity of this approach relies largely on the linear no-threshold theory, which assumes a linear relationship between dose and cancer risk even at the smallest doses. However, the linear no-threshold theory is controversial and the subject of debate (12–14). Therefore, estimations of risk from low doses of radiation delivered during medical imaging examinations must be interpreted with regard to the imprecision of the calculation. Further, any potential risk of future stochastic events must be balanced with the risk of forgoing a medically necessary examination (15).

Despite these cautionary notes, the dramatic increase in medical exposures to the population—particularly from CT— during the past 3 decades is indisputable (4). It is, therefore, not surprising that cardiovascular CT has taken a central role in the discussion about the risk–benefit of ionizing radiation-based diagnostic imaging procedures (16). Importantly, this has hastened the development and implementation of dose-lowering tools (17) and provided the young field of cardiovascular CT with an opportunity to aggressively incorporate radiation exposure into quality standards. Quality standards must consider applied radiation in the context of the clinical indication, the characteristics of the patient, the availability of alternative diagnostic (imaging) strategies, and the specific CT imaging technique available.

Consider the following hypothetical clinical scenarios: A 30-year-old male patient presents with symptoms highly suggestive of an acute aortic dissection in the emergency department. Performing an electrocardiography (ECG)-referenced CT angiography (CTA) of the aorta would be considered appropriate, even if scanning on the available system in the emergency department during off hours was associated with a relatively high radiation exposure. In contrast, for elective follow-up imaging of the same patient, magnetic resonance imaging should be recommended. More complex would be a female patient in her 40s with atypical chest pain, inquiring about coronary CTA. While CTA may be appropriate for the clinical situation, the patient should be advised about alternative imaging and nonimaging diagnostic strategies, even if low-dose CT imaging is available. These examples demonstrate the need for a comprehensive, individualized review of the clinical scenario before performing cardiovascular CT and also the need for standards.

ABBREVIATIONS AND ACRONYMS

CT = computed tomography

CTA = computed tomography angiography

ECG = electrocardiography

Based on growing clinical experience, guidelines describing appropriate indications for cardiovascular CT have been established, weighing procedural risk, pre-test probability, and expected benefit (18). Procedural risk is defined by the need for vascular access, amount of injected contrast media, and level of radiation exposure, and depends on patient-specific criteria, including age and sex (5). It is important to note that a significant reduction in radiation dose for CT imaging of a particular indication (e.g., coronary CTA with <1 mSv) could

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shift the risk-benefit ratio and subsequently have an impact on appropriateness criteria. However, the relatively noninvasive nature of a test alone does not establish its usefulness for screening, in particular because false positives in patients with low pre-test probability can be associated with untoward outcome (19). Further, CT guidelines should be considered in the context of similar guidelines for other diagnostic (imaging) tests (20–23). Although guidelines for individual modalities exist, current guidelines do not match indications and modalities in a comprehensive (multimodality) fashion because of a lack of data from comparative studies.

If CT is determined to be the most appropriate test, it is important to tailor the imaging protocol to the clinical question. For example, assessment of coronary anatomy requires high spatial resolution and, subsequently, high tube current to achieve acceptable image noise. In contrast, for the assessment of noncoronary cardiovascular anatomy (e.g., evaluation of pulmonary vein or aorta), lower spatial resolution may be sufficient, permitting the reconstruction of thicker slices and the lowering of X-ray tube current during data acquisition (17). The difference in radiation exposure is significant; reconstruction of 1.5-mm thick slices allows a 33% reduction in tube current and, subsequently, radiation dose, compared to reconstruction of 1-mm thick slices while providing the same image noise.

The CT imaging protocol should also be tailored to patient characteristics. Lower dose options including prospective ECG-triggered axial scanning (24,25) and high-pitch prospective ECG-triggered helical scanning (26,27) are available to cardiac patients with lower heart rates. Although higher dose, low-pitch retrospective ECG-gated helical scanning is required on all commercially available scanners for patients with very high or very irregular heart rates, most cardiac CT patients can be imaged with the lower dose techniques (28). In addition, X-ray parameters including tube voltage and tube current should be adjusted according to patient size (17). In particular, a peak tube voltage of 100 kVp is indicated for many smaller to average size patients (29,30) resulting in a theoretical dose savings of 31% compared to imaging at 120 kVp (radiation exposure with CT is approximately proportional to the square of the tube voltage). The X-ray tube current can also be reduced for many patients, causing a linearly proportional decrease in radiation exposure; a 30% decrease in tube current results in a 30% reduction in X-ray exposure. Although higher X-ray parameter settings are required for imaging of heavier patients, the increased X-ray exposure does not necessarily increase radiation risk in these patients (31).

Although tailoring the cardiovascular CT imaging protocol to the clinical indication and the patient is critical for the optimization of both image quality and dose, the rapid development of scanner hardware and software as well as manufacturer differences in scanner design have largely prevented standardization of protocols. This is reflected in recent studies (32) demonstrating large variations in coronary CTA protocols, resulting in a wide range of radiation doses at different centers as well as recent, highly-publicized egregious errors in noncardiovascular CT imaging that have resulted in dramatic patient overexposure. Clearly, a coordinated effort is needed to standardize and regulate radiation exposure during cardiovascular CT, including regular monitoring of the radiation burden (9).

In dedicated imaging centers, these issues are addressed by the formation of imaging groups with collective experience of various imaging modalities (multimodality imaging). In such groups, dedicated protocols are designed in collaboration by radiologists, cardiologists, physicists, and technologists. Based on individualized review of the clinical indication, the patient is directed toward the most appropriate diagnostic test or strategy. For a specific imaging modality, the image acquisition protocol is adjusted on the basis of the suspected condition, pre-test probability, patient criteria, and in the case of CT imaging, appropriate radiation exposure.

The concerns about the increase in medical exposures to the population and the potential for misuse of the available technologies have prompted both the National Institutes of Health (33) and the Food and Drug Administration to announce initiatives to reduce unnecessary exposure from medical imaging examinations. The Medical Imaging Technology Alliance, a group of medical imaging equipment manufacturers, innovators, and product developers, has also endorsed measures to promote the responsible use of ionizing radiation-based diagnostic imaging procedures. Proposed initiatives include promoting patient awareness of medical radiation, expanding appropriateness criteria into clinical decision making, incorporating safeguards into scanner designs, developing radiation dose reference values for specific procedures, incorporating radiation dose values into the electronic medical record, creating a national dose registry, establishing minimum standards for training and education of imaging personnel, and expanding mandatory accreditation for advanced imaging facilities.

Conclusions

The realization of the increase in radiation exposure to the population from medical procedures and the resulting potential cancer risk rightly sounded an alarm to which the medical imaging field has an obligation to respond aggressively. Careful adherence to appropriateness criteria, rapid development and implementation of dose-lowering techniques, and thorough scrutiny of protocols have already served to improve practice and advance the field of CT, particularly cardiovascular CT. However, continued efforts are essential to ensure optimal patient care.

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Key Words: computed tomography ■ radiation dose ■ cardiac ■ coronary.