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Computed Tomography and Composition of Renal Calculi

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Summary. The attenuation values of computed tomography were studied in 50 recovered renal calculi of more than 10 mm in diameter, in the hope of determining the composition of calculi in situ. The attenuation value of various calculi (mean ± s.d.) in a 5 mm slice with a maximal rectangular region of interest was as follows (Hounsfield units); mixed calcium oxalate and phosphate 1,555 ± 193 ($n = 22$), magnesium ammonium phosphate 1,285 ± 284 (n = 18), calcium oxalate 1,690 (n = 1), calcium phosphate 1,400 (n = 2), cystine 757 ± 114 (n = 5) and uric acid 480 (n = 2). Attenuation values ranging from 500 to 1,600 overlapped for various calculi, except those composed of uric acid calculi. There was no correlation between the attenuation value and the mineral content such as calcium or magnesium per unit weight of calculus. The mineral content per unit volume seemed to be attributable to the attenuation value. From the present results we conclude that the determination of calculous composition by the attenuation value is possible only for oxalate calculi of more than 1,600 and uric acid calculi of less than 500 attenuation value, provided that the proper CT slice location, the region of interest and the appropriate calculus size can be determined.

Key words: Computed tomography, Attenuation value, Composition of renal calculi, In vitro.

Introduction

Computed tomography (CT) has become a valuable diagnostic tool to detect a small difference in radiodensity for its high resolution capacity. In regard to urinary calculi, its usefulness is widely recognized in assessing radiolucent calculi [1–8]. Federle et al. [2] suggested the possibility of knowing the composition of calculi based on its characteristic attenuation value (ATV). Modern urological attitudes for management of urolithiasis are based on an analysis of calculi; the analysis, however, is performed only on the recovered calculi. Therefore, it would be useful to know the composition of calculi in situ. The aim of the present study was to elucidate the relationship between the composition of calculi and its ATV in vitro for clinical application.

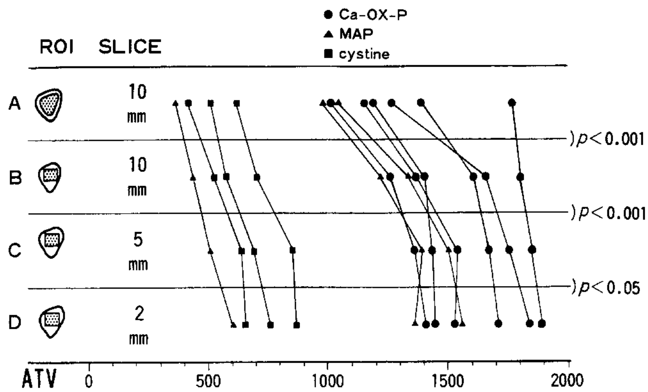

Fig. 1. CT attenuation value (*ATV*) in different regions of interest (*ROI*), and slice width. In comparison between a calculous analogous shape (**A**) and a maximal rectangle inside calculus (**B**), the latter value was significantly higher. In the maximal rectangular ROI the ATV was highest in the slice of 2 mm followed by the 5 mm and the 10 mm, successively. The statistical significance was much greater between the latter two than the former two

Material and Methods

Fifty surgically recovered renal calculi of more than 10 mm in diameter were used for the study. The composition of the calculi analyzed by an infrared spectrophotometer (EPI-S, Hitachi, Japan) was 2 calcium phosphate (Ca-P), 1 calcium oxalate (Ca-Ox), 22 mixed calcium oxalate and phosphate (Ca-Ox-P), 18 magnesium ammonium phosphate (MAP), 5 cystine and 2 uric acid. They were immersed in distilled water overnight, then placed in a tissue equivalent phantom (water bath) and treated for 1 h by a vacuum pump. The CT scans were usually obtained with a 5 mm collimeter.

The scans with a 10 mm and a 2 mm collimeter were added to compare the effect of slice width in 12 calculi. The region of interest (ROI) was set as a maximal rectangle inside a calculus. The ROI of a calculus of similar shape, as shown in Fig. 1A, was also obtained

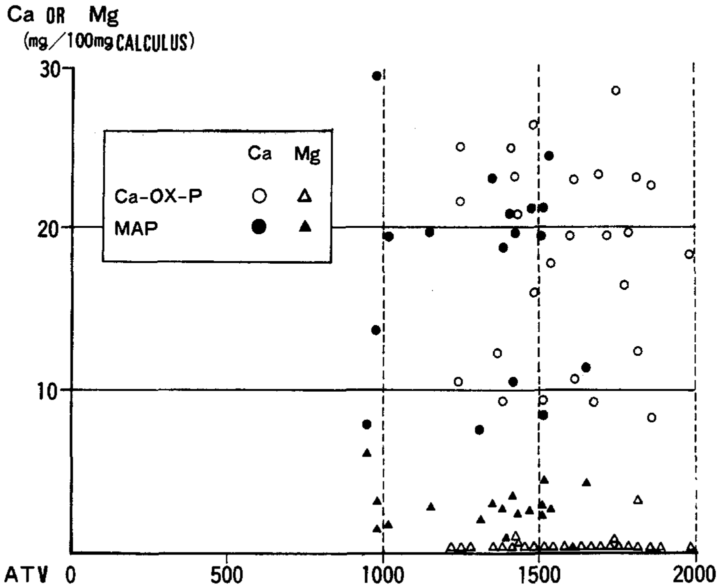

Fig. 2. CT attenuation value (*ATV*) and calcium or magnesium content of calculus. There was no correlation between the calcium or magnesium content per unit weight of two kinds of calculi, mixed calcium oxalate and phosphate calculi (*Ca-Ox-P*), and magnesium ammonium phosphate (*MAP*)

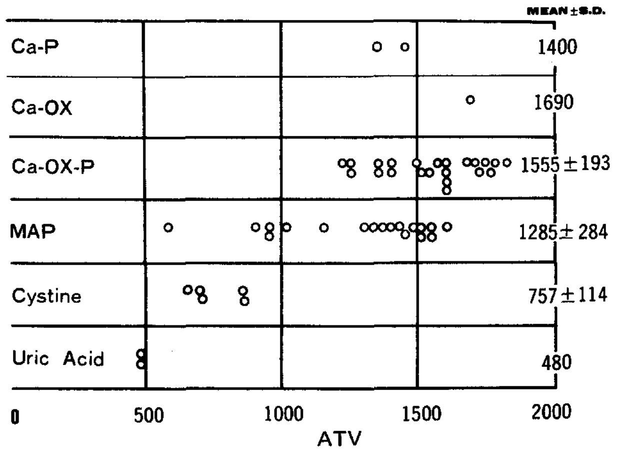

Fig. 3. CT attenuation value (*ATV*) of various calculi. Details see text

to compare with that of the maximal rectangle inside a calculus, as shown in Fig. 1, B, C, D in 12 calculi. The calcium or magnesium content of 43 calculi, except for cystine and uric acid calculi, was studied by the following method; 50 mg of calculus was dissolved in 1 ml of 10 N HCl overnight, then diluted to a total volume of 10 ml by deionized distilled water and kept standing for one week at room temperature. The calcium or magnesium content of the solution was analyzed by an atomic absorption flame emission spectrophotometer (AA-644, Shimazu, Japan). For statistical analysis a t-test was used. All studies were performed on Toshiba TCT-60A30 CT scanner. ATV was expressed here as Hounsfield units on a +/– 1,000 scale.

Results

1. CT Attenuation Value of Different Regions of Interest and Slice Width

Comparison of ATV between the ROI of a maximal rectangle inside a calculus and a calculus of similar shape in 10 mm slice showed that ATV of the former was significantly greater than the latter ($p < 0.01$). Comparison of ATV of the maximal rectangle inside a calculus in a 10 mm, a 5 mm and a 2 mm slice showed that the value was the greatest in the 2 mm slice, followed by the 5 mm and the 10 mm, successively. The statistical difference of the ATV in the 5 mm and the 10 mm ($p < 0.01$) was greater than that of the 2 mm and the 5 mm slices ($p < 0.05$). These findings are illustrated in Fig. 1. X-ray energy to obtain the same quality of CT figure is usually higher in the thinner slice than in the thicker one. In consideration of the clinical application, the 5 mm slice seems to be reasonable. Therefore, the following CT studies were performed in the ROI of maximal rectangle inside a calculus using a 5 mm slice width.

2. CT Attenuation Value and Calcium or Magnesium Content of Calculi

Calcium or magnesium content of various calculi is illustrated in Fig. 2. As seen in the figure, there is no correlation between the calcium or magnesium content of calculi and ATV. These findings suggest that the ATV of a calculus is determined mainly by the compactness of minerals. In other words, the mineral content per unit volume rather than per unit weight seems to determine the ATV.

3. CT Attenuation Value of Calculi

CT attenuation value of calculi in a 5 mm slice with a maximal rectangular ROI is as follows; Ca-Ox-P 1,555 ± 193 (n = 22), MAP 1,285 ± 284 (n = 18), Ca-Ox 1,690 (n = 1), Ca-P 1,400 (n = 2), cystine 757 ± 114 (n = 5) and uric acid 480 (n = 2), respectively. In oxalate and MAP calculi there was an overlapping zone, the ATV ranging from 1,200 to 1,600. The ATV of MAP of low density overlapped also with cystine calculi. Only the ATV of uric acid and oxalate calculi of more than 1,600 showed no overlap with other calculi. The result is shown in Fig. 3. It is also noteworthy that one MAP calculus showed a lower ATV (548) than all cystine calculi examined. This calculus was radiolucent on a plain film and was demonstrated as a non-opaque filling defect on an excretory urogram.

Discussion

In an evaluation of ATV, partial volume averaging and accuracy of CT slice location should be taken into consideration. In addition, the size of calculus is also important. Parienty et al. [5] noted that the ATV of calculi tended to increase according to the diameter of the calculus, although they did not find an absolute correlation between the apparent size and the CT density. For these reasons we studied calculi of more than 10 mm in diameter.

As to the setting conditions of CT, the thinner slice and the smaller ROI would be preferable in the calculi of homogenous composition. However, the composition would be variable from site to site in the calculus. Therefore, the smallest ROI is limited by sampling error and the largest ROI, such as the present stone analogous shape, tends to include a partial volume averaging. The 5 mm slice width with the maximal rectangular ROI inside the calculus seems to be reasonable for the evaluation of ATV in clinical application. Federle et al. [2] advised using a 5 mm collimetor for a small calculus.

The ATV hitherto reported of uric acid, cystine, struvite (MAP), calcium oxalate and calcium phosphate calculus in situ is 346–400 [2, 3, 5], 586 [2], 400 [1], 510 [2] and 278 [5], respectively. These values are smaller than the present findings. This discrepancy seems to be attributable mainly to the inaccuracy of CT slice location in situ. In this regard, Segal et al. [6], Federle et al. [2] and Greenberg et al. [3] advocated that the calculi should be scanned by contiguous slice, especially with the small one in order to eliminate the partial averaging effect.

In the present study the mean ATV of calcium containing calculi, such as Ca-P, Ca-Ox and mixed Ca-Ox-P, was about 1,550 ranging from 1,200 to 1,800. That of MAP was 1,285 ranging from 600 to 1,600. As shown in Fig. 3, the overlapping zone of ATV in the two kinds of calculi was approximately from 1,200 to 1,600. From this result we can predict the calcium containing calculi only when the ATV is more than 1,600, and MAP when the value is below 1,200. However, it is difficult to determine either calcium containing calculi or MAP in the overlapping zone from 1,200 to 1,600.

In cystine calculi, its ATV is located between 500 and 1,000. For this reason, care must be taken to differentiate cystine and MAP calculi of low density. Detection of characteristic hexogonal crystals and cyanide nitroprusside test in urine will be helpful for the determination of cystine calculi in these cases. One MAP calculus of a very low ATV will be analogous to that reported by Alter et al. [1], which was demonstrated as a calculus only by the CT. While we undertook only two studies of uric acid calculi, the value of 480 seems to be in accord with the observation of Federle et al. [2]. Although they showed the smaller value of 346–400 compared to the present study, the discrepancy is attributable to the causes already mentioned.

In conclusion, the determination of calculous composition by ATV is possible only for oxalate calculi of more than 1,600 and uric acid calculus of less than 500 ATV. And even for the determination of these two kinds of calculi, the proper CT slice location, ROI and an appropriate calculous size seem to be a prerequisite.

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