Relationship between the Pixel Value in Digital Subtraction Angiography and Iodine Concentration: Study in High Iodine Concentration with Original Phantom

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¹*Department of Clinical Radiology, Tohoku University Hospital,* ²*Section of Internal Medicine and Disability Prevention, Tohoku University Graduate School of Medicine,* ³*Department of Radiology, Tohoku University School of Medicine,* and ⁴*Department of Radiological Technology, College of Medical Sciences, Tohoku University, Sendai 980-8574*

CHIDA, K., SAI, M., SAITO, H., TAKASE, K., ZUGUCHI, M., SASAKI, M. and SATO, T. *Relationship between the Pixel Value in Digital Subtraction Angiography and Iodine Concentration: Study in High Iodine Concentration with Original Phantom.* Tohoku J. Exp. Med., 2000, **190** (3), 169–176 — Quantitative digital subtraction angiography (DSA) image analysis based on densitometry is widely accepted and used. For the densitometric DSA image analysis, it is required that there is a linear relationships between the pixel values on DSA images (DSA values) and contrast medium iodine concentration or the thickness of the vessels or the chambers filled with contrast material. We studied on relationship between the DSA value and iodine concentration especially in high iodine concentration. As for the relationship between DSA values and iodine concentration on the DSA images at low concentration, DSA phantom had a good linear relationship. However, the relationship at the high iodine concentration, DSA phantom sometimes lost this linear relationship. Our results suggested that it was necessary to identify relationship between DSA values and iodine concentration in each DSA system, especially in high iodine concentration setting, for densitometric DSA image analysis. ——— digital subtraction angiography; densitometric analysis; quantitative analysis; coronary arteriography; angiocardiology © 2000 Tohoku University Medical Press

Most important capability of digital subtraction angiography (DSA) is its great low contrast resolution. Widely used and commercially available DSA

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phantoms are the phantoms for examining DSA system's low contrast resolution. The quantitative DSA image analysis is also used in clinical practice. Quantitative analysis is widely used especially in the coronary arteriography and angiocardiology (i.e., analysis of coronary arterial stenoses and ventricular volume measurements). Many reports showed clinical usefulness of quantitative image analysis with DSA system (Tobis et al. 1983; Nichols et al. 1984; Detrano et al. 1985a, b). A quantitative information by single-plane method of DSA acquisition is obtained with densitometric image analysis. For densitometric image analysis, it is required that there is linear relationship between the pixel values of DSA image (DSA values) and contrast medium iodine concentration or the thickness of the vessels or the chambers filled with contrast material. However, to our best knowledge, there is no detailed report of them. Though a number of reports stated usefulness of quantitative image analysis using DSA system, there is no description of the linear relationship between DSA value and iodine concentration especially at high iodine concentration setting. The evaluation of it in the low iodine concentration alone is insufficient to assess DSA system's availability in quantitative image analysis. The evaluation of it in the high iodine concentration setting is necessary. Purpose of this report was to describe the relationship between the DSA values and iodine concentration especially in high iodine concentration setting by a home-made high iodine concentration phantom.

MATERIALS AND METHODS

A DSA system (DIGITRON 3VACI; SIEMENS, Elrangen, Germany) was used in entire study, and two other systems DIGITRON 3VA (SIEMENS), and DFP-50A (TOSHIBA, Nasu) were used for comparison among DSA systems. Our standard digital image acquisition on Digitron 3VACI system in clinical use was as follows: 3 frames/second in 512×512 matrix, 1024 shades of gray. x-Ray exposure factors used were 63 kV, 100 cm focal length, 10 inch image intensifier (I. I.) with grid (12 : 1, 40 lines/cm), and dose level at $500 \mu\text{R/frame}$. Original DSA values were measured by using the Digitron's software (SIEMENS). DSA values used in this study were determined as follows: "DSA values" = "averaged original DSA values in the Region of interest (ROI)" - "those in background."

The shape of ROI was circular, and its diameter was approximately 1 cm. It took approximately 5 minutes to readout of DSA values every sequence. A high iodine concentration (10.0~300.0 mg iodine/ml) phantom (Fig. 1) was prepared in our department using contrast medium (Iopamidol, Shering Japan, Osaka) and a low iodine concentration phantom (0.5~20.0 mg iodine/ml: DSA phantom type 76-700, VICTOREEN, Cleveland, OH, USA) were used in this study. The range of the contrast material thickness in our high iodine concentration phantom is from 0 to 20 mm. Thickness of 1.4 cm was used in entire study except in the comparison study between DSA values and contrast material thickness. Relationships between the DSA values and the iodine concentration and those between

Fig. 1. Schematic representation of the high iodine concentration phantom (Home made, range of thickness of contrast material was between 0~2.0 cm). Iodine concentration, A, 10 mg/ml; B, 20 mg/ml; C, 30 mg/ml; D, 50 mg/ml; E, 100 mg/ml; F, 150 mg/ml; G, 200 mg/ml; H, 300 mg/ml.

the DSA values and the thickness of contrast medium were obtained from the DSA images of the DSA phantoms. Evaluated factors in each comparison were as follows:

The dependence of different frames in the same exposure sequence frame on DSA acquisition

DSA images at the low iodine concentration phantom were obtained using standard clinical image acquisition setting (above). Time-density curves (TDC) and DSA value (mean value and standard deviation) at the each points of DSA phantom were obtained.

The effect of the acquisition settings for the linearity of DSA value

The effects of the matrix size (512×512 and 256×256), the acquisition type (pulse mode: 3 frames/second and cine mode: 25 frames/second), the exposure dose level (100, 200, 500, and $1000 \mu\text{R/frame}$), and the scattering x-ray (with and without added 15 cm aclyle) were evaluated.

Relationship between DSA value and thickness of contrast medium

DSA images were acquired with high iodine concentration phantom in a variety of contrast medium thickness. Contrast medium concentration examined were 50, 100, 150, and 300 mg iodine/ml.

Comparison of DSA systems. The high iodine concentration phantom was imaged in the three DSA systems (DIGITRON 3VACI and 3VA [SIEMENS], and DFP-50A [TOSHIBA]). The linear relationships between DSA values and iodine concentration in each system were compared.

RESULTS

There were no significant differences in the TDC at the each points of the low

Fig. 2. Time-density curve of low iodine concentration phantom in the same exposure sequence frame on DSA acquisition (mean $\pm$ s.d.).

—□—, 20.0 mg iodine/ml, ($57.14 \pm 0.72\%$); —○—, 10.0 mg iodine/ml, ($31.50 \pm 1.36\%$); —△—, 4.0 mg iodine/ml, ($11.81 \pm 2.91\%$); —◇—, 2.0 mg iodine/ml, ($6.75 \pm 5.34\%$).

Fig. 3. Relationship between DSA value and low iodine concentration in the variety of condition of DSA acquisition. H2, H1, L2 and L1 are dose levels at 1000 μ R/frame, 500 μ R/frame, 200 μ R/frame and 100 μ R/frame, respectively. (), x-ray tube potential.

—□—, H2 dose (63 kV); —○—, H1 dose (63 kV); —△—, L2 dose (63 kV); —◇—, L1 dose (63 kV); —●—, H1 dose (85 kV); —▽—, Cine mode DSA (63 kV).

Fig. 4. Relationship between DSA value and high iodine concentration in the variety of condition of DSA acquisition. H1 and L2 are dose levels at $500 \mu\text{R}/\text{frame}$ and $200 \mu\text{R}/\text{frame}$, respectively. (), x-ray tube potential. —□—, H1 dose (63 kV); —○—, L2 dose (63 kV); —△—, H1 dose (85 kV); —◇—, H1 dose (63 kV) DSA acquisition in 256×256 matrix; —●—, Cine mode DSA (63 kV); —▽—, H1 dose (85 kV) DSA acquisition in added 15 cm aclyle.

Fig. 5. Relationship between DSA value and thickness of contrast medium. —□—, 300 mg iodine/ml; —○—, 150 mg iodine/ml; —△—, 100 mg iodine/ml; —◇—, 50 mg iodine/ml.

Fig. 6. Relationship between DSA value and iodine concentration in the three DSA systems. (), x-ray tube potential.
 —□—, DFP-50A (64 kV); —○—, DIGITRON 3VACI (63 kV); —△—, DIGITRON 3VA (63 kV).

concentration DSA phantom images in the same exposure sequence (Fig. 2).

The matrix size of DSA and scattering x-ray made little change in the relationships between DSA values and iodine concentration in the clinical use level (Figs. 3 and 4). The acquisition type of DSA and exposure dose made significant difference in the relationships between DSA values and iodine concentration at the higher iodine concentration (Figs. 3 and 4).

The DSA values and the thickness of contrast media showed a good linear correlation when 50 and 100 mg iodine/ml contrast medium was used, or less than approximately 0.8 cm of contrast volume thickness was used. Increase of the DSA value became lower than expected when over 150 mg iodine/ml (Fig. 5).

The DSA values and the concentration of contrast media had good linear correlations in all three systems when less than 100 mg iodine/ml contrast medium was used (Fig. 6).

DISCUSSION

In a clinical setting, however, high iodine concentration contrast medium is usually injected directly into the coronary arteries or cardiac chambers. The evaluation of low-contrast resolution alone is insufficient to assess DSA's suitability in quantitative image analysis, and the evaluation of high-concentration resolution is necessary.

Quantitative information is obtained using densitometric image analysis with the single-plane method of DSA acquisition. Densitometric image analysis makes

it possible to evaluate vessel stenoses and chamber volumes quantitatively.

For densitometric image analysis, there must be a linear relationship between the DSA value and contrast medium (iodine) concentration. To our best knowledge, however, no study has examined this in detail. Published reports stating the usefulness of quantitative image analysis using DSA systems do not describe a linear relationship between DSA value and iodine concentration, especially at high iodine concentrations. Therefore, we built a high iodine concentration phantom and examined the relationship between DSA value and iodine concentration. Matrix size, acquisition type, and scattering x-ray had little effect on the relationship between the DSA value and iodine concentration at settings used clinically.

Our results at high-concentration phantom clearly showed that the DSA value was not increased as expected by the linear relation, which was determined by the examination at low-iodine-concentration. Our DSA system (Digitron 3VACI) lost linear relationship between the DSA values and iodine concentration at the DSA value over 500. DSA systems lost linear relationship between DSA values and iodine concentration especially in high-concentration setting. The point of losing linear relation was different among DSA systems which we compared to. These differences might be mainly caused by the variation in characteristic of electronic component such as television (TV) system and amplification. Because there is linear relation between the light output from the image intensifier (I.I.) and the x-ray intensity incident on the I.I. (Cohen et al. 1982; Seibert et al. 1984; Fujita et al. 1986). There might be variation in condition of electronic component, especially on TV system even in the same DSA equipment. This can cause the difference of linear relationship between the DSA value and the iodine concentration even in the same DSA system. Therefore, the adjustment of the TV camera gain, the linearity of DSA value should be kept approximately same condition subsequently. We believe that it is necessary to examine the linear relationship between the DSA values and iodine concentration with phantoms at least once a month for maintaining DSA system's quantitative capabilities. It is recommended that the DSA equipment should be adjusted periodically. If the relationship between the DSA values and the iodine concentration in the DSA system is not linear, it is necessary to correct the DSA values using relation curve between DSA value and iodine concentration for the quantitative analysis. High-concentration iodine contrast medium is usually used in the coronary angiography and angiocardiology. High-concentration iodine contrast medium in the coronary angiography can alter linear relationship between the DSA value and the iodine concentration. The thickness of the cardiac chamber in the left and right ventriculography also disturb that linear relationship. Therefore, it is necessary to examine DSA system using not only low iodine concentration phantom but also high iodine concentration phantom for the quantitative analysis of DSA images.

CONCLUSION

DSA values had a good linear relationship to the iodine concentration in the examination using a low-concentration phantom. However, examinations using a high-concentration phantom clearly showed that the DSA value was lower than expected from the linear relationship determined by the examination at low iodine concentration.

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