The effect of region extraction accuracy on the dose calculation with CBCT images combined with MSCT images.

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Purpose

In intensity-modulated radiation therapy (IMRT) and stereotactic radiation therapy (SRT), irradiation doses can be delivered so as to fit the planned dose distribution. Such irradiation techniques are important to localize the target area for realizing an accurate irradiation while minimize the adverse effects on neighboring critical organs [1-3]. Recently, a kilo-voltage cone-beam computed tomography (CBCT) system attached to a linear accelerator has become commercially available for image-guided radiotherapy (IGRT). The CBCT images are useful for verifying not only the position of a treated tumor, but also the regression or progression of the tumor. Optimal radiation therapy may be accomplished with regard to the field margin related to changes in the target size and position, as well as the location of critical organs on every treatment day [4, 5]. That is, a dose distribution that takes account of any modification of the targeted region is calculated at each radiation therapy session. If the CBCT images are used instead of the multi-slice CT (MSCT) images, the accuracy of the dose distribution will be less, because the quality of the CBCT images is inferior to that of the MSCT images. As a result, the use of the original CBCT numbers causes an inaccurate dose distribution [6]. Several reports [7]-[8] have been published to overcome this problem, but it is very difficult to use these methods in clinical situations.

We proposed a new method that is independent of data acquisition modes and scattered photons in a CBCT image as well as the size of a patient. In our method, we segmented the CBCT and MSCT images into several regions of three organs (lungs, bones and soft tissues) and replaced the CBCT numbers of each region with the median (or mean, mode) of the MSCT numbers of the corresponding region.

The accuracy of region extraction for each organ may depend on the accuracy of the dose calculation using the combined MSCT images. And so we evaluated the effect of region extraction accuracy on the dose calculation in this paper. In addition, we evaluated the validity of the proposed method with images of patients with lung diseases.
Methods and Materials

Image data acquisition

For initial treatment planning, MSCT images reconstructed with a helical-scan MSCT system (HiSpeed NX/i, GE Medical Systems, USA) with a tube voltage of 120 kV were used. CBCT images were acquired with an x-ray tube with a voltage of 125 kV and a flat panel detector attached to a linear accelerator (CLINAC 21EX, Varian Medical Systems, USA). The size of an image matrix was 512 x 512 pixels that of a CBCT image 450 x 450 mm$^2$, and that of an MSCT image 500 x 500 mm$^2$. In both systems, the slice thickness was 2 mm. To evaluate the clinical performance of these studies, images of eight patients with lung cancer were used.

Proposed methods

We segmented the CBCT and MSCT images into several regions of three major organs (lungs, bones and soft tissues). To determine the lung and bone areas correctly, we first binarized the CBCT and MSCT images and extracted the lung areas and the bone area by using the results of a histogram analysis. The threshold values (CT numbers) of the lung regions were -500 for CBCT images and -300 for MSCT images. And, the threshold value of the bone regions was 120 for both the CBCT and MSCT images. These threshold values for the lung and bone regions were determined by trial and error. After the segmentation of the lung and bone areas, we assumed that the rest of the area was the soft-tissue area. For the pixels in each region of the CBCT images, each representative MSCT number of the corresponding regions was set in the planning MSCT images. With regard to the representative MSCT number, we evaluated three parameters representing the pixel values of these three major regions, namely, the median, mean and mode of the MSCT numbers in each segmented organ. (refer to Fig. 1) We call this method the segmented region (SR) method.

Evaluation of dose calculation accuracy

To compare the clinical performance of this method, studies of patients with lung cancer were used. For this study, dose distributions were calculated with use of CBCT images after conversion of the CBCT numbers with the SR methods. The treatment-planning system Eclipse ver. 10.0 (Varian Medical Systems, USA) was used, and the anisotropic analytical algorithm ver. 10.0 was used for dose calculation. The differences between the dose distributions based on the SR methods and those of the initial plan were analyzed with distance-to-agreement (DTA) analysis and # analysis by use of commercially available software (MapCHECK, Version 3.02, Sun Nuclear, USA). The criterion for the pass rate in the DTA analysis was 2 mm, and those in the # analysis were 2 % absolute dose and 2 mm DTA. In this evaluation, the mean dose was used, and a
single beam planning and conformal radiotherapy with 4 beams (coplanar, 6 MV x-rays) were used to the lung images. Moreover, the dose distributions were evaluated with the dose volume histogram (DVH) for this treatment planning. Dose differences between the initial planning and the treatment planning using the SR method in the patient studies were quantified by the mean, maximum and minimum volume doses in each target area. In these evaluations, the planning geometry and the number of monitor units remained unchanged.

To evaluate the effect of the region extraction accuracy for the SR method on the dose calculation, we changed the threshold values of the CBCT images for lung and bone areas in the histogram analysis. And we evaluated the relationship between the volume of extracted regions and the accuracy of dose calculation. In this evaluation, we used the DTA and # analysis using the lung images. The criteria for the pass rate in the DTA and # analysis were the same as those in the previous studies. To evaluate the volume of the extracted regions of the lung and bone areas, we changed the threshold values (lung areas: -650 ~ -350, bone area: 90 ~ -150). In these evaluations, a single beam planning (6MV x-rays) was used with the DTA and # analysis, and conformal radiotherapy with 4 beams (coplanar, 6 MV x-rays) was used with the DVH evaluation. Dose volume differences between the initial planning and the planning with the SR method were quantified by the mean doses and the volume of 95% doses in each target area.
**Fig. 1:** Padding of the representative MSCT numbers to the extracted regions in a CBCT image after segmentation the CBCT and MSCT image.

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Results

Combined image using the CBCT and MSCT images

Fig. 2 shows an example of a modified CBCT lung image in the SR method, in which three regions (lung, bone and soft-tissue areas) were determined in the original CBCT image, and these pixel values were replaced with the median of the MSCT numbers in the corresponding areas.

Evaluation of the calculation accuracy using the CBCT image with the SR method

Fig. 3 shows an example of the dose distributions of a single-beam irradiation (6 MV x-rays) in the patient study, where (a) is the initial plan with MSCT images, (b) the dose distribution with the original CBCT numbers, and (c) is the dose distributions with the converted CBCT numbers result of the SR (median) method. These isodose curves are overlapped on the CBCT images. The dose distribution using the original CBCT numbers differs from the initial plan in terms of the shapes of isodose curves between the dose distributions (a) and (b), whereas the results with the SR method is in good agreement with the initial plan in terms of the shapes of isodose curves between the dose distributions (a) and (c). Fig. 4 shows the results of the DTA and # analysis of the lung studies. In this figure, 'w/o conversion' refers to the situation in which the original CBCT numbers were used. The dose distribution for the original CBCT numbers differs from that in the initial plan. The pass rates of the cases without conversion in the DTA and # analysis were significantly smaller compared with those with the SR methods. Figure 5 shows the results of the DTA and # analysis of 4 beams. Fig. 6 shows an example of the dose distributions of 4 beams. The pass rates of the cases without conversion in the DTA and # analysis were significantly smaller compared with those with the SR methods (median, mean). The dose distribution with the SR method (median) agreed with that of the initial plan with the MSCT images. Among the SR methods, replaced with the median was superior to the rest of the pixel number in terms of the pass rate and its variance.

Table 1 shows the results of the DVH analysis of 4 beams. The result of the DVH analysis shows that the difference in the doses between the initial plan and a dose distribution for the SR method is small, whereas those with the cases without conversion are large. The result shows that the difference doses between the initial plan and a dose distribution for the SR method is small. With regard to the statistical parameter, the median of the MSCT numbers yielded an accurate dose distribution in terms of the pass rate and its variance.

The effect of region extraction accuracy for the SR method

Fig. 7 shows an example of the extracted region by changing the threshold value of the CBCT images in the lung regions. And, Figures 8 and 9 show the volumetric change
ratios in lung and bone regions against the reference threshold values (lung: -500, bone: 120). Volumetric change ratios in the lung region were as small as about ±2%. On the other hand, large volume change ratios of about ±15% were shown in bone regions. Fig. 10 and 11 show the results of the DTA and g analysis comparing the dose distribution of the CBCT and MSCT in lung and bone regions for each threshold value. Slight decreases in the calculation accuracy were induced by changing the threshold value in the lung region. In addition, the effect of the bone area extraction on the calculation accuracy was small. Table 2 shows the result of the error ratios of the dose volume between the initial treatment planning and the planning with the SR method in each threshold value in the lung region. The accuracy of the dose calculation was not appreciably affected by the dose volume of the target area for each threshold value.

Discussion

CBCT images acquired with an imaging device attached to a linear accelerator can improve the accuracy of the localization of a targeted region [9]. If a dose distribution could be calculated with the CBCT images, the accuracy of the radiation therapy would be improved considerably. However, we cannot use the original CBCT numbers directly in the calculation of dose distributions, because there are some issues in the CBCT images. One of them is the scattered photons included in the acquired projection data, the photons scattered in the patient's body decrease the measured linear attenuation coefficients in the CBCT images. In addition, the number of scattered photons entering the detector depends on the distribution of scatter in the patient's body. As shown in Fig. 4 and 5, we confirmed that the accuracy of the dose distribution calculated with the CBCT numbers was degraded considerably in treatment planning for heterogeneous regions containing a low density material. These errors were mainly caused by scattered photons and the beam-hardening effect [10, 11]. To cope with such problems, we proposed a new method and compared the accuracy of the calculated dose distribution with initial treatment planning calculated by the MSCT images. In our method, we combined two kinds of information; that is, for the anatomic shape of major organs, we used the CBCT images on the treatment day, and for the quantitative CT values, which are closely related to the electron density, we used those in the MSCT images. The results of the experiments showed that we can improve the accuracy of a dose distribution with the use of the proposed segmentation based method.

The results of the DTA and # analysis of a patient's lung (Fig. 4, 5) showed that the SR methods could improve the accuracy of dose distributions compared to the method with use of the original CBCT values. Moreover, the results of the DVH analysis (Table 1) showed that the SR method yielded almost the same dose distribution as that of the initial plan. We attributed these differences mainly to the scattered photons; that is, the SR method is affected by a small number of scattered photons, because the SR method did not use the CBCT numbers at all, but rather the MSCT numbers that are less affected by scattered photons. In the previous studies, these methods use a conversion curve, which
is made based on the CBCT numbers that are affected by scattered photons. Thus, if we use conventional methods to calculate the dose distribution, we have to compensate for these scattered photons by obtaining the conversion curves for different object sizes and data acquisition modes. On the other hand, the SR method is less affected by the incident scattered photons and artifacts in a CBCT image compared with the conventional methods. And so, we think that we can easily obtain an accurate dose distribution with the use of CBCT images obtained on the treatment day as well as verification of the target size and its position. A calculation of a dose distribution with a combination of CBCT and MSCT images improved its accuracy in terms of the dose value and the dose distribution in IGRT.

Extracted regions in the SR method may depend on the threshold value in histogram analysis. Therefore, we evaluated the effect of region extraction accuracy on the dose calculation. The volumetric change ratios in lung and bone regions were small against the reference threshold value (Fig. 8 and 9), but in the bone region the change was slightly large. The results of the DTA and # analysis for each threshold value (Fig. 10 and 11) showed that the changes of the extracted regions of the lung and bone were small, whereas the calculation accuracy slightly changed in the lung regions. Because the soft tissue regions surrounding the lung areas were affected by the extracted region of the lung, the dose calculation accuracy was affected by the accuracy of the extracted lung areas.
Fig. 2: Example of a CBCT image converted with the median of MSCT numbers in each region. Region "a" is a lung area, "b" is a bone area and "c" is a soft issue area.

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Fig. 3: Example of the dose distributions. (a) is the initial plan using MSCT image, (b) is the dose distribution using original CBCT image and (c) is the dose distribution using the SR method.

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Fig. 4: Results of the DTA and # analysis of a single-beam irradiation with lung image study.

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**Fig. 5:** Results of the DTA and # analysis of 4 beams with lung image study.

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**Fig. 6:** This figure shows an example of the dose distributions of 4 beams.

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Table 1: Results of the DVH analysis of 4 beams.

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<table>
<thead>
<tr>
<th>Volume dose types</th>
<th>w/o conversion</th>
<th>Conversion methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SR (median)</td>
</tr>
<tr>
<td>Mean</td>
<td>2.8 ± 0.9</td>
<td>1.3 ± 0.5**</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.4 ± 1.4</td>
<td>0.9 ± 0.8**</td>
</tr>
<tr>
<td>Minimum</td>
<td>4.0 ± 2.1</td>
<td>3.4 ± 3.0*</td>
</tr>
</tbody>
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not significant ** significant (p < 0.05)

Fig. 7: Example of the extracted region by changing the threshold value of the CBCT images in the lung regions. Upper number shows the threshold value for each image.

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Fig. 8: Volumetric change ratios in lung regions for each threshold value.

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Fig. 9: Volumetric change ratios in bone regions for each threshold value.
**Fig. 10:** Results of the DTA and #analysis for each threshold value in lung region.

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Fig. 11: Results of the DTA and analysis for each threshold value in bone region.

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Table 2: Result of the error rate of the dose volume between the initial treatment planning and the SR method in each threshold value.

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Conclusion

We proposed a new method that uses CBCT images in the calculation of dose distributions for the IGRT. And we evaluated the effect of region extraction accuracy on the dose calculation. The results showed that the dose calculation accuracy with the SR method is not affected by the accuracy of the extracted regions.
References


