By Dr T Kudo & Dr H Hatabu

Current approaches to the reduction of radiation dose in CT: a brief review of methodology

The dramatic increase in the use of CT in recent years has brought with it growing concerns regarding the total radiation exposure involved. Recent technological advances have made possible several methods that can be used to achieve significant dose reduction without any clinically significant loss in image quality.

This article briefly reviews these methodologies and sumnmarizes their characteristics.

BASIC RATIONALE FOR DOSE REDUCTION

Thanks to its high spatial and temporal resolution and high diagnostic accuracy, CT has become a powerful and indispensable tool in medical imaging. Over the last few decades the applications of CT have expanded dramatically so that nowadays CT examinations are used in daily routine for a large number of clinical indications. However, this huge increase in the number of CT examinations being carried out has given rise to growing concerns regarding the total radiation exposure to patients. Of all the imaging modalities using ionizing radiation, CT is responsible by far for the largest contribution to the total level of radiation exposure from diagnostic imaging. The radiation exposure associated with CT has grown to such an extent that it has become the largest source of ionizing radiation, higher than natural background radiation from the environment. The radiation dose associated with CT has now reached a level where the risk associated with the examinations cannot be considered negligible.

It is true that the precise adverse effects caused by small amounts of ionizing radiation have not been fully elucidated. Nevertheless, it has been generally agreed that the ALARA principle (As Low As Reasonably Achievable) should be widely applied to avoid any possible harm to the patients undergoing CT examination. Recent technological advances have made available several methods and tools that can be used to achieve significant dose reduction.

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RADIATION DOSE MONITORING TOOLS

To reduce the radiation dose and lower the associated radiation-related risk, it is important to quantify and record the radiation dose. Several methods have been developed:

A CT dose registration system has been built by the American College of Radiology (ACR) to collect CT radiation exposure records (dose index registry, DIR), which is a part of the ACR National Radiology Data Registry (NRDR) databases. The ACR system consists of a network that connects a central database with radiation dose record servers in participating institutions so that real time CT dose data from these institutions can be continuously collected and integrated. Thus, the dose level in a particular medical institution in the network can be compared with the standard dose established from the total collected data. Each participating institution can then judge whether the dose level of its own facilities needs to be modified.

The International Atomic Energy Agency (IAEA) is promoting an initiative called Smart Card/SmartRadTrack Project whose aim is to track the radiological procedures that individual patients have undergone and record the radiation dose involved in these procedures. Patients or health care providers can retrieve the records of the radiation exposure history using Smart Card as a key to access.

PRINCIPLES OF RADIATION DOSE REDUCTION

There are three important tasks that need to be addressed to achieve radiation dose reduction:

(1) defining the adequate image quality for the clinical purpose,

(2) selecting the scan parameters, and

(3) choosing image production methods.

(1) The appropriate level of image quality varies as a function of the objective of the examination. Thus searching for very small lesions or faint lesions with low contrast requires images of high quality and with low noise levels. However, in the majority of clinical indications for CT, a moderate level of image noise may be acceptable

and does not prevent clinically relevant information from being obtained. In other words, in such cases an increase in image quality does not lead to any improvement in diagnostic value.

(2). The two major user-selectable scan parameters are tube current and tube potential. For selection of tube current, automatic exposure control systems can be utilized (see below). However, selection of the optimal tube potential is more complex than that of the tube current: the tube current needs to be modified at the same time as any change in the tube potential. Automatic selection of the optimal combination of mAs and kVp value is currently available in some scanner models and such systems are expected to become more widely available.

(3). Image reconstruction methods change the quality of CT images, with the newer reconstruction methods, e.g. iterative reconstruction (see below) generating images with much less noise than those produced by conventional filtered back projection (FBP) methods and consequently providing significant advantages as far as radiation dose reduction is concerned [Figure].

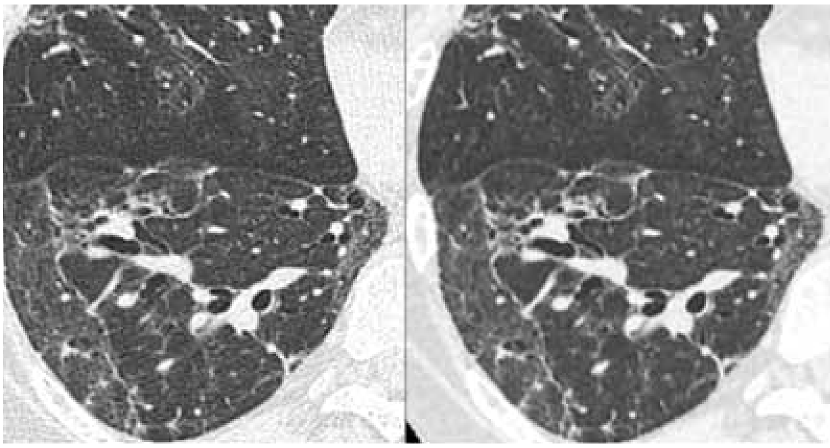

Figure. The noise reduction effect with iterative reconstruction techniques. Left Panel, Filtered Back Projection (FBP). Right Panel full-IR.

AUTOMATIC EXPOSURE CONTROL

Most modern CT scanners are equipped with automatic exposure control (AEC) systems which modulate the tube current to produce images with the desired image quality. The systems set the baseline tube current and adjust it dynamically during the scan, with the tube current being individualized by the AEC system according to the size of the patient.

In addition, the optimal tube current also changes during a single scan. Since the attenuation value of the body varies depending on the level of the scan and the direction of the X-ray, a constant, fixed tube current throughout the scan would lead to variations in image quality. To address this, the AEC system adjusts the tube current dynamically both along the table feed and gantry rotation to make the image quality uniform. In practice, when AEC is applied, the operators simply select the desired image quality, not directly the tube current.

It is important to note that the extent of dose reduction depends on the level of image quality chosen by the users. If the target image quality is set at a high level, the AEC can increase the radiation dose to maintain the image quality as set by the operator. Therefore, an understanding and knowledge of the image quality appropriate and sufficient for the clinical diagnostic objective is essential even with AEC systems. There are some minor differences in the AEC systems among CT vendors. The currently available AEC systems from the various vendors are 3D mA modulation (GE); Intelli EC (Hitachi); DoseRight (Philips); CARE Dose 4D (Siemens) ;and SureExposure 3D (Toshiba).

ITERATIVE RECONSTRUCTION

Iterative reconstruction (IR) in CT involves the use of reconstruction algorithms operating in a repetitive process. IR generally produces higher quality images with lower noise and fewer artifacts compared to the filtered back projection algorithm that has been the standard method of CT image reconstruction since the advent of clinical CT scanners.

There are two broad categories of modern reconstruction algorithms used in CT reconstruction: hybrid-IR algorithms and full-IR algorithms, with the computational demands of the methods differing significantly between these two classes.

In **hybrid-IR** systems, repeated image processing is performed within projection data domain and/or spatial domain and does not involve projections from the spatial domain onto the projection data domain. Currently available reconstruction algorithms from the various manufacturers are ASIR (GE), Intelli IP (Hitachi), iDose4 (Philips), IRIS and SAFIRE (Siemens), and AIDR 3D (Toshiba).

Hybrid-IRs require much less processor power than full-IR and are available in majority of CT scanners currently on the market. The processing time is only slightly longer than that of FBP algorithms. Thanks to the short processing time of hybrid-IRs, they can be used in routine CT protocols. The typical effective radiation doses of the thoracic CT using hybrid-IR range from 3 to 1 mSv.

Full-IRs consist of both forward and backward projection, thus making image processing by full-IRs far more computer-intensive. For this reason, an additional reconstruction processing unit is generally provided to meet the computational requirements. However, even with a dedicated unit, reconstruction by full-IRs takes much longer than FBP and hybrid IR. Processing times can range from several minutes to more than an hour. Therefore, at present Full-IR cannot be applied routinely for all examinations. The currently available Full-IR systems from the various manufacturers are VEO (GE), IMR (Philips), ADMIRE (Siemens) and FIRST (Toshiba).

Although suffering from the disadvantage of relatively long processing times, Full IR reduces noise more efficiently than hybrid-IR, making further dose reduction possible.

Images produced using IR techniques have low levels of image noise, with the result that the appearance of IR images can look somewhat "unnatural". It is true that the texture of the IR-generated images is different from those generated by FBP, but this does not mean that IR images are inferior to FBP images. Provided the normal and pathological structures are visualized as clearly as in FBP images, IR images are acceptable nad are likely to become more popular.

VERY LOW DOSE CT TECHNIQUES

There are have been several reports of "ultra-low dose" examinations, e.g. very low dose chest CT examinations with effective doses less than 1.0 mSv. Such protocols are generally made possible through use of iterative reconstruction algorithms. There have also been reports of chest CT examinations with radiation doses as low as that from a pair of standard chest X-ray images (namely posterior-anterior view and latero-lateral view). These ultra-low dose techniques may change the relative roles of chest X-ray and chest CT. For example, ultra-low dose CT methods could shift the risk-benefit balance favorably towards a wider application of CT-based cancer screening programs.

QUANTITATIVE IMAGING

Quantitative imaging is a recent, emerging concept in radiology and involves the generation of numerical indexes from medical images for use as biomarkers. Thanks to advances in information technology, the quantitative imaging approach is likely to become more popular and accessible in the future. The Quantitative Imaging Biomarkers Alliance (QIBA) and the European Imaging Biomarkers Alliance (EIBALL) have been set up under the aegis of the Radiological Society of North America and the European Society of Radiology, respectively, to establish the standards of qualitative imaging biomarkers. The precision of measurements on low dose images will be an important question in the development of quantitative imaging. The effect of image quality and radiation dose level on the biomarker indices needs to be more extensively evaluated. By the same token, the computer-assisted diagnosis (CAD) of CT images is expected to become more widely utilized in the future. The image quality suitable for these CAD application of CT images needs to be investigated further.

CONCLUSION

Recent developments of CT technology have brought important advances in radiation dose reduction, particularly AEC systems and IR methods. Judicious use of these technologies will improve patient safety.

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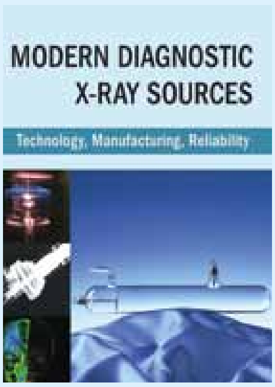
Book review

Modern Diagnostic X-Ray Sources: Technology, Manufacturing, Reliability

By Rolf Behling

Pub by CRC Press 2015, 423 pp, Hardback £88.00; ebook £61.60



Modern Diagnostic X-ray Sources: Technology, Manufacturing, Reliability gives an up-to-date summary of X-ray source design for applications in modern diagnostic medical imaging. It lays a sound groundwork for education and advanced training in the physics of X-ray production and X-ray interactions with matter. The book begins with a historical overview of X-ray tube and generator development, including key achievements leading up to the current technological and economic state of the field.

The book covers the physics of X-ray generation, including the process of constructing X-ray source devices. The stand-alone chapters can be read continuously or in selections. These take the reader inside diagnostic X-ray tubes, illustrating their design, functions, metrics for validation, and interfaces. The detailed descriptions enable objective comparison and benchmarking.

The book covers the full scope of medical diagnostic X-ray sources, including materials, processes, quality assurance, manufacturing, cost, operation, maintenance, and sustainability

It discusses existing and future technology design concepts, tube and high-voltage generator types, use in various modalities, standards, failure detection and repair, and other commercial aspects

The requirements for each of the different diagnostic system modalities, including computed tomography, interventional X-ray imaging, and general radiography are addressed and the book presents X-ray generation for medical diagnostics as compared to other applications to give the reader an understanding of the standard solution for medical imaging

The book gives an insider's view on technological limitations, comparisons of performance, key terminology, specifications, and rating charts.