Techniques and Tactics for Optimizing CT Dose in Adults and Children: State of the Art and Future Advances

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With growing concern over radiation exposure from CT, dose reduction and optimization have become important considerations. Many protocol factors and CT technologies influence this dose reduction effort, and as such, users should maintain a working knowledge of developments in the field. Individual patient factors and scanner-specific details also require care and expertise, which are vital to the success of any dose reduction effort. The authors review the content of the Virtual Symposium on Radiation Safety in Computed Tomography (University of California Dose Optimization and Standardization Endeavor), specifically that pertaining to the more practical aspects of dose optimization. These range from prescan tips to postscan factors, as well as protocol definition itself. Topics discussed include localizer radiograph acquisition, tube current modulation, reconstruction methods, and pediatric considerations, with the content biased toward a CT technologist or protocol manager. Near-term innovations, including new iterative reconstruction methods, tube potential modulation, and dual-energy CT, are presented, and their capability for dose reduction is briefly discussed.

Key Words: CT, CT protocol, radiation dose, dose optimization, pediatric

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INTRODUCTION

CT has proliferated as an imaging technique in recent years, with a 7.8% annual increase in examinations between 1996 and 2010 in the United States [1]. This has resulted in a significant increase in the annual population exposure from medical radiation and growing concern over radiation exposure, for both individuals and the population as a whole [2]. As a result of this concern, considerable effort has been made to reduce CT dose levels in routine practice, both through CT equipment developments and by the use of lower dose imaging protocols; however, greater dose reduction is achievable. The complexity of modern CT scanner systems, combined with myriad individual patient considerations, precludes a "one size fits all" approach to dose reduction. The Virtual Symposium on Radiation Safety in Computed Tomography (University of California Dose Optimization and Standardization Endeavor, May 8−10, 2013) highlighted this, with numerous lectures detailing various dose reduction strategies [3]. These helped spread essential knowledge of how current CT technologies and strategies influence both patient dose and image quality. Trade-offs among the technical factors that affect image quality and dose may influence diagnostic accuracy and may ultimately confer better or worse patient outcomes. It is also important to understand how technological advances in the near future will affect current methods and dose levels. In this paper, we distill many of the concepts provided in the virtual symposium concerning dose reduction in CT, from prescan techniques to postscan processing. This will be followed by a discussion of future developments in the field and how these could assist in dose reduction efforts.

CURRENT STATE OF PRACTICE

Prescan Considerations

Before a CT acquisition itself, a number of factors should be considered to confirm that dose will be kept to a minimum. The most straightforward way to reduce radiation dose is to ensure that the scan is justified and perform it in such a way that eliminates repeat scans [4]. Nonionizing radiation techniques should be used

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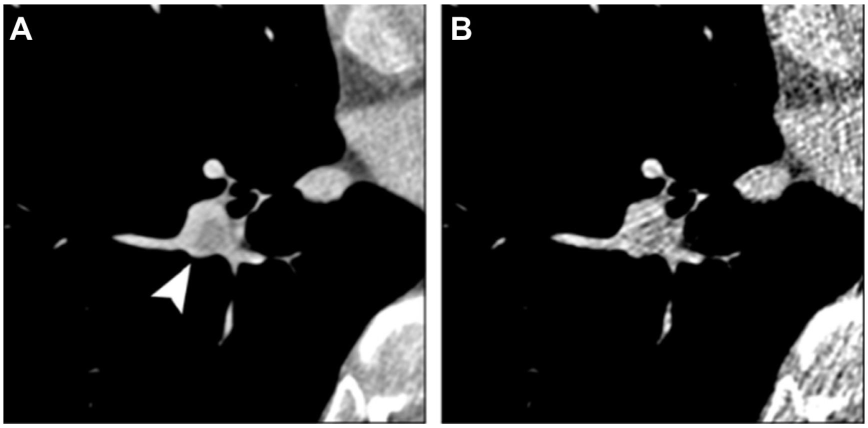

Fig 1. Axial CT images of a 64-year-old man with pulmonary embolism: (A) low-dose (90 mAs_{eff}) image and (B) simulated ultra-low-dose (10 mAs_{eff}) image. The poor bolus timing during the scan precludes confident diagnosis in the ultra-low-dose image. Reprinted, with permission, from Mackenzie et al [10].

wherever possible. MRI is often a suitable substitute, as is ultrasound, particularly for children, whose smaller size allows superior organ detail to be resolved [5]. In addition, the use of multiphase examinations should be limited where possible, particularly in children, and overlapping scan regions should be avoided [6].

The CT localizer (scout) scan represents a key part of the CT examination process, as the image that is generated governs the subsequent tube current modulation (TCM) by the scanner. Several factors must be carefully considered to maximize dose efficiency using the localizer for TCM. First, accurate localizer acquisition is vital to a correct prescription of TCM. Patients should be centered in the gantry because incorrect table height will result in an unrepresentative magnification of the patient, who will be interpreted by the scanner software as being either physically larger or smaller. This in turn will affect the prescribed TCM and resulting volumetric CT dose index of the scan [7]. Second, inaccuracy in positioning is compounded by the beam-shaping filters of the scanner, which distribute higher x-ray fluence to the center of the field of view and can introduce errors into the resulting images when the patient is not well centered in the gantry [7]. Third, a high enough tube potential should be used for the localizer. Acquiring the localizer radiograph at $<$120 kV may cause overly high attenuation, which could in turn result in the scanner's assuming a higher patient density and prescribing a higher tube current. Fourth, the localizer scan should include the entire region to be scanned. If the scan itself is subsequently extended into an "unknown" region beyond the original localizer radiograph, an unduly high tube current may be applied to compensate [8]. Finally, it is important not to use any surface shield during the localizer scan because the system will interpret this as a denser patient and prescribe a higher tube current [9]. The same is true for extraneous objects on the patient, such as keys and zippers; if these are identified from the localizer image, it should be repeated without them.

Special attention must be given when scanning pediatric patients. A combination of good communication and a child-friendly environment helps ensure patient cooperation, increasing the chance of obtaining a good scan. Anesthesia or sedation may also be required to avoid patient motion in very young or uncooperative patients [5].

In addition to these methods, operator experience is critical to effectively implementing dose reduction strategies. With experience, a CT operator will gain skill in patient communication, bolus timing, and choosing the most suitable scan methodology. Without this, a lack of patient cooperation, motion artifacts, and poor bolus timing (Fig. 1) can work separately and in concert to degrade image quality and may be compounded by a reduced-dose examination [10].

Scan Parameters and Strategies

Most technical CT settings (such as tube potential, pitch, beam width, reconstructed image thickness, and automatic exposure control selection) are interrelated, and therefore many compromises are present in each scanning scenario. Of further importance is that with CT operator input, some of these settings are automatically modified in an attempt to maintain consistent image quality, while others are not. The details of this depend on the specific scanner but can have a profound effect on radiation dose, and as such, users should have a detailed understanding of their particular CT system. For example, GE scanners automatically adapt the tube current to match a user-prescribed change in reconstructed image thickness, whereas Siemens scanners do not [11]. Another consideration is that parameter descriptors vary greatly between vendors. Users should make full use of the American Association of Physicists in Medicine's intervendor CT lexicon (Table 1), which compares the terminology and gives generic explanations of each term [12].

Although TCM is a valuable and now routine tool in optimizing patient dose, it should still be treated with care because of the automated nature of the selections the scanner makes. Image quality reference levels used for TCM vary by manufacturer and affect dose levels in different ways. GE and Toshiba both use noise indices, which seek to maintain a prescribed standard deviation