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Comparison of Male and Female Pediatric Phantom Doses in the Same Age Group on Whole Body Tomography: A Monte Carlo Simulation Study

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ABSTRACT

Objective: In this study, it was aimed to calculate and compare organ doses of male and female pediatric phantoms in the same age group applied whole body tomography using Monte Carlo method. Materials and Methods: The simulation was performed on a GE Discovery CT750 HD model tomography instrument with a tube voltage of 100 kVp, a current irradiation time of 100 mAs and a dose index (CTDI) of 5,31 in the VirtualDose program. Five groups of anatomic phantoms called new born, 1, 5, 10 and 15 years old, as stated in the ICRP-89 report for male and female phantoms in the same age group, were used. Results: The total effective dose was found 13.92, 12.28, 11.70, 10.31 and 8.82 for new born, 1, 5, 10 and 15 years old groups, respectively. New born group male phantom testes dose was found 14.08 mGy, female phantom ovaries dose was found 13.05 mGy. In the 1 year old group male phantom testes and prostate doses were found 14.92 and 12.24 mGy, female phantom ovaries and uterus doses were found 12.44 and 10.98 mGy, respectively. In the 5 year old group male phantom testes and prostate doses were found 14.33 and 12.53 mGy, female phantom ovaries and uterus doses were found 11.65 and 10.25 mGy, respectively. In the 10 year old group male phantom testes and prostate doses were found 13.69 and 10.80 mGy, female phantom ovaries and uterine doses were found

9.51 and 8.50 mGy, respectively. In the 15 year old male phantom doses of brain, colon, liver, stomach, testes, thyroid, adrenal, gall bladder, kidney, pancreas, prostate, small intestine, spinal cord, spleen, thymus were found 8.81, 8.51, 8.60, 8.22, 12.43, 12.76, 7.36, 7.44, 8.49, 6.88, 7.88, 9.84, 7.42, 8.48, 8.45, 8.56 mGy, female phantom doses of brain, colon, liver, stomach, ovaries, thyroid, adrenal, gall bladder, kidney, pancreas, uterus, small intestine, spinal cord, spleen, thymus were found 9.30, 10.45, 9.34, 9.41, 7.95, 14.66, 7.85, 8.33, 10.10, 8.39, 8.86, 6.88, 9.11, 9.03, 9.48, 9.32 mGy. Conclusion: There was no sex-dependent difference in total effective dose in 5 groups. Male phantom testes doses in 5 groups were found higher than female phantom ovarium doses. There is no significant difference in organ doses of newborn, 1, 5, 10 year old male and female phantoms out of 15 year old.

Keywords: Monte Carlo Simulation, Pediatric Phantom, Effective Dose

ÖZET

Amaç: Bu çalışmada, Monte Carlo yöntemi kullanılarak tüm vücut tomografi uygulanan aynı yaş grubundaki erkek ve kız pediatrik fantomları üzerinden organ dozlarının hesaplanması ve karşılaştırılması amaçlanmıştır.

Materyal ve Metot: Simülasyon VirtualDose programında, tüp voltajı 100 kVp, akım ışınlama süresi 100 mAs, doz indeksi (CTDI) 5,31 olan GE Discovery CT750 HD model tomografi cihazına göre yapılmıştır. Aynı yaş grubundaki erkek ve kız pediatrik fantomları için ICRP-89 raporunda belirtilen yeni doğan, 1, 5, 10 ve 15 yaş olmak üzere 5 grup anatomik fantom kullanılmıştır. Bulgular: Total efektif doz değeri yeni doğan, 1, 5, 10 ve 15 yaş grubu için sırasıyla 13.92, 12.28, 11.70, 10.31 ve 8.82 bulundu. Yeni doğan grubunda erkek fantom testis dozu 14.08 mGy, kız fantom ovaryum dozu 13.05 mGy bulundu. 1 yaş grubunda erkek fantom testis ve prostat dozları 14.92 ve 12.24 mGy, kız fantom ovaryum ve rahim dozları 12.44 ve 10.98 mGy bulundu. 5 yaş grubunda erkek fantom testis ve prostat dozları 14.33 ve 12.53 mGy,

kız fantom ovaryum ve rahim dozları 11.65 ve 10.25 mGy bulundu. 10 yaş grubunda erkek fantom testis ve prostat dozları 13.69 ve 10.80 mGy, kız fantom ovaryum ve rahim dozları 9.51 ve 8.50 mGy bulundu. 15 yaş grubunda erkek fantom beyin, kolon, karaciğer, mide, testis, tiroid, böbreküstü bezi, safra kesesi, böbrek, pankreas, prostat, ince barsak, spinal kord, dalak, timüs dozları 8.81, 8.51, 8.60, 8.22, 12.43, 12.76, 7.36, 7.44, 8.49, 6.88, 7.88, 9.84, 7.42, 8.48, 8.45, 8.56 mGy, kız fantom beyin, kolon, karaciğer, mide, ovaryum, tiroid, böbreküstü bezi, safra kesesi, böbrek, pankreas, rahim, ince barsak, spinal kord, dalak, timüs dozları 9.30, 10.45, 9.34, 9.41, 7.95, 14.66, 7.85, 8.33, 10.10, 8.39, 8.86, 6.88, 9.11, 9.03, 9.48, 9.32 mGy bulundu. Sonuç: 5 grupta total efektif doz değerinde cinsiyete bağlı bir farklılık görülmemiştir. 5 grupta erkek fantom testis dozu, kız fantom ovaryum dozuna göre yüksek bulunmuştur. Yeni doğan, 1, 5, 10 yaş kız ve erkek fantom organ dozlarında anlamlı bir farklılık bulunmazken 15 yaş grubunda doz dağılımları değişmiştir.

Anahtar Kelimeler: Monte Carlo Simülasyonu, Pediatrik Fantom, Efektif Doz

Introduction

Computed Tomography (CT) is one of the most widely used medical imaging techniques in clinics and is increasingly adopted because of the improvements in medical technology [1, 2–4]. The high number of and high contribution of CT scans to medical exposure raised concerns about the radiation protection in radiology community. The International Commission on Radiological Protection (ICRP) emphasized the importance of CT patient dose management in 2007 [3]. The principles of optimization and 'as low as reasonably achievable' (ALARA) have been major principles and have been adopted in the radiation protection of patients, the public, and radiological workers for decades [5–8].

Children are generally considered to be at higher risks of developing radiation-induced tumors because of the young age of exposure and increased tissue radiosensitivity in some of the organs [9–11]. For the 23 types of cancers reviewed recently by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) committee, children are clearly more likely to develop one of a quarter of these types, including leukemia, brain, breast, skin and thyroid cancer [9]. However, for the other three quarters of the cancer types, children are no more sensitive such as colon or lung cancer than adults or there is either not enough data or no clear relationship between radiation exposure and cancer risks [9]. The UNSCEAR committee recommends avoiding the use of generalized radiation risks for children and emphasizes the evaluating of and using specific organ dose, the importance of which has been recognized by the radiology community with respect to radiation induced cancer risk estimations [9, 12–18].

Organ dose is the absorbed dose to a specific organ or a tissue in the body and is generally estimated as the ratio of the amount of ionizing radiation energy deposited in the organ, representing an estimate of the average damage to the organ per unit mass. Although organ dose cannot be directly measured on living tissues or organs, measurements in physical

anthropomorphic phantoms are possible. A practical method of accurate organ dose estimation is to use Monte Carlo (MC) methods and anatomically realistic computational anthropomorphic phantoms to simulate the CT scans and to calculate the organ doses [12, 14, 15, 17, 19, 20].

A few newly developed dose calculators utilize anatomically realistic phantoms and provide better patient-matching options for organ dose calculation. VirtualDose is an effective dose calculator that incorporates anatomically realistic phantoms for patients of various ages (including pediatric ages 0 through 15), gender, pregnancy stages, or body sizes [17].

The objective of this study is to calculate and compare organ doses of male and female pediatric phantoms in the same age group applied whole body tomography. In addition, it is investigated whether there is a sex-dependent difference in organ doses or not in the study.

Materials and Methods

Organ dose and total effective dose for pediatric phantoms who received whole body CT scans were calculated with VirtualDose. VirtualDose uses cutting-edge advances on Monte Carlo simulation software to estimate doses for CT exposure and ICRP recommendations across multiple anatomically realistic patient phantoms for average (or median) adult patients, children at different ages (newborn, 1-, 5-, 10- and 15-year-old), a pregnant female at three gestational stages (3-, 6- and 9-month), overweight and obese patients. The program lists the simulation results from the library according to the selected parameters. In this respect, it does not require repeated measurements and is user friendly. With VirtualDose, pediatric pantoms at 5 different age groups were covered: New born, 1 year old, 5 year old, 10 year old and 15 year old. Phantoms are shown in figure 1.

The simulation was performed on a GE Discovery CT750 HD model tomography instrument with a tube voltage of 100 kVp, a current irradiation time of 100 mAs and CTDI of 5,31 in the VirtualDose. The effective dose was calculated using tissue weighting factors and organ doses was determined according to ICRP No. 103 publication [7].

The relationship between doses was assessed by looking at the variance value. Significantly different variance value was accepted as 5% and over.

Results

The total effective doses and organ doses of 5 different pediatric phantoms are shown in detail in Table 1. The total effective dose was found 13.92, 12.28, 11.70, 10.31 and 8.82 for new born, 1, 5, 10 and 15 years old groups, respectively.

New born male phantom's testes dose was found 14.08 mGy, female phantom's ovaries dose was found 13.05 mGy. In the 1 year old male phantom's testes and prostate doses were found 14.92 and 12.24 mGy, female phantom's ovaries and uterus doses were found 12.44 and 10.98 mGy, respectively. In the 5 year old male phantom' testes and prostate doses were found 14.33 and 12.53 mGy, female phantom's ovaries and uterus doses were found 11.65 and 10.25 mGy, respectively. In the 10 year old male phantom' testes and prostate doses were found 13.69 and 10.80 mGy, female phantom's ovaries and uterine doses were found 9.51 and 8.50 mGy, respectively. Considering these 4 groups, there were significant differences only in testes and ovarium doses in male and female pediatric phantoms. Testes doses were found to be 7.89%, 19.94%, 23.00%, 43.95% higher than ovarium doses in new born, 1, 5, 10 year old groups, respectively. Additionally, prostate doses were found to be 11.48%, 22.24%, 27.06% higher than uterus doses just in 1, 5, 10 year old groups, respectively.

There was a difference in the dose of many organs in the 15 year old group. In the 15 year old male phantom's doses of brain, colon, liver, stomach, testes, thyroid, adrenal, gall bladder, kidney, pancreas, prostate, small intestine, spinal cord, spleen, thymus were found 8.81, 8.51, 8.60, 8.22, 12.43, 12.76, 7.36, 7.44, 8.49, 6.88, 7.88, 9.84, 7.42, 8.48, 8.45, 8.56 mGy and female phantom's doses of brain, colon, liver, stomach, ovaries, thyroid, adrenal, gall bladder, kidney, pancreas, uterus, small intestine, spinal cord, spleen, thymus were found 9.30, 10.45, 9.34, 9.41, 7.95, 14.66, 7.85, 8.33, 10.10, 8.39, 8.86, 6.88, 9.11, 9.03, 9.48, 9.32 mGy.

Male phantom's testes and prostate doses were higher than ovarium and uterus doses by 56.35% and 43.02% in this group. Except this, female phantom doses were found to be high in other organs.

Discussion

Fast and accurate estimation of organ doses for patients, especially for pediatric patients, are essential for radiologists and radiation protection professionals in clinical practice. In this study we compared CT based organ doses and investigated sex-depended organ doses differences in pediatric phantoms.

In all male pediatric phantoms the testes dose is higher than the ovaries dose in the female phantoms, which is because the testes volume is larger than the ovaries as seen in literatüre [21].

Both male and female pediatric phantoms were found to have decreased organ doses as age increased, as shown in figure 2 and 3. The reason for this is thought to be the growth of organ volumes and body surface area depending on age. This conclusion is consistent with many studies in the literatüre [22, 23].

A limitation of this study was that no real measurement was involved. In addition, the calculations in this study were performed on only a few VirtualDose phantoms and it was hard to obtain enough data for statistical testings. Measurements on physical human phantoms are planned to validate the computational methods based on experiment design. Future work involves the application of the method discussed in this study to a number of pediatric patients for organ doses and effective dose estimation.

Acknowledgements

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Tables and Figures

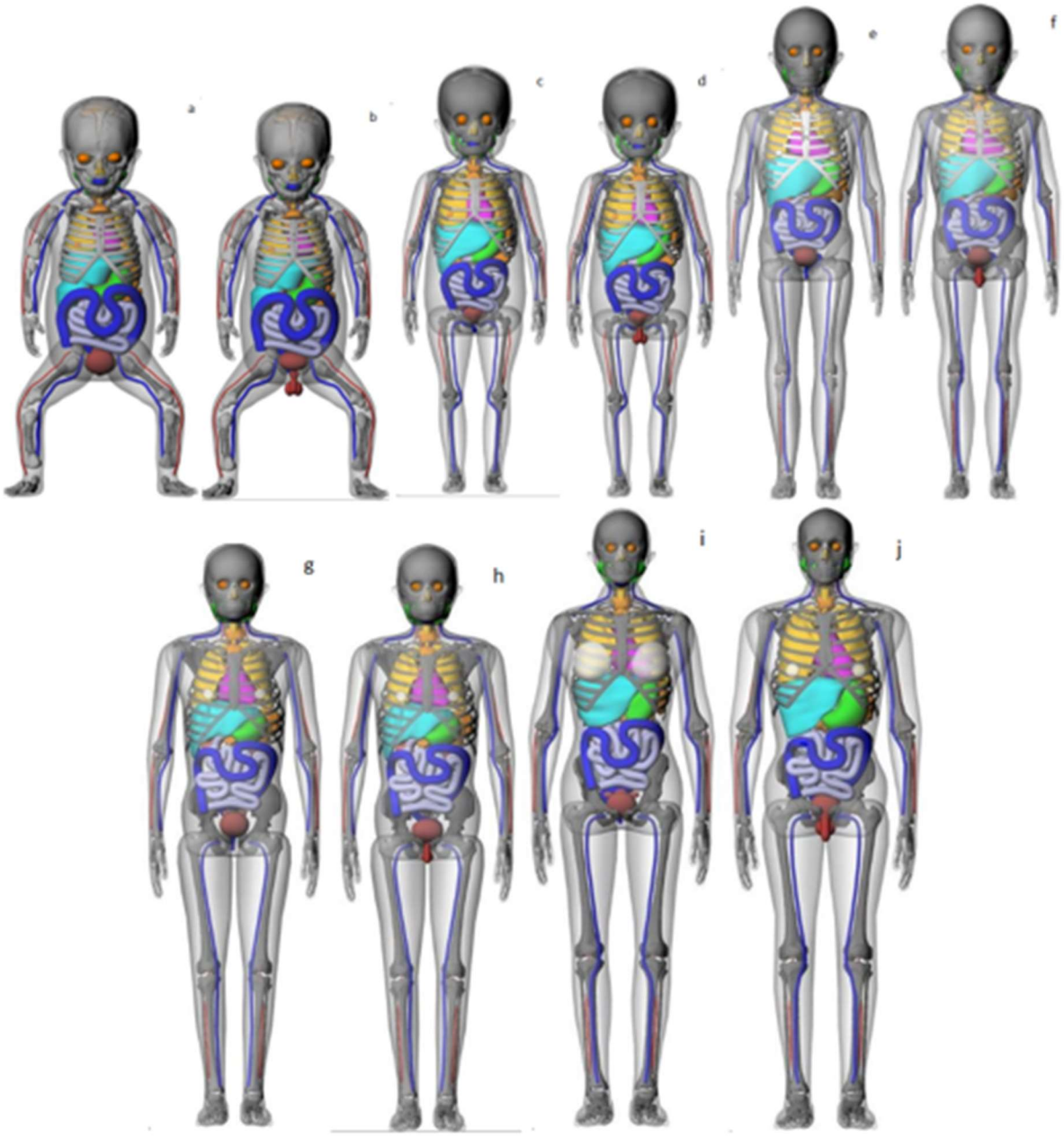

Figure 1: Pediatric Phantoms of VirtualDose. a) New born female phantom, b) New born male phantom, c)1 year old female phantom, d) 1 year old male phantom, e) 5 year old female phantom, f) 5 year old female phantom, g) 10 year old female phantom, h) 10 year old male phantom, i) 15 year old female phantom, j) 15 year old male phantom.

	NewBorn			1 year old			5 year old			10 year old			15 year old		
	M	F		M	F		M	F		M	F		M	F	
Organ/Tissue Name	Doses (mGy)		Variance (%)	Doses (mGy)		Variance (%)	Doses (mGy)		Variance (%)	Doses (mGy)		Variance (%)	Doses (mGy)		Variance (%)
Bone Surface	12,43	12,49	-0,48	11,02	11,10	-0,72	9,58	9,66	-0,83	8,68	8,76	-0,91	9,33	9,82	-4,99
Brain	12,71	12,73	-0,16	11,12	11,15	-0,27	9,76	9,78	-0,20	9,76	9,79	-0,31	8,81	9,30	**-5,27**
Breast	13,31	13,36	-0,37	10,01	10,29	-2,72	10,20	10,50	-2,86	8,16	8,41	-2,97	7,59	7,41	2,43
Colon	14,43	14,55	-0,82	12,29	12,48	-1,52	12,27	12,43	-1,29	10,90	11,06	-1,45	8,51	10,45	**-18,56**
Esophagus	13,12	13,24	-0,91	12,76	12,92	-1,24	11,57	11,73	-1,36	9,58	9,74	-1,64	7,93	8,26	-4,00
Liver	14,80	14,91	-0,74	12,65	12,77	-0,94	11,55	11,67	-1,03	10,41	10,53	-1,14	8,60	9,34	**-7,92**
Lung	14,37	14,47	-0,69	13,58	13,72	-1,02	12,07	12,20	-1,07	10,66	10,81	-1,39	8,65	8,86	-2,37
Red Bone Marrow	11,77	11,83	-0,51	10,48	10,56	-0,76	9,86	9,94	-0,80	9,16	9,24	-0,87	6,89	7,22	-4,57
Salivary Glands	14,61	14,11	3,54	12,88	12,49	3,12	12,32	11,93	3,27	12,64	12,23	3,35	11,46	11,11	3,15
Skin	13,80	13,85	-0,36	12,76	12,83	-0,55	11,96	12,02	-0,50	11,03	11,10	-0,63	9,56	9,81	-2,55
Stomach	14,31	14,43	-0,83	12,27	12,44	-1,37	11,38	11,54	-1,39	10,30	10,48	-1,72	8,22	9,41	**-12,65**
Testes / Ovaries	14,08	13,05	**7,89**	14,92	12,44	**19,94**	14,33	11,65	**23,00**	13,69	9,51	**43,95**	12,43	7,95	**56,35**
Thyroid	17,82	17,98	-0,89	14,83	15,05	-1,46	16,40	16,54	-0,85	14,27	14,42	-1,04	12,79	14,66	**-12,76**
Urinary Bladder	14,47	14,76	-1,96	12,75	12,98	-1,77	12,59	13,07	-3,67	10,35	10,85	-4,61	8,75	8,60	1,74
Adrenals	13,08	13,19	-0,83	11,57	11,71	-1,20	10,20	10,36	-1,54	8,90	9,07	-1,87	7,36	7,85	**-6,24**
Eye Lens	12,76	12,78	-0,16	10,45	10,48	-0,29	11,69	11,71	-0,17	11,84	11,86	-0,17	12,10	12,38	-2,26
Eyeballs	12,72	12,75	-0,24	11,70	11,74	-0,34	10,96	11,00	-0,36	11,17	11,21	-0,36	11,26	11,45	-1,66
Gall Bladder	13,46	13,56	-0,74	11,68	11,84	-1,35	10,90	11,06	-1,45	9,87	10,03	-1,60	7,44	8,33	**-10,68**
Heart	14,73	14,84	-0,74	13,52	13,66	-1,02	12,24	12,37	-1,05	10,82	10,95	-1,19	9,10	9,32	-2,36
Kidneys	14,62	14,76	-0,95	13,77	13,96	-1,36	12,78	12,96	-1,39	11,18	11,36	-1,58	8,49	10,10	**-15,94**
Muscle	13,37	12,90	3,64	12,51	12,11	3,30	11,66	11,29	3,28	10,39	10,08	3,08	8,65	8,71	-0,69
Oral Mucosa	14,58	14,08	3,55	12,03	11,66	3,17	10,99	10,64	3,29	10,26	9,94	3,22	11,18	10,73	4,19
Pancreas	14,07	14,20	-0,92	12,02	12,21	-1,56	10,95	11,14	-1,71	9,36	9,56	-2,09	6,88	8,39	**-18,00**
Pituitary Gland	11,92	11,97	-0,42	10,03	10,09	-0,59	9,17	9,20	-0,33	8,92	8,94	-0,22	7,88	8,86	**-11,06**
Prostate / Uterus	12,79	12,71	0,63	12,24	10,98	**11,48**	12,53	10,25	**22,24**	10,80	8,50	**27,06**	9,84	6,88	**43,02**
Rectosigmoid Colon	13,20	13,34	-1,05	11,59	11,78	-1,61	10,91	11,12	-1,89	9,15	9,35	-2,14	8,00	7,62	4,99
Small Intestine	14,22	14,35	-0,91	11,95	12,15	-1,65	11,64	11,83	-1,61	9,95	10,14	-1,87	7,42	9,11	**-18,55**
Spinal Cord	13,97	14,07	-0,71	12,52	12,70	-1,42	11,01	11,15	-1,26	9,28	9,42	-1,49	8,48	9,03	**-6,09**
Spleen	14,62	14,74	-0,81	12,99	13,12	-0,99	11,53	11,66	-1,11	10,43	10,58	-1,42	8,45	9,48	**-10,86**
Thymus	13,66	13,77	-0,80	12,72	12,88	-1,24	12,08	12,20	-0,98	10,10	10,23	-1,27	8,56	9,32	**-8,15**
Trachea	13,52	13,64	-0,88	13,70	13,89	-1,37	12,32	12,47	-1,20	10,04	10,21	-1,67	8,75	8,99	-2,67
Total Effective Dose(ICRP103) (mSv)	**13,92**	**13,92**		**12,28**	**12,28**		**11,70**	**11,70**		**10,31**	**10,31**		**8,82**	**8,82**	

Table 1: Organ doses calculated by VirtualDose and percentage of sex-dependent dose change for 5 pediatric phantom groups.

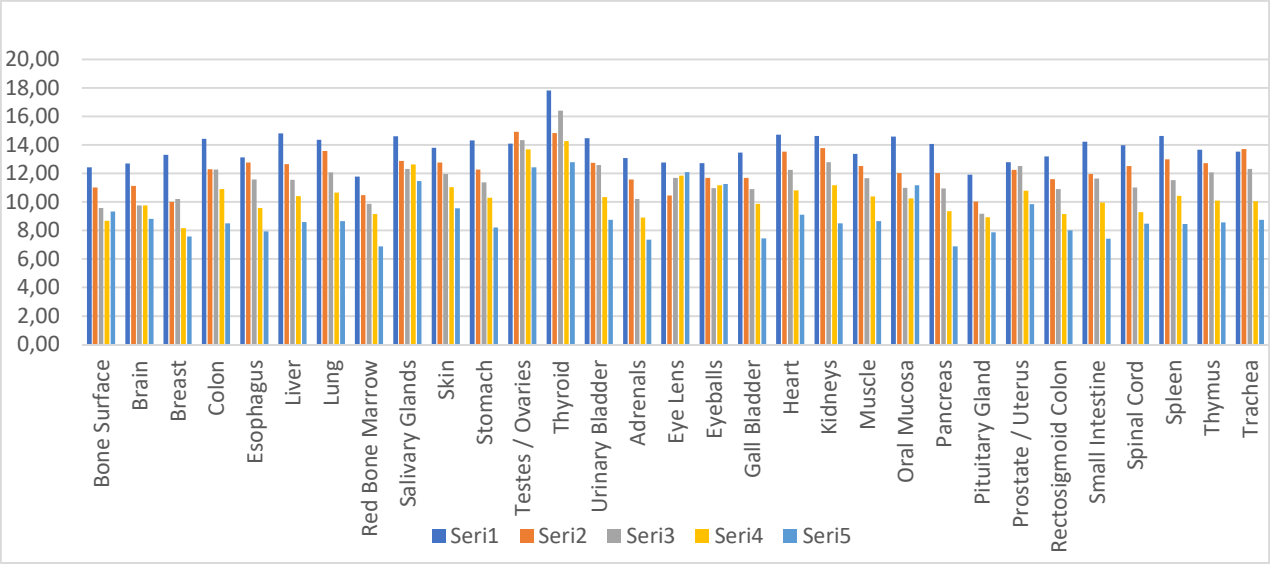

Figure 2: Organ Doses (mGy) of Male Pediatric Phantoms. (Blue, orange, grey, yellow and turquois colours shows the new born male, 1 year old male, 5 year old male, 10 year old male and 15 year old male phantom, respectively.)

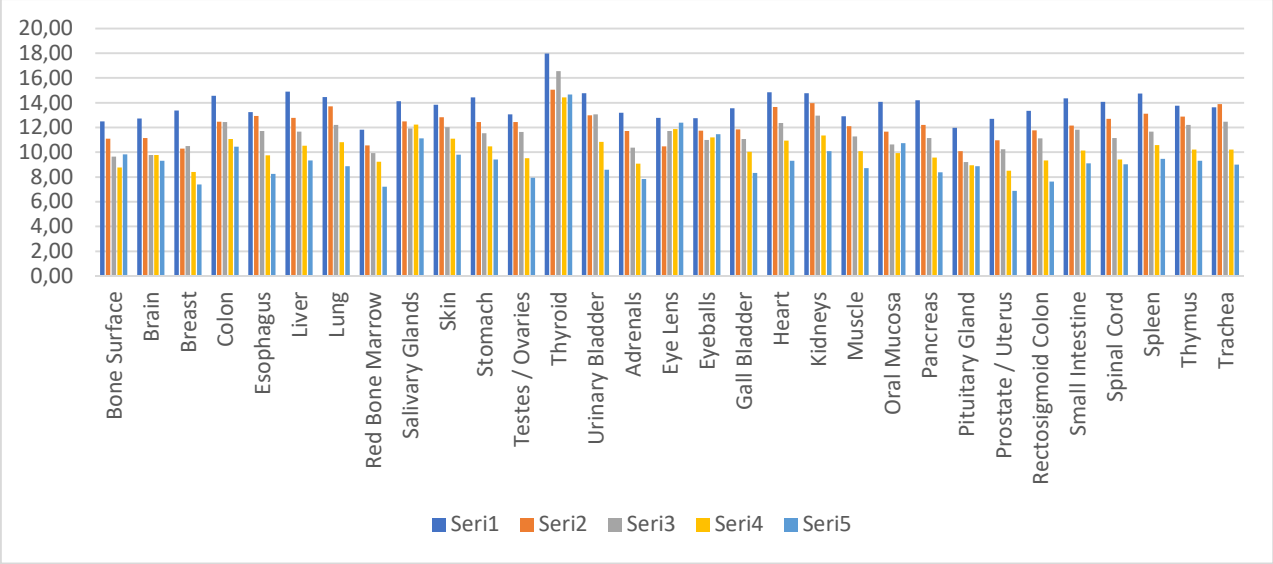

Figure 3: Organ Doses (mGy) of Female Pediatric Phantoms. (Blue, orange, grey, yellow and turquois colours shows the new born female, 1 year old female, 5 year old female, 10 year old female and 15 year old female phantom, respectively.)