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### Imaging Factors Influencing Spine and Cord Measurements by CT: A Phantom Study

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Metrizamide computed tomography (CT) of the spine allows evaluation of the contents and measurement of the size of intracanalicular structures. The relative size (linear and area measurements) of spinal structures can be changed by varying imaging factors or the density of intrathecal contrast material. Two phantoms, one consisting of rods embedded in a plastic cylinder and the other of a vertebral body with a central rod simulating spinal cord, were evaluated with varying imaging factors (window width and window level) and different contrast concentrations within the surround. It was found that wide window widths allowed the most consistent measurements independent of window level, that a window level midway between the CT number of rod and surround would facilitate uniform measurements independent of window width, and that the use of high concentrations of contrast material (high CT number) in the surround, in combination with a wide window width, was most effective in establishing consistent measurements.

Spinal computed tomography (CT) with intrathecal metrizamide has been used to demonstrate anatomic relations between intradural contents, epidural space, and the spinal canal [1.]. Measurements of spinal cord and spinal canal size on CT, facilitated by intrathecal contrast enhancement, might aid in evaluating pathologic changes such as cord enlargement, cord atrophy, or cord compression [2], which are difficult to evaluate because changes in the attenuation values of the surrounding metrizamide-filled subarachnoid space and the conditions of imaging (window width and window level) all affect measurements. Resjo et al. [3] observed variation in measurements of spinal cords in children with changes in imaging factors. Since their work was done on living subjects, correlation of actual size and CT-derived measurements for quantitative evaluation of the effect of imaging factors was not feasible. Previous phantom studies used models of chest, spinal axis, or spinal canal with intrathecal contrast enhancement to evaluate linear diameter measurements. These studies suggested that window level (or center) was the primary factor influencing measurements [4, 5]. No attempt was made to assess area measurements. We believed that cross-sectional area measurements might be helpful when evaluating a region with irregular shape such as the spinal canal and sometimes the spinal cord. We also wanted to estimate the effects of changes in intrathecal attenuation values on measurements. This phantom study addresses the effect of window width, window level, and CT number of "intrathecal" contrast material on linear and area measurements of spinal cord and canal.

#### Materials and Methods

Two phantoms were scanned using a GE CT/T 8800. Phantom I was a high-density cylindrical container within which were embedded four plastic cylindrical rods varying in composition, CT attenuation value, and in diameter. The rods were surrounded by fluid consisting of water mixed with incremental amounts of contrast medium (Renografin-76) (fig. 1). CT numbers of the rods (cord phantoms) varied with the amount of contrast material in the surround, presumably due to a beam-hardening effect. Axial cuts were taken at a 5 mm thickness perpendicular to the axis of the rods at 120 kVp and 768 mAs for both phantoms. Linear diameter of the rods was obtained by ruler measurements on a two times magnified image using window levels of 160, 600, and 1,200 Hounsfield units (H). All area measurements were made at similar window widths. Window widths larger than 1,000 H used an extended scale mode. Areas were derived from a track-ball outline of the image using GE supplied software (region of interest function). For each window width, window levels were varied over the range, which resulted in images with clear boundaries.

Two of the four available rods were examined in phantom I. Rod 1, of lower CT number than all surrounding fluid media, was measured linearly and by cross-sectional area. Rod 2, which was intermediate in CT number between the lowest and highest density surrounds, was evaluated by linear diameters only.

Phantom II consisted of a lumbar vertebral body placed in a cylindrical container of water. A latex balloon surrounding a plastic rod was placed within the bony canal. Contrast concentration was varied within the balloon to yield CT numbers of 11–850 H (fig. 2). Axial 5 mm cuts were obtained through foramen and through pedicle for each concentration of contrast material within the balloon. After early analysis of results from phantom I, wide windows (300, 1,000, and 4,000 H) were used to evaluate phantom II.

#### Results

Three factors, window level, window width, and concentration of contrast material in the surrounding medium, were examined. Each separately affected the rod and bony canal measurements. Results were similar for linear diameter and for track-ball-defined area evaluations.

#### Phantom I: Window Level

Change of window level, independent of either the window width or the density of the surrounding medium, changed measured linear

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Fig. 1.—5 mm CT image of phantom I. Largest lucent circle in phantom is cross section through rod 1. Denser circle to right of rod 1 is cross section through rod 2. Rods 3 and 4, not used, are denser rod imbedded in rod 2 and lucent rod below rod 2. Small collection of air superiorly in phantom.

Fig. 2.—Phantom II was scanned with 5 mm cuts through foramen and pedicle levels. ''Intrathecal'' contrast material within latex balloon outlines rod ''cord'' phantom.





Fig. 3.—Graphs showing relation between CT number of surrounding medium and linear diameter measurements of rod 2 from phantom I. A, Surround has lower CT number than rod. Linear diameter measures decline with increments in window level. B, With surround denser than rod, measurements increased with window level. All measurements were made at window width of 160 H. In A, circles = 7 H, squares = 19 H, and triangles = 79 H; in B, circles = 288 H, closed triangles = 365 H, squares = 493 H, and open triangles = 717 H for surround density.

diameters. The direction of the change depended on the CT number of the surrounding medium relative to the rods, while the magnitude of the change per change in window level was related to window width. If the CT number of the surround was less than that of the rod, increments in window level led to progressive underestimation of rod size (fig. 3A). When attenuation values of the surround were greater than that of the rod, the usual case in metrizamide myelography, rod diameter measurements increased as window level was raised (fig. 3B). Within the range of window levels examined, the minimum linear diameter of rod 2 was 1.0 cm and the maximum was 1.4 cm. The actual diameter of the rod was 1.2 cm, yielding a maximum measurement error of 15%-16%.

Area measurements performed on rod 1 demonstrated a similar relationship to window levels. In this case, the attenuation value of the surrounding fluid was always higher than that of the rod. At a given window width, each increase in window level corresponded to an increase in area measurement. The minimum area measured for rod 1 was 17.8 cm<sup>2</sup>, and the maximum area was 21.4 cm<sup>2</sup>, with an actual area of 19.7 cm<sup>2</sup>. Percentage error related to variation in window levels was 8%–9%.

#### Phantom I: Window Width

The window width affected both the range of window levels, which resulted in images with clear boundaries (useful levels), as well as the magnitude of the change in size of a measured structure per change in window level. For example, for rod diameter measurements the average range of useful window levels was 267 H at window width of 160 H and 795 H at window width of 1,000 H. The slope of the curve depicting measured rod size as a function of window level is much steeper at window width 160 H than at window width 1,000 H (0.11 cm/100 H vs. 0.22 cm/100 H) as seen in figure 4. When the window width is wide (1,000 H), there is a plateau or flat spot over which measured size does not vary significantly with window level. This plateau is narrower at window width of 600 H and is not observed at window width of 160 H. We found that a window level midway between the CT number of the rod and the CT number of the surround would lie within the plateau region. defining an "ideal" window level at which rod measurements are consistent and close to accurate independent of window width. Similar findings have been reported by others [4, 5].

#### Phantom I: Density of Surround

When window width was held wide (1,000 H) and constant, increments in surround density yielded progressively smaller measurements of cord size for all window levels. Expectedly, measurements were most accurate when window level approached ideal window level for the particular pair of rod CT number and surround CT number in Hounsfield units. Overestimates of rod area were obtained when window level above the ideal was used, and area was underestimated at window levels significantly below the ideal. At the wide window width of 1,000 H, accurate estimates of rod



Fig. 4.—Rod area is examined as function of window level at three window widths: circles = 80 H, squares = 300 H, and triangles = 1,000 H. Rod area measurements show plateau effect at about ideal window level (dashed line). This plateau effect is most marked at wide window widths. At ideal window level, measurements at all three window widths are relatively accurate.

Fig. 5.—Rod area in phantom II evaluated as function of window level at three window widths: circles = window width of 300 H, triangles = 1,000 H, and diamonds = 4,000 H. Ideal window level indicated by dashed line. As

seen in fig. 4, plateau region is evident at wider window widths, and measurements made at plateau range of window level are accurate and reproducible. Ideal window level lies within plateau range.

Fig. 6.—Spinal canal area examined as function of window level for two window widths: open circles = 4,000 H and closed circles = 1,000 H. Wider window, 4,000 H yields track-ball-measured areas, which are more stable over a range of window levels than 1,000 H window level.

size could be made at appropriate window levels for most of the range of densities of surround. Only when the surround CT number approached the CT number of the rod was the boundary between the two obscured at wide window widths, preventing accurate measurements. We did not study the effect of increments of surround contrast density on measurements taken at narrow window width.

#### Phantom II: Window Level and Cord Measures

Measurements of the diameter and area of the rod in phantom II showed relations to window width, window level, and CT number of the surrounding fluid similar to those in phantom I. As noted in the simpler phantom, the rod areas measured at window levels closest to the ideal showed the least error. When the fluid surround was more dense than the rod, window levels lower than ideal generally underestimated rod size, whereas higher levels tended to overestimate it.

#### Phantom II: Window Width and Cord Measures

The effect of window width on area measurements in phantom II, particularly the existence of a plateau in the curve relating cord measurements and window level at wider window widths, is demonstrated by figure 5. In this example the surround is higher in CT number than the cord. Area measurements were made at window widths of 300, 1,000, and 4,000 H. When the 4,000 H window was employed, there was a plateau range of window levels at which the rød area measurement was nearly constant. The ideal window level

fell within this range, and measurements in the range were consistent. In comparison, the narrower window of 300 H generated area measurements that varied greatly with window level, and no plateau range was identified. At all three window widths examined, area measurements made at the ideal window level (vertical dashed line in figure 5) closely approximated the actual area of the rod.

#### Phantom II: Surround CT Number and Cord Measures

Variation in rod area measurement with changes in the density of the surround were evaluated using foraminal cuts at a window width of 1,000 H. The surrounds were 41–841 H. When imaging factors were limited to ideal window levels, measured areas were 0.72–0.83 cm<sup>2</sup>. Actual area was 0.77 cm<sup>2</sup>, and errors ranged from 0 to 8%. Measurement error was greatest when rod and surround were close in density. However, when the window level was not limited to the ideal, measurement differences were found between the low and high surround densities. At a low surround density (less than 300 H) the average minimum and maximum measurements were 0.69 cm<sup>2</sup> and 0.88 cm<sup>2</sup>, respectively. If the surround density was greater than 300 H, the range of variation in measurements was wider: 0.49 cm<sup>2</sup> and 0.99 cm<sup>2</sup>.

#### Phantom II: Canal Size

Measurement of bony canal area was also affected by imaging variables. Data analysis here is somewhat less satisfying than for the rod phantoms, since accurate physical measurements of canal area in the plane of CT sections could not be accomplished. When wide window width (1,000–4,000 H) and dense intrathecal contrast (CT number 841 H) was used, canal area measurements taken at the pedicle level were nearly constant over a wide range of window levels. A slight increase from canal area of 2.49 cm<sup>2</sup> to about 2.6 cm<sup>2</sup> was associated with the change from window level –600 to 1,400 H. Since there is so little difference between these values, the percentage error in these measurements is probably very small, although actual area is not available for comparison.

For less dense intrathecal contrast (CT number 41 H) a rather sharp rise in canal area measurements was observed for window width of 1,000 H as window level was increased (fig. 6). At a still wider window, 4,000 H, the measurements were more stable, even at low intrathecal CT number. A slight measurement increment with increases in window level was still observed, however. The results suggest that canal area is best measured at the widest possible window width, and that, at a given window width, the higher the CT number of the canal contents, the more reproducible the measurements of canal size become.

#### Discussion

The accuracy of measurements on CT is significant as it is pertinent for defining the range of normal variation in size of the spinal cord, spinal canal, and other spinal structures [6] as well as identifying and appraising pathologic states such as cervical spondylosis, spinal injuries, spinal cord tumors, inflammations, syrinx, or atrophy. Despite the use of favorable imaging factors, we found errors of 10%–20% in linear measurements of structures of about 1 cm in diameter. Error in area measurements was slightly less. For large objects, such as rod 1 of phantom I, which had a 5 cm diameter, a 6%–8% error was found. Expected percentage error is higher, then, in measurements of small objects on CT, regardless of imaging factors. For objects less than 1 cm in diameter, measurement error may represent a considerable fraction of object size.

As already detailed in the results section, imaging done for measurements of CT should be done at the ideal window level, which is the average between the CT number of the object to be measured and the surrounding material in Hounsfield units. The best window width is the widest that permits a sharp boundary between object and surround. This will depend on the object contrast between object and surround, that is, on the difference between their CT numbers in Hounsfield units. The advantage of a high concentration of intrathecal contrast material in CT metrizamide myelography is that it permits the use of wide window widths for measurements. Under these circumstances, there is a larger range of possible window levels at which reproducible and accurate measurements can be made. While high metrizamide concentration thus alows more stable measurements, it also offers a pitfall: the improved object contrast facilitates the use of inappropriate imaging factors by extension of the range of window levels at which a sharp object contour can be identified. The unwary observer may be lulled into making unreliable measurements.

When the difference in CT number between object and surround is less, object boundaries become difficult to detect at wide window widths, and narrowed windows must be used. Because measurements at these windows are more inconsistent, window levels become critical. We believe that measurements are most reliable with higher windows and greater contrast differences between object and surround. Use of ideal window levels for measurements facilitates comparison of measurements made at different anatomic levels or with different amounts of intrathecal contrast, alleviating the concern that imaging factors significantly distort the measurements.

An advantage of track-ball-derived area measurements is applicability to irregular geometric forms. Although the cross section of normal spinal cord is approximately oval, the shape of the diseased or compromised cord can be irregular, and the shape of the spinal canal can be irregular [7]. Cord and canal size, therefore, may be best assessed by area measurement of observer-defined irregular spaces. The consistent results of spinal canal measurements at the widest window widths evaluated, 4,000 H, suggest that this may be optimal for linear or area canal measurements. If sufficient intrathecal contrast material is present, these window widths may also be useful for spinal cord measurements. When the degree of object contrast is less, so that edges are poorly defined at wide window widths, imaging at ideal window levels and with the widest practical window width affords the most accurate and most reproducible results.

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