Computed Radiography Excretory Urography: Can the System Sensitivity Value be Used as an Image Quality Indicator?

Kazuo Andoh, Kunio Odagiri, Toru Matsumoto, Kousuke Yamashita, Ichiro Ogino, and Toshihiro Otsuka

The purpose of this study is to determine whether the computed radiography system sensitivity value can be used as an image quality indicator for computed radiography excretory urography with radiation dose reduction. One hundred and twenty-four patients with gynecological malignancies were studied prospectively. Five-minute and 10-minute computed radiographic images of excretory urography were obtained in each patient with different radiation doses (ie, a standard dose image required with screen-film method and a reduced dose one). The images were subjectively scored by three radiologists without knowledge of the exposure factors or the system sensitivity values. The quality scores of the reduced-dose images used in the five steps were compared with those of the standard dose images (the system sensitivity value was 80 to 120). The images with reduced exposures were arbitrarily divided into five steps according to the system sensitivity value (ie, 150 to 250, 260-400, 410-600, 610-1000, and 1010-1500). There was a gradual degradation of the image quality as the system sensitivity value was increased. In terms of visualization of the bones, the images taken with the system sensitivity values of 150-250 (40%-67% of the standard dose system) showed no statistically significant difference from the standard dose images. As for visualization of the renal pelvic margins, the images taken with the system sensitivity values of 260 to 400 (25%-38% of the standard dose system) showed no statistically significant difference. We conclude that system sensitivity value can be used as a practical though approximate indicator of the image quality.

KEY WORDS: computed radiography, system sensitivity, excretory urography, dose reduction, computers, radiology

A COMPUTED RADIOGRAPHY (CR) system has been evaluated to determine whether acceptable radiographic images could be obtained with lower doses of radiation than with the screen-film method. Several studies have evaluated its use for chest imaging,[1,2] hysterosalpingography,[3] leg-length radiography,[4] and excretory urography.[5] For pediatric chest imaging, Kogutt et al showed that high-quality images could be produced by a CR system at 15% of the radiation dose required with the screen-film method.[1] For hysterosalpingography, the mean CR system dose to the ovary was reported to be many times lower than the lowest previously reported dose using the screen-film method.[3] For CR leg-length radiography, it was reported that exposure reductions of 96% to 98% were readily reached and consistently maintained.[4] As for excretory urography, Fajardo et al reported no difference in making specific diagnosis between screen-film images and CR images at a radiation dose reduction of about one half.[5] The system sensitivity value (S value) is a number correlating to the accumulated radiation dose or the amount of phosphostimulated light emission of halogen crystals on the imaging plate. By definition, the S value correlates with the accumulated dose on the imaging plate. Degradation of the image quality dose correlate with dose reduction.

In this study detailed analysis of the image quality of CR images obtained with lower radiation doses during excretory urography were performed to determine whether the S value could be used as an image quality indicator. To our knowledge, there is no prior report dealing with the S value and dose reduction.

MATERIAL AND METHODS

Material

CR excretory urography was prospectively performed in 124 patients between the ages of 39 and 72 years with gynecological malignancies including uterine cancer and ovarian cancer. The urographic diagnosis included normal (n = 75), hydronephrosis (n = 17), renal anomaly (n = 6), reduced renal function (n = 10), foreign body (n = 11), and spondylosis (n = 5). The contrast medium, iohexol (Omnipaque 300; Daiichi, Tokyo, Japan) was introduced intravenously by rapid hand-injected bolus technique in a dose of 300 mg/kg body weight.

System Sensitivity Value (S Value).

The S value is a number indicating the sensitivity of the image reading device of a CR system. The image reading device

From the Department of Radiology, Kanagawa Cancer Center, Yokohama, Japan; and the Division of Clinical Research, National Institute of Radiological Sciences, Japan.

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Address reprint request to Kazuo Andoh, Radiology, Kanagawa Cancer Center, 1-2 Nakao-cho, Asahi-ku, Yokohama 241, Japan.

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calculates the S value for each image based on a histogram of the accumulated radiation dose and frequency (number of pixels) on an imaging plate. The S value of a given image is calculated as follows:

$$\text{S value} = \frac{200 \times 2.58 \times 10^{-7}}{\text{Sc}}$$

where Sc (C/kg) is the dose corresponding to the median value on the histogram (Fig 1). When the S value of the first exposure is 2,000 and that of the second exposure is 200, the radiation dose of the former is 10% of that of the latter. When the histograms resulting from both exposures are different this relationship cannot be applied, for example, when the first exposure is made of the chest and the second exposure of the abdomen. This relationship can be applied when the histograms of two images are similar; that is, the exposures are made in the same exposure field. Thus, the S value is not absolute but relative depending on the exposure fields.

Experimental design

An image pair consisting of five-minute kidney, ureter, and bladder (KUB) and ten-minute KUB for each patient made up the experimental material. The exposure fields of the two KUBs were the same. In order to average the bias of S value by the difference in amount of the contrast medium of the urinary system of the two KUBs in a patient, we randomly divided the patients into two groups. In each patient, one of the two KUBs (the standard dose image) was taken with the radiographic factors, 64 ± 4 kV and 54 ± 6 mAs, required with the screen-film method. The other was taken with the same kV and reduced mAs (Fig 2).

CR System.

Digital imaging was performed with the FCR 7000 computed radiography system (Fuji Film Co, Tokyo, Japan). This system scans and digitizes images recorded on an imaging plate with a pixel size of 0.2 mm and a maximum resolution of about 2.5 lp/mm. This system is directly coupled to a laser imager where the CR images are printed to hard copies for viewing. The system routinely provides an unmodified image that simulates a screen-film radiograph and a frequency-modified image that enhances the edges of structures. Both types of images from the same picture information were evaluated in all cases. Our CR system was programmed to have the S value routinely appear on all hard-copy images; whether the S value is printed on hard copies is a user-programmable feature on FCR 9000 CR system supplied in 1993.

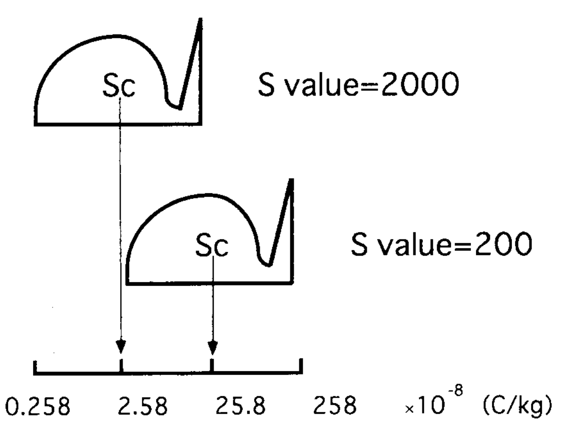


Fig 1. Histogram of accumulated radiation dose (C/kg) and frequency (number of pixels). Sc is the dose corresponding to the median value on the histogram.

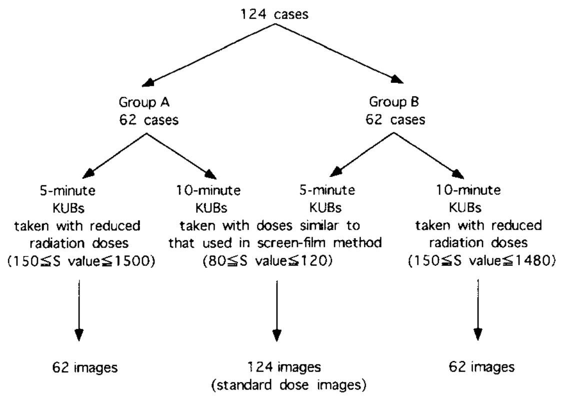


Fig 2. Experimental design. S value in parentheses appears in the text in the results section.

Skin Doses.

Radiation exposures in free air were determined with a commercially available ion chamber (Exposure Meter Model 192; Capintec, Pittsburgh, PA) placed on the phantom of the 20-cm thick acrylic plate. Measurements were made at the phantom placed on the table top. The tube-radiation meter and the table-imaging plate distances were 90 cm and 10 cm, respectively. A plot of the radiation dose versus mAs for kV was obtained. From these data the skin doses of each patient were calculated.

Image Quality Evaluation.

All the images were evaluated by three radiologists who were unaware of the radiation doses or the S value. The S value printed on each image was covered by masking tape. Observations were focused on the clarity of the bones and the renal pelvic margins. Quality of the image was rated by a scale from 1 to 5:

1. Much better than usual
2. Better than usual
3. Usual
4. Poorer than usual
5. Much poorer than usual

The scores were based on the readers' subjective assessment of quality and arrived at by consensus. No specific criteria were imposed on the readers. For statistical analysis, the Student's *t*-test (Welch's method) was used.

RESULTS

The S values of the standard dose images varied from 80 to 120, with an average S value of 100. The S values of the images taken with reduced doses varied from 150 to 1,500.

The skin dose of the standard dose images was $7.6 \times 10^{-5} \pm 0.9 \times 10^{-5}$ (C/kg). There was a mild linear correlation ($r = -0.875$) between skin dose (C/kg) and $\log_{10}$ S value in the images taken with reduced doses (Fig 3). The regression equation by the least squares method was as follows:

$$\log_{10} \text{S value} = 3.06640 - 15604.7\text{X} \sim \text{skin dose}$$

The images with reduced doses were subjectively divided into five steps according to the S value: 150 to 250, 260 to 400, 410 to 600, 610 to 1,000, and 1,010 to 1,500 S levels. There was a gradual degradation of the image quality as the S value was increased (Fig 4). Deterioration of the image quality was mainly due to background granularity caused by quantum mottle and so on. There were no statistically significant differences in the average scores among the groups of the standard dose images at the 80 to 120 S level. There was a significant difference in terms of visualization of the bones between the average scores of the groups of the images taken with 260 to 400 S level or more and those of the standard dose images ($P < .05$) (Table 1). As for visualization of the renal pelvic margins, a statistically significant difference was seen between the average scores of the standard dose images and those of the groups of the reduced dose images at the 410 to 600 S level or higher levels ($P < .05$) (Table 2).

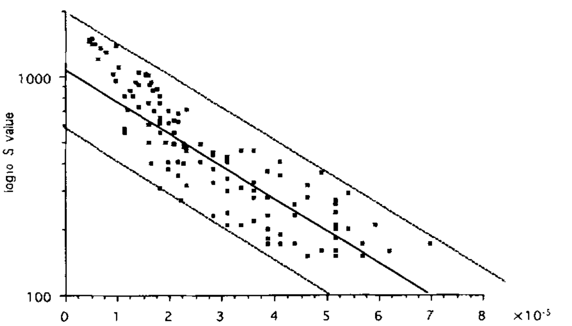


Fig 3. Skin dose and system sensitivity value (S value). The data of the 124 CR images taken with reduced doses of radiation are plotted. Mild linear regression of $\log_{10}$ S value on skin dose with 95% confidence bands (dashed lines) ($r = -0.875$).

DISCUSSION

In our study, comparison was made between the standard dose images and the lower dose images using a grading system. Although subjective, this grading system is similar to that used by other investigators.[6,7] To exclude the subjective preference for screen-film radiography primarily caused by readers' familiarity with and confidence in screen-film studies, we chose to use CR images taken with screen-film method level radiation exposures as the standard dose images (average S value of 100). Using the average S value, the relative dose as compared with the standard dose can be calculated roughly as follows:

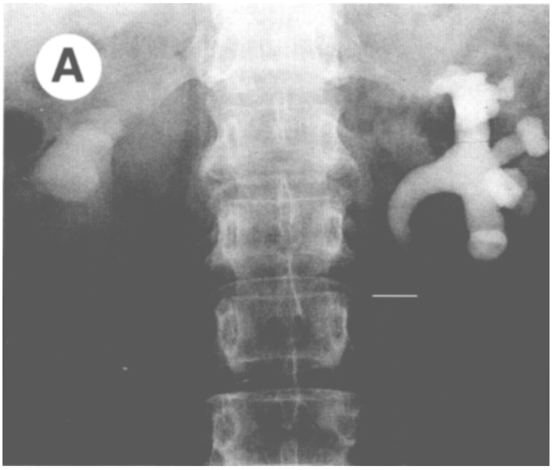
$$\text{Relative dose (\%)} = \frac{100}{\text{S value}} \times 100$$

Images taken with 150 to 250 S level (40% to 67% of the standard dose system) showed no statistically significant difference from the standard dose images in terms of visualization of the bones. As for visualization of the renal pelvic margins, images taken with 260 to 400 S level (25% to 38% of the standard dose system) or less showed no statistically significant difference.

In CR excretory urography, a possible dose reduction of more than 80% has been described in an experimental setting.[8] In other studies,[4,9] the limits of dose reduction are determined by the minimum tolerable signal-to-noise ratio for a specific imaging task. Because a high signal-to-noise ratio is not required for studies such as leg-length radiography, a larger dose reduction is possible. Dose reduction opportunities, however, are more limited in studies that require a great deal of spatial and contrast information, such as in the assessment of fine skeletal structures. In CR excretory urography, exposures may be made at reduced radiation doses corresponding to the different S levels presented in this report. This is particularly important in pediatric radiology because decreasing the radiation dose is an important goal in children.

The S value did not have a strong correlation with skin dose as illustrated by Figure 3. By definition, the S value correlates with the accumulated dose on the imaging plate. Because degradation of the image quality correlates with dose reduction, it was expected that the S value might correlate with the image quality. The image quality did degrade as the S level was increased in our materials.

Our preliminary study suggests that total radiation dose during CR excretory urography could be decreased by combining exposures with different dose factors. For example, a filming sequence of a scout image taken with 150 to 250 S level; 1-minute,



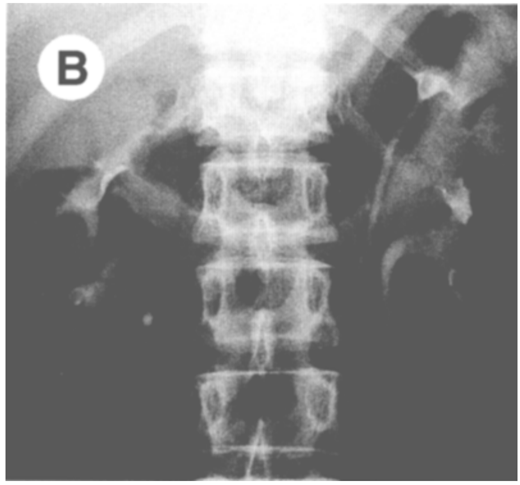


Fig 4. Unmodified CR images taken with reduced doses of radiation in 3 different patients. Close-up views. The image quality was gradually degraded as S value was increased. (A) Bilateral hydronephroses. Factors for radiographic technique: 68 kV, 44 mAs, 7.48 × 10^{-5} C/kg. S value = 160 (150-250 S level). (B) L. duplex kidney. Factors for radiographic technique: 66 kV, 17 mAs, 2.84 × 10^{-5} C/kg. S value = 340 (260-400 S level). (C) Normal study. Factors for radiographic technique: 60 kV, 4 mAs, 5.68 × 10^{-6} C/kg. S value = 1400 (1010-1500 S level).

Table 1. Quality Scores of Bone Visualization and System Sensitivity Value (S value)

S Value	Case	Quality Score 1	2	3	4	5	Mean Score	
80-120	30	2	11	15	2	0	2.57 (±0.73)	NS
150-250	30	0	6	22	2	0	2.87 (±0.51)	
80-120	26	1	11	12	2	0	2.58 (±0.70)	*
260-400	26	0	3	17	6	0	3.12 (±0.59)	
80-120	28	1	8	18	1	0	2.68 (±0.61)	*
410-600	28	0	1	13	13	1	3.50 (±0.64)	
80-120	25	1	12	11	1	0	2.48 (±0.65)	*
610-1000	25	0	0	8	15	2	3.76 (±0.60)	
80-120	15	1	6	7	1	0	2.53 (±0.74)	*
1010-1500	15	0	0	1	9	5	4.27 (±0.59)	

Note: Data in parentheses are standard deviation.
Abbreviation: NS, not significant.
$*P < .05$.

Table 2. Quality Scores of Renal Pelvic Margin Visualization and System Sensitivity Value (S value)

S Value	Case	Quality Score 1	2	3	4	5	Mean Score	
80-120	30	2	13	15	0	0	2.43 (±0.63)	NS
150-250	30	0	10	18	2	0	2.73 (±0.58)	
80-120	26	1	10	14	1	0	2.58 (±0.64)	NS
260-400	26	0	6	16	4	0	2.92 (±0.63)	
80-120	28	1	11	16	0	0	2.54 (±0.58)	*
410-600	28	0	2	20	6	0	3.14 (±0.53)	
80-120	25	2	12	10	1	0	2.40 (±0.71)	*
610-1000	25	0	1	13	11	0	3.40 (±0.58)	
80-120	15	1	7	7	0	0	2.40 (±0.63)	*
1010-1500	15	0	0	4	8	3	3.93 (±0.70)	

Note: Data in parentheses are standard deviation.
Abbreviation: NS, not significant.
$*P < .05$.

5-minute, 10-minute, and 20-minute images taken with 260 to 400 S level might be used. Furthermore, the S value might be used longitudinally over time as part of a continuous quality improvement program. (As the S value is unique to the particular system used in the Fuji and the Toshiba CR devices, our data may not be applicable to other types of CR systems.)

In conclusion, although our data cannot be applied in the other parts of the body we believe that the S value can be used as a practical though approximate indicator of the image quality in CR excretory urography.

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