Measurement of Patient Dose from Computed Tomography Using Physical Anthropomorphic Phantom

Ki Won JANG a, Jae Ki LEE b, and Jong Kyung KIM b

a.Innovative Technology Center for Radiation Safety, Hanyang Univ., Haengdang, Seongdong, Seoul 133-791, Korea
kwjang@itrs.hanyang.ac.kr
b. Dept. Nuclear Engr., Hanyang Univ., Haengdang, Seongdong, Seoul 133-791, Korea

1. Introduction

The computed tomography (CT) provides a high quality in images of human body but contributes relatively high patient dose compared with the conventional X-ray examination. Furthermore, the frequency of CT examination has been increasing in Korea for the last decade owing to the national health insurance benefits.

Increasing concerns about high patient dose from CT have stimulated a great deal of researches on dose assessment, which many of these are based on the Monte Carlo simulation [1,2]. But in this study, absorbed doses and effective dose of patient undergoing CT examination were determined experimentally using anthropomorphic physical phantom and the measured results are compared with those from Monte Carlo calculation.

2. Methods and Results

2.1 Anthropomorphic phantom

The physical phantom manufactured by CIRS, ATOM 701-C model, was used as a substitute for the human body. This phantom represents an adult male and consists of five different materials, which are equivalent to the average bone, soft tissue, spinal cord, lung, and brain respectively. And this phantom is divided into 39 slices whose thickness is 2.5cm and a number of holes, where a dosimeter is inserted, are made at intervals of 1.5cm on each slice.

In order to estimate the effective dose recommended by the International Committee on Radiological Protection (ICRP), absorbed doses of the 12 organs and the remainder must be first determined. Unfortunately these organs are not indicated within the phantom, the organ segmentation is needed prior to the measurement in the radiation field. The organ location and volume in each slice are determined based on the information of MIRD mathematical phantom designed by Eckerman and Cristy [3]. Despite the difference in contours of the human body, the mathematical phantom was used because its descriptions of organs and the tissues were thought to be objective and representative.

2.2 Measurement of organ doses with TLDs

The organ doses are measured during CT examinations of abdomen, where most organs essential for estimating the effective dose are located, using a GE Hispeed CT/i. The measurements were done for both axial and spiral scan mode and technical parameters used in each scan are summarized in the Table 1. Thermoluminescent dosimeter (TLD) inserted in the phantom is composed of LiF;Mg,Cu,P (Conqueror Electronics Technology Co, Beijing, GR-200). The TLDs were calibrated by exposing them to air kerma of about 8.76mGy using a ^{137}Cs source and the TLDs were selected to have sensitivity within 10% of the mean value.

Table 1. Scan parameters of the CT abdomen examination

Scan mode	Tube voltage (kVp)	Tube current (mAs/rotation)	Slice width (mm)	Slice increment (mm)	pitch
Axial	120	220	7	7	-
Spiral	120	220	7	-	1.8

To account for the difference of beam quality between in air and in the phantom, the correction factors calculated according to the equation (1) were applied to the responses of the TLDs [4].

$$D_{mat} = D_{air} \frac{\int E\phi(\mu_{en}/\rho)_{mat}\, dE}{\int E\phi(\mu_{en}/\rho)_{air}\, dE} \qquad (1)$$

where $E\phi$ is the energy fluence generated by SPEC78 program using information of the X-ray tube in CT [5] and (μ_{en}/ρ) is the mass-energy absorption coeffiecient.

As a result, the range of absorbed dose was 15-20mGy for a routine axial CT scan and 9-12mGy for a routine spiral CT scan and the estimated effective doses were 17.78mSv and 10.01mSv respectively. It was confirmed that dose reduction can be accomplished by spiral scan and the dose is inversely proportional to the pitch, which means the ratio of the table travel per gantry rotation to the beam collimation, that is, image thickness. These results are showed in the Figure 1.

2.3 Comparison with Monte Carlo simulation

The Monte Carlo calculation using MCNPX2.4.0

code was accompanied with the experimental dose determination. The MIRD mathematical phantom is irradiated with a fan-shaped beam in the simulation and photons transported through the phantom are emitted from the point sources on a circle with radius equal to the focus-to-axis distance of the scanner. CT scanner is often equipped with the beam shaping filter to help the beam to be fan-shaped and compensate for the different intensity of photons between pass through the periphery of the phantom and pass through the center of the body. But we could not get information about this filter from the manufacturer, perfect beam shaping filter was assumed whose shape was calculated to give a constant path length through the cylindrical body phantom [6].

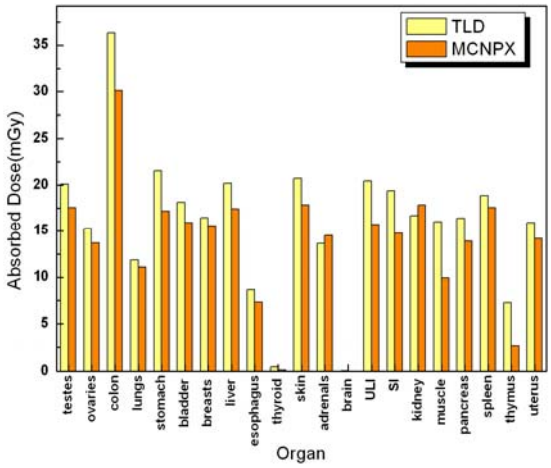

Figure 1. Comparison of organ doses from axial CT scan with spiral scan

The results compared with the TL responses are showed in the Figure 2. The direct measurements are up to 30% higher than the Monte Carlo technique. Gleijins et al. have already reported that TL measurements were up to 40% higher than the Monte Carlo calculation [7]. These differences are maybe due to the difference in the shape and compositions of the phantoms used in the experiment and simulation. The physical phantom is fundamentally different from the mathematical phantom so the estimated organ locations during the segmentation in the physical phantom would be significantly different from those in the MIRD phantom. In addition, the lack of information of the beam shaping filter such as the thickness and material, which affects the beam quality, could be considered as the factor contributes to the different results.

3. Conclusion

For the purpose of the dose assessment for the computed tomography which gives considerable doses to the patient, the experimental techniques were used and the measured doses are analyzed and compared with the Monte Carlo calculation. The both methods suggested in this study can be used to determine a dose of specific patient whose mass and shape is different from the standard phantoms in reality and they can be also applied for the reassessment of patient dose when the technique in CT equipment is developed or the protocol to CT scan is changed.

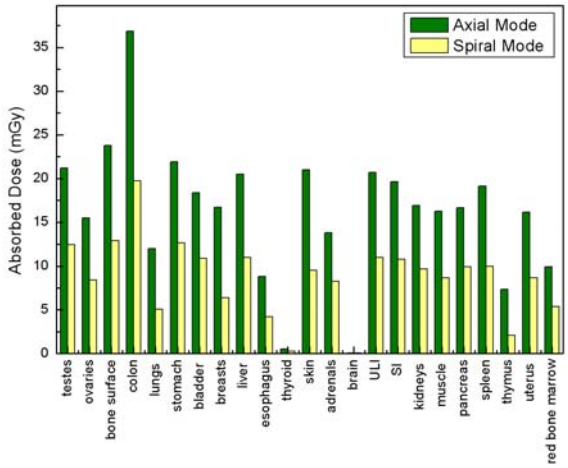

Figure 2. Comparison of organ doses from TL response with Monte Carlo simulation

Acknowledgment

This study was supported by Innovative Technology Center for Radiation Safety (iTRS).

REFERENCES

[1] D.G. Jones, P.C. Shrimpton, "NRPB-R250 part3: Normalized Organ Doses Calculated using Monte Carlo Techniques", NRPB, 1991.

[2] M. Zankl, G. Drexler et al, "Rep 30/91: The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods, Part VI: Organ doses from tomographic examinations", GSF, 1991.

[3] M. Cristy, K. F. Eckerman et al, The ORNL mathematical phantom series", Oak Ridge National Laboratory, 1996

[4] J. L. Ioppolo, R. I. Price, T. Tuchyna, C. E. Buckley, Diagnostic X-ray Dosimetry using Monte Carlo Simulation, Phys. Med. Biol., Vol. 47, p.1707-1720, 2002.

[5] K. Cranley, B. J. Gilmore, G. W. A. Fogarty, L. Desponds, "Report No.78: Catalog of Diagnostic X-ray Spectra and Other Data", The Institute of Physics and Engineering in Medicine, 1997

[6] James V. Atherton, Walter Huda, CT Doses in Cylindrical Phantoms, Phys. Med. Biol., Vol. 40, p.891-911, 1995.

[7] J. Geleijns, J. G. Van Unnik, J. Zoeteliff, D. Zweers, J. J. Broerse, Comparison of two methods for assessing patient dose from computed tomography, Br. J. Radiol., Vol. 67, p.360-365, 1994.