Development of Neonate Phantom for Estimating Medical Exposure

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INTRODUCTION

The recent progress in medical technology causes the decreases in the mortality rate of neonates with their birth weight less than 1,000g. Many X-ray examinations of neonates in NICU are usually done for various body size. The Frequencies of radiation exposure per neonate are high compared to general diagnosis for adults. It is important for radiation protection to consider that the radiation sensitivity of neonates is higher than that of adults. Especially, red bone marrow, which is one of high sensitive organs, is spread in their body almost uniformly. Although, for medical radiation protection, the estimation of neonatal dose is needed in order to optimize X-ray examinations, few quantitative studies have been reported (1,2). In addition, few neonatal physical and mathematical phantoms have been reported in estimating medical exposure. For this reason, a physical neonatal phantom was developed for estimating medical exposure in NICU. The mathematical phantom was also made for computer simulation to calculate doses.

METHODS

Phantom development

Although it is difficult to make the standard of neonatal phantom due to the variation of body sizes among neonates, mean values of neonatal body sizes were adopted for practical development. The phantom was designed to consist of some rectangular solids. As the basis, the body size data of neonates were investigated in the NICU of Oita prefectural hospital. The number of neonates considered was 30. Measured data were sizes of head, chest, abdomen, and values of body height and weight. Body weights were distributed between 600g and 3,190g among them, and the mean value was about 2,000g. Based on the results, the size of neonatal phantom was determined to be 2,000g, and other body sizes were calculated for each size using least squares method from the data (Table 1). As materials of the phantom, soft tissue and lungs were selected excluding skeleton. The materials for soft tissue and lungs were tough water phantom and tough lung phantom of Kyoto kagaku Co.Ltd., respectively. The lung weights were calculated using the regression equations of lungs in NIRS-115 (3). The actual weight and height of the phantom were 1990.5g and 43.5cm, respectively.

Table 1. Neonatal phantom size of each part

Body part	axis	cm	Body part	axis	cm
Head	x	10.5	Abdomen	x	7.5
	y	7.5		y	9.5
	z	7.5		z	6.5
Chest	x	8.5	Waist	x	2.5
	y	9.5		y	9.5
	z	6.5		z	6
Left lung	x	6.7	Arm	x	14.5
	y	2.3		y	2.3
	z	4.8		z	2.3
Right lung	x	6.7	Foot	x	14.5
	y	3.5		y	2.8
	z	4.8		z	2.8
body height		43.5			
body weight		1990.5 g			

Dose measurement

As instruments for dose measurement, film badges and glass dosimeters were selected in order to measure the surface dose of the phantom. In our experiment, X-rays were irradiated for the phantom under the condition of actual X-rays examinations for neonates in NICU. The exposed sites of the phantom were chest, chest-abdomen and abdomen under the condition of 55kV and 1.6mAs. For head picture, the condition of 60kV and 2mAs was selected. The distance between X-ray tube focus and films was 90cm. Instruments were located on the center of exposed area on the phantom surface. Film badges and glass dosimeters were used under the same exposure condition in order to compare between the measured values.

Dose calculation

For the estimation of dose distribution in the phantom using simulation method, mathematical phantom were developed as the same geometries of physical neonatal phantom. It was mathematically divided into 1mm voxels. These voxels were partly gathered and treated as one for each region of the phantom, and absorbed dose for each region were calculated. The incubator was not considered as the materials for the simulation. A Monte-Carlo simulation was done using the EGS4 code with a Alpha/Linux machine and g77 fortran compiler. The history number of simulation was 2 million. X-ray spectra data were referred from a literature (4).

RESULTS

Phantom development

Developed neonatal physical phantom is shown in Figure 1. Each part is removable in order to apply any posture. It is characteristic of neonates that head size is big compared to other body parts. Since the volume of heart is comparatively high, the lungs were not symmetrical. Arms and foot were determined based on the whole body shape and height.

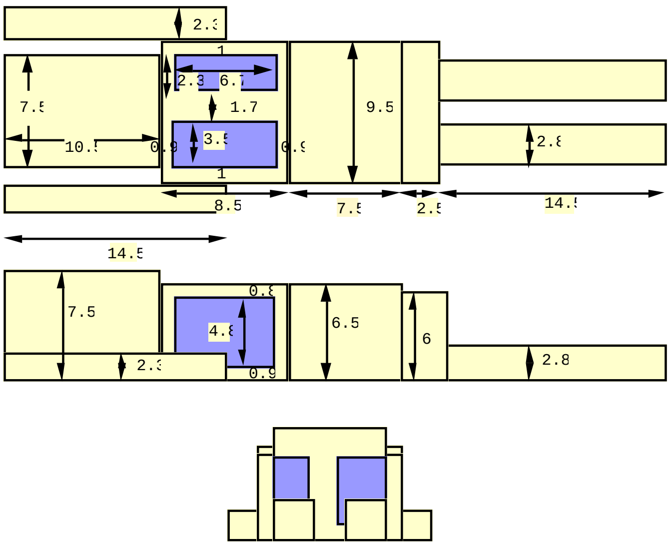

Figure 1. Developed neonatal phantom

Dose measurement

The measured values using glass dosimeters were 0.1mSv for chest, ,chest-abdomen and abdomen examination, and 0.17mSv for head. The film badge resulted in 0.1mSv for all examinations condition (Table 2). The hands surface dose were 0.04mSv for head side hand, and 0.05mSv for foot side shown by glass dosimeter. The measured values with glass dosimeters were higher than film badge measurement.

Table 2. Measured surface doses of neonatal phantom using glass dosimeters and film badges

Site	Dose (mSv)	
	Glass dosimeter	Film Badge
Chest/abdomen	0.12	0.1
Chest	0.12	0.1
Abdomen	0.12	0.1
Head	0.17	0.1

Dose calculation

The absorbed dose ratio in lungs were shown by gray scale in Figure 2. as a Monte-Carlo simulation result. The absorbed doses of anterior side were relatively higher than posterior side of the phantom.

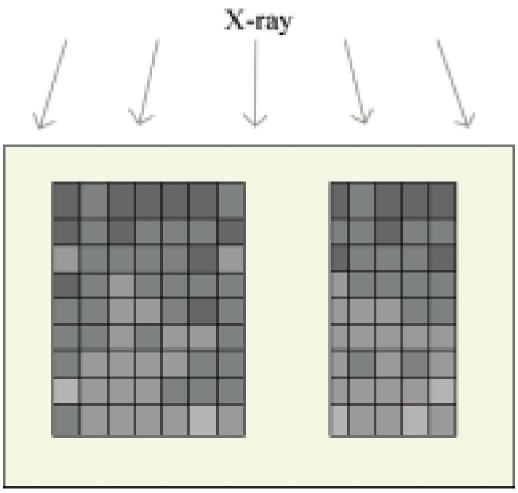

Figure 2. Absorbed dose ratio in lungs

DISCUSSIONS

Phantom development

There is wide variation of body weights of neonates in NICU. The mean neonatal weight, 2,351.2g, was reported in a reference (5), and some studies adopted 2,500g (1,5) or several values (6). In NICU, however, 2,500g weight is not suitable as a mean value. These mean values are not applied to estimation for each neonates directly. However, it is effective to estimate neonatal doses using ideal body size. Over 2,000g weight neonate might be heavier as a neonate in NICU when including VLBWI or ELBWI in estimation.

As means for measurement of radiation exposure, some physical phantoms for neonates were reported. Simple shapes and materials, such as a rectangular solid and water, were used (6) for them. Compared with them, the neonatal phantom in this study has not an exact but a similar shape to neonate. By using it, more approximate value can be obtained keeping the error caused by the shape smaller. However, lack of bones might affect measured dose. The neonate physical phantom involving skeleton material has not reported, and there is no means to estimate its effect physically. Mathematical phantom is another method to be considered for the problem.

Dose measurement

Although TLD measurement method to put on each neonates directly is effective to measure entrance skin doses (5,7), this method is not always available in actual medical fields. The various measurements of surface doses have been reported not only using physical phantoms (6) but also calculation by conversion factors(1,8,9,10,11). The scattering tissue was also used as materials of conversion factors (2), and entrance dose is 0.055mGy in the report. In this study, chest/abdomen surface doses were 0.1-0.12mSv. The measured doses obviously depend on the conditions. Considering the unit Sv/Gy, the effect of low dose technique (7,11) and the sensitivity of instruments, measured data of this study, 0.1-0.12mSv, are similar compared to other studies, such as 0.07mGy for chest-abdomen (1) and 0.055mGy (2).

Dose calculation

Modified mathematical phantoms, e.g. 2,500g phantom based on MIRD phantom, was used for the Monte Carlo simulation method (5). A 5cm slab was also used for calculation of EGS4 Monte Carlo simulation code (2). Recently, voxel phantoms based on anatomical three-dimensional data of human body have developed, and been applied for dosimetry purposes. The advantage of the voxel phantom is analysis of the dose distribution in each organ and reduction of errors caused by the simplified shapes. Actually, the calculated results of this study showed the distribution of absorbed doses in sectional voxels. The accuracy of estimated dose depends on the geometry of mathematical phantom and the history number of simulation.

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