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Object Size Determination at Computed Tomography

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ABSTRACT

To investigate whether large differences in attenuation between an object and its background at CT examination alter the apparent size of the object on the image compared with the conditions with a small attenuation difference, phantom experiments were performed. At the same time the influence of large attenuation differences on the geometric resolution was examined. The results show that neither the size reproduction of the object nor the geometric resolution is altered by variations in attenuation differences.

Especially with large differences in attenuation between the object and background, however, the window centre setting was of greatest importance for correct reproduction of the object.

INTRODUCTION

In computed tomography (CT) sharp borderlines between structures of different density are reproduced as blurred contours. The degree of blurring depends, among other things, on the X-ray beam width, the dimensions and properties of the detectors, and the reconstruction algorithms employed. This blurring is of importance when measuring the size of structures in the image (1,3).

When an object which differs markedly in attenuation from its background is examined by CT, its apparent size varies with the viewing conditions. A decisive factor in this context is the question of which part of the CT-calculated attenuation profile is utilized to produce the image. This is determined by the setting of the window centre (WC) and window width (WW) (Fig. 1).

When patients have undergone CT examination both before and after bipedal lymphography, the lymph nodes have appeared larger after the contrast filling, when the image has been viewed with the window setting normally used for evaluation of the retroperitoneal space. This enlargement has considerably exceeded that caused by the contrast filling in itself (2,4).

It is not clear whether the apparent enlargement is solely an effect of the WW and WC settings or whether it is due to an error of measurement or of

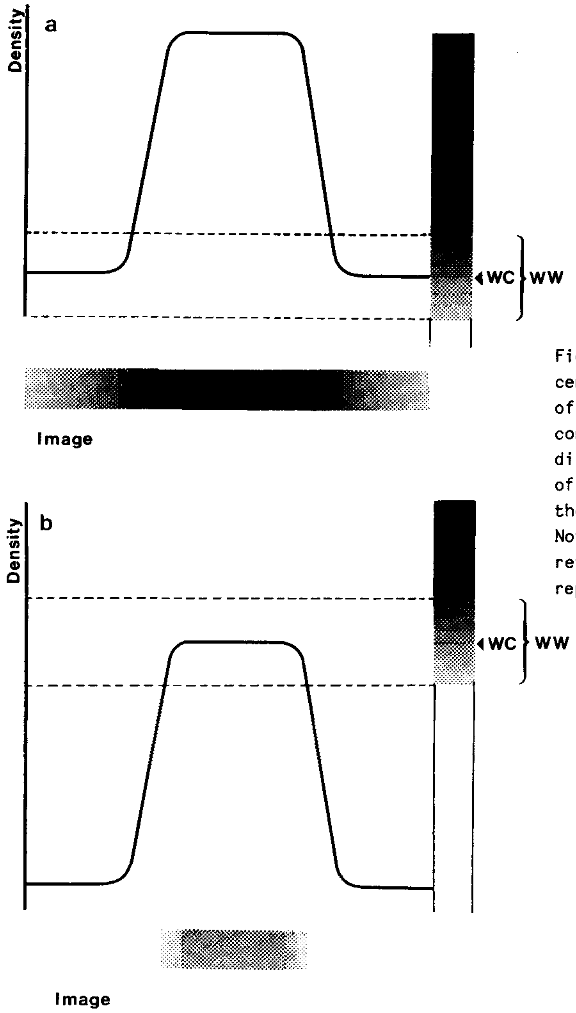

Fig.1. The influence of different window centre (WC) settings on the CT reproduction of an object when the window width (WW) is considerably smaller than the attenuation difference in the image. a) WC at the level of the background attenuation and b) WC at the level of the attenuation of the object. Note that in this image the grey scale is reversed, so that high attenuation values are represented by black and low ones by white.

reconstruction. An investigation was therefore undertaken to elucidate the way in which the interpretation of the CT image is influenced by the difference in attenuation between an object and its background, different reconstruction algorithms and different window settings. In addition, the geometric resolution with various attenuation differences and window settings was examined.

MATERIAL AND METHODS

A Siemens Somatom DR2 whole-body scanner with a 256 x 256 matrix was used for the investigation. The exposure data were 120 kV, 0.518 As, exposure time 4.5 s, 480 projections and a slice thickness of 8 mm. Reconstructions were performed with a zoom factor of 1.7, corresponding to a normal abdominal examination, giving a pixel size of 1.27 mm, and a zoom factor of 6, with a pixel size of 0.36 mm. For the reconstructions both the standard algorithm (Kernel 1), which is normally used for abdominal examinations, and an algorithm with strong edge enhancement (Kernel 7) were employed. The images were analysed on the standard diagnostic console with different window settings (scale: air -1000 Hounsfield units (HU), water 0 HU). The term image is defined in this article as the image reproduced on the monitor screen. Areas of interest were magnified; measurements were performed directly on the image screen and on the attenuation profiles, with the cursor incorporated in the console.

For investigation of the influence of the attenuation difference on the apparent size of the object, a polystyrene phantom with a diameter of 20 cm was used. In its centre there was a cylindrical hole 23 mm in diameter. The attenuation of the phantom was -10 HU. The hole was filled with Gastrografin® (370 mg I/ml) in dilution of 0.75 and 25%, which gave the hole attenuation values of 75 and 2050 HU respectively. The phantom was placed in the centre of the gantry and the cylindrical hole passed perpendicularly through the entire CT slice. The width of the attenuation profile was measured at 10%, 50% and 90% of the profile height.

To examine the effect of different attenuation differences and window settings on the geometric resolution, a phantom of parallel plexiglass rods with a square 5 x 5 mm cross-section was used. The distance between the rods was 1 mm. The plexiglass rods were examined both in air and when surrounded by water. The attenuation value for plexiglass was 120 HU, which means that the difference in attenuation between plexiglass and air was 1120 HU and between plexiglass and water 120 HU. The CT slice was perpendicular to the longitudinal axis of the rods.

RESULTS

The attenuation profiles for the cylindrical hole when it was filled with Gastrografin of different concentrations, are given in Fig. 2. When the standard algorithm was used for reconstruction, the width of the profile was independent of the difference in attenuation between the object and background (Table 1). Neither did the zoom factor used in the reconstruction influence the apparent dimensions. Reconstruction with the edge-enhancing algorithm resulted in a decrease in profile width by a maximum of 1 mm on examination of the high-density object.

The impact of different WC settings on the apparent size of the object in the image when the object-background difference in attenuation was large (2060 HU), is illustrated in Figs 3 and 4. When measured on an image of the object, reconstructed with a standard algorithm and a zoom factor of 6 at different WC settings (from 0 to 2300 HU) and at a constant WW (400 HU), the diameter varied from 26 to 20 mm. The true diameter (23 mm) was reproduced at a WC setting of between 1000 and 1200 HU, thus at about half the attenuation difference between the object and background.

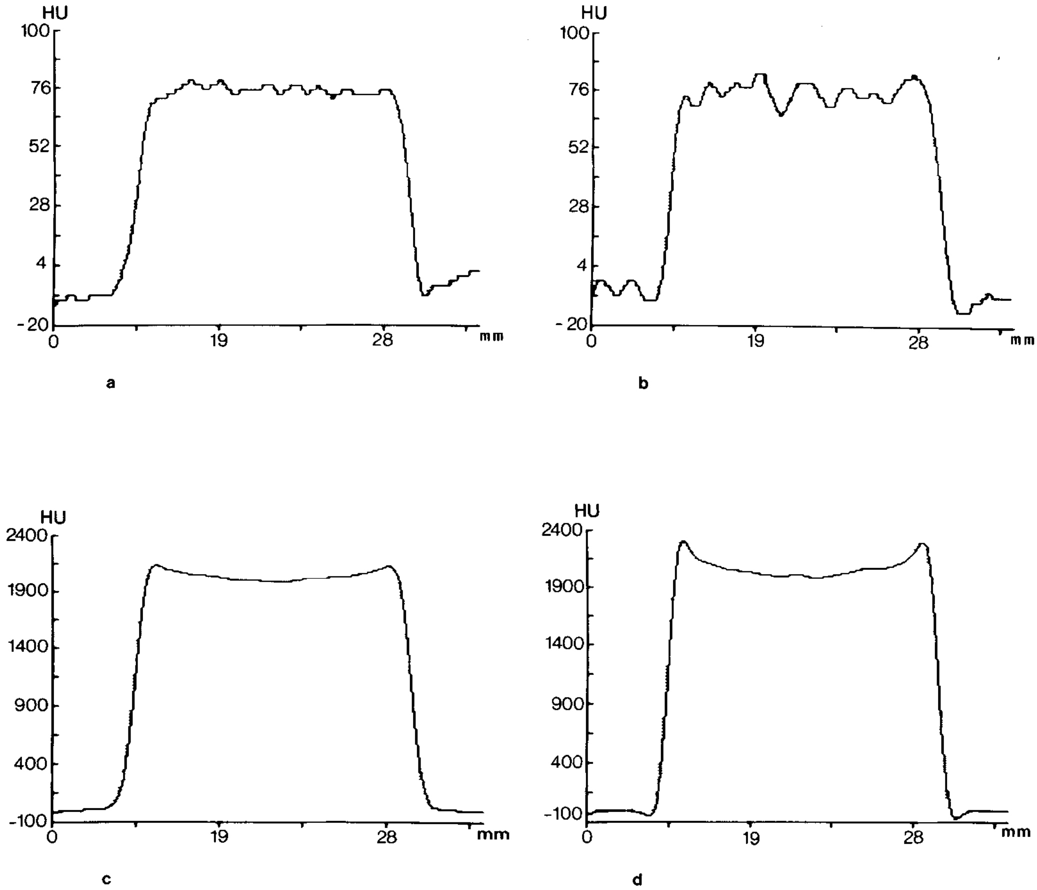

Fig.2. Attenuation profiles for the 23 mm object with attenuations of 75 (a and b) and 2050 HU (c and d), reconstructed with standard (a and c) and edge-enhancing algorithms (b and d).

Table 1

The width of the attenuation profile in mm at 10% (d_1), 50% (d_2) and 90% (d_3) of its height.

Attenuation difference object-background	Zoom 1.7			Zoom 6					
	Standard algorithm			Standard algorithm			Edge enhancement		
	d_1	d_2	d_3	d_1	d_2	d_3	d_1	d_2	d_3
85 HU	25	23	21	25	23	21	25	23	21
2060 HU	25	23	21	25	23	21	24	23	21

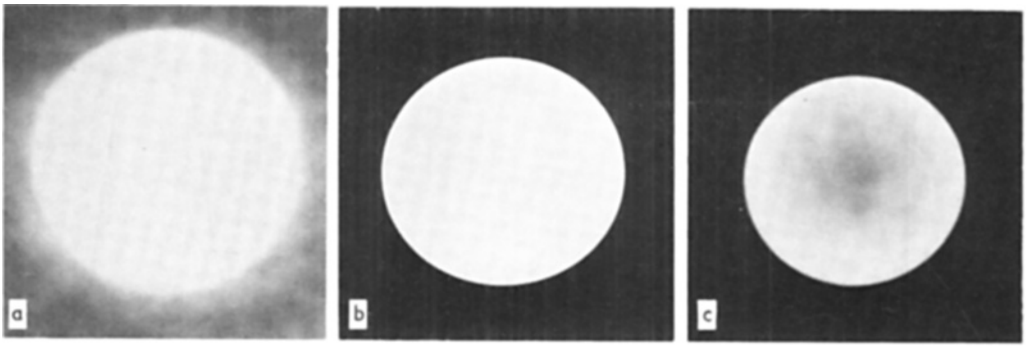

Fig.3. The CT image of an object of high attenuation (2050 HU) at different window centre (WC) settings and a constant window width (400 HU). WC = 0 (a), 1200 (b) and 2000 HU (c).

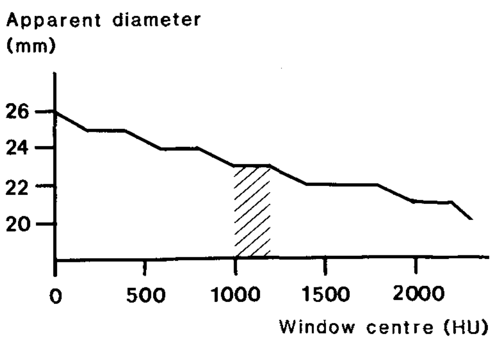

Fig.4. Effect of window centre on the object diameter. The window width is set at 400 HU. The true diameter (23 mm) is reproduced at a window centre of between 1000 and 1200 HU (shaded column).

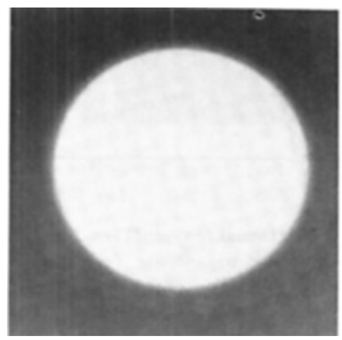

Fig.5. The 23 mm object of high attenuation (2050 HU) reproduced with a window centre of 1000 HU and a window width of 4000 HU.

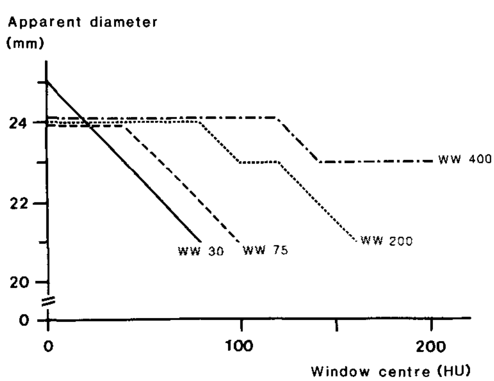

Fig.6. The influence of the window centre and window width (WW) settings on the reproduced diameter of an object with an attenuation of 75 HU.

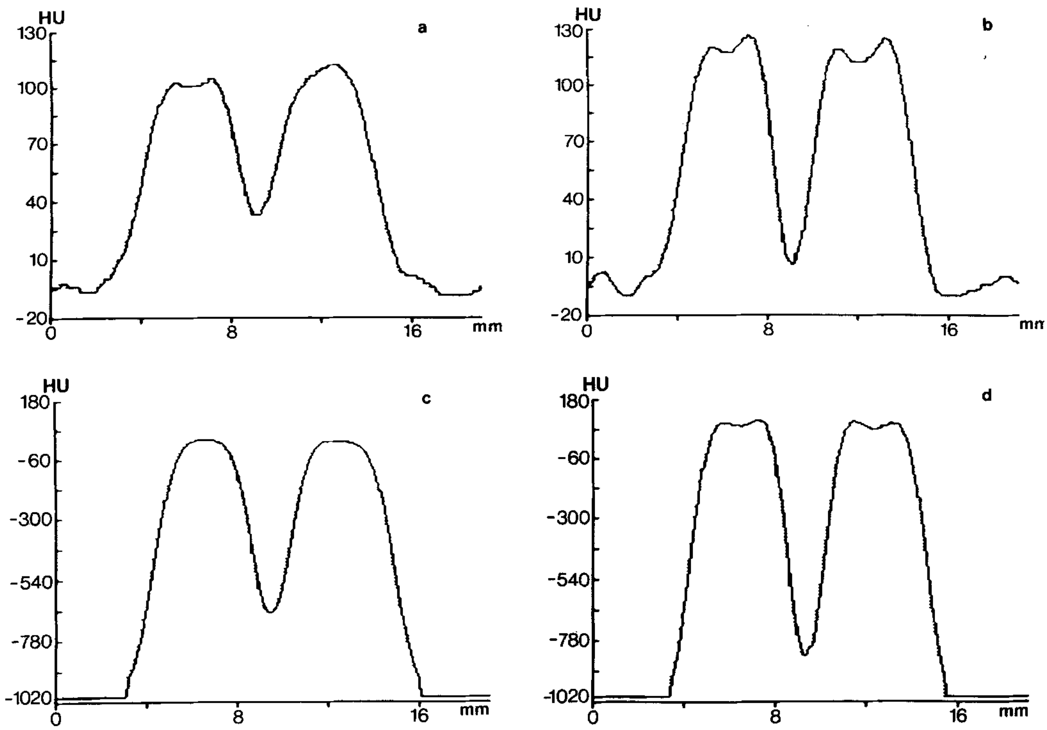

Fig.7. Attenuation profiles for two plexiglass rods situated 1 mm from each other, examined in water (a and b) and air (c and d), with the use of standard (a and c) and edge-enhancing (b and d) algorithms for reconstruction.

When the high-density object was viewed with a large WW, so that the entire attenuation difference between the object and background was covered by WW, the border of the object against the background became diffuse and it was difficult to define any exact measurement points for the diameter in the image (Fig. 5).

The WC setting also influenced the reproduction of an object which differed relatively little in attenuation from its background (by 85 HU), but only when WW was narrow (Fig. 6). When WW was smaller than the object-background attenuation difference, the apparent size of the object varied with different settings of WC, and this size variation increased with decreasing WW. When, on the other hand, WW was larger than the attenuation difference, the size was not affected by changes in WC as long as the entire attenuation profile lay within the WW limits.

On examination of the plexiglass phantom with parallel rods with a square cross-section, in air and in water, parts of the attenuation profiles of the two objects coincided under all tested conditions (Fig. 7). The lowest attenuation value for the "space" between the rods, when the images were reconstructed

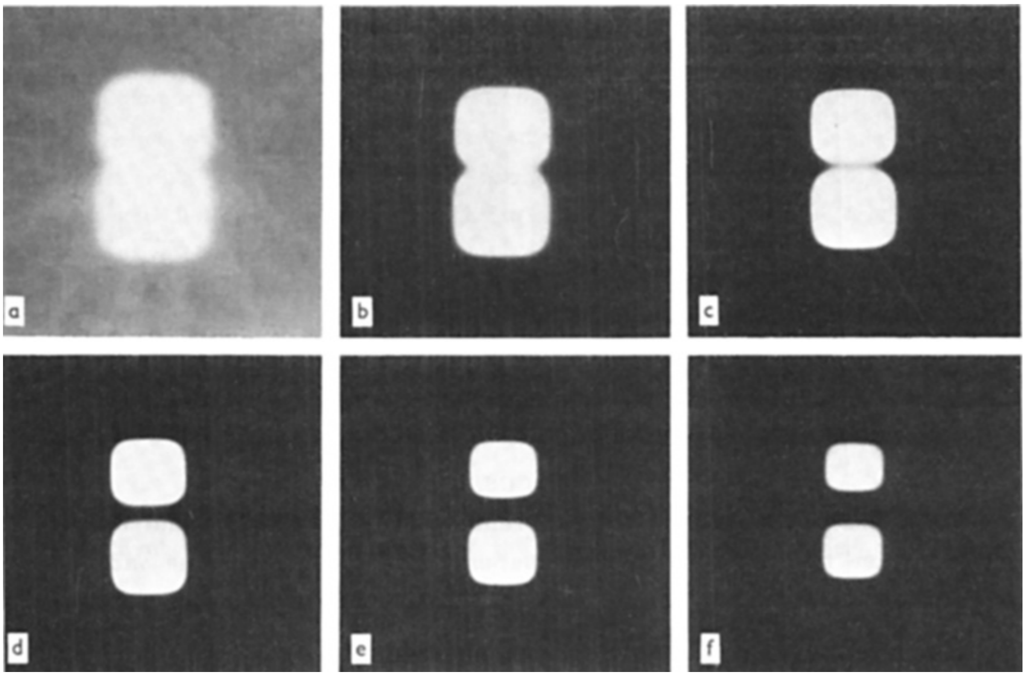

Fig.8. The image of the two closely adjacent plexiglass rods surrounded by air, at a constant window width (400 HU) and with different window centres: -1000 (a), -850 (b), -700 (c), -550 (d), -400 (e) and -250 HU (f).

with a standard algorithm, was found to be higher than the attenuation value of the background by 30% of the object-background attenuation difference (Fig. 7 a and c). This finding was independent of the magnitude of the attenuation difference and of the zoom factors employed. On examination both in air and in water, too low values (20 and 110 HU) were obtained for the maxima of the profiles, thus 100 and 10 HU, respectively, below the true attenuation value for plexiglass (120 HU). On reconstruction with an edge-enhancing algorithm, the attenuation values for the "space" were lower than when a standard algorithm was used; thus it was now higher than the background value by only 15% of the object-background attenuation difference, both when the examination was performed in air and in water (Fig. 7 b and d).

The position of WC was of importance for the geometric resolution, especially on reconstruction with a standard algorithm. When the plexiglass rods, surrounded by air, were viewed with a WC of -1000 HU and a WW of 400 HU, they appeared to form one figure (Fig. 8 a); when WC was increased stepwise while WW was kept constant, the rods were reproduced as one unit (Fig. 8 b) until the upper limit of WW exceeded the lowest attenuation value for the "space" between the rods. Thereafter the space began to appear in grey tones. The space increased in width with increasing WC up to about -500 HU, and parallel with the increase in width of the space the size of the rods decreased (Fig. 8 c and d). When WC was so high that the entire WW lay above the lowest attenuation value for the space, this appeared black (Fig. 8 e). The same effect was observed when the image of the plexiglass rods surrounded by water was viewed with varying WC. As long as WC lay within the values for the attenuation profile, 0-110 HU (Fig. 7 a), however, WW had to be relatively small - no greater than 60 HU at a WC of 0 HU, for the two rods to converge. However, with the window settings that are normally used at abdominal examinations, 400 HU for WW and 100 HU for WC, the rods appeared clearly separated.

DISCUSSION

Variation of the attenuation difference between the object and background did not alter the shape of the attenuation profile. Similarly, the width of the profile was influenced to only a minor extent by the use of different algorithms in the reconstruction. The setting of WC, on the other hand, was of great importance for the reproduced size of the object. Thus the apparent diameter of the object of high attenuation (2050 HU) varied by 6 mm when the image was viewed with different WC settings. Baxter & Sorensen (1) found that when WC was set at half the attenuation difference between the object and background, the size of the object was reproduced correctly, a finding in accordance with the present results (Fig. 4). When WC is set at the level of the background attenuation on examination of an object of high attenuation, the apparent size of the object is greater than its real size, and its greatest part appears completely white, as this part of the attenuation profile lies above the upper limit of WW (Fig. 1 a). This occurs in clinical examinations when contrast-filled retroperitoneal lymph nodes are being evaluated with settings of WC (100 HU) and WW (400 HU) that are normal for abdominal examinations, on account of the fact that the attenuation value of the contrast-filled lymph nodes (1000-2000 HU) is considerably higher than the upper limit of WW. If, on the other hand, WC is chosen according to the attenuation of the contrast-filled lymph nodes, with WW unchanged, only the maximum of the attenuation profile will give an image, which will mean that the apparent size will be smaller than the real one, at the same time as the image will appear in grey tones (Fig. 1 b).

For the object of low attenuation, the WW setting also influenced the apparent size in those cases where WW was smaller than the object-background attenuation difference (Fig. 6). With decreasing WW the object became more and more distinctly outlined in the image, but in parallel with this the size reproduction became more sensitive to changes in WC.

When closely adjacent objects of high attenuation were examined and WC was

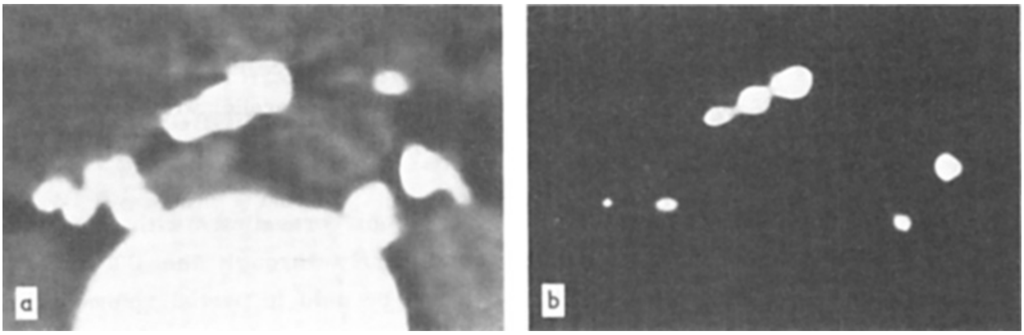

Fig.9. CT image of contrast-filled lymph nodes. a) Window setting normal for abdominal examinations. Window centre 70 HU, window width 400 HU. b) Window centre 1000 HU, window width unchanged.

set at a level with the attenuation of the background, at the same time as the selected WW (400 HU) was considerably smaller than the object-background attenuation difference (1110 HU), the geometric resolution was poor. On CT examination of closely adjacent contrast-filled lymph nodes, these nodes, with WC and WW settings normal for abdominal examinations (100 and 400 HU respectively), may converge and be interpreted as one large single node (Fig. 9). On reconstruction with the edge-enhancing algorithm, the geometric resolution was improved at low WC values. This means that in clinical examinations of structures differing largely in attenuation, an edge-enhancing algorithm should be used. When WC was set at a level corresponding to half the attenuation difference, good resolution was obtained. The maximal attenuation values for the plexiglass rods, when examined in air and water and with use of a standard algorithm for the reconstruction, lay 100 and 10 HU, respectively, below the real attenuation value for plexiglass. This is explained by the fact that the spatial resolution for the algorithm used is insufficient for a correct reproduction of the attenuation values of such small objects.

CONCLUSIONS

1. The difference in attenuation between an object and its background has very little influence on the reproduced size of the object and on the geometric resolution with the CT scanner used for this investigation.

2. For correct reproduction of the size of an object and for good geometric resolution in the monitor image, the WC setting is of the greatest importance. A correct reproduction of the object of interest was achieved when WC was set at a value in the middle of the attenuation values of the object cand the background.

3. With a WW that is smaller than the object-background attenuation difference, good delineating of the reproduced object is achieved. The edge will become sharper the smaller the WW setting used. Parallel with a decreasing WW, however, the sensitivity to the setting of WC increases.

4. In the present experiments ideal conditions prevailed, with objects of similar thickness which passes perpendicularly through the CT slice. In practice, however, consideration must also be paid to partial volume effects when measuring the sizes of structures.

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