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Title: Perceptual and objective physical quality of chest images: a comparison between digital radiographic chest images processed for cancer screening and pneumoconiosis screening in Japan

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Abstract: This study (1) evaluated the perceptual and objective physical quality of digital radiographic chest images processed for different purposes (routine hospital use, lung cancer screening, and pneumoconiosis screening), and (2) quantified objectively the quality of chest images visually graded by the Japan National Federation of Industrial Health Organization (ZENEIREN). Four observers rated the images using a visual grading score (VGS) according to ZENEIREN's quality criteria. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were measured. Between groups, differences were assessed using ANOVA (followed by Bonferroni multiple comparisons) or unpaired t-test. The Pearson's correlation coefficients were calculated for the correlation between perceptual quality and objective physical image quality. The image quality perceived by the observers and the SNR measurements were highest for the images generated using parameters recommended for lung cancer screening. The images processed for pneumoconiosis screening were rated poorest by the observers and showed the lowest objective physical quality measurements. The chest images rated high quality by ZENEIREN generally showed a higher objective physical image quality. The SNR correlated well with VGS, but CNR did not. Highly significant differences between the processing parameters indicate that image processing strongly influences the perceptual quality of digital radiographic chest images.

Keywords: Chest radiography, Contrast-to-noise ratio, Quality control, Signal-to-noise ratio, Visual grading analysis, X-Rays

INTRODUCTION

Chest radiography is one of the most frequently performed radiographic examinations in routine clinical diagnosis and health screening worldwide. Digital image acquisition and processing techniques can enhance the diagnostic image quality by improving contrast and spatial resolution, and by reducing noise[1)]. Parameters for image processing differ depending on the targeted anatomical and pathological structures and the radiologists' preference. In Japan, it is recommended that digital radiographic chest images for lung cancer screening be processed using parameters such as multi-frequency processing and dynamic range compression[2)]. These parameters were designed for better visualization of images and enable demonstration of certain pathological lesions more clearly. However, for pneumoconiosis screening, the Japanese Ministry of Health, Labour and Welfare (MHLW) recommends processing parameters that appear to produce an image similar to the film-screen radiograph[3, 4)]. The setting uses almost no processing applicable to the digital image; for example, greyscale processing of the mediastinum is omitted, spatial frequency processing is off, and multi-frequency processing that enables differential processing at the areas with high and low frequencies also is not applied[3, 4)]. Therefore, the images produced for the two screening purposes might differ in perceptual and objective physical quality. However, no reports have evaluated the quality of these images.

In Japan, general health check-ups and medical screening in workplaces are typically provided by health check-up facilities, public and private hospitals, and health facilities owned by large-scale enterprises. Good quality chest imaging is essential to accurate diagnosis of pulmonary disease. To maintain the quality of chest images, the Japan National Federation of Industrial Health Organization (ZENEIREN) has since 1980 offered an annual quality assurance program[2)]. The designated quality assurance committee evaluates the image quality using a visual grading analysis according to the quality criteria developed by ZENEIREN. Images are assessed for clinical quality (visibility of anatomical structures) and technical quality (satisfactory level of contrast, exposure, sharpness, and graininess) and are assigned a visual grading score (VGS). Three hundred fifty medical facilities submitted a total of 1,050 images in 2019. Image quality can be determined subjectively by performing a visual assessment or objectively by measuring physical parameters (such as signal-to-noise ratio [SNR] and contrast-to-noise ratio [CNR])[5]. The visual assessment method used by ZENEIREN requires predefined quality criteria and experts' evaluation; the grading reflects the image quality perceived by the experts and has potential for variation. On the other hand, measuring SNR or CNR is relatively simple, easy to perform, and consistent. However, we found no study, at least in the English language literature, that has objectively evaluated the quality of chest images visually assessed and graded by ZENEIREN.

For the reasons mentioned above, we conducted the present study. Firstly, we compared the perceptual and objective physical quality of clinical chest images produced using different processing parameters. Secondly, we evaluated whether objective physical quality assessment (by measuring SNR or CNR) was appropriate as an alternative method to the visual grading analysis used by ZENEIREN.

SUBJECTS AND METHODS

We obtained prior approval from Kochi Medical School and ZENEIREN for chest images used in this study. Since this study used only anonymized images, written informed consent from the patients was waived. The study protocol was approved by the institutional review board of Kochi Medical School. Image quality was evaluated using a visual grading analysis[6] and objective physical measurements.

Images acquisition

This study used two sets of chest images. Set 1 included 30 chest images with no abnormal shadow taken from thirty patients between August and October 2017 at Kochi Medical School Hospital. Set 2 included a total of 12 images (6 high-quality images and 6 low-quality images graded by ZENEIREN) randomly selected from the images submitted to ZENEIREN from various medical facilities for quality assessment in 2014 and 2016. We re-developed every image in set 1 (30 images) using three different processing parameters: (1) parameters recommended by ZENEIREN for lung cancer screening (Ca-parameter)[2]; (2) parameters recommended by the MHLW for pneumoconiosis screening (P-parameter)[3, 4]; and (3) parameters used clinically at Kochi Medical School Hospital (generally, routine hospital chest images are aiming to detect lung cancer) (H-parameter) (Table 1). The resulting set of 90 chest images was used in the analyses to evaluate the quality of images produced using different processing parameters.

Set 1 images were acquired using MRAD-A80S RADREX (High voltage unit: KXO-80SS, X-ray tube: DRX-4634HC) general X-ray system (CANON MEDICAL SYSTEMS CORPORATION, Ohtawara, Tochigi, Japan), We also used CALNEO Smart DR-ID1200 Digital radiography (DR) system (FPD: CALNEO Smart C77 DR-ID 1212SE, workstation: Console Advance DR-ID 300CL) (FUJIFILM, Minato, Tokyo, Japan), FM-PU1 digital bucky stand (OBAYASHI MFG.CO., LTD, Bunkyo, Tokyo, Japan) and anti-scatter grid (strips per centimetre: 40, grid ratio:12/1, focusing distance: 200cm, interspace material: aluminium)

(MITAYA MFG.CO., LTD, Kawagoe, Saitama, Japan). We set focus-FPD distance 200cm, X-ray tube voltage was 120kV, tube current was 320mA, photographing time set auto exposure control (AEC), and set the 1.5mmAl＋0.1mmCu filter.

(insert Table 1)

Assessment of perceptual image quality

Four experienced observers, who were blinded to the processing parameters, independently assessed the set of 90 images on a diagnostic monitor (5-megapixel [2,048 X 2,560 pixels]) using a DICOM-Viewer. The illumination in the room was dim and kept constant. There was no limitation concerning viewing time or viewing distance. The assessment was made for both clinical and physical image quality using absolute visual grading analysis according to ZENEIREN's quality criteria[2)]. Clinical image quality was determined by the visibility of anatomical structures. These include skeletal structures (clavicles, ribs, thoracic vertebrae), mediastinal structures (heart shadow and pulmonary arteries), tracheobronchial and pulmonary parenchymal structures (lung margin, vascular markings of lung zones). Physical quality was determined by satisfactory levels in the contrast, exposure, sharpness, and graininess of the images. Two observers, an occupational physician with over twenty years of experience (who is a NIOSH certified B Reader and also a member of ZENEIREN’s quality assurance committee) and a radiologist with six years of experience in general radiology, assessed and provided the clinical image quality aspect of VGS (total 70 points). Two radiologic technologists with more than eight years of working experience assessed and provided the physical image quality aspect of VGS (total 30 points). Combining the assessment results for both quality aspects gave a total score of 100 points. Before starting the assessment, the observer who is a member of

ZENEIREN's quality assurance committee explained the quality assessment criteria of ZENEIREN. Every image was assessed and graded accordingly as "A" (excellent quality, 85–100 points; overall abnormalities can be recognized easily), "B" (good quality, 70–84 points; not the quality of grade "A" but abnormalities can still be recognized easily), "C" (fair quality, 60–69 points; possible/adequate for routine diagnostic radiography), and "D" (poor quality, <60 points; not suitable for routine diagnostic radiography).

Assessment of objective physical image quality

We selected the regions of interest (ROIs) based on the image's fields defined by ZENEIREN in the quality evaluation of chest images[2)]. To calculate SNR, we established two rectangle-shaped ROIs (ROI-I and ROI-II) and one right lung field ROI (ROI-III) (Fig. 1a). The ROI-I covers both sides of the chest and contains heart shadow, while the ROI-II encloses the right half of the chest, including a part of heart shadow and mediastinum, and the ROI-III includes only the right lung field. Measurement of CNR was carried out using four pairs of ROIs: ROI-1, 7th thoracic vertebral body and right 6th–7th intercostal lung field; ROI-2, left 10th–11th intercostal cardiac shadow and left lower lobe lung field; ROI-3, right middle diaphragm and right lower lobe lung field; and ROI-4, the soft tissue of right shoulder and right 4th–5th intercostal lung field (Fig. 1b). We measured the mean values and standard deviation (SD) of all the pixels contained within the selected ROI of the images by using an open-source image processing program ImageJ ver.1.49v[7)]. The image noise level was defined by the SD of the pixels in the selected ROI. We computed the SNR and CNR using the following equations: SNR (ROI) = Mean signal (ROI)/SD (ROI); and CNR = [Mean signal (tissue) – Mean signal (lung field)]/ SD (ROI-5). ROI-5 covers both sides of the chest as in ROI-I of SNR measurement.

(insert Fig. 1)

Statistical analysis

Mean scores of VGS, SNR, and CNR were used to assess the differences in the perceptual and objective physical quality of images due to differences in image processing parameters. The significance of differences was determined using one-way analysis of variance followed by Bonferroni multiple comparisons. Correlation between the perceptual (VGS) and objective physical (SNR and CNR) image quality was determined by Pearson's correlation coefficient. To examine whether the objective physical quality assessment was appropriate as an alternative method to the visual grading analysis, we measured the SNR and CNR of high- and low-quality images (graded by the ZENEIREN) and compared their mean values using unpaired t-test. A p-value of <0.05 was considered statistically significant. All statistical analyses were performed using Microsoft Excel for Windows.

RESULTS

Tables 2–4 compare the mean VGS, SNR, and CNR between images produced using different processing parameters. Mean VGS for both the clinical quality and technical quality of images processed using the Ca-parameter were significantly higher than those images processed using P-parameter and H-parameter (Table 2). Differences in VGS were mainly found in subcategory scores for visibility in skeletal structures (particularly thoracic vertebrae) and pulmonary parenchymal structures (particularly lung margin under diaphragm and vascular markings of lung zones) in clinical quality assessment and contrast, mediastinal density, and sharpness in technical quality assessment (data not shown). A significantly higher mean SNR was also found for images processed using Ca-parameter (Table 3), whereas no difference in the mean CNR was observed between images developed by different processing parameters (Table 4).

(insert Table 2, Table 3, and Table 4)

Figures 2 and 3 show the correlation between perceptual quality (VGS) and objective physical quality (SNR and CNR) of the images. Correlation between VGS and SNR was stronger in ROI-I (r = 0.77, p <0.01) and in ROI-II (r = 0.76, p <0.01) than that seen in ROI-III (r = 0.40, p = 0.01) (Fig. 2). Pearson's correlation coefficients between VGS and CNR were -0.16, 0.35, 0.15 and -0.01, for ROI-1, ROI-2, ROI-3 and ROI-4, respectively (Fig. 3).

(insert Fig. 2 and Fig. 3)

Table 5 presents the mean SNR and CNR for high-quality and low-quality images visually graded by ZENEIREN. When compared with low-quality, high-quality images show significantly higher mean SNR in ROI-I and ROI-II (p <0.001) and higher mean CNR in ROI-4 (p <0.05) (Table 5).

(insert Table 5)

DISCUSSION

In the present study, we attempted to compare the quality of chest images generated using different processing parameters and found significant differences. We found that the image processing parameter used for cancer screening produces significantly higher quality chest images than the parameters for routine hospital chest images and pneumoconiosis screening in

Japan. We also observed that SNR showed a strong positive correlation with perceived image quality, whereas CNR showed a poor correlation. Moreover, chest images rated high-quality by ZENEIREN were generally found to have higher objective physical quality.

We found image processing had a significant effect on the quality of digital radiographic chest images. One African study also reported that visibility of the object and objective physical quality (SNR and CNR) were different with different processing parameters[8)]. However, in a recent study, Smet et al.[9)] found no effect of image processing on perceived image quality, measured by the visibility of anatomical structures. The discrepancy among studies might be due to the differences in the processing parameters studied (the use of manufacturer-specific processing software or pathology-specific processing parameters) or the evaluation methods (object detection or visibility of anatomical structures). In the present study, the image quality perceived by the observers was highest for the images processed using parameters recommended for lung cancer screening, and the SNR also reflected the perceptual image quality. The images processed using parameters recommended for pneumoconiosis screening were rated poorest by the observers and showed the lowest objective physical quality measurements. The main differences between processing parameters used in our study are the presence or absence and the degree of dynamic range compression and multi-frequency processing. As seen in Table 1, image processing for lung cancer screening applied these techniques, whereas image processing for pneumoconiosis screening omitted or used them to a lower degree. These processing techniques provide the potential to improve image quality[10)]. Multi-frequency processing decomposes the image into a series of sub-frequency images and reconstructs them back into a single image with optimized contrast. Dynamic range compression allows viewing detail behind the heart and diaphragm while retaining the greyscale and detail of the lung field. Therefore, in the present study, images processed using these techniques received a higher appreciation of image quality by the observers.

In the present study, we observed a good correlation between SNR and perceived image quality, and this finding was consistent with other past studies[11, 12)]. Image quality assessment using visual grading analysis involves observers considering how much image detail (i.e., the anatomical structures or abnormalities) they could see. In digital chest images, the noise would possibly hinder the visualization of subtle anatomical structures and pathological lesions. Thus, improving SNR would enhance perceived image quality. We found the correlation between VGS and CNR was poor and inconsistent. However, Moore et al. reported a significant correlation between VGS and CNR[13)]. This discrepancy might originate from differences in the study design. In their study, Moore et al. tested the correlation between VGS (scored using chest images) and CNR (measured using chest phantom); however, we used the same chest images for both subjective and objective quality assessments. In addition, they generated images by changing tube voltages, whereas we generated them using different processing parameters. Huda and Abrahams described that although a high lesion contrast improves diagnostic quality, it is not important for perceived image quality[14)]. We suggest that, in some cases, an increase in the density of soft tissue shadows such as the heart may hinder visualization of the anatomical structure behind it. In quality evaluation, the evaluators of ZENEIREN assess several specified regions of the images, combine the scores, and determine image quality using quality criteria. The use of the overall VGS score in our study might be the reason for the observed reduced correlation with SNR measurement in ROI-III (which includes only the right lung field) and the poor correlation with CNR measurements in all ROIs. In a study, Lin and coworkers have demonstrated a significant correlation between physical quality measurements and perceptual quality of clinical chest radiographs[15]. In their study, the authors specified several ROIs; then examined the correlation of quantitative quality measurement of a region with the corresponding perceptual evaluation.

Chest images rated high-quality by ZENEIREN generally have higher objectively-measured physical image quality. However, significant differences between the low-quality and high-quality images were observed only for SNR measurements performed in ROI-I and ROI-II and CNR measurement in ROI-4. We suggest that the correlation observed between perceived image quality (VGS) and objective quality measurements (SNR and CNR) and the choice of ROI for measuring SNR and CNR might be the possible explanations. We found the correlation between VGS and SNR was stronger when SNR measurement contained the whole (ROI-I) or half (ROI-II) of the cardiac shadow, mediastinal structures, and thoracic vertebrae. However, the correlation attenuated when the SNR measurement included only the right lung field (ROI-III). In digital chest images, structures such as the heart, mediastinum, thoracic vertebrae, and diaphragm can negatively affect the visibility of subtle anatomical structures, and consequently, the observer's perception of image quality. These anatomical structures also influence the image's noise level, and subsequently, SNR. Thus, SNR measurements that include these anatomical structures (ROI-I and ROI-II) better reflect the VGS. We also observed that the mean SNR values of Set 1 images were higher than those of Set 2 images. A potential reason for the observed difference may be that the images in Set 2 were generated using different modalities or manufacturer-specific processing software, because they were submitted to ZENEIREN from various medical facilities.

The Pneumoconiosis law of Japan requires screening and legal judgements of pneumoconiosis to be performed using a chest radiograph. However, the application of multi-frequency processing or dynamic range control is not fully allowed in image processing. These parameters were designed for better visualization of digital chest images, and we found using them received a higher appreciation of image quality by the observers. Although we did not investigate it, we suggest these parameters may enable the demonstration of pneumoconiosis more clearly. Since over- or under-classifying pneumoconiosis severity imposes substantial social and economic costs, we recommend further research to evaluate adequacy in classifying chest images for pneumoconiosis (using the classification system specified by the Pneumoconiosis law of Japan) using images processed with different parameter settings, including the one recommended by ZENEIREN. Among the strengths of this study are that it is the first to compare the quality of chest images generated using different processing parameters for different purposes in Japan. The quality evaluation was performed using clinical chest images according to ZENEIREN's quality criteria. One potential limitation of this study is the small number of chest images evaluated by ZENEIREN, which we used for the objective image quality quantification. In recent years, the number of digital chest images graded poor-quality by ZENEIREN has been on the decline. However, we believe that the inclusion of more images would not substantially change the results.

CONCLUSION

This study demonstrates that the parameters used to process lung cancer screening images in Japan produce significantly better quality images than those used to process pneumoconiosis screening images. However, at present, we cannot conclude that the chest images for lung cancer screening are better at detecting or classifying pneumoconiosis severity. Further investigation evaluating the diagnostic ability as well as the adequacy in classifying pneumoconiosis severity of these images is needed. A strong correlation between SNR and perceived image quality suggests that measuring SNR could be an alternative to visual grading analysis when expert judgment is not readily available. However, the perceptual quality of chest images cannot be predicted from the measurement of CNR alone.

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Figure legends

Fig 1. Illustration of the regions of interest (ROIs). **(a)** Measurement of signal-to-noise ratio: ROI-I, both sides of the chest; ROI-II, right half of the chest; ROI-III, right lung field; **(b)** Measurement of contrast-to-noise ratio: ROI-1, 7th thoracic vertebral body and right 6th–7th intercostal lung field; ROI-2, left 10th–11th intercostal cardiac shadow and left lower lobe lung field; ROI-3, right middle diaphragm and right lower lobe lung field; and ROI-4, soft tissue of right shoulder and right 4th–5th intercostal lung field.

Fig 2. Correlation between visual grading score and signal-to-noise ratio (SNR) in **(a)** ROI-I, **(b)** ROI-II, and **(c)** ROI-III. ROI, region of interest: ROI-I, both sides of the chest; ROI-II, right half of the chest; ROI-III, right lung field. *r*, Pearson's correlation coefficients; Ca-parameter, parameters recommended by ZENEIREN for lung cancer screening; P-parameter, parameters recommended by Japanese Ministry of Health, Labour and Welfare for pneumoconiosis screening; and H-parameter, parameters used clinically at Kochi Medical School Hospital for routine chest images.

Fig 3. Correlation between visual grading score and contrast-to-noise ratio (CNR) in **(a)** ROI-1, **(b)** ROI-2, **(c)** ROI-3, and **(d)** ROI-4. ROI, region of interest: ROI-1, 7th thoracic vertebral body and right 6th–7th intercostal lung field; ROI-2, left 10th–11th intercostal cardiac shadow and left lower lobe lung field; ROI-3, right middle diaphragm and right lower lobe lung field; and ROI-4, soft tissue of right shoulder and right 4th–5th intercostal lung field. *r*, Pearson's correlation coefficients; Ca-parameter, parameters recommended by ZENEIREN for lung cancer screening; P-parameter, parameters recommended by Japanese Ministry of Health, Labour and Welfare for pneumoconiosis screening; and H-parameter, parameters used clinically at Kochi Medical School Hospital for routine chest images.