Monte Carlo Simulation Based Digitally Reconstructed Radiographs

Yasumasa Kakinohana, Kazuhiko Ogawa, Takafumi Toita and Sadayuki Murayama

Dept. of Radiology, Faculty of Medicine, University of the Ryukyus, Okinawa, 903-0215 Japan
e-mail : kakihana@med.u-ryukyu.ac.jp

ABSTRACT

As the use of virtual simulation expands, digitally reconstructed radiographs (DRRs), which mimic conventional simulation films, play an increasingly important role as reference images in the verification of treatment fields. The purpose of our study is to develop an algorithm for computation of digitally reconstructed radiographs based on Monte Carlo simulation that take into account almost all possible physical processes by which photons interact with matter. The Monte Carlo simulation based DRRs have the following features.

1) Account has been taken of almost all possible physical processes of interaction of photons with matter, including a detector (film) response. In principle, this is equivalent to X-ray radiography.

2) Arbitrary photon energies (from diagnostic to therapeutic) can be used to produce DRRs. One can even use electrons as the source.

3) It is easy to produce a double exposure, which mimics the double exposure portal image and may have superior visual appeal for treatment field verification, with weighting within the treatment field.

Keywords: Digitally reconstructed radiographs, Monte Carlo, Virtual simulation, Radiotherapy

1. INTRODUCTION

Delivering the maximum dose to a cancerous tumor while minimizing the dose received by normal tissue is an important goal in the treatment planning process in radiation oncology. To meet this goal, CT or virtual simulation based on CT images is becoming widely used.

Because one of the primary purposes of simulation is to provide a method of treatment verification, one useful image from virtual simulation is the digitally reconstructed radiograph (DRR), which mimics the conventional simulation film. There are several studies on DRR calculation algorithms[1-4]. These algorithms are based on ray tracing methods, take into account only the primary photon attenuation, and do not consider any other effects such as scattering and energy deposition in matter.

The purpose of this study is to demonstrate Monte Carlo simulation based digitally reconstructed radiographs for clinical application.

2. MATERIALS AND METHODS

In principle, Monte Carlo simulation based DRR is equivalent to X-ray radiography. A schematic diagram for the DRR calculation is shown in Fig.1. The detector was modeled as an Ag plate, 0.001 cm thick with a matrix size of 512×512. The Monte Carlo code used in this study was EGS NOVA (C language version of EGS4, URL: http://www.nemc.org/nova).

Two phantoms and clinical CT images from radiotherapy cases were used. The two phantoms included a burger (contrast detail) phantom and a homemade phantom.

The burger phantom was used to ensure that our code worked properly and to confirm the ability of Monte Carlo simulation. Monte Carlo simulations of electron radiography images of the phantom were performed using the mathematically modeled geometry. Also, actual electron radiographs were obtained with electron beams from a medical linear accelerator. This phantom was also used for comparison of DRR calculation algorithms.

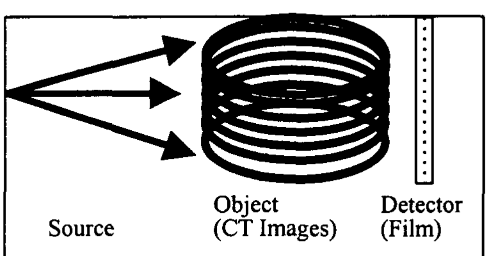
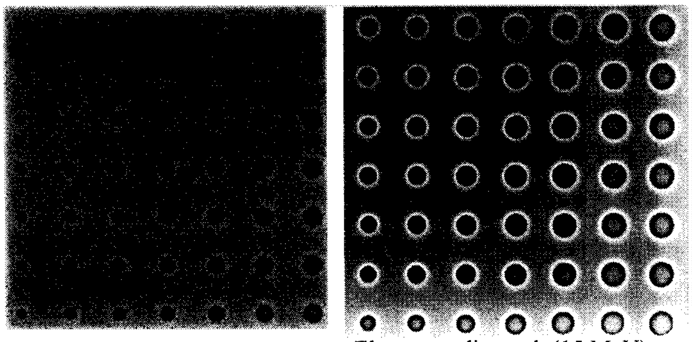


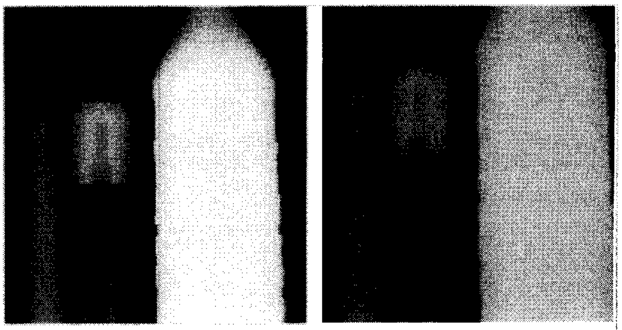
Fig.1 Schematic diagram for the DRR calculation

The homemade phantom was used to check image interpolation effects on DRR quality. The burger phantom and the homemade phantom underwent CT scans with conventional parameters (similar to clinical scans), and Monte Carlo



Monte Carlo (10 MeV) Electron radiograph (15 MeV)

Fig.2 Comparison of calculated and actual electron radiograph
Two images show relatively good qualitative agreement.



Without interpolation Linear interpolation

Fig.3 Comparison of image interpolation effects.

based DRRs were generated from the CT images. To compare the image quality of the DRRs generated, DRR calculations were also performed on a treatment planning workstation (FOCUS Ver. 2.3.0, CMS Co. Ltd. St. Louis, MO).

To use CT images in Monte Carlo simulation, the CT number should be converted into electron density or an equivalent material. The relationship between CT number and relative electron density was measured using several materials with known electron density and chemical composition[5)]. A linear relationship between CT number and relative electron density was found. Using this relationship, each pixel was classified into one of 34 materials[6,7)].

3. RESULTS AND DISCUSSION

As shown in Fig. 2, a qualitative comparison between the calculated and the actual electron radiograph of the burger phantom showed relatively good agreement.

This result shows that the Monte Carlo approach has the ability to perform DRR calculation.

Figure 3 shows the effects of image interpolation on the DRR quality. It is clear that the stair-step artifacts are less pronounced for linear interpolation.

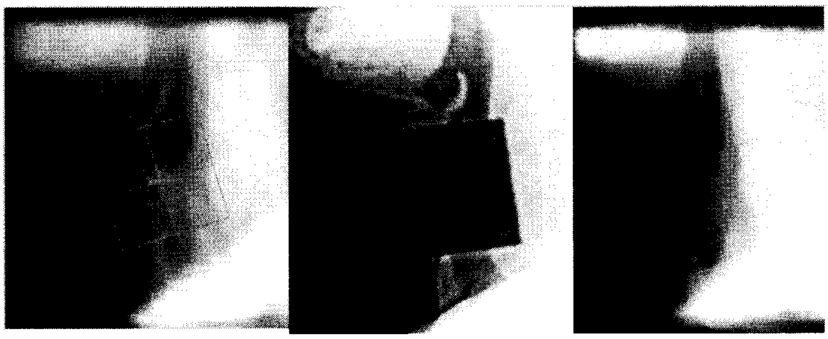
DRR examples from clinical CT images are shown in Fig. 4 and Fig. 5.

To compare DRR quality between ray-tracing and the Monte Carlo method, we also performed DRR calculations using the ray-tracing method (Fig. 6). These two images appear similar. However, the image contrast was superior for the ray tracing based DRR (Fig. 7), although more detailed studies should be undertaken.

The Monte Carlo based DRRs described here have following features:

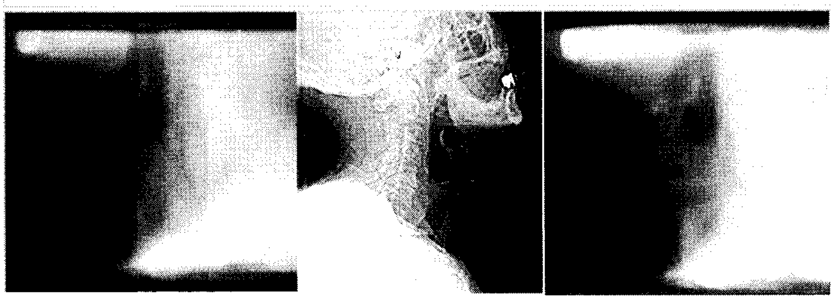
1) DRR calculation with arbitrary photon energies (Fig.4): as shown in the figure, a marker to identify the isocenter is recognizable at the photon energy of 25 keV but is difficult at 40 keV.

2) Simulation of double exposure image mimicking the double exposure technique used in portal image acquisition (Figs. 4,5): this may be *visually* superior for treatment field verification.



FOCUS Portal image Monte Carlo (40

Fig.4 Clinical example (5 mm slice thickness). Simulation of double exposure was



40 keV CT Scanogram 25 keV

Fig.5 Clinical examples (5 mm slice thickness). DRR images for different photon energies.

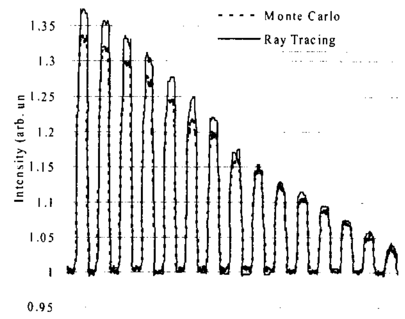
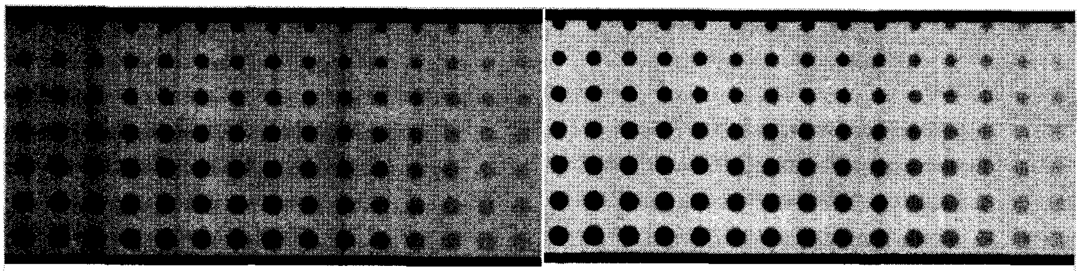


Fig.7 Comparison of profile curves



Ray-tracing method Monte Carlo method

Fig.6 Comparison of DRR calculation algorithms.

4. SUMMARY

It has been demonstrated that the Monte Carlo method has the ability to perform DRR calculation. However, like other Monte Carlo studies, the Monte Carlo based DRR is very time consuming; therefore, further improvements in the calculation algorithm should be sought.

REFERENCES

1. N. Milickovic, D. Batlas, S. Giannouli, M. Lahanas and N. Zamboglou, "CT Imaging Based Digitally Reconstructed Radiographs and their Application in Brachytherapy", *Phys. Med. Biol.* **45**, pp. 2787-2800, 2000.
2. G. W. Sherouse, K. Novins and E. L. Chaney, "Computation of Digitally Reconstructed Radiographs for Use in Radiotherapy Treatment Design", *Int. J. Radiat. Oncol. Biol. Phys.* **18**, pp. 651-658, 1990.
3. E. L. Chaney, J. S. Thorn and G. Tracton, "A Portable Software Tool for Computing Digitally Reconstructed Radiographs", *Int. J. Radiat. Oncol. Biol. Phys.* **32**, pp. 491-497, 1995.
4. L. Dong and A. L. Boyer, "An Image Correlation Procedure for Digitally Reconstructed Radiographs and Electronic Portal Images", *Int. J. Radiat. Oncol. Biol. Phys.* **18**, pp. 651-658, 1990,
5. J. A. Kalef-Ezar, A. H. Karantanas, T. Koligliatis, A. Boziari and P. Tsekeris, "Electron Density of Tissues and Breast Cancer Radiotherapy: A Quantitative CT Study", *Int. J. Radiat. Oncol. Biol. Phys.* **41**, pp. 1209-1214, 1998.
6. ICRU "Tissue Substitutes in Radiation Dosimetry and Measurement", *ICRU Report 44*, 1989.
7. ICRU "Photon, Electron, Proton and Neutron Interaction Data for Body Tissues", *ICRU Report 46*, 1992.