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Low and ultra-low dose radiation in CT: Opportunities and limitations

In recent years, there has been a dramatic increase in the use of computed tomography (CT), leading to an increase in the collective amount of radiation applied to patients. This public health issue requires strict application of two radiation protection principles: justification of examinations and optimization of doses. CT manufacturers have proposed many tools to reduce the radiation dose, including the use of iterative reconstructions (IR) when reconstructing raw data.

IR algorithms were introduced in 2008 to replace conventional filtered back projection (FBP) for CT image reconstruction. Compared to FBP, IR algorithms decrease noise for the same dose, while maintaining image quality with reduced doses. In addition, IR algorithms take advantage of the physical characteristics of the CT system. The major CT system manufacturers have produced several generations of IR algorithms, the two most recent being the hybrid/statistical IR (H/SIR) and model-based iterative reconstruction (MBIR) algorithms. H/SIR combines FBP and IR in different proportions to achieve reconstruction. MBIR uses a probabilistic method, deriving a statistical cost function by incorporating X-ray physics and CT optics modeling to reduce noise and artifacts. Reconstruction with the full MBIR algorithm is relatively time-consuming, thus a faster partial/advanced version has been developed. However, using IR changes the image component (such as image smoothing). Furthermore, IR uses non-linear and non-stationary properties that make spatial resolution dependent on contrast and dose. All these image changes may disturb the radiologist and require a fair amount of training to become familiar with this new image type.

Many clinical studies have shown the contribution of IR in dose reduction and these are now widely used in clinical practice [1—4]. Major dose reductions were achieved compared to previous CT protocols, allowing the appearance of low-dose (LD) and ultra-low-dose (ULD) protocols. The LD protocol was defined to correspond to the first quartile of the diagnostic reference level (DRL) distribution that corresponds to a dose reduction of more than 50% compared to standard CT acquisition. The ULD protocol was defined as an effective dose level for the CT-scan inferior or similar to the X-ray effective dose for the same organ. For example, the effective dose of national DRL (2011) for chest CT was 7mSv whereas chest LD-CT was 3.4 mSv and chest ULD-CT was 0.225 mSv (DRL of front and lateral chest X-ray).

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If radiologists adapt their practices in order to follow the radiation protection principles such as justification and optimization, image quality should be sufficient to interpret CT examinations. Optimization is dependent of many factors, mainly indications, patients, CT system being used, and medical practices. Dose optimization is a complex task that requires finding the best compromise between the lowest dose delivered while maintaining an image quality suitable for diagnosis. By reducing kVp or mAs, image quality is modified and deteriorated as noise is increased. Radiologists should always adapt the protocol to the indication in order to obtain sufficient image quality to benefit the individual patient.

In addition to studies on phantoms or cadavers, clinical studies need to be performed in order to confirm the ability to detect or characterize diseases [4,5]. Recent publications reported false negative findings in liver nodule detection [1] and the inability to characterize some others lesions [2] when LD or ULD acquisitions were performed. By reducing dose, the contrast between lesions and the normal liver structure was altered and IR could not be adapted enough to yield images sensitive enough for visual detection of the lesions.

For chest CT, ULD acquisitions were similar to LD acquisitions in detecting traumatic lesions such as pneumothorax, pneumomediastinum, hemothorax, rib fractures, pneumonias, hemopericardium, and others [3,4]. If chest ULD-CT should to be recommended in the emergency department for minor blunt trauma, other indications should be evaluated such as for interstitial lung diseases. ULD-CT could also be indicated for bone fracture detection, but first needs to be evaluated for bone cancer semiology.

To our knowledge, with major dose reduction such as ULD acquisition, indications seem limited to organs with high spontaneous contrast between structures and pathologies. On the other hand, when contrast between structures and/or pathologies are similar, dose reduction is limited. Also, indications for the LD and ULD CT-scan depends on two decisions. The first is whether or not to replace the standard CT with LD-CT or ULD acquisitions. By how much could we reduce the dose in CT acquisitions without altering images for diagnosis? The second decision is whether or not to replace the X-ray with ULD-CT. Since the doses are similar between the classical X-ray and ULD-CT, does this three-dimensional acquisition offer better sensitivity compared to X-ray in the detection of lesions? To answer both questions in practice, radiologists should refer to the initial clinical indication: do we need a CT or do we need an X-ray examination?

In conclusion, recent technological improvements push radiologists to modify their practices, but clinical evaluation should be done in order to evaluate the impact of these changes on disease management. IR and other improvements in CT offer the possibility to drastically reduce the dose in CT. Benefit for the patient depends mainly on the indication, in addition to CT and medical practices. It is important for the radiologists to consider justification and optimization before interpretation and patient management. These four parts of our job are in perpetual evolution due to technical innovations [6]. In this context, and in the near future, artificial intelligence software will modify practices, such as dose optimization, detection, and characterization of lesion [7,8]. If standardization is to be obtained between practices, a pilot is necessary to drive CT in order to offer the most benefit to the patient. The pilot will be part of a team comprised of medical physicians and dedicated technicians. The pilot is the radiologist who will be responsible for the entire process, and for giving the best answer to the question with the best technique and the best value.

Disclosure of interest

The authors declare that they have no competing interest.

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