Clinical Expansion of CT and Radiation Dose

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Abstract

The principles of protecting the patient undergoing clinical investigation using radiation are clear and well established: it is the responsibility of all radiological services to ensure the information required for the clinical management of the patient is obtained with the lowest practicable exposure to radiation. Within this clear objective, however, medical investigation operates in a constantly changing scenario influenced by increasing knowledge of disease processes and advancing technological development. This syndrome ensures that as time passes differing objectives and concerns come to the fore. With the now widespread adoption of multidetector computed tomography (MDCT), for a broad range of examinations, MDCT continues to be the dominant source of dose from medical X-ray examinations, thereby posing significant challenges in radiological protection to the extent that some now claim that this represents today's greatest single challenge in radiation protection in diagnostic use. This book expounds the challenges posed by MDCT to scientists and physicians and in this chapter we provide an introduction to the main themes which are of concern.

1 Introduction

The principles of protecting the patient undergoing clinical investigation using radiation are clear and well established: it is the responsibility of all radiological services to ensure the information required for the clinical management of the patient is obtained

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D. Tack et al. (eds.), *Radiation Dose from Multidetector CT*, Medical Radiology. Diagnostic Imaging,
DOI: 10.1007/174_2012_541,

with the lowest practicable exposure to radiation. Within this clear objective, however, medical investigation operates in a constantly changing scenario influenced by increasing knowledge of disease processes and advancing technological development. This syndrome ensures that as time passes differing objectives and concerns come to the fore. With the now widespread adoption of multidetector computed tomography (MDCT), for a broad range of examinations, MDCT continues to be the dominant source of dose from medical X-ray examinations, thereby posing significant challenges in radiological protection to the extent that some now claim that this represents today's greatest single challenge in radiation protection in diagnostic use. This book expounds the challenges posed by MDCT to scientists and physicians and in this chapter we provide an introduction to the main themes which are of concern.

Since its inception in 1973 (Hounsfield 1973) the development of computed tomography (CT) has been dramatic and the technique continues to mature and expand. Over 30 years ago a typical study consisted of 10 mm sections, a 20 s exposure time and a 60 s image reconstruction time. Technical developments including the development of slip rings, increased X-ray tube heat capacity, advances in multi-detector technology and improvement in computer processing now permit rapid sub-second exposures for acquiring sub-millimeter sections and almost instantaneous image reconstruction along with options of multiplanar reconstruction and three-dimensional (3-D) imaging. These improvements have brought benefits in clinical examination, extending the applications of CT into new areas and facilitating difficult or demanding examinations in all applications. The major development in technology has been MDCT, which has dramatically increased the performance capability of CT. It is now routine to expect modern radiology departments to have systems capable of acquiring 64 or more sections simultaneously have been introduced (Berland and Smith 1998; Hu et al. 2000; Kalender 2000; Prokop 2005). Even greater configurations are now becoming available, with the latest cone beam systems capable of simultaneously acquiring 256 sections (Mori et al. 2006). Beyond this dual energy scanners, for the distinction of bone and vessel structures (Morhard et al. 2009), and iterative reconstruction methods, as a means for dose reduction with controllable noise reduction (Gervaise et al. 2011), are both being trialled clinically. The incorporation of slip ring technology into the design of scanners in the late 1980s removed the need for rigid mechanical linkage between the power cables and the X-ray tube. The ability to rotate the tube continuously in one direction allowed the development of helical CT and re-established CT as a front-line imaging modality. Helical CT allows a volume of tissue rather than individual slices to be scanned as the table supporting the patient also moves continuously while the tube is rotating; the data are reformatted automatically to display the images as axial slices. Furthermore, whereas conventional and spiral scanners use a single row of detectors, MDCT scanners now have multiple active rows of detectors and selectable geometry. The increased number of detectors combined with sub-second tube rotation times have increased the speed and the ability to cover large body areas without anatomical misregistration (Garney and Hanlon 2002). Whole CT examinations may now be carried out within a single breath-hold (e.g. thorax, abdomen and pelvis in a trauma patient in 20 s) (Kalender et al. 1990). As well as increased speed and volume coverage, MDCT offers excellent opportunities for dedicated 2-D and 3-D visualization and post processing. Continuous data acquisition also means lesions can be evaluated during different phases of contrast enhancement and small lesions which may be missed with conventional CT can now be detected (Ichikawa et al. 2006).

Thus, modern CT scanners now offer clinical tools of vast flexibility. However, these benefits have not been without a price and it is arguable that MDCT has become Diagnostic Radiology's major radiation protection challenge.

2 Clinical Expansion

The continued development of MDCT means it remains a challenge of patient protection, owing to increased use in established applications and the introduction of a wide range of new applications. Despite efforts to move away from CT in some traditional examination areas, using either ultrasound (US) or magnetic resonance imaging (MRI) as the first imaging modality for patient examination, the further development of new CT technology and associated applications means the volume of patient examinations shows no signs of decreasing yet.

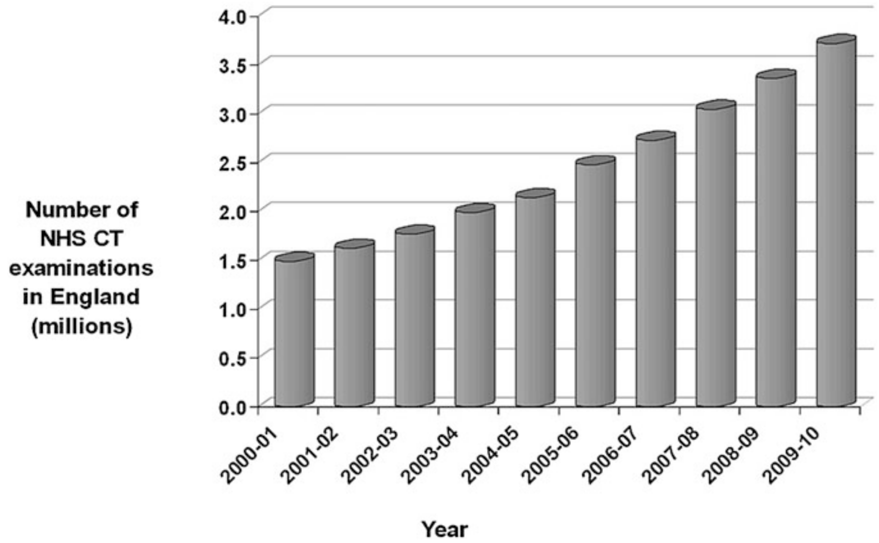

Fig. 1 Annual numbers of NHS CT examinations in England, showing the growth in frequency of scans since the millennium

Figure 1 shows how in England CT use has continued to grow (Hart et al. 2010) with the National Health Service (NHS) referral frequency increasing year on year since the millennium (Meeson et al. 2011).

MDCT is routinely used for multiphase enhancement studies (Zoetelief and Geleijns 1998) including optimized injection protocols in multiphasic contrast-enhanced MDCT of the liver (Ichikawa et al. 2006). CT angiography continues to expand (Makayama et al. 2001; F or Lederlin et al. 2011), with CT urography (Anderson and Cowan 2004) and CT virtual colonoscopy (VC) (Landeras et al. 2007) contributing to greater use of 3-D imaging and virtual reality (Caramella and Bartolozzi 2002). For example, in the case of a neoplasm of the pancreas, it is possible to outline the primary neoplasm at an optimal phase of enhancement while at the same time gathering images of the liver in different phases of enhancement in order to examine for metastatic disease (Johnson 2001). Where the investigation is justified, completing it in one sitting is clearly of benefit in terms of facilitating treatment planning and for the patient.

It is recognized that the effective dose from CT scans of the head and neck is considerably lower than that from CT examinations of the abdomen or chest. However, head and neck CT examinations for well-established clinical indications (such as sinusitis, unilateral conductive hearing loss and acute stroke) are more common and the collective dose to the population from cranial examinations is therefore higher. Scan parameters for head and neck CT examination protocols are generally chosen to obtain the best image quality and meet the highest diagnostic criteria, but with an associated radiation dose cost. Radiation dose from head CT scans may vary considerably as a result of inherent differences in equipment and because of variations in exposure technique and scanning protocol. Previous studies where systematic changes in scanning parameters were analyzed with respect to resulting image quality have reported dose reductions of 40% or more in CT scans of the head without loss of relevant information or diagnostic image quality (Smith et al. 1998; Cohnen et al. 2000; AC or Kröpil et al. 2010; AD or Abul-Kasim et al. 2011).

The use of CT for the evaluation of cervical spine trauma achieves an end health state of high value compared to just conventional radiography (Theocharopoulos et al. 2009; European Commission 2008). However, our latest cervical spine test phantom and low dose CT studies suggest there is clear latitude for reducing dose while preserving image quality (publication forthcoming).

Well-established clinical indications for CT of the chest include bronchiectasis and the evaluation of interstitial lung disease. Chest CT is also commonly used to detect pulmonary metastases. CT is now the "gold standard" in imaging suspected pulmonary embolism (PE) (European Commission 2008; Henzler et al. 2011) replacing pulmonary scintigraphy or angiography as a first line investigation for PE

(Mayo 1997). While traditional angiography will continue to be used for various treatment options (such as the placement of stents or angioplasty) the diagnostic role of angiography is increasingly being carried out using the non-invasive procedure of CT angiography. A meta-analysis of this technique has demonstrated sensitivities of 53–100% and specificities of 83–100%, wide ranges which are partly explained by technologic improvements over time (Rathburn et al. 2000; Wittram et al. 2004).

MDCT has reduced scan times to a few seconds allowing patients to be scanned with very high resolution. Also, patients with severe pulmonary disease and congestive heart failure can be examined in a single breath-hold. Fast acquisition of narrow slices combined with ECG gating permits scans with greater temporal resolution. The main use of these images is for the visualization of the coronary arteries and calcium scoring for assessment of stenoses. The evaluation of the effect of ECG controlled tube current modulation on radiation exposure in retrospectively ECG-gated multi-slice CT of the heart has been shown to reduce dose by 37% (Poll et al. 2002) or more (Lehmkuhl et al. 2010).

Established indications for CT of the abdomen include detecting causes of sepsis (sensitivity 95% and specificity 91% (Meeson et al. 2009)), and detection of retroperitoneal lymphadenopathy or liver metastases from neoplasms. A relatively new clinical indication is urolithiasis. CT urography (CTU) allows comprehensive evaluation of the urinary tracts and it is now the primary imaging study for the evaluation of adults over 40 years old with hematuria (European Commission 2008). Together with other genitourinary conditions CTU has become an established technique for examining patients with acute renal colic (Kawashima et al. 2004; Wells et al. 1998). The sensitivity and accuracy of non-contrast CT in assessing ureteral calculi has been reported to be as high as 97% (Smith et al. 1996). Both CT angiography and CT urography cover large body areas with several hundred sections. The field of 3-D imaging and virtual reality is too large to cover here but MDCT has made these studies remarkably easy, for example, facilitating the development of CT virtual colonography. The technique of virtual colonoscopy was first introduced in the mid-1990s as a non-invasive technique to image the colon (Vining 1997). Thin axial slices through the abdomen are obtained in supine and prone positions and may be reconstructed into 3-D surface rendered images giving the impression of viewing the large bowel via an endoscope. It has now been suggested that best practices for polyp size measurement with VC include the use of 3-D endoluminal displays, 2-D displays with a window level near −500 HU and automated measurement software (Summers 2010).

A further development has been CT fluoroscopy which enables real-time monitoring for image-guided biopsy procedures. Improved needle manipulation has made previously difficult procedures easier. However, careful use of this technique is essential as there is potential for large skin doses to both patient and operator (Olerud et al. 2002). The use of tube currents as low as 10–30 mA have been shown to give significantly lower patient skin doses while still providing sufficient image quality in order to control the difficult steps of the procedure. In addition, lead protection has been shown to reduce the scattered dose to the operator by more than 90% (Irie et al. 2001).

CT screening is an emerging concept targeting early detection of disease entities such as lung cancer, colon cancer and coronary artery disease. The issue of screening for disease by CT is a difficult area, as clinical benefit has to be demonstrated conclusively to justify irradiation of a large number of normal individuals. Furthermore the impact on patients and health care services also needs to be quantified to determine the physical, psychological and financial costs of false negative impressions and subsequent unnecessary clinical interventions. One American study of the detection of pulmonary nodules found a primary neoplasm rate of only 0.03% (Benjamin et al. 2003).

In situations where the diagnostic yield of CT is expected to be so low, alternative, safer examinations should always be considered. Contrary to the general expectation that, with the advent of magnetic resonance imaging and its widespread use the use of X-ray computed tomography would decline rapidly, MDCT has continued to gain importance (Kalender 2000). However, MRI is an imaging modality that is considerably safer than CT on the basis of a number of factors, of which radiation dose is perhaps the most significant. It therefore provides the main “competition” for MDCT in clinical practice where it is available and applicable. A recent article has shown that screening MRI of the entire body may be more accurate than individual "gold standard" diagnostic investigations of individual organ systems (Lauenstein et al. 2004). There are important differences between MDCT and MRI, including speed, metal object compatibility, availability and cost. However, the present high use of MDCT suggests powerfully that whether MRI can replace CT for various indications should be continuously re-evaluated, perhaps even in circumstances where MDCT may be diagnostically more accurate (Semelka 2005).

The extension of CT into new areas continues. Several studies have already demonstrated that CT is ideally suited to the challenges posed by patients with suspected appendicitis. Raptopoulos et al. (2003) have reported the use of CT for selecting patients for management of acute appendicitis, finding that with increased use of CT there were less severe imaging findings, a significant decrease in surgical–pathologic severity and shortened hospital stay. These would seem to be clinical benefits but the routine use of a high radiation dose in a relatively benign process requires careful study of costs and benefits, especially as most patients with acute appendicitis, of whatever stage, are managed effectively without specialized investigation. In the latest update to the European Guidelines on the use of MDCT (European Commission 2008) US is now recommended as the first modality of imaging in acute abdominal pain, with CT used in clinically equivocal cases.

3 The Dose Problem

The fact that CT is a modality giving significant exposure is well known. In the past this was seen as permissible as in areas of its greatest application, such as the investigation of malignancy; its diagnostic value was greater than its inherent risk. However, CT is now used extensively in benign disease and in the young in whom cumulative dose considerations are of the utmost importance.

This issue of radiation dose from CT has received much attention in both the popular media and scientific literature, due in part to the fact that the dose levels from CT typically exceed those from conventional radiography and fluoroscopy, and that the use of CT continues to grow. CT contributes a significant portion of the total collective dose from ionizing radiation delivered to the public from medical procedures. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has highlighted that medical radiology is the largest artificial source of exposure to ionizing radiation (UNSCEAR 2010) and that in the USA there about 67 million CT examinations performed annually at a rate of about 223 examinations per 1000 persons. UNSCEAR also estimated previously that CT constitutes about 5% of all X-ray examinations worldwide while accounting for about 34% of the resultant collective dose. In the countries that were identified as having the highest levels of healthcare, the corresponding figures were 6 and 41%, respectively (UNSCEAR 2000). In the UK the most recent estimate from the Health Protection Agency (HPA) put the contribution from medical X-ray examinations (including dental) at 90% of the dose from all artificial sources of exposure in the UK.

In a frequently cited study performed by the Federal Bureau on Radiation Protection in Germany, it was found that between 1990 and 1992 only 4% of all X-ray examinations were performed on CT scanners, yet CT accounted for 35% of the collective effective dose (BMU 1996). In the United Kingdom, in 1991 the National Radiological Protection Board (NRPB) pointed out that CT makes a disproportionately large contribution to dose, at that time representing only 2.5% of examinations but constituting 25% of the collective dose to the population from diagnostic use (Shrimpton et al. 1991). Subsequent studies indicate that this proportion has increased; in 1998 Shrimpton and Edyvean (1998) suggested that the cumulative radiation dose was closer to 40%. Mettler et al. (2000) have indicated that in their department CT comprises 11% of examinations and 67% of the collective dose, 11% of these examinations being carried out in children, in whom radiation protection considerations are paramount. These growing trends have continued with population doses from diagnostic X-rays in the UK and USA showing CT remains the dominant source of dose from medical X-ray examinations. In the UK 68% of the population dose comes from CT examinations, while CT represents only 11% of all of the X-ray examinations performed (excluding nuclear medicine) (Hart et al. 2010). Similarly in the USA the percentages are 66 and 18%, respectively (NCRP 2009). In the UK HPA (includes former NRPB) report of 2010, per caput CT dose in the UK was less than five times the equivalent figure in the USA. However, in the UK there were typically 56 CT examinations per 1000 population rising to 223 per 1000 in the USA.

Whereas, there is still a paucity of published data available on the trends in patient doses following the introduction of MDCT, an increased contribution to patient dose may be expected due to reduced geometric efficiency and the more prominent impact of the additional tube rotations necessary before and after data acquisition over the planned scan range. When scanning in helical mode, all CT scanners acquire additional rotations at each end of the scan length in order to obtain sufficient data to reconstruct the full imaged volume. Two studies have reported significant increases in effective dose per patient of 10% and 34% for multislice compared with single slice CT (Brix et al. 2003; Yates et al. 2004a, b). Reconstruction methods on multidetector systems sometimes require a greater number of additional rotations. This together with greater X-ray beam widths used can result in a significant increase in effective dose, particularly for short scan lengths (Nicholson and Fetherston 2002). Published results from the 2003 UK CT dose survey (Shrimpton et al. 2005), a review of CT practice after the introduction of helical CT nationally, show that there has been a reduction in average patient doses from CT examinations since the previous national CT dose survey published in 1991. However, they also show that doses from MDCT are consistently slightly higher than dose levels from single slice CT scanners. The Third UK national CT dose survey of current practice (2010/2011) is currently under way with the aims of updating existing examination-specific national reference doses and providing guidance for some new establishing examinations.

Of particular concern is the fact that many of the new applications are especially applicable to young patients and those with benign disease. However, this challenge is not the only problem facing radiation protection in CT. The short scanning time of MDCT means there is a danger of uncritical use being made of the technique and previous studies have shown that there are large variations in the scanning protocols employed for the use of CT (Lewis and Edyvean 2005). The risk is that the flexibility of MDCT in terms of long scan lengths and use of narrow imaged slices with high mAs values can lead to unnecessarily high doses if diagnostic requirements are not adequately considered (Shrimpton et al. 2005).

Controlling technique variations may be problematic. Recommendations of CT manufacturers vary with regard to clinical protocols and cannot be compared easily because of different scanner makes and models (Scheck et al. 1998). Institutions may also change protocols according to their needs with variations even noted between different departments in the same hospital where equivalent technology is in use. Further, different CT scanners employ specific detector geometry and filtration characteristics. As a result it has been shown that even identical scanning parameters can result in considerable dose differences in the patient (Scheck et al. 1998). Consequently, there is a worrying level of variation in exposure for examinations carried out for identical purposes.

Shrimpton et al. (2005) reported that effective dose could differ by a factor between 10 and 40 in examinations for the same application and Olerud (1997) has reported variations between 8 and 20 times. These differences seem to relate principally to variations in examination technique. In our experience (unpublished data) a 10-fold variation in the number of sections and exposure factors is found across the work of one general department. It is inevitable that some complex cases will require a larger number of CT sections and multiple phases, but the disparity occurring between apparently similar applications is of serious concern.

It is now widely accepted that unoptimized CT examination protocols are a significant contributor of unnecessary radiation dose. There appears to be much scope for dose optimization through use of appropriate protocols (Lewis and Edyvean 2005). Efforts and measures to reduce dose can be initiated by the examiner by critically considering the indication and the choice of scanning protocols and parameters for CT examination.

There may be justifiable reasons for some variability in practice, of which the most important one is the difference in clinical indication. Furthermore, as techniques develop there is a period of learning during which the examination technique should develop to a mature level. This difference is greater if operators and practitioners are insufficiently educated in newly emerging technology. Further, increasing demand in radiology may induce radiologists to use over-intense protocols for CT, for viability to supervise the examination directly while engaged in other work. It is perceived that this is more likely to occur with relatively inexperienced workers and, it is also possible that some examinations are carried out more intensively than needed as a means of clinical risk limitations. These factors indicate strongly against measures to provide effective radiation protection. Low annual referral frequencies for examinations may also lead to unnecessarily high patient exposures where a lack of familiarity with the procedure and a failure to optimize the examination parameters increase the dose cost to the patient. This is particularly the case for centers with low numbers of pediatric referrals.

A further factor is the frequency with which patients may undergo CT in a single illness. Surveys have shown that it is not difficult for a patient with a complex illness to acquire several exposures in a short time (European Commission 2008). In our own study in patients with abdominal sepsis (Meeson et al. 2009)—a non-malignant condition—we found when looking at all CT referrals locally a maximum of 18 examinations for a single patient during one year. The relative percentages of patients with six or more CT in a year were comparable with other institutes taking part in the European survey. It was agreed that the high number of patients receiving more than six CT examinations in a year raised concern about the appropriateness of the repeated CT examinations. This has significant implication for interpreting the impact of population exposure; many population surveys give an average exposure per caput, whereas what is happening in practice is that there are patients who are receiving a large number of exposures over a short period. This makes protection measures even more important in the individual case.

One of the critical questions to ask is to what extent developments in technology should alter examination technique. There is a natural tendency for changes in the examination technique to be driven by advances in technology but the person carrying out the examination has to ask if there is added benefit in intensifying the examination and therefore the radiation exposure. It has to be accepted that clinical demand and workload pressures currently motivate against protection measures and that optimization of practice is one of the greatest challenges facing dose constraint in CT (Golding and Shrimpton 2002).

Unfortunately, despite the development of exposure reducing technology, the evidence base for practice is limited (Kalra et al. 2004). Optimization of scanning protocols involves many parameters including tube voltage, tube current, section thickness, collimation and pitch (McCollough et al. 2006). A dose reduction of 90% has been reported in high resolution CT of the face in patients with orbital trauma (Jackson and Whitehouse 1993), and in CT of the chest minimizing tube current has been reported to reduce the dose by 50%. Starck et al. (1998) reported that in very specialized circumstances a 96% reduction in dose can be achieved and similar levels of reduction may be possible in CT colonography (Iannaccone et al. 2003). Our own studies in this area bear out this experience. These studies related to areas of high natural contrast and high resolution imaging, where large exposure latitude may be expected. However, research is needed in the main areas of application of CT, where detection of low contrast lesions is paramount. It is necessary to establish the minimum exposure threshold that will deliver adequate image quality in each application, preferably expressed in terms of clinical effectiveness (Mini et al. 1995). Dose reductions achieved in studies with test objects also need to be confirmed in clinical trials, demonstrating image suitability, before potential dose savings can be achieved more widely.

4 Approaches to the Problem

The answers to the challenges facing the use of MDCT must come both from technological development and from the clinical practice. On the industrial side the significant developments that have already been achieved in dose-constraint technology must continue and must impact on the way that MDCT operates in practice, as described in the following chapters. A harmonization of dose-constraint methods employed by all manufacturers, including the different options for automatic tube current modulation, is also desirable to achieve the best possible image with the lowest dose and to ensure that operators understand both the protocol settings selected and the impact of modifying them. The advances in practice must be based upon a clear perception of the factors important in protecting the patient in MDCT, as outlined below.

5 The ALARA Principle

The ALARA principle states that all medicinal exposure for diagnostic purposes shall be kept as low as reasonably achievable. It is based on the radiation assurance recommendations of various international expert committees and organizations and forms the cornerstone of radiation protection. Based on the assumption that there is no lower threshold for carcinogenesis (i.e. there is no dose that can be considered completely safe or harmless), the reduction of radiation exposure to 'ALARA' remains an ongoing challenge.

6 The Role of the Referrer: Justification

It is a sine qua nom of investigational medicine that the risk of the procedure is outweighed by the putative benefit to the patient. Although simple in essence, this principle may be difficult to put into practice. In many areas of established use of CT the potential benefit to the patient is clear and its application therefore well justified. However, patients are all individuals and in other areas it may be difficult to quantify accurately the potential benefit to the patient in many instances, it is accepted, clinicians may tend to refer patients for examination in order to give themselves reassurance concerning their intended management regime; in such cases benefit is difficult to demonstrate and dose constraint should be employed here.

The aims of radiation protection—and of effective justification and the ALARA Principle—may best be met by encouraging referring clinicians to adopt a critical appraisal of their own referral practice. The clinician needs to ask, before referring a patient for MDCT, "do I really need this investigation? Will it change what I do?" If the answer to these questions is positive, the next critical question is to ask whether the information that is needed could be obtained without the use of ionizing radiation. In many abdominal and pelvic applications ultrasound and MRI provide acceptable alternatives to MDCT, and MRI is also an effective competitor elsewhere in the body. Even where these two techniques may not be as sensitive as MDCT, there may be a case for employing them first, especially in young patients, on the basis that if they yield the required information then exposure of the patient to radiation may not be required. In our own practice the investigation of some cases of orbital fracture—an application usually regarded as exclusively a requirement for CT—have been successfully achieved using MRI. In such clinical decisions referral guidelines such as those issued by the Royal College of Radiologists in the UK have an established value.

7 The Role of the Operator: Optimization

It should be a given principle that all MDCT equipment is operated at optimum technical performance and subject to regular quality assurance. However, the objectives of optimization of the examination go beyond this. As indicated above, there are current technological advances which may be used to constrain exposure and, in appropriate circumstances, image quality can be manipulated to reduce exposure, provided that the resulting examination does not fall below an acceptable threshold of image quality and therefore of sensitivity appropriate to the clinical application. All departments should have in place local guidelines, based on the best evidence to date, to ensure that these objectives are met.

8 The Role of Guidelines in MDCT

As indicated above, the evidence base for dose constraint in CT is not strong and in these circumstances practice guidelines may be important. In 1994, the European Commission set up a working group on image quality and dose in CT, resulting in publication in 2000 of the European Guidelines on Quality Criteria for Computed Tomography (European Commission 2000). This group continued its work and produced updates to the guidelines. The second edition of the guidelines (European Commission 2000) surveyed technical and clinical principles in MDCT and made recommendations on good technique in common areas of application, together with the guidelines on dose measurement and audit. Particular attention was also paid to pediatrics, a group of patients who should always be examined using protocols that have been optimized for children and not adults. In 2008, the updates concentrated on MDCT scanners that can acquire data with at least 16 slices simultaneously (European Commission 2008).

One problem that the group has had to face is the variation in the performance of individual CT scanners. Whereas, in the first edition it was possible to make specific recommendations on slice thickness and pitch, only ranges can now be specified. As in the first edition, the guidelines recommend quality criteria that enable examinations to be assessed. However, the key issue of diagnostic effectiveness and exposure still needs to be addressed by robust research studies for both established and emerging applications of MDCT.

9 The Role of Evidence: Vigilance

Overall, experience indicates that the dramatic rise in applications of CT has not yet reached a plateau. This is despite the fact that both technically and clinically, MSCT may be used in a way to aid dose constraint (Olerud 1997; Kalendar 2004; Yates et al. 2004a, b). A number of factors actually offer the potential of dose reduction if taken into consideration by clinicians. For example, repeat scans which were frequently required if the patient moved significantly or breathed between single scans, have been practically eliminated by MDCT. Overlapping scans which were often selected for good multiplanar or 3-D displays and led to corresponding increases in dose are no longer a necessity because overlapping images are routinely available in helical CT with no additional exposure. Also, the selection of pitch factors >1 results in a reduction in dose corresponding to the pitch factor (Kalender 2000). Significant reduction of dose can also be obtained through attenuation-dependent tube current modulation which allows constant image quality to be maintained regardless of patient attenuation characteristics and is now widely available on most MSCT systems (Yates et al. 2004a, b).

It is important that all practitioners in CT continue to review emerging evidence and adapt their practice accordingly. For the present dose audit remains mandatory and further surveys of practice are required. Departments must ensure that their justification criteria are soundly applied, and that examinations are carefully targeted to clinical applications and do not exceed the clinical requirements. Where evidence supports the approach, exposure should be adjusted to the lowest threshold that delivers the required clinical sensitivity. It is necessary to follow published guidelines and observe all updates in these. Beyond this, however, new legislation has now been passed in the USA to enforce radiation protection at a patient level. The Governor of California, Arnold Schwarzenegger, has signed a bill into law related to CT dose. SB1237, that was signed into law September 30, 2010, paves the way for the implementation of the first state law aimed at protecting patients from excessive radiation exposure received during CT scans and radiation therapy procedures. The bill will impose strict new procedures and reporting requirements to protect patients from medical radiation overdoses when it becomes effective July 1, 2012. The bill also provides an accreditation mandate for CT scanners that will take effect from January 1, 2013 (American Association of Physicists in Medicine (AAPM) 2011). The bill requires that dose be recorded on the scanned image and in a patient's health records, and that radiation overdoses be reported to patients, physicians, and the state Department of Public Health.

CT manufacturers are constantly reviewing dose optimization and regulation. Five companies that manufacture the majority of the world's CT scanners are cooperating in an initiative to improve patients' safety by including additional radiation dose safeguards on their equipment. Under the Medical Imaging and Technology Alliance (MITA) "dose check" initiative (Computed Tomography Dose Check (NEMA Standards Publication XR 25-2010) 2010), manufacturers of computed tomography equipment have agreed to add an alert feature to notify CT operators when recommended radiation dose levels are exceeded. The AAPM have also issued dose check recommendations regarding notification and alert values for CT scanners (AAPM Dose Check Guidelines 2011).

Overall, the challenge of patient exposure in MDCT will best be served by continuing vigilance; from the manufacturers toward new dose-saving developments and advice to their uses, from clinical referrers to ensure that over-demand is avoided, and from radiology department staff to ensure that the principles of best practice are always applied. This is, therefore, a field in which understanding of the balance between risks and benefits is most likely to be served by effective inter-disciplinary communication, education and vigilance.

10 Conclusion: The Professional Responsibility

It is an unfortunate fact of radiation protection in this field that we are not in a position to judge definitely whether the increase in population exposure due to CT will or will not create a future problem in radiation-induced disease, as many claim. All our estimations of risk are based on extrapolation from outside the range of diagnostic exposures. It is not even known if the Linear No Threshold (LNT) model is applicable at this level of exposure. However, in Medicine it is insufficient practice to assume safety; if we do not know for certain that we are safe we have a professional obligation to proceed with caution. The evidence from successive surveys makes it clear that this is not happening.

It is essential that all available guidelines for patient protection and adherence to protection law are applied. Wide variations in exposure for similar indications need to be outlawed, possibly by international action. However, we also need to reverse the climb in exposure. This may be done by replacement of CT wherever practicable but also by department staff taking a proactive approach to introducing the results of protection research as they become available. Diagnostic Radiology staff should also be alert to the number of examinations that patients may have in a single disease episode, together with their total numbers of examinations in any given year, and be prepared to modify examination protocols to limit repeat exposures. While departments carry the legal responsibility for protection, there is much that individual staff can achieve by being sensitive to the perceived challenge in exposure from MDCT and having the aspiration to go further in protecting the patient than required by law. In this sense the issues addressed in this book are as much a matter of individual professional responsibility as the application of science.

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Radiation Dose from Multidetector CT
Tack, D.; Kalra, M.K.; Gevenois, P.A. (Eds.)
2012, XVIII, 650 p. 380 illus., 80 illus. in color. With online files/update., Hardcover
ISBN: 978-3-642-24534-3