European Journal of Radiology 76 (2010) 28–35

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Impact of new technologies on dose reduction in CT

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ARTICLE INFO

Article history:
Received 14 June 2010
Accepted 15 June 2010

Keywords:
Automatic exposure control
X-ray tube current modulation, ECG gating
Iterative image reconstruction techniques
Dual source CT
High pitch helical scanning

ABSTRACT

The introduction of slip ring technology enables helical CT scanning in the late 1980's and has rejuvenated CT's role in diagnostic imaging. Helical CT scanning has made possible whole body scanning in a single breath hold and computed tomography angiography (CTA) which has replaced invasive catheter based angiography in many cases because of its easy of operation and lesser risk to patients. However, a series of recent articles and accidents have heightened the concern of radiation risk from CT scanning. Undoubtedly, the radiation dose from CT studies, in particular, CCTA studies, are among the highest dose studies in diagnostic imaging. Nevertheless, CT has remained the workhorse of diagnostic imaging in emergent and non-emergent situations because of their ubiquitous presence in medical facilities from large academic to small regional hospitals and their round the clock accessibility due to their ease of use for both staff and patients as compared to MR scanners. The legitimate concern of radiation dose has sparked discussions on the risk vs benefit of CT scanning. It is recognized that newer CT applications, like CCTA and perfusion , will be severely curtailed unless radiation dose is reduced. This paper discusses the various hardware and software techniques developed to reduce radiation dose to patients in CT scanning. The current average effective dose of a CT study is ~10 mSv, with the implementation of dose reduction techniques discussed herein; it is realistic to expect that the average effective dose may be decreased by 2–3 fold.

1. Introduction

Since its introduction in the 1970s, computed tomography (CT) has seen increasing use in medical diagnosis [1]. In a recent report by NRCP, it is estimated that, on average, the number of CT studies in the US increased by ~10% per year from 1993 to 2006 [2]. For the year of 2006 alone, 62 million CT examinations were performed in the US, which accounted for 15% of all diagnostic and therapeutic procedures involving ionizing radiation and contributed a collective radiation dose of 440,000 person-Sv vs 918,000 person-Sv from background radiation [2]. The reasons for the increasing use of CT in diagnostic procedures are several. First, CT scanners are the workhorse of diagnostic imaging in emergent and non-emergent situations because of their ubiquitous presence in medical facilities from large academic to small regional hospitals and their round clock accessibility due to their ease of use for both staff and patients as compared to MR scanners. Second, technological advances in helical scanning [3] have increased the speed with which scans of the body at thinner slices can be accomplished making three-dimensional imaging a reality while multi-row detector CT [4] have further enhanced this capability by allowing more axial coverage in a single rotation of the detector. Third, high speed imaging enabled by helical scanning with multi-row detector has spawned new CT applications including computed tomography angiography of the brain and heart, virtual colonoscopy, and perfusion studies.

The increasing use of CT has sparked concern over the effects of radiation dose on patients, particularly for those who had repeated CT scans. The effective dose [5] from a CT scan on average is ~10 mSv [6]. The health risks, mainly cancer induction and mortality, from this level of radiation dose has been considered in detail by an expert Committee of the National Research Council of the National Academies of the US and published as BEIR VII Phase 2 report [7]. Table 1 from the report shows the estimated number of cancer cases and deaths expected to result in 100,000 males or females (with an age distribution similar to that of the entire U.S. population) exposed to 100 mSv. For comparison, the number of expected cases and deaths in the absence of exposure is also listed. The BEIR VII estimates were used in two recent studies on cancer risks from CT scanning. Berrington de Gonzalez et al. [8] estimated that from CT scans perform in 2007 alone, 29,000 (95% confidence limits, 15,000–45,000) future cancers could result in the US population as a whole. Smith-Bindman

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doi:10.1016/j.ejrad.2010.06.036

et al. [9], on the other hand, estimated the lifetime risks of cancer from different types of CT scans; they range from a high of 1 in 270 women (1 in 600 men) for CT coronary angiography to a low of 1 in 8100 women (1 in 11,080 men) for routine CT head scan at the same age. Not surprisingly, the risks were doubled for 20-year-old patients and were halved for 60-year-old patients.

CT scanning has consistently been found to result in higher effective dose than other medical imaging procedures [1,2,6]. In fact, the newer CT applications of cardiac CTA and whole organ CT perfusion studies are among the highest dose studies medical imaging procedures [10,11]. It is not surprising that dose reduction for CT scanning has become an important concern for both equipment manufacturers and end users of this important imaging modality. In the following, recent developments in CT dose reduction for both routine CT scanning and the newer cardiac CTA and CT Perfusion studies are discussed.

2. Automatic exposure control (AEC) system

Noise patterns in CT images are oriented in the directions of high attenuation because only a small number of photons are transmitted through the patient to generate signals used for image reconstruction. When photons are not evenly transmitted through the patient in the scan plane, for example, lateral vs anteroposterior direction in the shoulder and abdominal region, excessive noise in the 'photon starved' projections will cause streaks to appear in images reconstructed with filtered backprojection [12], Fig. 1 [13]. If a fixed high mA is used to overcome the photon starvation problem in the lateral direction, then there will be an excess of photons in the anteroposterior direction, or the patient is exposed to a radiation dose that is higher than is required for image quality. Similar consideration also applies in the Z-direction, with a fixed mA either image quality suffers at high attenuation regions, for example, the abdomen and pelvis or there will be radiation overdose at low attenuation regions, for example, the cervical region and thorax.

AEC is used to adjust the mA automatically according to the thickness of the body in the z-direction and scan plane the X-ray beam has to pass through to minimize image noise and radiation dose [14,15]. AEC can be implemented using three methods [14].

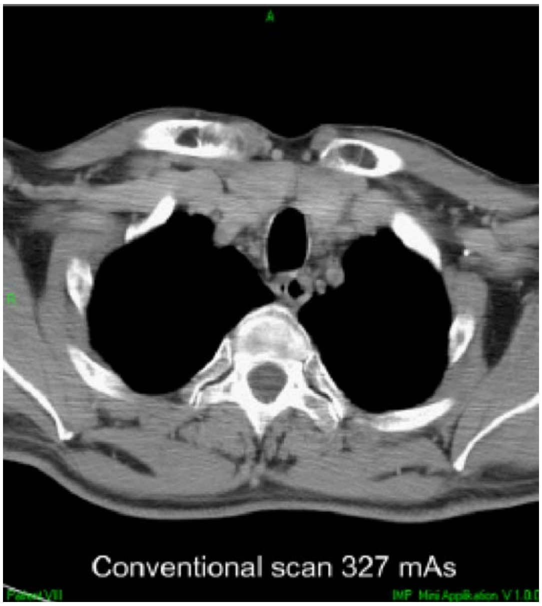

Fig. 1. CT scan of the pelvic region using constant tube current. Attenuation is much higher in the lateral direction than the anteroposterior direction. Projections in the lateral direction is 'photon starved' or have higher noise than those in the anteroposterior direction resulting in noise streaks in the lateral direction [13].

2.1. *Patient size AEC*

As discussed by McNitt-Gray [16], in CT scanning the patient is exposed to both the entrance and exit radiation; when the same mAs is used because the exit radiation is close in intensity to that of the entrance radiation in smaller patients, a more uniform dose distribution and higher dose than those in larger patients will result. Patient size AEC adjusts X-ray tube current or mAs according to the overall patient habitus. It is particularly relevant in the pediatric population. The combination of higher radiation dose with the same mAs and increased lifetime radiation risks in children produced an estimated lifetime cancer mortality risks attributable to the radiation exposure from a CT that is an order of magnitude higher than for adults [17].

Although patient size AEC prevents overdosing of small patients and children because adult mAs instead of those appropriate to the patient size are used, the drawback is that a fixed mAs is used throughout the scan irrespective of the change in patient thickness in the scan plane and z-direction. As such, further dose reduction is possible with the next two implementation of AEC to be discussed.

2.2. *Z-axis AEC*

Because attenuation changes along a patient's longitudinal (z) axis, high at the shoulder region, low at the thorax, and high again at the abdomen and pelvis, using a fixed current throughout a thorax, abdomen and pelvis scan will lead to varying noise levels in the images. If the tube current is set by choosing an acceptable level of noise in the thoracic images, then the shoulder and abdominal images will have an unacceptable level of noise. On the other hand, if the tube current is set using the abdominal images, then the thorax will be overexposed. Z-axis AEC will modulate the tube current according to attenuation inferred from scan projection radiographs (SPR also known as scout, scanogram or topogram by different CT vendors) so that a consistent level of noise is present in all images [13,18]. Fig. 2 shows an anteroposterior and a lateral SPR from the same patient with the attenuation along the z-axis superimposed [14]. Kalra et al. [18] found that scanning the abdomen with Z-axis AEC reduced dose by 34.1–44.9% compared to scanning with fixed tube current with no increase in noise (Fig. 3 [18]).

2.3. *Rotational AEC*

In this implementation, the X-ray tube current is modulated as it rotates around the patient [19,20]. At angles where there are more (less) attenuation because the patient thickness is large (small), the current is increased (decreased). The modulation of the tube current is based either on attenuation measured on-line (in the immediate previous rotation of the X-ray tube around the patient) (CARE dose 4D, Siemens Medical Solutions; DoseRight Dose Modulation, Philips Medical Systems; SureExposure, Toshiba Medical Systems) and the current varies as the square root of the measured attenuation [13,19] or on patient asymmetry measured in anteroposterior and lateral SPRs and the tube current varies sinusoidally between limits defined by the asymmetry [14] (SmartMA, GE Healthcare). In phantom studies, rotational AEC with tube current modulation as the square root of attenuation resulted in greater dose reduction than sinusoidal tube current modulation [20]. A number of studies on the application of rotational AEC to clinical CT scanning have been reported. The radiation dose for scanning six different anatomical regions: head, shoulder, thorax, abdomen, pelvis, and extremities (knee) were found to be reduced with on-line modulation of tube current by 15–50% relative to con-