Quantitative Analysis of Resolving Power forComputed Radiographic Portal Images

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Abstract

This study presents a quantitative analysis method of resolution for computed radiography (CR) portal images using three different types of cassettes. A copper wire chart (test piece, Shimadzu Medical Corp.) for fluoroscopy was selected as the test tool for analysis. Images of the test chart were obtained on a linear accelerator operating at nominal beam energies of 4 MV. The CR portal imaging data were transmitted to a personal computer via a DICOM network system. The imaging data were imported into NIH Image, which is public domain software. The extent of analysis was established on the chart image (160 × 540 pixels). A density profile plot was generated based on the current rectangular selection and this plot was used for quantitative analysis of the resolution. This quantitative analysis method using NIH Image is expected to prove useful for digital portal images.

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1. Introduction

Portal images are used to evaluate the position of the radiation treatment beams for radiotherapy. As these beams have mega-voltage energy, there is inherently less subject contrast in portal images compared with that of diagnostic X-rays. To improve the image quality, most institutions transform the conventional screen-film system to a digital portal imaging system, such as one of the various types of electronic portal imaging devices (EPIDs), or computed radiography (CR). Digital portal images are expected to provide the most anatomical information and to produce consistently sharp images.

To improve image quality, objective methods of evaluating image quality are indispensable. Many evaluation methods such as the modulation transfer function (MTF) for diagnostic X-ray images have been established. For EPID images, there are special evaluation systems using phantoms such as the QC-3V phantom (Masthead Imaging Corp., Canada). In this system, the relative measure of the square wave modulation transfer function (RMTF) and f50 (f50: 50% of the maximum from the RMTF data) calculated from this value are used for image analysis.

In each objective evaluation method, it is necessary to obtain stable output characteristics from images of the test phantom. However, satisfactory output characteristics can not be obtained from CR-portal images, and there is as yet no commonly-accepted image evaluation method.

Fig. 1 shows an example line plotting after radiography of a wire chart using a CR apparatus. Here, (a) is the line plot of a chart obtained under diagnostic X-ray conditions and (b) is the line plot of a chart obtained under portal image conditions of the Linac. The image contrast of the portal image data obtained using a CR apparatus is much lower than that of diagnostic CR images. In addition, portal image data are affected by noise, and therefore, these images as they are can not be applied to the existing analyzers or image evaluation software. In addition, we have experienced difficulty in selecting high quality CR portal image systems, such as selecting the best material and the best thickness of metallic plate, or evaluating the metallic plate and imaging plate.

To supplement the sight evaluation, we designed a quantitative analysis method of resolution for CR portal images. This method provides easy analysis and has a low cost due to the use of public domain image analysis software (NIH Image...
Ver. 1.61) and a personal computer.

The analysis tools for NIH Image include "plot profile". The mean value of pixels corresponding to the row/column of ROI can be displayed using this function. Fig. 2 shows conceptual figures of this function. The profile in the marked row of (a) represents the plotting of values with a measurement width of 1 pixel, and the profiles in the lowest rows of (b) and (c) represent plotting with measurement widths of 4 and 160 pixels, respectively. Line plotting with a measurement width of 1 pixel shows the influences of noise and no effective signals. However, with an increase in the measurement width to 160 pixels using the "plot profile" function, stable chart signals with only slight influences of noise can be obtained.

Fig. 3 shows an example of profiles obtained by actual measurements. The broken line is a profile obtained with a measurement width of 1 pixel and the solid line is one with a 160 pixel width.

This study presents the quantitative analysis method we developed for examining the resolution property of CR portal images that uses a commercially available cassette. We also look at two improved products based on the commercially available one.

**Materials and Methods Image acquisition**

A QC phantom for fluoroscopy (test piece, Shimadzu Medical Corp. Fig. 4) was designed for use in the test, which consists of ten sets of high-contrast bars with spatial frequencies of 0.71, 0.77,
0.83, 0.91, 1.00, 1.11, 1.25, 1.43, 1.67, and 1.92 cycles/mm. The frame of the phantom was made of iron, and the ten test sections were made of copper and plastic. The phantom was 5 mm thick and had 2 mm acrylic cover plates on the top.

Images of the test chart were obtained on a Mitsubishi ML-15MDX linear accelerator operating at nominal beam energies of 4 MV. The chart was placed on the front surface of the cassette 1.1 m from the focus position at a gantry angle of 0 degrees. Processed images were acquired using 20 monitor units with the system in LG mode. LG mode is 1/10 quantity of the monitor units compared with that of the therapy mode.

All images in this study were produced using a FCR-5000R computed radiography system (Fuji Photo Film Co., Japan).

The image processing parameters were as follows. The gradation range and the sensitivity range were determined as \( L = 0.5 \) and \( S = 10 \), respectively. Gradation type (GT), one of the gradation-processing parameters, was A-type and the exposure data recognizer (EDR) type was selected as the FIX mode. Frequency processing, control of the frequency response of the imaging system, was not carried out for this quantitative analysis. The created images were downloaded onto a personal computer (G3: Macintosh) from an image-processing computer (HIC-655QA: Fuji Photo Film Co., Japan) via a DICOM image archiving system. Finally, the received image data were saved as a PICT-type graphics file.

At this time, we excluded test chart images that diverged from the measurement object. We also did not carry out processing of image data, such as density correction and/or angle correction.

**Image analysis**

The analyses of all the images were carried out on a personal computer.

![Copper wire chart](image)

*Fig. 4 Copper wire chart adopted for this study (test piece, Shimadzu Medical Corp.). This chart is mainly used for quality assurance of diagnostic x-ray fluoroscopic devices.*

![Current rectangular selection in the chart image](image)

*Fig. 5 Current rectangular selection in the chart image (160 x 540 pixels).*
The analysis procedure was as follows. First, we used the open command to load and display the images in PICT-type files using NIH Image. Second, we established the extent of analysis, which was the generated density profile plot based on the current rectangular selection in the chart image (160 × 540 pixels) (Fig. 5).

Then, a "column average plot" was produced, where the width of the plot is equal to the width of the selection and each point in the plot represents the average gray value of the pixels in the corresponding column in the selection. A plot of the gray values along the selected area was also displayed, and the average gray value of the pixels was established using the rectangular area. The options command of the "plot profile" function could be used to vary the way profile plots were displayed (pixel value in the range of 0-255) (Fig. 6).

The calculated data could be copied in text format to the clipboard using the copy command. The pixel values were pasted into the spreadsheet software of Microsoft Excel. The pixel size was approximately 0.15 mm per side, when the graphics files were opened using an 10 × 12 inch imaging plate in NIH Image.

The average pixel values were calculated using the "plot profile" function. Therefore, with extended width, we achieved stable pixel data with little noise. This method was applied to 160 pixels as the short axis and 540 pixels as the long axis, which covered from 0.71 cycles/mm to 1.43 cycles/mm on the spatial frequency of the chart image. We calculated the difference of two points, which is the average of four minimum values and the average of three maximum values on each spatial frequency using Excel.

We designated this calculated value as the "amplitude value". We then calculated the amplitude value of each spatial frequency. Finally, we constructed a graph and compared the resolution at each spatial frequency (Fig. 7).

\[
\text{Amplitude} = \text{Average } (A_1 A_2 A_3) - \text{Average } (B_1 B_2 B_3 B_4)
\]

Fig. 7 Definition of "amplitude value".
Visual estimation

We took a portal image of the copper wire chart, which was taken for the same method of quantitative analysis. An equal magnification image was prepared. The gradation range was determined as $L = 0.5$. The gradation type (GT) was A-type and the EDR type was selected as the SEMI-AUTO mode.

Three frequency-processing parameters were tested. We selected the frequency rank (RN) "3", the response of which was maximal at 0.25 cycles/mm frequency processing. The frequency type (RT) and degree of enhancement (RE) were selected as F-type and 5.0, respectively.

The resolving powers (R.P.) of each cassette type are shown by the following equation:

$$R.P. = \frac{1}{(2d)}$$

(1)

[d]: the diameter (mm) of the wire at the limit at which visual resolution is possible.

Visual estimation was carried out by ten radiological technologists, who had considerable experience in verification using CR portal images in clinical practice.

Illustrations for quantitative analysis

To estimate the usefulness of the quantitative analysis, we tested three types of cassettes for resolution. The image quality using a commercially available cassette for portal images (Type H: Fuji Photo Film Co., Japan) has already been noted to have inferior capability.

The reason for the poor image quality was thought to be the loose contact between the metal plate and imaging plate of the cassette. Furthermore, the presence of a canvas sheet (0.3 mm thick) on the metal plate, which protects the metal plate and imaging plate from rust and scratching, also made the contact loose. We tried to verify the suspected cause of the poor image quality by analyzing three types of cassettes for different qualities of contact between the metal plate and the imaging plate.

   This cassette had a canvas sheet pasted on the metal plate. This was regarded as standard contact between the metal plate and the imaging plate.

2. Improved product-type 1: to promote close contact between the metal plate and imaging plate, a sponge (10-mm thick) was inserted into the back of the imaging plate inside the commercial-type cassette. The canvas sheet was kept on the metal plate.
   This cassette had good contact between the metal plate and the imaging plate.

3. Improved product-type 2: The canvas sheet was removed from the metal plate and a sponge was inserted at the same point as with the improved product-type 1 cassette.
   This cassette had very close contact between the metal plate and the imaging plate.

We compared the commercial type with the two improved products for resolution using the developed quantitative analysis method.
Results and Discussion

Quantitative analysis of resolution property

A graph was computed for each cassette type one, the commercial type, the improved product-type 1, and the improved product-type 2. Some of these graphs are presented in Figs. 8-10. The mean and standard deviations for the quantitative analysis of the resolution are given in Table 1.

The gray level of 10 bits was converted automatically to 8 bits using NIH Image. Therefore, there is a possibility that the software acts as a modulation filter. However, we consider that its influence can be ignored when all samples are analyzed using the same parameters. To obtain more accurate values, the use of raw image data may be desirable. However, analysis of raw data at each treatment institution is difficult, and in the present stage, it may be necessary to entrust the analysis to the manufacturer. This may limit the number of samples that can be measured. For CR-portal images that are readily influenced by random noise, as many samples as possible should be measured to increase accuracy. For this purpose, as we proposed, a simple analysis method that is

<table>
<thead>
<tr>
<th>Spatial frequency</th>
<th>Commercial type</th>
<th>product-type 1</th>
<th>product-type 2</th>
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<tr>
<td>0.71</td>
<td>1.79±0.12 (SD)</td>
<td>2.15±0.18</td>
<td>3.34±0.20</td>
</tr>
<tr>
<td>0.77</td>
<td>1.64±0.12</td>
<td>1.78±0.16</td>
<td>2.92±0.13</td>
</tr>
<tr>
<td>0.83</td>
<td>1.32±0.10</td>
<td>1.55±0.16</td>
<td>2.45±0.11</td>
</tr>
<tr>
<td>0.91</td>
<td>1.04±0.17</td>
<td>1.30±0.26</td>
<td>2.11±0.12</td>
</tr>
<tr>
<td>1.00</td>
<td>0.94±0.19</td>
<td>0.96±0.14</td>
<td>1.67±0.12</td>
</tr>
<tr>
<td>1.11</td>
<td>0.77±0.13</td>
<td>0.82±0.12</td>
<td>1.39±0.10</td>
</tr>
<tr>
<td>1.25</td>
<td>0.57±0.07</td>
<td>0.64±0.10</td>
<td>1.06±0.12</td>
</tr>
<tr>
<td>1.43</td>
<td>0.50±0.11</td>
<td>0.54±0.16</td>
<td>0.75±0.12</td>
</tr>
</tbody>
</table>

(cycles/mm) (pixel value)

Fig. 8 Quantitative resolving power using the commercial type cassette.

Fig. 9 Quantitative resolving power using the improved product-type 1 cassette.
only slightly affected by differences in analysis experience is necessary.

Figure 11 shows the relative amplitude in each frequency area by means of normalizing the amplitude value at 0.71 cycles/mm of each type as 1.0. The results showed almost the same trend for all three types. If the superiority or inferiority of the resolving power in each type of cassette are compared simply, only one frequency area needs to be measured. When the amplitudes of the three types of cassette were compared in the frequency band of 0.71 cycles/mm, the amplitudes of the commercial type, improved product-type 1, and improved product-type 2 were 1.78, 2.15, and 3.34, respectively (Table 1). The amplitude of the commercial-type cassette was approximately 20% lower than that of the improved product-type 1. The adherence of the commercial-type cassette was comparatively fine for an article requiring various restrictions. However, the value of the improved product-type 2 was twice that of the commercial type. The thickness of the protection sheet (0.3 mm) was conceivably the major cause of the decreased image quality from this result.

Visual estimation of the resolving power

The results of the visual estimation of the resolving power are shown in Table 2. We compared the results of the quantitative analysis with the sight evaluation. The resolving power of the sight evaluation was almost identical, at an amplitude of 1.5, to the results of the quantitative analysis. The results of the visual estimation were in agreement with the results of the quantitative analysis.
Necessity of a special evaluation method for CR-portal images

EPID images are aimed at automatic collation with reference images by extracting the outer contour of the vertebral body. Therefore, in the evaluation of image quality, importance is placed mainly in the low frequency region at about 0.2 cycle/mm. For example, the frequencies in the measurement using the QC phantom of the special image evaluation system for EPID are 0.1, 0.2, 0.25, 0.4, and 0.75 cycles/mm. The evaluated matrix size of the image acquisition apparatus is 0.5-2.0 mm/pixel, which is higher than that of the diagnostic apparatus.

However, CR-portal images are aimed at visual collation with reference images. Therefore, the visualization of not only the outer contour of the vertebral body but also fine bone structure and lung air space is required. In addition, an increase in the amount of information is important in accurate collation.

CR-portal images have a matrix size (0.1 mm/pixel) similar to that of the diagnostic apparatus. Evaluation of image quality in a frequency region similar to that of diagnostic images is ideal.

In this study, we introduced a method for readily obtaining stable data using familiar materials. However, the results of this study only show the association between this method and the conventional visual evaluation method. Further improvement of our method is necessary for clinical application.

We hope that this paper will contribute to the establishment of a CR-portal image evaluation method.

Conclusions

We investigated the usefulness of an easy quantitative analysis technique. The following results were obtained.

1) We acquired good reproduction data and made a comparative study at different resolutions of different materials with ease.
2) We did not measure the resolving power for CR portal images using an extant analysis device (such as a micro densitometer). However, the quantitative measurement technique of this study can easily be analyzed.
3) It is easy to acquire the software for image analysis and the results of the analysis can be saved in the form of text files. These files utilize other types of analysis.
4) The results of the quantitative analysis were in agreement with the results of the visual estimation.

<table>
<thead>
<tr>
<th>Type of cassettes</th>
<th>Resolving Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial type</td>
<td>$0.81 \pm 0.03$ (S.D.)</td>
</tr>
<tr>
<td>Improved product-type 1</td>
<td>$0.86 \pm 0.06$</td>
</tr>
<tr>
<td>Improved product-type 2</td>
<td>$1.04 \pm 0.11$</td>
</tr>
</tbody>
</table>

(unit: line pair/mm)
Measurement of the resolving power is a key component in accepting and commissioning tests for a digital portal imaging device. The easy technique of quantitative analysis is useful as a supplement to visual evaluation when many samples are measured simultaneously.

References