AJNR

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AJNR Am J Neuroradiol 1981, 2 (3) 269-271
http://www.ajnr.org/content/2/3/269

Patient Dose and Image Quality in Computed Tomography

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The relation between radiation dose in neurologic computed tomography scanning and image quality is described. Three different sets of images were obtained at varying exposures and were quantitatively evaluated by a panel of neuroradiologists. Anatomic information in the image varied with exposure. The relation of image quality and dose conforms to previous theoretical results and suggests that an optimal exposure level can be established.

Image quality in computed tomography (CT) as in other types of diagnostic imaging, has been quantitated by measuring noise, modulation transfer function, spatial resolution, contrast resolution, dose, etc [1, 2]. The evaluation of the effects of noise in both the imaging system and observer has been considered by several authors [3, 4], who have used the threshold detection curve approach to this problem. The threshold detection curve is a measure of the minimum contrast material required to observe an object of varying size, using a particular imaging system. It is measured by correlating a physical parameter characteristic of the target with the observer accuracy in detecting that target. This method was extended by Charman and Olin [5], who showed a high correlation between observer performance and the area between the threshold detection curve and the imaging system modulation transfer function. They used this parameter, the threshold quality factor, in the evaluation of aerial camera systems.

In a previous publication, one of us (M. T.) showed that for CT systems the threshold quality factor varies with radiation exposure [6]. In that publication, the comparative performance of three different CT systems and the subjective ranking of cadaver images were established. The purpose of this investigation is to use the threshold detection curve analysis and the threshold quality factor to determine more precisely the relation between dose and the detection of individual anatomic structures in neurologic CT scanning.

Materials and Methods

A cadaver brain was prepared for scanning with methods previously described [7]. The brain and two patients were scanned with the General Electric CT/T 8800. One level in each of the three subjects was chosen for study at various exposures. The exposure was varied by changing milliamperage of the pulsed x-ray tube, while the other factors (120 kVp, 3 msec pulse width, 10 sec scan time, and 10 mm slice thickness) were kept constant. Exposure was calculated from the applied milliamperage, using measurements made previously in a head phantom [6]. Table 1 summarizes the subjects, milliamperages and the radiation exposures, and structures studied.

Each of the images was copied three times. The original and the copies were shown in random order to a panel of three neuroradiologists. Each observer was asked to score the 14 structures on a 0–4 scale according to whether they were obvious (4), identifiable (3), probably identifiable (2), questionably identifiable (1), or not identifiable (0). The scores for each observer and each image were averaged and normalized so that the maximal score

Received September 26, 1980; accepted after revision November 21, 1981.

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This article appears in May/June 1981 *AJNR* and July 1981 *AJR*.

***AJNR* 2:269–271, May/June 1981**
0195–6108/81/0203–0269 $00.00

for a structure for each observer was 100%. Statistical analysis was limited since the purpose of this work was to show the dose response effect for this scanner and not to define an optimal dose for this scanner or other models of scanners. The structures studied included internal capsule, external capsule, cortical gray and white matter, third ventricle, and cortical sulci. Figure 1 shows scans of the normal patient at 5 R (12.9 × 10^{-4} coulombs/kg), 1.3 R (3.4 × 10^{-4} coulombs/kg), and 0.3 R (0.8 × 10^{-4} coulombs/kg).

Results

The normalized scores for four structures are plotted versus entrance exposure (fig. 2). These curves were derived by drawing a "smooth" curve through the data points. The large number of responses for each exposure level resulted in a standard deviation too small to be meaningfully displayed on this scale and, therefore, for purposes of clarity, both data points and standard deviations were omitted. Also plotted is the theoretical relation between image quality and exposure. This calculated curve (threshold quality factor) is the area between the measured, normalized system modulation transfer function (in this case normalized to a subject contrast of 10%) and the observer threshold detection curve [6].

Detection of the third ventricle was 100% at 0.5 R (1.3 × 10^{-4} coulombs/kg) while detection of the external capsule at the same exposure was 0%. Gray and white matter and sulci detection was intermediate between third ventricle and external capsule at this exposure. At 5 R (12.9 × 10^{-4} coulombs/kg), only the external capsule was less than 100% detectable. Detection of the third ventricle did not increase above 2 R (5.2 × 10^{-4} coulombs/kg) and detection of the sulci and gray and white matter did not improve above 3 R (7.7 × 10^{-4} coulombs/kg). The standard deviation of detection score was less than 5%. Some features, such as the lateral ventricle, were obvious (100% detectable) at all exposure levels, and some features, such as choroid plexus (in subject 3) were undetectable (0 detectability) at all exposure levels.

TABLE 1: **Summary of Materials and Methods**

Subjects:
Fresh brain specimen; patient with pseudotumor; normal patient
Exposures—mA (R [coulombs/kg]):
600 (5[12.9 × 10^{-4}]); 320 (2.6 [6.7 × 10^{-4}]); 160 (1.3 [3.4 × 10^{-4}]); 80 (0.6 [1.5 × 10^{-4}]); 40 (0.3 [0.8 × 10^{-4}])
Anatomic features studied:
Internal capsule; external capsule; white matter; gray matter; third ventricle; lateral ventricle; choroid; habenula; pineal; insula; sulci; cortex; medulla; septum

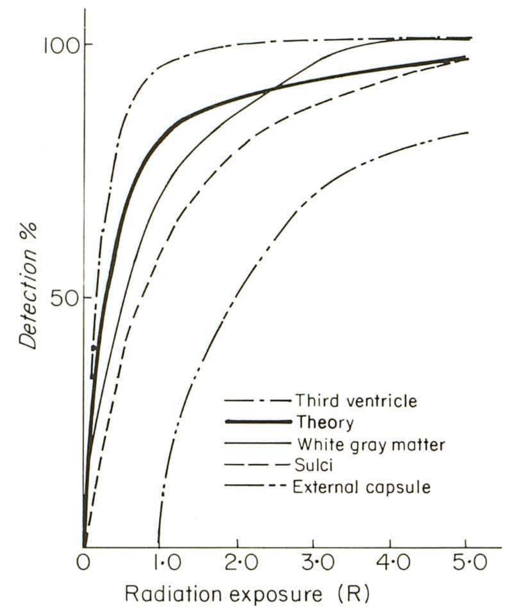

Fig. 2.—Detection of anatomic features in CT images at different exposures.

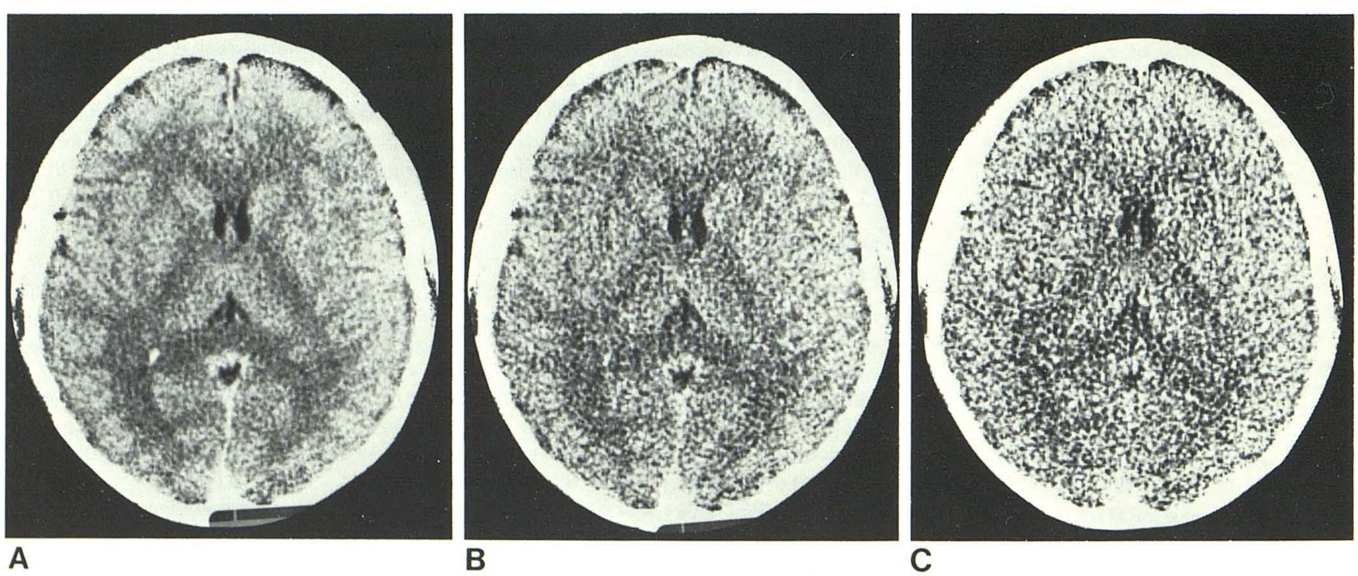

Fig. 1.—**A–C**, CT images at 5 R (12.9 × 10^{-4} coulombs/kg), 1.3 R (3.4 × 10^{-4} coulombs/kg), and 0.3 R (0.8 × 10^{-4} coulombs/kg), respectively, represent three of the 52 images used to quantitate observer detection accuracy in our study.

Discussion

Three observations can be made from figure 2. First, reliability of detection increases with increasing exposure and approaches a limiting value. Second, the limiting value of detection probably depends inversely on the intrinsic contrast difference between the feature and its surroundings. Contrast differences were not reliably measured in this study because partial volume averaging in the anatomic structures was not controlled. Other factors beside intrinsic contrast, such as conspicuity [3], may also limit detection. Third, the form of the curves implies that an optimal exposure can be chosen for an individual anatomic structure. The optimal exposure level is found at the shoulder of the detection curve. For example, if the third ventricle is to be examined, little information is obtained by increasing exposure beyond 1.5 R (3.9×10^{-4} coulombs/kg) whereas if the external capsule is to be examined, progressively more information is obtained as dose is increased up to 4.5 R (11.6×10^{-4} coulombs/kg).

Although the images were obtained using only one model of scanner, the form of the threshold detection and modulation transfer function curves is similar in other scanners. The resultant image quality depends on a combination of: (1) geometric factors, resulting in an upper limit to spatial resolution, and (2) noise (system, observer, and photon), leading to a lower limit on contrast resolution. It can be anticipated, therefore, that for other scanners, although the particular value of the optimal exposure level will be different, the concept will have similar applicability.

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