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ORIGINAL ARTICLE

Investigation of the relation between administered dose and image quality for pediatric ^{99m}Tc-DMSA renal scintigraphy: clinical study applying the JSNM (Japanese Society of Nuclear Medicine) pediatric dosage card

The Japanese Society of Nuclear Medicine Technology (JSNMT), the Optimization of Imaging Technique Committee for Pediatric Nuclear Medicine Studies

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Abstract

Purpose In 2013, the Japanese Society of Nuclear Medicine (JSNM) announced consensus guidelines for pediatric nuclear medicine. These JSNM guidelines proposed use of lower administered doses compared with traditionally determined doses, which were estimated from age, weight or body surface area (BSA) based on the administered dose for adults in Japan. When the JSNM guidelines are used, the relationship between this recommended administered dose and image quality remains unclear. In this study, we clarified the relationship between administered dose and image quality for pediatric ^{99m}Tc-DMSA renal scan retrospectively, and verified the diagnosable image quality with the recommended administered dose of the JSNM guidelines.

Materials and methods Data from 7 pediatric patients who underwent ^{99m}Tc-DMSA dynamic renal scans according to the guidelines' recommended doses were collected. Scan frame rate was 1 frame/min, and scan time was up to 8 min. Eight images, which had different acquired time periods from 1 min to 8 min were prepared by adding each frame. Nine nuclear medicine specialists determined 8 images with different acquired times as diagnosable or undiagnosable. A region of interest (ROI) with 50% thresholds was placed on each kidney of every image. Coefficient of variation (CV) was calculated by dividing the standard deviation (σ) by the mean counts (μ) of each ROI ($CV = \sigma/\mu \times 100$). ^{99m}Tc-DMSA renal scans (total of 2821 cases) that were performed previously in collaboration with 6 hospitals were collected, and CVs of these images were calculated in all cases. These 2821 cases were separated into 5 groups for every 10 kg weight; i.e., (1) less than 10 kg, (2) 10–19.9 kg, (3) 20–29.9 kg, (4) 30–39.9 kg, and (5) above 40 kg. Regression line of each group was analyzed in relation to the CV and administered dose. The CV at the point of intersection with the recommended dose range from the guideline was determined for each group. This CV value was considered as the estimated CV of the image obtained when the recommended dose of the guideline was used. Thus, if the CV was equal to or less than the estimated CV value, then the diagnostic image quality was deemed satisfactory.

Results Average CV of the lower limit of diagnosable images in 7 cases as determined by 9 nuclear medicine specialists was 19.9%. Estimated CV was 21.2–24.2% in the group weighing < 10 kg (group 1), 19.9–20.6% in the group weighing > 10 kg and < 20 kg (group 2), 19.6% in group weighing > 20 kg and < 30 kg (group 3), 19.4–19.5% in the group weighing > 30 kg and < 40 kg (group 4), and 19.8% in the group weighing > 40 kg (group 5). The estimated CVs from groups 1 and 2 with weight < 20 kg exceeded 19.9%.

Conclusions Although ^{99m}Tc-DMSA renal scan can be carried out using the guidelines' recommended dose with conventional image acquisition time in patients weighing 20 kg or more, those < 20 kg need consideration for a longer image acquisition time to obtain diagnosable images.

Extended author information available on the last page of the article

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Keywords ^{99m}Tc-DMSA · Pediatric · Dosage card · Renal · JSNM

Introduction

Japan consensus guidelines for pediatric nuclear medicine (JCG) were published by the Japanese Society of Nuclear Medicine (JSNM) in March, 2013 [1]. Recommended administered dose in the JSNM guidelines was determined conforming with the European Association of Nuclear Medicine (EANM) guidelines [2]. Calculation method for the appropriate dose in the JCG was based on the EANM pediatric dosage card. The Society of Nuclear Medicine and Molecular Imaging also proposed consensus guidelines to determine appropriate administered doses of radiopharmaceuticals for pediatric nuclear medicine in 2010 [3].

In Japan, we have performed pediatric nuclear medicine examinations using recommended calculated doses based on administered doses which were estimated from age, weight or body surface area (BSA) as recommended by the Japan Radioisotope Association in 1988 [4]. This recent recommended dose in the JCG is generally determined as lower than the traditionally calculated dose. Therefore, if conventional acquisition time and methods are used for pediatric nuclear medicine examinations, some hospitals will be concerned about deterioration of image quality leading to lowered diagnostic performance.

In this study, our committee investigated the relationship between administered dose and image quality of ^{99m}Tc-DMSA (^{99m}Tc-dimercaptosuccinic acid) renal planar image, which is the most frequent examination in pediatric nuclear medicine in Japan, and then explored the appropriateness of the JSNM guidelines.

Materials and methods

Patients

Between 2006 and 2013, ^{99m}Tc-DMSA renal scanning was carried out in collaboration with 6 hospitals belonging to the Optimization of Imaging Technique Committee for Pediatric Nuclear Medicine Studies of the Japanese Society of Nuclear Medicine Technology (JSNMT). In total, 2821 cases were collected and analyzed retrospectively with a mean patient weight of 15.5 ± 11.0 kg, and age between from 0 to 15 years. Their main diseases were vesicoureteric reflux (VUR), hydronephrosis, and congenital solitary kidney. This clinical study was approved by the respective institutional review board of each of the 6 institutions.

Determination of diagnosable image quality

Planar images of 7 patients who received JCG recommended doses of ^{99m}Tc-DMSA were used for diagnosable image quality judgment. We extracted seven patients whose weights did not overlap with any cases from the cases administered close to the JCG dose. The average body weight of the 7 cases was 16.8 kg (5.1–32 kg), and the average administered dose was 66.5 MBq (39.5–100 MBq). All images were acquired with a low-energy high-resolution (LEHR) collimator on 2 detector gamma camera systems (E.CAM; SIEMENS, Germany). From 2 h after injection of ^{99m}Tc-DMSA, posterior planer images were acquired as dynamic data during 8 min with 1 min per frame rate. Matrix size was 256×256. Eight images that had different acquired time periods from 1 to 8 min were obtained by adding each frame (Fig. 1). Their 8 images were printed on films (Laser printer Horizon SF, Codonics, Japan).

Nine expert physicians with 2–30 years' experience in nuclear medicine at 6 collaborating hospitals made a visual assessment of 7 cases. This evaluation was performed to determine the limit of diagnosable image in the 7 images that equaled to the fully acquired image (8 min acquired image); i.e., a diagnosable image with minimal image acquisition time was determined as the minimum required by expert diagnostic physicians in nuclear medicine.

As a quantitative index of image quality evaluation, a coefficient of variation (CV) was calculated in the 50% threshold region of interest (ROI) of the kidney of a diagnosable image. The CV was calculated by dividing the standard deviation by mean counts of each ROI. The CV was determined by the formula:

$$\mathrm{CV} = \sigma / \mu \times 100, \tag{1}$$

where σ is the standard deviation, and μ is the mean count in the ROI [5].

Average value of image acquisition time, which 9 expert physicians determined as the minimum required for a

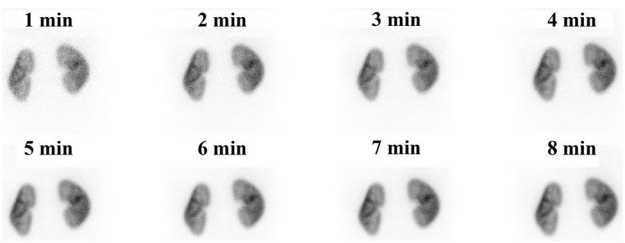

Fig. 1 A typical case of a pediatric patient with 26.7 kg body weight who received 88.2 MBq ^{99m}Tc-DMSA based on the JCG guidelines

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diagnosable image for each case was considered as the minimum required for the acquisition time of diagnosis. Furthermore, the mean value of CVs of both kidneys in the minimum required diagnosable images of 7 cases was determined as a threshold CV value of diagnosable image in this study.

Evaluation of ^{99m}Tc-DMSA clinical image analysis

Posterior planar images of 2821 cases that underwent ^{99m}Tc-DMSA scans at 6 hospitals were analyzed at each institution. All scan images were acquired according to the respective institutional routine scan protocol. The average acquisition time for images at the 6 institutions was 4.8 min (1.0–10 min), and the average pixel size was 0.94 mm (0.6–1.6 mm).

The diagnosis of all cases had already been determined at each institution. Various models of gamma cameras were used at each institution, namely E.CAM (Toshiba, Tokyo), E.CAM (SIEMENS, Germany), INFINIA (GE healthcare, USA) and Discovery NM630 (GE healthcare, USA). A ROI with 50% threshold was placed on each kidney of every image, and then CV of each image was evaluated. The CV in the ROI was calculated by Eq. (1).

Here, the analyzed images were obtained with various scanning protocols at each institution. Therefore, a correction for acquisition conditions was essential for the comparison. In this study, the administered dose was corrected by the acquisition time and pixel size. The acquisition time correction coefficient was determined as a relative value to the baseline time, which was 3 min acquisition time:

$$\mathrm{ATc} = T/3, \tag{2}$$

where ATc is the correction coefficient of the acquisition time, and T is the acquisition time of each image.

Moreover, a pixel size correction coefficient was needed to correctly adjust for the differences in mean counts by magnification ratio and acquisition matrix size. In this study, pixel size correction was carried out based on a pixel size of 0.9 mm. Therefore, a pixel size correction coefficient was determined with the formula:

$$\mathrm{PSc} = \mathrm{PS}/0.9, \tag{3}$$

where PSc is the correction coefficient of the pixel size, and PS is the pixel size of each image.

The corrected administered dose was determined as the actual administered dose of each case multiplied by the collection time correction coefficient and the pixel size correction coefficient. This corrected administered dose was normalized by the correction coefficients to compare image quality using the same scale; i.e., image quality of all images was compared as an image quality with 0.9 mm pixel size and 3 min acquisition time.

The cases were divided into 5 groups according to every 10 kg of body weight, and the relationship between the corrected dose and CV was determined. The CV was plotted on the vertical axis and the corrected dosage was plotted on the horizontal axis. A regression line was obtained for each group, and the CV of the point intersecting the recommended dose range from the guidelines was obtained. The CV of the obtained image when using the recommended dosage of the JCG was estimated using this CV value. In other words, if CV of the acquired image was equal to or less than this estimated CV value, then the acquired image was considered as having sufficient quality for diagnostic purposes.

Results

Determination of diagnosable image quality

Figure 2 shows the relationship between the CV value of both kidneys and acquisition time in each added image of a 26.7 kg case. Average acquisition time of diagnosable images as judged by the 9 nuclear medicine physicians was 2.8 min. CV of right kidney was 18.5, CV of left kidney was 22.5, and average CV of this case was 20.3. Table 1 shows the acquisition time of diagnosable images and CV in 7 cases. The average acquisition time of diagnosable image

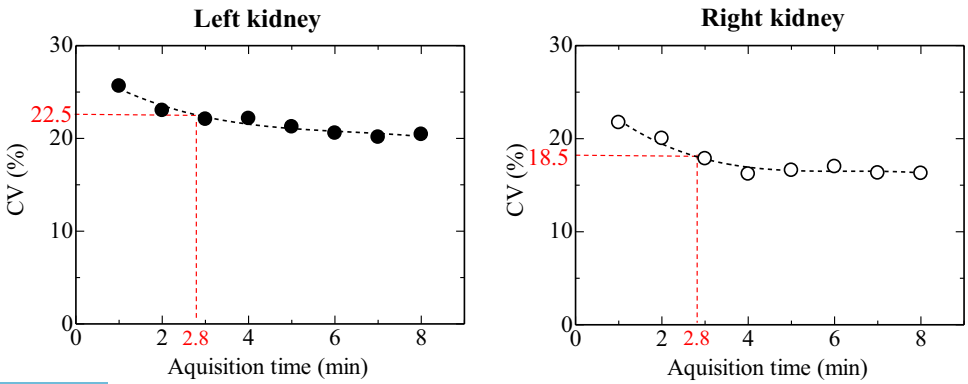

Fig. 2 CV and acquisition time curve of each kidney in the typical case shown in Fig. 1. Nine experts defined the image which was acquired in over 2.8 min as diagnosable images. CV was 22.5% in left kidney and 18.5% in right kidney

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Table 1 CV of the limit image which 9 expert physicians could diagnose in 7 cases

Patient no.	Body weight (kg)	Dose (MBq)	Diagnosable acquisition time (min)	Kidney	CV (%)
1	5.1	39.5	3.2	Right	17.4
				Left	20.0
2	7.3	39.7	3.8	Right	19.3
				Left	20.3
3	10.9	57.5	3.7	Right	20.4
				Left	18.0
4	15.6	65.0	3.1	Right	19.2
				Left	20.4
5	20.0	76.0	3.6	Right	18.9
				Left	25.4
6	26.7	88.2	2.8	Right	18.5
				Left	22.5
7	32.0	100.0	2.8	Right	19.4
				Left	18.9
Average ± SD	16.8 ± 10.0	66.6 ± 23.1	3.29 ± 0.41		19.9 ± 2.01

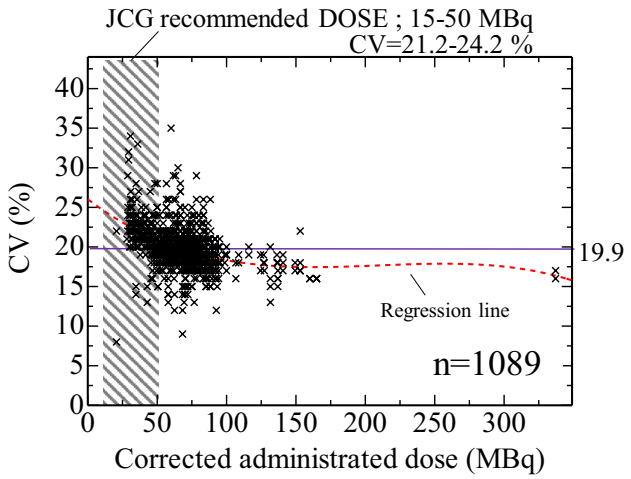

Fig. 3 Relationship between CV and corrected administered dose in the under 10 kg weight group (group 1)

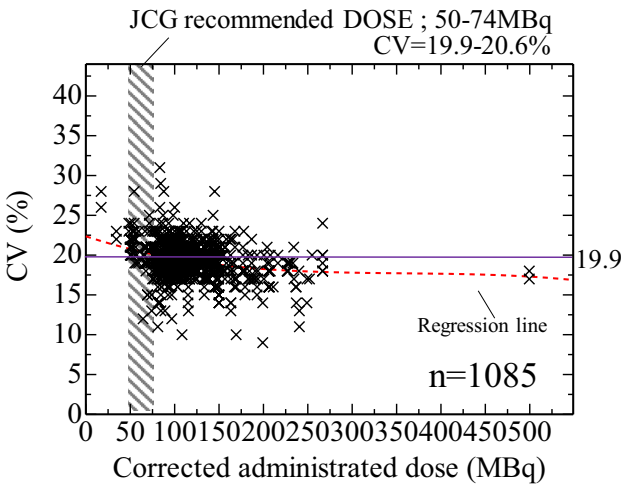

Fig. 4 Relationship between CV and corrected administered dose in the cases weighing more than or equal to 10 kg and under 20 kg (group 2)

and CV in all body weight ranges were 3.29 ± 0.41 min and 19.9 ± 2.01%, respectively.

^{99m}Tc-DMSA image analysis of clinical cases

The relationship between CV and corrected administered dose of each weight group is shown in Figs. 3, 4, 5, 6, and 7. CV tended to decrease as the corrected administered dose in all groups increased. This indicated that the image quality improved as the corrected administered dose increased. Here, JCG recommended the administered dose of each group to be 15–50 MBq in group 1, 50–74 MBq in group 2, 74–93 MBq in group 3, 93–110 MBq in group 4, and 110 MBq in group 5.

The cases under 10 kg (group 1) numbered 1089. The CV of the point intersection of regression line and the JCG recommended dose range in group 1 was 21.2–24.2%; therefore, their CV was larger than the CV of diagnosable images (19.9%). The cases greater than or equal to 10 kg and under 20 kg (group 2) numbered 1085. The CV of the point intersection of regression line and the JCG recommended dose range in group 2 was 19.9–20.6%; therefore, their CV was larger than that of diagnosable images (19.9%), similar to group 1. The cases greater than or equal to 20 kg and under 30 kg (group 3) numbered 372. One hundred and thirty-seven cases were greater than or equal to 30 kg and under 40 kg (group 4). The cases greater than 40 kg (group 5)

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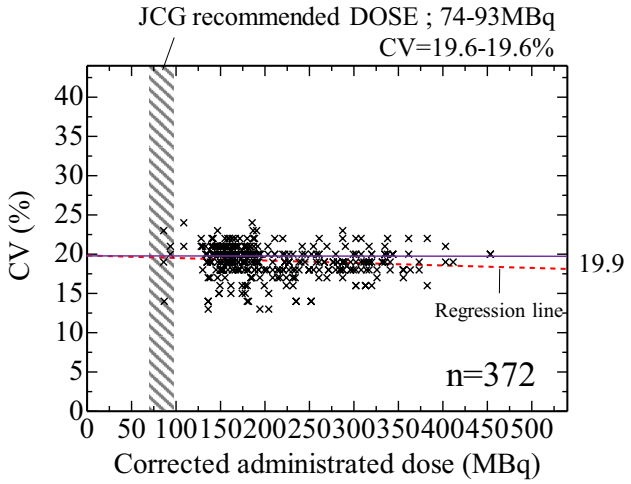

Fig. 5 Relationship between CV and corrected administered dose in the cases weighing more than or equal to 20 kg and under 30 kg (group 3)

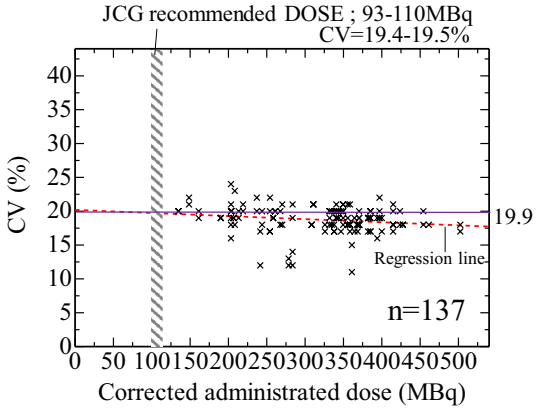

Fig. 6 Relationship between CV and corrected administered dose in the cases greater weighing more than or equal to 30 kg and under 40 kg (group 4)

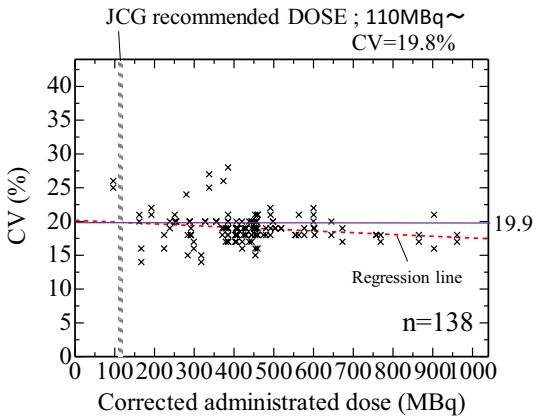

Fig. 7 Relationship between CV and corrected administered dose in the cases weighing more than 40 kg (group 5)

numbered 138. In groups 3–5, the CV of the point intersection of the regression line and the JCG recommended dose range were 19.6%, 19.4–19.5%, and 19.8%, respectively. These CVs were below the CV of diagnosable images (19.9%).

Discussion

The administered dose recommended by JCG is calculated from the weight of the patient. This recommended administered dose is determined to be lower than the dose calculated from the age or body weight based on the conventional adult dose. This is to keep low the effective dose of patients.

After announcement of the EANM guidelines in 2007, the guidelines of image acquisitions for ^{99m}Tc-DMSA scintigraphy in children were published in 2009. According to them, at least 300,000 counts per image collection or use of a preset time of approximately 5 min in the case of parallel hole collimator for ^{99m}Tc-DMSA study is needed [6]. On the other hand, after announcement of the consensus guidelines for appropriate administered doses of radiopharmaceuticals for pediatric nuclear medicine in 2010 by the SNMMI, an investigation on the examination situation in daily clinical study with recommended administered doses was published [7, 8]. However, there was no report on the estimation of the image quality at the recommended dose.

Images used in this study were collected between 2006 and 2013 in collaboration with 6 hospitals that belong to the JSNMT Optimization of Imaging Technique Committee for Pediatric Nuclear Medicine Studies. Before the announcement by JCG, the administered dose was defined by using BSA, age, and weight based on the administered dose for adults, while afterwards from 2013, ^{99m}Tc-DMSA scintigraphy in children was performed with the nearest administered dose recommended by JCG. The data included in this study were from cases both before and after the announcement. Therefore, even in different cases with the same body weight, high administered dose (before JCG guideline) and recommended dose (after JCG guideline) were mixed in this study. In fact, each patient's dose was higher than the JCG recommended dose. Many images that were included in this analysis were acquired before announcement of the recommended dose by the JCG (Figs. 5, 6). Therefore, the main reason for each patient's dose being higher than the JCG recommended dose was that many cases administered in the conventional manner were included in the collected data [1]. Due to inclusion of the data with various administered doses, acquired image quality varied in each image. Therefore, it was difficult to determine the recommended administered dose for obtaining diagnosable images without corrections.

Furthermore, in pediatric nuclear medicine examinations, we tend to make an acquisition with bigger magnification

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size for patients with small physique. As the magnification changed, the acquisition pixel size varied in each case. In this study, to evaluate various cases with the same scale, which had different acquisition times and pixel sizes at different institutions, the administered dose was corrected by multiplying the dose by the acquisition time and pixel size. Therefore, we could compare the image quality with comparable conditions for all cases in this study. Here, we investigated over 2000 cases to obtain reliable results. In this study, although we normalized the data to a reasonable extent with respect to the acquisition time and pixel size, which markedly affect image quality, there are limitations to the extent of the corrections that can be feasibly made.

A regression curve was calculated from the relation between the corrected administered dose and image CV. By using this regression curve, we thought that the administered dose to obtain diagnosable images could be determined; i.e., CV of the obtained image with the JCG recommended dose could be estimated. In this study, first, to determine the CV of diagnosable images, nine expert nuclear medicine physicians evaluated the planar image of ^{99m}Tc-DMSA scintigraphy. Nine expert diagnosticians observed the planar images in order from the image with 8-min acquisition time, which had the best image quality, and judged the limit by which they could still confirm the structure of the kidney cortex and morphology of the lesion. The CV of the image with diagnosable image quality was 19.9%. If the CV of the obtained image was equal to or less than the CV value (19.9%), the image was judged to have sufficient image quality for diagnostic purposes.

For patients with body weight of less than 20 kg, the regression formula in the recommended dose range of the JCG exceeded 19.9% (Figs. 3, 4). This makes it difficult to obtain images of sufficient quality for diagnostic purposes with a pixel size of 0.9 mm and 3 min acquisition at the recommended dose with body weight of <20 kg. In the case of image acquisition of infants weighing <20 kg, there is a tendency to increase the magnification ratio. With a matrix of 256×256, if the magnification rate is exceeded twofold, then the pixel size falls below 1 mm, and statistical noise increases significantly. This increase in the noise leads to an increase in CV, which is considered to be the cause of CV exceeding 19.9% at a body weight of <20 kg. Therefore, it is difficult to acquire diagnostic image quality using the JCG recommended dose when the body weight is <20 kg with 3-min acquisition. In this weight range, if the JCG recommended dosage is used, then an acquisition time of 3 min or longer is recommended. To avoid the effect of statistical noise, it is necessary to lower the magnification ratio or extend the acquisition time.

On the other hand, with body weights greater than 20 kg, the CV is 19.9% or less in the recommended dose range (Figs. 5, 6, 7), and it was considered that diagnosis is possible in 3 min.

Conclusion

In ^{99m}Tc-DMSA renal scintigraphy, planar images obtained by using the recommended dose of JSNM consensus guidelines of patients with body weight of 20 kg or more can be examined by conventional acquisition methods based on 3-min collection. However, in patients with body weight of less than 20 kg, it is necessary to improve the acquisition conditions by maneuvers such as reducing the magnification rate or prolonging the acquisition time to prevent degradation of the image quality of the obtained image.

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