REVIEW ARTICLE

CME

Radiation Protection in Paediatric Computed Tomography Revisited

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ABSTRACT

Advances in medical imaging have been exponential in recent years, resulting in significant improvements to patient care. This has also incurred an increase in radiation exposure for patients, primarily due to the increased use of relatively high radiation dose imaging modalities, namely computed tomography. It is widely recognised that children are generally at higher risk of the adverse effects of radiation than adults. This article revisits the general principles of radiological protection, and provides updates and highlights of the practice in paediatric computed tomography.

Key Words: *Child; Radiation dosage; Radiation protection; Tomography, X-ray computed*

中文摘要

再探討小兒CT掃描的輻射防護

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近年醫療成像技術不斷進步，使對病人的治療有了顯著改善，但同時令病人有機會暴露於輻射中，尤其是包括CT掃描在內相對較高劑量的成像技術。普遍認為暴露於輻射環境下的兒童產生病患的風險比成人高。本文重溫放射防護的一般原則，並提供有關小兒CT掃描的資料更新及作重點討論。

INTRODUCTION

The clinical demand and application of imaging in medical diagnosis has increased substantially over the past decades. Medical exposure remains by far the largest man-made source of exposure to ionising radiation (95%) and continues to grow at a substantial rate. This has resulted in a situation where the annual collective and per-capita dose of ionising radiation due to diagnostic radiology has exceeded that from the natural background radiation in several developed countries. There are now about 3.6 billion medical radiation procedures performed annually, a number that has more than doubled over the last two decades from 1988-2008.[1]

Radiological examinations generally pose a higher risk

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for development of cancer per unit of radiation dose in infants and children than in adults, and is estimated to be 2 to 3 times that of the general population.[2] In children, approximately 25% of tumour types are clearly more radiosensitive, including leukaemia, thyroid, skin, breast, and brain cancers.[3] This is due to the increased radiation sensitivity of growing organs and bones, and children's longer expected life span. Tissues with a high mitosis rate are fundamentally more vulnerable than inactive tissues, as DNA metabolism is damaged by radiation. The radiation risk is therefore highest in infancy and early childhood, in line with general growth patterns, and in adolescence it gradually approaches the risk to which adults are exposed.[4-6] Children's tissues also have a higher water content. This means that more radiation is absorbed and dispersed, so a higher dose is needed to penetrate a layer of tissue of the same thickness. Moreover, the small size of newborn infants brings all organs within or closer to their radiated volume, resulting in a higher radiation dose per procedure than may be the case with adults.[7,8] Hence, a more cautious approach to the use of ionising radiation is recommended in children than in adults.

USE OF COMPUTED TOMOGRAPHY IN CHILDREN

Computed tomography (CT) is a relatively high radiation dose imaging modality. Whilst comprising approximately 17% of all radiological examinations, it contributes half the effective dose of all radiological examinations.[1] CT scans in children account for 3% to 8% of the total number of CT scans.[1] With improved education and awareness of the need for radiological protection, plus the increased availability of magnetic resonance imaging (MRI), there has been a decreasing trend in the use of CT in children in developed countries in recent years.[9] Nonetheless, there is still concern about the use of unjustified CT examinations; based on the referral criteria provided by the European Commission, a study in Finland found that approximately 30% of CT examinations in young patients were unjustified.[10]

The International System of Radiological Protection developed by the International Commission on Radiological Protection (ICRP) is anchored by the principles of justification and optimisation of protection in medicine.[11] These general principles and their application in paediatric CT are addressed below.

Justification

ICRP recommends justification of medical exposure on three levels: (1) that use of radiation in medicine should do more good than harm; (2) that a given type of procedure is justified for a particular clinical indication as it will improve the diagnosis or treatment of patients; and (3) that a medical examination for an individual patient will do more good than harm, by contributing to the management of the patient's treatment.

Referral guidelines for the appropriate use of imaging examinations are readily available from, for example, the American College of Radiology (ACR Appropriateness Criteria, www.acr.org/ac) and the Royal College of Radiologists, UK (2007; http://www.rcr.ac.uk) to assist with level 2 justification. Further recommendations have been effectively advocated by the *Image Gently* Campaign (http://imagegently.org). Clinicians are responsible for carrying out level 3 justification for every patient for whom an imaging procedure that uses ionising radiation is requested, based on the patient's clinical condition and history.

The appropriateness of alternative techniques that do not use ionising radiation, such as ultrasonography and MRI, should always be considered. For example, ultrasonography should be the first-line consideration for imaging the abdomen and pelvis in paediatric patients, as their small size and slim body habitus allows the use of high-resolution ultrasound probes that provide good visualisation of abdominal structures and can obviate the use of CT, such as in the evaluation of acute abdomen for possible acute appendicitis. For detailed information of the musculoskeletal system and nervous system (with the exception of neonatal head and spine sonography), MRI is often the modality of choice due to its superior contrast resolution.

Follow-up CT scans should not be performed too early when, according to the known biology of the disease, one cannot yet expect any treatment response.[12] Justification has to be as rigorous as for the first examination, and alternative modalities may suffice. Also, scanning should be limited to the minimum length needed, and repeated scanning of identical areas (i.e. the use of multiphase CT scans) should be justified in every patient.[13] Regular audits of referral criteria should be implemented to improve practices. Examples of recommendations based on audit include guidelines for head CT for paediatric skull trauma and headaches presenting to the emergency department that have resulted in downward adjustments in CT scans,[14-16] and the recommendation that CT is not indicated for uncomplicated acute bacterial sinusitis in children.[17]

Optimisation

The basic aim of optimisation of radiological protection during an examination is to adjust imaging parameters and institute protective measures in such a way that the required image is obtained with the lowest possible radiation dose, and net benefit is maximised, i.e. the ALARA (as low as reasonably achievable) principle, and it should be adhered to for every examination.

Computed Tomography Equipment

Special consideration should be given to dose-reduction measures when purchasing new CT scanners as part of the optimisation process. Of note, new scanners whilst being equipped with advanced dose-reduction technology are becoming increasingly complex. There may be a tendency to favour the adoption of new practices without giving full regard to the optimal use of dose-reduction algorithms. Hence, it is important that expert advice is sought from a medical physicist not only for procurement, commissioning, and quality-control tests, but also for optimisation of protocols.

Image Quality and Study Quality

Both image quality and study quality should be optimised. To ensure optimal quality of the study, the patient should be well prepared prior to the scan. This includes the selective use of sedation that is essential in eliminating or reducing patient movement and degradation of image quality and the meticulous administration of intravenous contrast if required. In planning the scan, objective attributes to quality to be considered include image noise and image contrast. For the purpose of minimising radiation dose exposure, noisier images, if sufficient for radiological diagnosis, should be accepted. More image noise may be acceptable in skeletal or lung parenchymal examination than in brain and abdominal examinations, due in part, to the higher contrast differences in the former.[18] A chest examination with higher noise may have the same study quality as a lower noise abdominal study. This has been evaluated in chest CT of children with cystic fibrosis where 0.5-mm thin sections were used instead of 1.0-mm sections, providing sufficient diagnostic acceptability for the depiction of bronchovascular structures at lung window settings and reducing the radiation dose (0.14 mSv ± 0.04 vs. 0.19 mSv ± 0.03).[19] Abdominal organs such as the liver, kidney, and pancreas may only show minimal density differences between normal tissue and pathological lesions, and may require a higher patient dose to obtain diagnostic quality. The acceptable scan quality may also be determined by the clinical indication of the study. For example, for follow-up evaluation of ventricle size after ventricoperitoneal shunt insertion, it was determined that use of low-dose head CT (80 mA) is acceptable.[20] High-contrast lesions, even small, such as kidney stones, are amenable to low-dose CT techniques in children.[21] On the contrary, small low-contrast lesions require higher-contrast resolution. For example, more image noise may be tolerated in a follow-up study to assess a fracture of the liver than in a study to assess the presence of small liver metastases. Also, three-dimensional (3D) reconstruction to determine bony outlines for surgical planning may be performed at low-dose levels.[22] After acquisition of the scan, post-processing techniques are important to further improve study quality. This includes the use of multiplanar and 3D reformations. The perception of study quality is also related to the display of the data, and therefore reporting monitors should be optimised, and the ambient environment adjusted to enhance viewing.

Use of Diagnostic Reference Levels in Computed Tomography

To assist in the optimisation process of medical exposure of patients, the concept of diagnostic reference levels (DRLs) is applied. It should be noted that DRLs and image quality evaluation should be implemented together in optimisation. DRL is considered to be exceeded when the median value of the DRL quantity for a representative sample of comparable patients at a facility is greater than the local, national, or appropriate reference DRL value from available published data. In the selection of reference DRLs for comparison, it is important that the data are comparable, including detector technology, detector configuration, image reconstruction algorithms, patient size, scan protocol, etc. For CT, the radiation dose quantity used for DRL is volume computed tomography dose index (CTDIvol) and dose-length product (DLP). In children, due to the variation in patient size and weight, even within the same age band, it is now recommended that appropriate weight bands (generally with 10-kg intervals) be used in establishing paediatric DRLs.[23] In future, DRLs based on patient dimensions may be used. A parameter known as the size-specific dose estimate that allows estimation of patient dose based on CTDIvol and patient size has been proposed.[24] This may be used in addition to CTDIvol and DLP for optimisation. Of note is the paucity of available published DRL for paediatric

CT and the slow updating of paediatric DRLs, recommended to be 3 to 5 yearly, due to the relatively few examinations performed compared with adults. Some paediatric CT DRLs are summarised in ICRP publication 121,[25] and more recently, published data derived from the United States,[26,27] Japan, and Korea.

CONCLUSION

A thorough understanding of the principles and practice of radiological protection is imperative. Finally, the delivery of clear, balanced, and accurate communication of risk-benefit of CT to our referrers, patients and their parents is important.

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