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Dynamic x-ray beam positioning for low-dose CT
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Paper Selection

With the increasingly frequent use of x-ray computed tomography (CT) in medicine, especially in emergency medicine applications, dose consequences become a concern and prompts the development of new ways of dose reduction. The paper selected discusses a method for dose reduction without sacrificing image quality. A method of tube current modulation during CT acquisition was used for noise and does reduction. The paper was chosen because it provides the background for investigating noise amplitude levels and noise distribution in CT images, which is a crucial step in evaluating the technical approach of our project.

Background

Gies begins by discussing the significance of does reduction, the current dose-reduction strategies, and some of the challenges of dose reduction commonly encountered by researchers. For example, some researchers have suggested decreasing the tube current. However, this results in an increase in image noise. Another approach adjusts the tube current based on attenuation over each projection angle by lowering tube current for projections with lower attenuation. This can be achieved by taking two projections at the lateral and a.p. view to estimate the minimum and maximum attenuation, and, using the estimates, the tube current is modulated sinusoidally. In the paper, the authors investigated dose-reduction based on variations of the current-modulation approach to demonstrate that image quality is not lost using simulations.

Methods

Simulations were performed on four phantoms, shown in Figure 1 with a constant attenuation coefficient μ for a 120 kVp spectrum. In this investigation, the total scan dose was kept constant and the noise levels were evaluated. The authors evaluated noise and dose under sinusoidal and attenuation-based modulation functions with different values of the control parameter $\alpha \in [0,1]$, which is incorporated into the attenuation $A = e^{\mu \cdot L}$ to compute the attenuation-based current modulation $A^{\alpha} = e^{\alpha \cdot \mu L}$. Noise was computed in the central pixel of

the phantoms by approximating the central beam. Let N_P be the number of projections (views), N_{0i} be the number of emitted quanta for the central ray in view i, and N_i the number of quanta in view i passing through the object, pixel noise variance σ_P^2 is then computed as $\sigma_P^2 = \sum_{i=1}^{N_P} \sigma_i^2 = \sum_{i=1}^{N_P} \frac{A_i}{N_{0i}}$. The final result of noise derivation can be given by the equation

$$\sigma_P^2 = \sum_{i=1}^{N_P} \frac{A_i}{N_{0i}} = \sum_{i=1}^{N_P} \frac{A_i}{\left(\dfrac{N_0}{\sum_{k=1}^{N_P} \sqrt{A_k^\alpha}}\right) \cdot A_i^\alpha}$$

$$= \frac{1}{N_0} \left(\sum_{i=1}^{N_P} A_i^{1-\alpha} \right) \cdot \left(\sum_{i=1}^{N_P} A_i^\alpha \right).$$

Note that $\alpha = 1$ (control proportional to attenuation) and $\alpha = 0$ (no control) give the same noise $\frac{N_P}{N_0} \sum_{i=1}^{N_P} A_i$. Dose per view was characterized by the number of quanta emitted by the tube and noise was computed from the number of registered quanta in terms of variance.

To carry out the simulation, the attenuation-weighted path length $\mu \cdot L$ is first computed. Then, the attenuation of the central ray $A(\phi) = e^{\mu \cdot d(\phi)}$ was calculated in order to compute the current modulation function. Finally, the pixel noise is computed to evaluate noise levels. Simulations were done on the shoulder phantom in Figure 1.

'Hip Phantom'
16cm x 36cm oval
PMMA

'Shoulder Phantom'
14cm x 40cm ellipse
water

'Abdomen Phantom'
20cm x 30cm oval
water

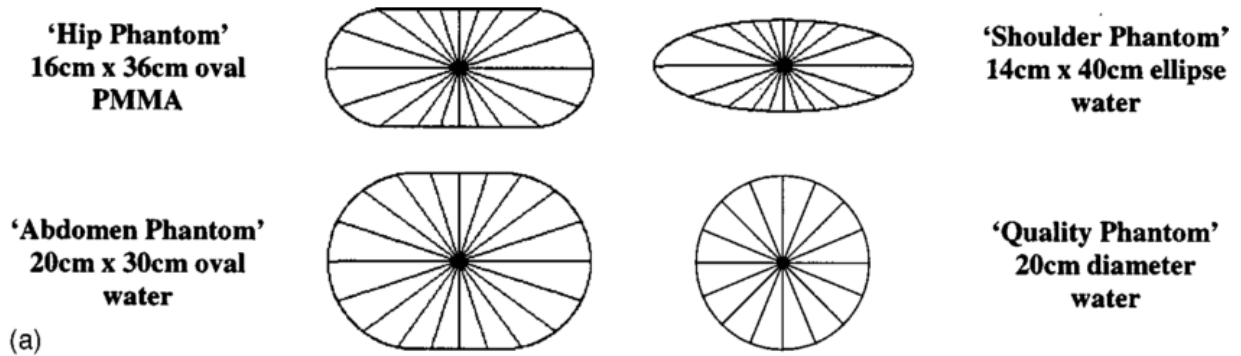**'Quality Phantom'**
20cm diameter
water

(a)

Figure 1. Mathematical phantoms used in the study.

A Shepp-Logan convolution kernel was used to reconstruct the images. Relative, instead of absolute, degree of noise reduction was used so that the choice of kernel for reconstruction would not affect the metric.

Results and Discussion

The optimal control parameter α was computed to reduce noise. It was found that $\alpha = 0.5$ provides optimal noise reduction as shown in Figure 2. The impact of attenuation-based modulation on noise in relation to object size was investigated using relative noise reduction, which can be computed as the ratio of max to min

Figure 2. Noise reduction as a function of control strength α.

$$H = \frac{A_{\max}}{A_{\min}} = \frac{e^{\mu\, d_{\min}}}{e^{\mu\, d_{\max}}} = e^{\mu(d_{\max} - d_{\min})}.$$

attenuation   Gies et al. found that objects with the same $d_{max} - d_{min}$ have similar noise reduction behaviors as shown in Figure 3a and that potential noise reduction increases with axis difference in Figure 3b. Here, the potential for noise reduction was defined as the decrease in total scan dose without loss in i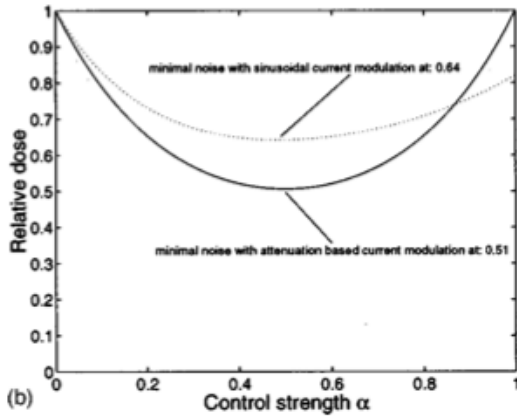mage quality. Simulated images showing noise structure on an ellipse is shown in Figure 4. Noise reduction is maximal at $\alpha = 0$ but, at $\alpha = 1$, the noise structure is more isotropic.
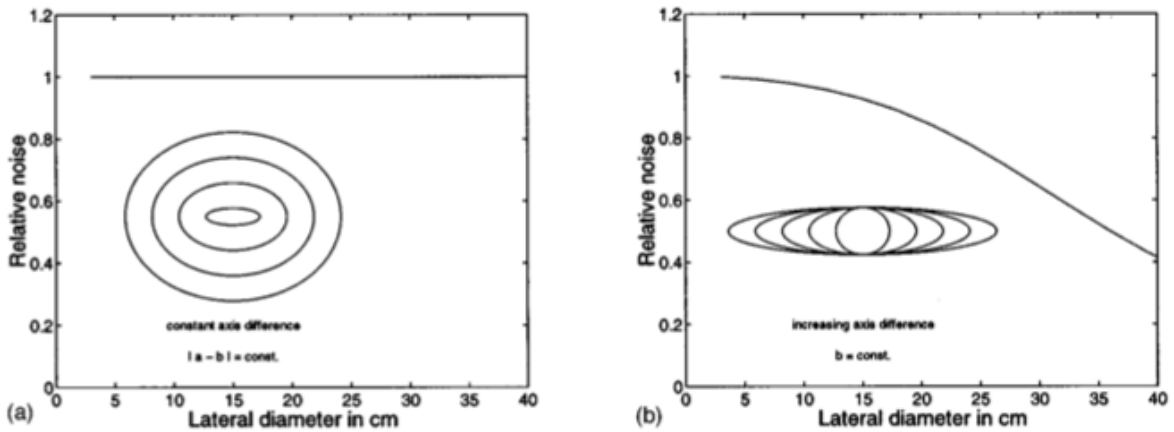

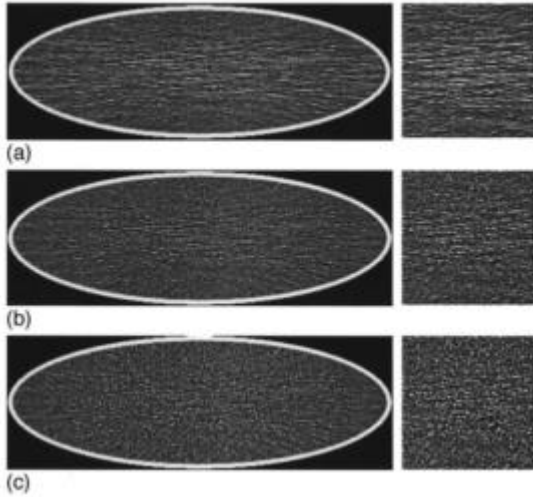Figure 3. Dependence of noise reduction on object shape and size.

Figure 4. Simulated images of an ellipse with noise. (a) Constant current ($\alpha = 0, SD = 16.3\ HU$) (b) $\alpha = 0.5$ generates minimal pixel noise levels (11.1 HU). (c) $\alpha = 1.0$ generates isotropic pixel noise levels (15.5 HU).

Assessment

The derivations and simulations discussed in this paper was very thorough, taking into consideration the effect of control strength α as well as object shape and size on noise level and structure.

Using simulation performed on phantoms of various shapes, Gies et al. showed that the optimal control strength for noise minimization is $\alpha = 0.5$. This means that the intensity is weighted by the square root of attenuation. The main weakness of the paper is that the investigators only took into account the noise from the central ray. Although it is a reasonable approximation as the central ray usually generates the most dose, it does not provide a comprehensive assessment on dose and noise. Furthermore, the paper seems to suggest that the best way to minimize noise is to optimize on a non-flat fluence profile, which is misleading.

Conclusion

This paper provides important insight into dose and noise measurements in relation to tube current modulation and object shape. It also provides background for our project concerning dose and noise measurements and comparison. In our project, we will take into account how noise and dose change depending on the shape of the phantom being used. In our project, we will be optimizing on the flatness of the fluence profile to minimize noise and dose.