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CLINICAL REPORT

Radiation Risk to Children From Computed Tomography

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Guidance for the Clinician in Rendering Pediatric Care

ABSTRACT

Imaging studies that use ionizing radiation are an essential tool for the evaluation of many disorders of childhood. Ionizing radiation is used in radiography, fluoroscopy, angiography, and computed tomography scanning. Computed tomography is of particular interest because of its relatively high radiation dose and wide use. Consensus statements on radiation risk suggest that it is reasonable to act on the assumption that low-level radiation may have a small risk of causing cancer. The medical community should seek ways to decrease radiation exposure by using radiation doses as low as reasonably achievable and by performing these studies only when necessary. There is wide agreement that the benefits of an indicated computed tomography scan far outweigh the risks. Pediatric health care professionals' roles in the use of computed tomography on children include deciding when a computed tomography scan is necessary and discussing the risk with patients and families. Radiologists should be a source of consultation when forming imaging strategies and should create specific protocols with scanning techniques optimized for pediatric patients. Families and patients should be encouraged to ask questions about the risks and benefits of computed tomography scanning. The information in this report is provided to aid in decision-making and discussions with the health care team, patients, and families.

INTRODUCTION

Computed tomography (CT) is a valuable and essential addition to the array of imaging modalities for children. CT uses x-rays to provide rapid, consistent, and detailed information about virtually any organ system in infants and children. Because x-rays are an integral component for image formation with CT, there is an obligatory radiation exposure during the CT examination. Ionizing radiation has been demonstrated to increase the risk of cancer in individuals exposed to high doses of radiation. Moreover, recent reports have discussed the potential risk of cancer that results from the lower radiation exposure from CT examinations. These publications have raised concerns on the part of pediatricians, patients, and families. A review of this literature, however, shows widely differing opinions concerning the cancer risk of diagnostic imaging studies. Although many different statements on ionizing-radiation risk exist in the literature, one principle has been supported consistently by the authors of articles to which this report refers: any estimated risk of a CT scan is far less than the likely benefit to the patient for indicated examinations.

This clinical report is intended to serve as a resource for pediatric health care

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The recommendations in this report do not indicate an exclusive course of treatment or serve as a standard of medical care. Variations, taking into account individual circumstances, may be appropriate.

Key Words

computed tomography, diagnostic imaging, ALARA, ionizing radiation, cancer

Abbreviations

CT—computed tomography

BEIR—Biological Effects of Ionizing Radiation

ALARA—as low as reasonably achievable

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professionals and to improve understanding of pediatric CT radiation and its potential risk in the development of cancer. The report also includes suggestions for an informed discussion of this issue between those who provide and those who receive care. It is important to understand that the purpose of this commentary is not to perform an exhaustive review of the literature regarding low-level radiation biological effects; rather, the purpose is to summarize current opinions about the risks of cancer from exposure to radiation from imaging studies and to provide pediatricians with information that will be helpful in discussions with patients and families/caregivers regarding the radiation risks of CT examinations and the important clinical advantages of these studies.

IONIZING RADIATION

Ionizing radiation is defined as high-energy radiation that is capable of producing ionization in the tissues through which it passes and can be absorbed. One gray (Gy) is the absorption of 1 joule (J) of radiation energy by 1 kg of matter. One Gy equals 100 radiation absorbed doses (rads). The sievert (Sv) takes into account the biological effects of radiation and is determined by multiplying the gray by a quality factor. It is important to realize that ionizing radiation is continuously present in our environment. This radiation exposure is termed "background radiation" and includes natural and man-made sources. Natural sources of radiation include cosmic rays, radon, radiation from terrestrial rock, and natural radionuclides. These sources account for most of the radiation exposure received by all inhabitants of the United States. The amount of background radiation varies depending on location. Residents of Denver, Colorado, for example, receive approximately twice the annual background radiation received by those who live at sea level. This is because of increased cosmic ray exposure at the higher elevation as well as increased terrestrial radiation from the rock in the surrounding mountains. In the United States, the average background radiation is approximately 3 mSv/year per person.

Man-made radiation includes that of industrial and medical origins, with the latter being the larger source by far. Medical radiation can be measured several different ways. For example, the exposure to radiation from diagnostic radiologic procedures can be described as the dose that strikes the surface of the body, or entrance dose. However, the entrance dose is higher than the average dose to which the entire body is exposed. This entrance dose will not necessarily reflect the risk, because different parts of the body vary in their sensitivity to the effects of ionizing radiation. For example, studies of the Japanese survivors of atomic bomb detonations have demonstrated that the lung is more sensitive to the oncogenic risks of high doses of radiation than the liver, which in turn is more sensitive than skeletal muscle or skin. Radiation energy deposited in an individual organ

is the organ dose (measured in grays). When several organs are irradiated, the effective dose (measured in sieverts) is used to quantify the total patient risk and is computed by taking into account the dose to each organ as well as that organ's relative radiosensitivity (eg, lungs are more susceptible than skin).

For a given dose, there is a difference in cancer risk from radiation exposure to children compared with adults. There are several reasons for this difference. First, for the most part, tissues and organs that are growing and developing are more sensitive to radiation effects than those that are fully mature.^{1,2} Second, the oncogenic effect of radiation may have a long (for example, decades) latent period. This latent period varies with the type of malignancy. Leukemia has a shorter period (approximately ≤ 10 years) than solid malignancies. An infant or child, therefore, has a longer life expectancy in which to manifest the potential oncogenic effects of radiation compared with older adults. For example, a solid radiation-induced malignancy with a 30-year latent period will more likely occur in a 10-year-old than in a 50-year-old, on the basis of life expectancy. Pierce et al¹ summarized the radiation cancer risk at different ages and stated that those exposed at 50 years of age have approximately one third of the risk of a 30-year-old and that "[p]rojection of lifetime risks for those exposed at age 10 is more uncertain. Under a reasonable set of assumptions, estimates for this group range from about 1.0–1.8 times the estimates for those exposed at age 30." This increased sensitivity varies with age, with the younger ages being more at risk. Because the risk varies with age, the increased pediatric risk compared with adults will also vary depending on exactly which age groups are compared.¹ Third, in the case of CT scanning, the radiation exposure from a fixed set of CT parameters results in a dose that is relatively higher for a child's smaller cross-sectional area compared with an adult.³

DIAGNOSTIC IMAGING

X-rays are used in radiography, fluoroscopy, angiography, and CT. The dose depends on patient factors (such as age and size), technical factors (equipment settings and procedure length), and equipment model. Nevertheless, it is helpful to be familiar with some representative doses for common imaging studies (Table 1).

Three factors have made CT scanning the focus of much of the recent interest in ionizing-radiation exposure from diagnostic imaging. First, CT scanning provides a disproportionately higher amount of the radiation exposure from diagnostic imaging. In 2000, Mettler et al⁴ reported that CT scanning accounted for 11% of procedures that used ionizing radiation in a large academic radiology department but accounted for 67% of the radiation exposure. Second, indications for CT scanning and the number of CT scans are increasing rapidly. In a more recent study at the same institution, CT scan-

TABLE 1 Estimated Medical Radiation Doses for a 5-Year-Old Child

Imaging Area	Effective Dose, mSv	Equivalent No. of CXRs
3-view ankle	0.0015	1/14th
2-view chest	0.02	1
Anteroposterior and lateral abdomen	0.05	2½
Tc-99m ² radionuclide cystogram	0.18	9
Tc-99m radionuclide bone scan	6.2	310
FDG PET ³ scan	15.3	765
Fluoroscopic cystogram	0.33	16
Head CT	4	200
Chest CT	3	150
Abdomen CT	5	250

CXR indicates chest radiograph; Tc-99m, technetium 99m; FDG PET, fluorodeoxyglucose positron emission tomography.

Data were provided by R. Reiman, MD (Duke Office of Radiation Safety [www.safety.duke.edu/RadSafety], written communication, 2006).

ning accounted for 15% of the procedures and 75% of the dose.⁵ Third, CT scanning can be performed by using a wide range of techniques with variable radiation exposures that produce very similar image quality. With conventional (“plain”) radiographs, an increase in radiation dose makes the image darker, and most individuals will recognize that the film was overexposed. However, changing the amount of radiation for a CT study affects the amount of mottle (or image noise) with little other effect on the appearance of the image. Above a level of diagnostic quality, this decrease in mottle with increasing radiation will have no effect on diagnostic accuracy of the CT study and may not even be appreciated, but the exposure may have been unnecessarily high, especially in children.⁶ Until recently, the same CT-examination parameters were used for children and adults. In fact, a change in these parameters with a resultant reduction in dose, ranging from approximately 50% to 90%, has been shown to be satisfactory for a child’s CT study.

RISKS OF IONIZING RADIATION FROM DIAGNOSTIC IMAGING

No published studies have directly attributed cancer to CT scanning, and it is important to recognize how difficult it would be to perform such a study. The lifetime risk of fatal cancer in the general population is approximately 1 in 5. To perform a study to detect an increase from 0.2000 (the 1-in-5 risk in the general population) to 0.2002 (the 1-in-5 risk seen in the general population plus a 1-in-5000 potential risk from a CT scan) would require hundreds of thousands to millions of subjects and extremely careful matching of the subjects in the study to ensure an accurate result. Until such a study is completed and verified by the scientific community, estimates of risk must be based on other forms of ionizing-radiation exposure, and some assumptions must be made to apply these risks to the risks from diagnostic imaging. The most widely used source of risk estimates comes from data on atomic bomb survivors.

CT scanners and other diagnostic imaging equipment

use low-dose radiation, which is defined as a dose of less than approximately 100 mSv. There are numerous studies of populations receiving high doses of radiation above 500 mSv that have demonstrated an increased risk of cancer. These studies, reviewed in the 2005 report of the Biological Effects of Ionizing Radiation (BEIR) Committee of the National Academy of Sciences,⁷ provided widely accepted evidence that, at higher exposures, the risk of cancer increases linearly with increasing dose until extensive cell killing takes place at very high exposures. The relationship between radiation exposure and cancer risk from low-dose radiation is less clear.

Because of the diversity of opinion and the many different studies that have been performed, a broad range of estimates of the risk of ionizing radiation from diagnostic imaging can be supported by selecting specific publications from the peer-reviewed literature. It is impossible to provide a complete review of this literature here, and without a complete review, any summary could be biased. To our knowledge, there are no reviews that are considered to be authoritative.

Statements that are based on expert panel reviews of available information are additional sources of estimates of the risks of low-level radiation. The BEIR Committee of the National Academy of Sciences recently released their seventh statement in 2005. The committee concluded that “the risk of cancer proceeds in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increased risk to humans.”⁷ The United Nations Subcommittee on Atomic Radiation 2000 report stated that “an increase in the risk of tumor induction proportionate to the radiation dose is consistent with developing knowledge and that it remains, accordingly, the most scientifically defensible approximation of low dose response.”⁸ The International Commission on Radiation Protection recommendations (2005) stated that “the weight of evidence on fundamental cellular processes supports the view that in the low dose range up to a few tens of mSv, it is scientifically reasonable to assume that in general and for practical purposes cancer risk will rise in direct proportion to absorbed dose in organs and tissues.”⁹

In the absence of definitive evidence of the effects of low-level radiation, these consensus statements provide useful guidance. They suggest that it is reasonable to act on the assumption that the low-level radiation used in diagnostic imaging may have a small risk of causing cancer. If one assumes that radiation from a CT examination may cause cancer, it is reasonable that the medical community seek ways to decrease radiation exposure. Two ways to achieve this reduction are to use radiation doses that are as low as reasonably achievable (ALARA), which means that no more radiation should be used than is required to achieve the necessary diagnostic information, and to perform these studies only when they are necessary.

ROLE OF PEDIATRIC HEALTH CARE PROFESSIONALS

Pediatric health care professionals have an important role in the use of CT on children.¹⁰ The health care professional ultimately decides whether a CT examination is necessary. With this important role comes a responsibility to recognize both the value of CT and its risks, which, as described previously, it is reasonable to assume are very small but real. The health care professional should also be able to discuss these risks in a manner that is informative and understandable to patients and families. One must recognize that the decision regarding a CT examination will often depend on the combination of the interaction with consultants, such as radiologists, and the family. There is a vast pool of information available on the Internet, much of which may be confusing with respect to CT, radiation, and cancer. The pediatric health care professional should be in a position to be able to answer questions and address concerns.

The pediatric health care professional is usually the first, and often the only, source of direct communication with the child and the family. This relationship carries with it an opportunity to inform and educate the family. Recent reviews that covered CT technology and its role in the imaging armamentarium^{11,12} are salient for pediatric health care professionals. CT has an increasingly recognized role as the first, if not only, imaging examination for a wide variety of disorders that affect infants and children. What is most important to realize is that the use of CT is not infrequent in children and that the frequency of CT examinations is increasing. A recent review summarized investigations indicating that CT use has increased substantially over the last 1 to 2 decades, including estimates of at least 10% growth per year.¹³ Currently, approximately 11% of CT examinations are performed on children,⁴ which could account for more than 7 million pediatric CT examinations per year in the United States.^{13,14} The use of CT for common problems such as trauma (closed head injury, skeletal evaluation including cervical spine assessment, and blunt abdominal trauma), appendicitis, and renal calculi has increased the frequency of CT examinations in adult and pediatric populations. Most clinicians believe that CT studies on children prevent hospitalization for head injuries and that negative findings in patients with acute onset of abdominal pain can obviate surgical explorations. These studies provide information that leads to earlier and more definitive diagnosis.

This increased use, however, must be based on a firm understanding that the CT study is the best study for the clinical situation being evaluated and that the possibility of a very small risk of cancer is considered when making the decision to order the study. The possible cancer risk is not clearly understood by many health care professionals, as concluded by 2 recent investigations. In the first investigation, Lee et al¹⁵ surveyed emergency de-

partment patients, physicians, and radiologists. The results indicated that only 7% of patients indicated that there was any discussion outlining the radiation risks and benefits from an abdominal CT examination. In addition, only 9% of emergency department physicians believed that the lifetime risk of cancer was potentially increased by CT scanning. Moreover, 75% of physicians surveyed underestimated the accurate range for the equivalent number of chest radiographs for a CT examination (Table 1). In another recent investigation, Jacob et al¹⁶ surveyed physicians in the United Kingdom and found that only 12.5% were aware of the potential association of CT radiation and cancer. Less than 20% correctly identified the relative radiation dose of CT examinations.¹⁶ These studies support a continued and compelling need for radiation safety education for health care professionals and the public.

The pediatric health care professional should also be able to provide summary information to families on local practice patterns of radiology colleagues. It is reasonable to have information immediately available from the radiology practice in addition to that stated above. This information should include:

- additional expertise of the practice (pediatric radiology fellowship training, American Board of Radiology Certificate of Added Qualification, and current Maintenance of Certification in pediatric radiology);
- appropriate pediatric head and body CT protocols consisting of size- or age-based adjustments in scanner settings; and
- American College of Radiology accreditation of the CT scanners and the radiologists who interpret those studies in the practice.

An important role of the pediatric health care professional is to communicate with the radiologist to decide whether CT is the best study to perform. This consultation will vary from practice to practice, but it should be the goal of both parties to facilitate discussions on imaging strategies. These discussions provide an opportunity to share information, such as the number of studies using ionizing radiation to which the patient has been exposed. In addition to the pediatric health care professionals and radiologists, the integration of other care providers, such as surgical consultants or emergency department physicians, in decisions regarding pediatric CT policy or practice should also be fostered. Other imaging techniques such as ultrasonography or MRI may be suitable alternatives to CT examination, and they do not use ionizing radiation. If the CT examination is indicated and the radiology department uses a low-dose technique, another way to reduce CT dose is to limit the number of times (or phases) the child is scanned for the individual examination. It is very common for adult CT protocols to involve multiple scans through the same body part, which can double or triple the radia-

tion dose to the patient. For most indications for pediatric CT scans, a single pass through the body part of interest is usually sufficient for diagnostic purposes.

ROLE OF THE RADIOLOGIST

The value of having the pediatrician consult with the radiologist in the process of forming imaging strategies, such as with suspected appendicitis, as well as performing individual indicated CT examinations was discussed above. The importance of this consultation role should not be understated. The decision whether CT imaging should be obtained is determined, in large part, by the pediatric health care professional. However, the radiologist also has a responsibility to perform only those examinations that are appropriate. Any question by either party should trigger communication to be mutually certain about optimizing the child's care.

The radiologist also has a responsibility to create protocols and adjust scanning techniques on the basis of special considerations of pediatric patients.¹⁷ These technical considerations have been reviewed recently for chest and abdomen CT.¹² In short, the exposure factors, many of which contribute to the radiation dose, must be adjusted. The amount of radiation necessary for diagnostic CT examinations in infants and young children is less than that in adults. If the same settings are used for both children and adults, children will receive an unnecessary and excessive amount of radiation. Many manufacturers now provide at least some basic pediatric guidelines, but it is still the decision of the radiology practice if these are to be used.

Additional expertise in pediatric imaging may be available in certain practice settings. Although this is not requisite for appropriate CT examinations on children, it would be unusual for a practice with this expertise not to align with the current recommendation of size-adjusted pediatric CT. Radiologists, regardless of whether they are fellowship-trained pediatric radiologists, should be able to provide either health care professionals or families with information on the CT protocols and techniques used and be able to discuss the radiation equivalent of CT, potential risks, and any additional techniques (such as breast shields) used in the practice. In addition, radiologists must keep up to date with rapidly evolving CT technology. For example, the newest multidetector array CT scanners are extremely fast (a complete infant chest examination is possible in approximately 1 second). This fast technology is accompanied by expanded uses in current applications as well as new applications. Furthermore, the radiology practice should also be able to keep pace with potential changes in radiation exposure from this technology as well as new technology to help manage radiation doses.¹⁸

CONCLUSIONS AND INFORMATION FOR FAMILIES AND PATIENTS

Concerns about radiation exposure are understandable, and questions should be encouraged, particularly when scientific communications are reported in the lay press.¹⁹

The following information can serve as a foundation for this discussion of CT examination and risks.

- Radiation is an essential component of a CT examination.
- The amount of radiation that a CT examination provides is low-level radiation.
- The cause-and-effect relationship between low-level radiation, such as with CT, and cancer is not certain, but expert panels that have examined this question have suggested that there is a small risk that increases with increasing dose.
- No direct connection between CT examinations and subsequent development of cancer has been demonstrated, so the risks of CT scans must be estimated, and these estimates vary depending on the information used.
- The amount of radiation that CT provides depends on many factors, especially the protocols used and equipment settings for the individual examination.
- In general, properly performed CT examinations of children should expose a child to much lower exposures than those for the same procedure on an adult.
- The potential benefit from an indicated CT examination is clinically recognized and documented and is far greater than the potential cancer risk.
- Radiologists are specialists in CT who are trained to use the least amount of radiation necessary (the ALARA principle, discussed previously).

In summary, there is wide agreement that the benefits of an indicated CT scan far outweigh the risks. It is the responsibility of those health care professionals who use CT scanning to ensure that each CT scan is indicated. It is the responsibility of radiology personnel to ensure that radiation risk is minimized by using the ALARA principle to determine the correct technique. The information provided in this clinical report is offered to aid in decision-making and discussions with the health care team, patients, and families.

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