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FULL PAPER

Effective radiation doses of CT examinations in Japan: a nationwide questionnaire-based study

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Objective: The aims of this study were to estimate the effective radiation doses from CT examinations of both adults and children in Japan and to study the impact of various scan parameters on the effective doses.

Methods: A questionnaire, which contained detailed questions on the CT scan parameters employed, was distributed to 3000 facilities throughout Japan. For each scanner protocol, the effective doses for head (non-helical and helical), chest and upper abdomen acquisitions were estimated using ImpACT CT Patient Dosimetry Calculator software v. 1.0.4 (St George's Hospital, London, UK).

Results: The mean effective doses for chest and abdominal examinations using 80–110 kV were significantly lower than those using 120 kV. However, there was no statistically significant difference in the mean effective doses for head scans between facilities employing 80–110 kV and 120 kV. In chest and abdominal examinations, the mean

effective doses using CT scanners from Western manufacturers [Siemens (Forchheim, Germany), Philips (Eindhoven, Netherlands) and GE Medical Systems (Milwaukee, WI)] were significantly lower than those of examinations using Japanese scanners [Hitachi (Kashiwa, Japan) and Toshiba (Otawara, Tochigi, Japan)], except for in paediatric chest examinations.

Conclusion: The mean effective doses for adult head, chest and abdominal CT examinations were 2.9, 7.7 and 10.0 mSv, respectively, whereas the corresponding mean effective doses for paediatric examinations were 2.6, 7.1 and 7.7 mSv, respectively.

Advances in knowledge: Facilities using CT scanners by Western manufacturers commonly adopt low-tube-voltage techniques, and low-tube-voltage CT may be useful for reducing the radiation doses to the patients, particularly for the body region.

INTRODUCTION

The use of CT in medicine is now firmly established and represents one of the most important radiological procedures performed worldwide. In particular, Japan has the highest estimated annual exposure frequency in the world.¹ A consequence of this wide adoption of CT in clinical practice is that the radiation dose from CT is now representing a high, and potentially continuously increasing, component of the total radiation dose received by patients and the general population.² CT exposes the body to relatively high amounts of radiation, which is especially concerning in paediatric patients because of their high sensitivity to ionizing radiation and longer expected life.^{3,4} A great deal of recent research and successful efforts have been directed at reducing unnecessary CT usage, as well as decreasing the CT dose, especially in children.⁵ Because paediatric CT scans should be obtained using lower doses

that still provide sufficient image quality for diagnostic purposes, it is important that radiologists, technologists and clinicians, and not just physicists understand CT dose levels in patients.

Various dose-reduction techniques such as tube current modulation and the use of an iterative reconstruction (IR) algorithm and low tube voltage technique are available in modern CT scanners.^{6–8} Accordingly, currently used scan parameters in Japan are different from those used several years ago.

In 2008, Tsushima et al⁹ surveyed the radiation doses of patients undergoing CT examinations in a single prefecture in Japan. This previous report indicated that there was a very large variation in the radiation exposure from CT among the hospitals surveyed. In order to reduce the

patient exposure and narrow this variation, diagnostic reference levels (DRLs) need to be established for optimization of the CT scan protocols. In 2015, Matsunaga et al¹⁰ suggested establishing the DRL using volume CT dose index (CTDI_{vol}), based on a nationally distributed questionnaire in Japan. Their report indicated that the CTDI_{vol} in Japan was higher than the previously reported DRLs from other countries for head, chest and abdominal CT. Several dose surveys in other countries have also been carried out to suggest not only the DRLs for the dosimetric quantities, such as CTDI_{vol} and dose-length product, but also to estimate the effective doses for specific scan regions.

The term effective dose reflects the dose quantity that is related to the probability of health detriment due to stochastic effects from exposure to low doses of ionizing radiation.¹¹ Furthermore, the effective dose can be of value for comparing the relative doses from different diagnostic procedures and for comparing the use of similar technologies and procedures in different hospitals and countries, as well as the use of different technologies for the same medical examination.³ However, there is no recent study (since 2008) investigating the representative effective dose in Japan, and updated typical effective doses in Japan hence need to be provided, especially in children. Furthermore, the impact of various scan parameters on the effective doses in Japan has not been previously described.

With this in mind, the aims of this study were to estimate the effective doses of CT examinations for both adults and children in Japan, obtained using a nationally distributed questionnaire, and to evaluate the impact of various scan parameters on the effective doses.

METHODS AND MATERIALS

The authors collected data concerning the scanner protocols for CT from facilities all over Japan during 3 months (May to July 2014). These collected scanner protocols were data from real patient examinations in the given time period, rather than pre-programmed protocols in the CT control computers. For each scanner protocol, the organ doses were calculated and the effective doses were obtained. The current study reports further analyses of data collected from a questionnaire-based survey previously reported by Matsunaga et al.¹⁰

National questionnaire survey

A questionnaire was sent to 3000 facilities throughout Japan. The distributed questionnaire contained detailed questions on the CT scan parameters employed, including the manufacturer, specific CT scanner model, tube voltage (kV), tube current (mA), rotation time, number of channels, beam width, pitch factor, reconstruction algorithm [IR or filtered back projection (FBP)] and displayed CTDI_{vol}. In case of modulated tube current, the mean of overall slices (mean tube current) was collected and used for analysis. The scanned anatomical regions were divided as follows: head (non-helical and helical), chest and upper abdomen (hereafter called “abdomen”), for both adults and 5-year-old children. The questionnaire sought to obtain data for scanning performed on standard (average-sized) patients to represent usual practice with non-contrast CT, which excludes specialized examinations.

Calculation of doses for each scanner protocol

The effective doses for the head (non-helical and helical), chest and abdomen acquisitions were estimated using ImPACT CT Patient Dosimetry Calculator software v. 1.0.4 (2011; St George's Hospital, London, UK).¹² This software makes use of the National Radiological Protection Board Monte Carlo dose data sets produced in report SR250 (Health Protection Agency Centre for Radiation, Chemical and Environmental Hazards, Didcot, UK). SR250 provides normalized organ dose data for irradiation of a mathematic phantom. The collected data concerning the CT scanner protocols, including the tube voltage and other data, from all over Japan were entered in a spreadsheet, and the effective doses for each CT protocol were calculated. The scan length on each anatomical region was the same (head: 140 mm, chest: 320 mm and abdomen: 330 mm). Of the major vendors in Japan, most modern CT scanners were provided by Toshiba (Otawara, Tochigi, Japan). We modified the ImPACT software to evaluate the effective doses with the following modern CT scanners: Toshiba Aquilion™ RXL, Toshiba Aquilion™ 64 and Toshiba Aquilion ONE™. This correction method was based on that used in the study by Kobayashi et al.¹³ If a CT scanner used in a facility in this study was not included in this software, the available data from the most similar CT scanner were used.

The estimate provided by the ImPACT software is for a standard adult computational human phantom; thus, the effective dose from paediatric CT examination was calculated according to age in this study. This calculation was performed based on the results from the study by Khursheed et al,¹⁴ who performed a series of Monte Carlo calculations on a range of phantoms corresponding to newborns; 1-, 5-, 10- and 15-year olds; and adult patients. From this result, the effective doses for 5-year-old children were calculated by multiplying the adult effective doses calculated in the spreadsheet by the conversion factor specified by Khursheed et al.¹⁴

Differences between two groups were evaluated using Student's or Welch's *t*-test following the *F*-test, which was used for analysis of variance. Statistical analyses were performed using Student's *t*-test when the two groups had equal variances, whereas Welch's *t*-test was used for unequal variances. All details on statistical tests and analyses are provided in Tables 1–7. A *p*-value of ≤0.05 was considered to be statistically significant.

RESULTS

National questionnaire survey

The questionnaire was sent to 3000 facilities; of these, responses were received from 656 (21.9%). Sufficient details on the CT scan parameters were provided by 460 of the 656 facilities (70.1%).

CT scan parameters

Nearly all CT manufactures were represented, with Toshiba machines being the most prevalent (48%). The percentages of CT systems included in the study manufactured by GE Medical Systems (Milwaukee, WI), Siemens (Forchheim, Germany), Philips (Eindhoven, Netherlands) and Hitachi (Kashiwa, Japan) were 26%, 18%, 5% and 3%, respectively.

Table 1. Comparisons of the distributions of the effective dose according to the tube voltage used in the CT examinations

Anatomical regions		Tube voltage (kV)	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	80–100	6	3.8	96	0.55 ^a
		120	841	2.8	65	
Head	Children (5 years)	100–110	38	2.3	67	0.22 ^b
		120	473	2.6	53	
Chest	Adults	100–110	5	5.6	34	0.05 ^a
		120	438	7.8	63	
Chest	Children (5 years)	80–110	47	4.3	108	< 0.05 ^a
		120	191	7.8	105	
Abdomen	Adults	100–110	5	5.9	37	0.05 ^b
		120	426	10.1	48	
Abdomen	Children (5 years)	80–110	44	3.9	64	< 0.05 ^a
		120	183	8.7	97	

^aStatistical analyses were performed using Welch's *t*-test.^bStatistical analyses were performed using Student's *t*-test.

The adult and paediatric protocols were reviewed with respect to the imaging parameters used for each anatomic region, including tube voltage, mean tube current, rotation time, tube current–time product, beam width, pitch factor and number of channels (Table 8). Figure 1 shows the utilization rates of tube voltage according to the different manufacturers for all protocols. The utilization rate of low voltage in CT scanners from Western manufactures (Siemens, Philips and GE Medical Systems) was higher than that in scanners from Japanese manufacturers (Hitachi and Toshiba). Overall, a tube voltage of

120 kV was the leading choice in all scans. The mean tube current values for the chest of both adults (200 mA) and children (128 mA) showed the lowest median values out of all anatomic regions. For the chest and abdominal scans of both adults and children, the rotation time was also quite low, with median values of 0.5 s. The highest median value (1.5 s) was found for adult head non-helical scans. Helical CT was used in most chest and abdominal scans (98%). The median pitch factor of the head scans (helical CT) was lower than that of the chest and abdominal scans. The median beam width was 32 mm in the

Table 2. Comparison of the distributions of the effective dose according to the tube current–time product used in the CT examinations

Anatomical regions		Tube current–time product (mAs)	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	<300	309	2.3	136	<0.05 ^a
		≥300	572	3.1	37	
Head	Children (5 years)	<180	258	1.9	37	<0.05 ^a
		≥180	260	3.3	49	
Chest	Adults	<120	223	5.2	46	<0.05 ^a
		≥120	234	10.1	54	
Chest	Children (5 years)	<60	116	3.3	52	<0.05 ^a
		≥60	123	10.6	88	
Abdomen	Adults	<150	186	6.9	51	<0.05 ^a
		≥150	259	12.2	39	
Abdomen	Children (5 years)	<75	107	4.2	48	<0.05 ^a
		≥75	122	10.9	88	

^aStatistical analyses were performed using Welch's *t*-test.

Table 3. Comparison of the distributions of the effective dose according to the beam width used in the CT examinations

Anatomical regions		Beam width (mm)	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	<10	394	2.9	71	0.58 ^a
		≥10	487	2.8	77	
Head	Children (5 years)	<16	252	2.7	53	0.11 ^a
		≥16	266	2.5	58	
Chest	Adults	<32	228	7.9	62	0.39 ^a
		≥32	229	7.5	65	
Chest	Children (5 years)	<32	105	8.1	121	0.08 ^b
		≥32	134	6.3	86	
Abdomen	Adults	<32	217	9.9	50	0.62 ^a
		≥32	228	10.1	51	
Abdomen	Children (5 years)	<32	98	7.6	58	0.76 ^b
		≥32	131	7.9	123	

^aStatistical analyses were performed using Welch's *t*-test.^bStatistical analyses were performed using Student's *t*-test.

chest and abdominal scans for both adults and children. The median beam width of head helical scan for adults and children (19.2 and 24 mm, respectively) was longer than those of the head non-helical scans (8 and 10 mm, respectively).

Organ dose and effective dose

Figure 2 shows the mean organ doses for adults. The highest mean organ doses for the adult head (all), head (non-helical), head (helical), chest and abdominal CT examinations were 65.6 (brain), 63.7 (brain), 67.6 (brain), 23.9 (thyroid) and 23.9 mGy (stomach), respectively.

The results of the statistical analysis for the effective doses are presented in Table 9. The effective dose data are presented in terms of the number of data points, mean, coefficient of variation (CV) and quartiles (25th percentile, median and 75th percentile). A large variation was observed in the effective dose among the different facilities. In particular, in the paediatric chest and abdominal CT scans, the CVs of the effective doses were 108% and 102%, respectively.

Table 1 shows the mean effective dose for each anatomical region, classified in terms of the tube voltage used: 80–110 vs

Table 4. Comparison of the distributions of the effective dose according to the pitch factor used in the CT examinations

Anatomical regions		Pitch factor	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	<1.000	431	3.0	94	0.11 ^a
		≥1.000	450	2.7	43	
Head	Children (5 years)	<1.000	233	2.6	53	0.69 ^b
		≥1.000	285	2.6	58	
Chest	Adults	<0.984	207	9.1	61	<0.05 ^a
		≥0.984	250	6.6	59	
Chest	Children (5 years)	<1.015	119	8.9	82	<0.05 ^a
		≥1.015	120	5.2	146	
Abdomen	Adults	<0.875	219	10.7	48	<0.05 ^b
		≥0.875	226	9.3	51	
Abdomen	Children (5 years)	<0.938	109	9.5	106	<0.05 ^a
		≥0.938	120	6.1	74	

^aStatistical analyses were performed using Welch's *t*-test.^bStatistical analyses were performed using Student's *t*-test.

Table 5. Comparison of the distributions of the effective dose according to the number of channels used in the CT examinations

Anatomical regions		Number of channels	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	1–40	246	2.6	42	< 0.05 ^a
		64–320	635	2.9	82	
Head	Children (5 years)	1–40	108	2.5	67	0.27 ^a
		64–320	410	2.6	53	
Chest	Adults	1–40	115	7.6	62	0.82 ^b
		64–320	342	7.7	64	
Chest	Children (5 years)	1–40	35	10.4	127	0.09 ^a
		64–320	204	6.5	94	
Abdomen	Adults	1–40	115	9.7	46	0.38 ^a
		64–320	330	10.1	51	
Abdomen	Children (5 years)	1–40	33	8.2	59	0.58 ^a
		64–320	196	7.7	108	

^aStatistical analyses were performed using Welch's *t*-test.^bStatistical analyses were performed using Student's *t*-test.

120 kV. The mean effective doses for the chest and abdominal examinations using 80–110 kV were significantly lower than those of examinations using 120 kV (*t*-test, $p \leq 0.05$). However, there was no statistically significant difference in the mean effective doses for head scans between facilities employing 80–110 and 120 kV.

Table 2 shows the mean effective dose for each anatomical region, classified in terms of the median tube current–time product. All mean effective doses using less than the median tube current–time product were significantly lower than those of examinations using a tube current–time product greater than or equal to the median (*t*-test, $p < 0.05$).

Table 6. Comparisons of the distributions of the effective dose according to the different CT scanner manufacturers

Anatomical regions		Manufacturer	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	Japanese	477	2.9	75	0.76 ^a
		Western	404	2.8	73	
Head	Children (5 years)	Japanese	290	2.4	45	< 0.05 ^b
		Western	228	2.8	64	
Chest	Adults	Japanese	220	8.9	59	< 0.05 ^b
		Western	237	6.6	64	
Chest	Children (5 years)	Japanese	113	7.8	87	0.16 ^b
		Western	126	6.4	130	
Abdomen	Adults	Japanese	209	11.3	43	< 0.05 ^a
		Western	236	8.8	55	
Abdomen	Children (5 years)	Japanese	106	9.6	106	< 0.05 ^b
		Western	123	6.2	76	

Japanese manufacturers: Hitachi (Kashiwa, Japan) and Toshiba (Otawara, Tochigi, Japan).

Western manufacturers: Siemens (Forchheim, Germany), Philips (Eindhoven, Netherlands) and GE Medical Systems (Milwaukee, WI).

^aStatistical analyses were performed using Welch's *t*-test.^bStatistical analyses were performed using Student's *t*-test.

Table 7. Comparisons of the distributions of the effective dose according to the different CT scanner manufacturers

Anatomical regions		Reconstruction algorithm	Effective dose			<i>p</i> -value
			<i>n</i>	Mean (mSv)	Coefficient of variation (%)	
Head	Adults	FBP	670	2.9	69	0.69 ^a
		IR	131	2.8	112	
Head	Children (5 years)	FBP	404	2.7	55	0.32 ^b
		IR	83	2.5	57	
Chest	Adults	FBP	284	7.8	61	0.60 ^a
		IR	149	7.6	70	
Chest	Children (5 years)	FBP	145	7.5	109	0.17 ^a
		IR	83	6.2	109	
Abdomen	Adults	FBP	277	10.2	49	0.14 ^b
		IR	143	9.5	53	
Abdomen	Children (5 years)	FBP	134	8.0	65	0.49 ^a
		IR	83	7.1	156	

FBP, filtered back projection; IR, iterative reconstruction.

^aStatistical analyses were performed using Welch's *t*-test.

^bStatistical analyses were performed using Student's *t*-test.

Table 3 shows the mean effective dose for each anatomical region, classified in terms of the median beam width. There was no statistically significant difference in any of the mean effective doses between facilities employing less *vs* greater than or equal to the median beam width.

Table 4 shows the mean effective dose for each anatomical region, classified in terms of the median pitch factor. The mean

effective doses for the chest and abdominal examinations using a pitch factor greater than or equal to the median pitch factor were significantly lower than those of examinations using a pitch factor lower than the median value (*t*-test, $p < 0.05$).

Table 5 shows the mean effective dose for each anatomical region, classified in terms of the number of channels used: 1–40 *vs* 64–320 channels. There was no statistically significant

Table 8. Scan parameters of the CT protocols for adults and children in Japan

Anatomical regions		Tube voltage (kV)	Mean tube current (mA)	Rotation time (s)	Tube current–time product (mAs)	Beam width (mm)	Pitch factor	Number of channels
Head	Adults	120 (3)	280 (37)	1.0 (42)	300 (53)	10 (110)	1.000 (24)	64 (105)
	Children (5 years)	120 (4)	200 (47)	1.0 (44)	180 (67)	16 (119)	1.000 (21)	64 (100)
Non-helical	Adults	120 (2)	250 (37)	1.5 (35)	358 (54)	8 (141)	1.000 (–)	64 (106)
	Children (5 years)	120 (4)	200 (50)	1.0 (43)	200 (68)	10 (146)	1.000 (–)	64 (104)
Helical	Adults	120 (3)	300 (35)	1.0 (32)	270 (40)	19.2 (80)	0.641 (26)	64 (102)
	Children (5 years)	120 (4)	200 (44)	0.75 (35)	150 (55)	24 (81)	0.656 (26)	64 (95)
Chest	Adults	120 (2)	200 (53)	0.5 (27)	120 (52)	32 (77)	0.984 (54)	64 (102)
	Children (5 years)	120 (8)	128 (73)	0.5 (39)	60 (91)	32 (84)	1.015 (37)	64 (92)
Abdomen	Adults	120 (2)	280 (42)	0.5 (25)	150 (42)	32 (77)	0.875 (39)	64 (103)
	Children (5 years)	120 (8)	150 (69)	0.5 (26)	75 (85)	32 (84)	0.938 (38)	64 (91)

The data are presented as the median value (coefficient of variation, %).

Figure 1. Utilization rates of different tube voltages for each manufacturer. Location of manufacturers: Hitachi—Kashiwa, Chiba, Japan; Toshiba—Otawara, Tochigi, Japan; Siemens—Forchheim, Germany; Philips—Eindhoven, Netherlands; and GE Medical Systems—Milwaukee, WI.

difference in the mean effective doses between facilities employing 1–40 vs 64–320 channels, except for in adult head examinations.

Table 6 shows the mean effective doses for each anatomical region, classified according to the type of CT manufacturer used: Japanese (Hitachi and Toshiba) vs Western manufacturers (Siemens, Philips and GE Medical Systems). In the head examinations, there was no statistically significant difference in the mean effective dose for adults between facilities employing different manufactures, although the mean effective doses for children using CT scanners by Japanese manufacturers were barely, but significantly, lower than those of examinations using CT scanners by Western manufacturers (t -test, $p < 0.05$). In the chest and abdominal examinations, the mean effective doses using Western-manufactured CT scanners were significantly lower than those using Japanese scanners (t -test, $p < 0.05$), except for in paediatric chest examinations.

Table 7 shows the mean effective doses for each anatomical region, classified according to the type of reconstruction algorithm used: FBP vs IR. There was no statistically significant difference in any of the mean effective doses between facilities using different reconstruction algorithms.

Finally, the mean effective doses for each anatomical location are summarized in Table 10, along with comparable data reported from other countries.^{9,15–20}

DISCUSSION

In this study, the fundamental CT scan parameters (tube voltage, mean tube current, rotation time, tube current–time product, beam width, pitch factor and number of channels) used in Japanese facilities were presented and analysed. The tube voltage and number of channels were similar to those of previously published reports.^{21–23} However, the tube current–time product (mAs) for the adult head in this study was higher than the values in previous studies.^{21,23} Moreover, the pitch factors of each anatomical region in this study were lower than those reported in Switzerland,²¹ and these parameters have been shown to have a major influence on the radiation dose.²⁴ Furthermore, there are some previous reports^{25,26} that a high pitch typically resolves the issue of overlapping helical sections. Moreover, this study also showed that the tube current product and pitch factor have a major influence on the effective dose, suggesting that the CT parameters must be selected carefully to ensure that the diagnostic benefits outweigh the potential radiation risks.

Recent research studies have recommended the use of lower tube voltages (from 120 to 80 kV) to aid with dose optimization, especially for smaller-size patients and during angiographic studies.^{7,23} In one previous study focusing on paediatric head examinations, the CTDI_{vol} using low tube voltage was significantly lower than that using 120 kV.¹⁰ However, the effective dose using low tube voltage was not significantly lower than that using 120 kV in the present study. There are only two organs for which the tissue-weighting factor has been specified within the scan range in head CT examinations, namely the brain and salivary glands, and the values of these tissue weighting factors are both 0.01. Hence, if the low tube voltage technique was used to reduce the organ doses to the brain and salivary gland, it would not reduce the effective doses of all specified organ doses of the body. Therefore, for head examinations, the low tube voltage technique may not contribute to radiation risk reduction. On the other hand, for chest examinations, principally, tissue weighting factors are available for the lung (0.12), breast (0.12), oesophagus (0.04) and thyroid (0.04) within the scan range. Furthermore, for abdominal examinations, principally, tissue weighting factors are available for the stomach (0.12), colon (0.12) and liver (0.04) within the scan range. As there are many radiosensitive organs and tissues within the chest and abdominal scan range, the chest and abdominal examinations of both adults and children upon using the low tube voltage technique resulted in significantly lower effective doses than

Figure 2. Mean organ doses for adult CT examinations.

Table 9. Distributions of the effective dose for the CT examinations

Anatomical regions		Effective dose					
		<i>n</i>	Mean	Coefficient of variation (%)	25th percentile	Median	75th percentile
Head	Adults	881	2.9	74	2.0	2.6	3.2
	Children (5 years)	518	2.6	56	1.7	2.4	3.1
Non-helical	Adults	460	2.8	42	2.0	2.6	3.2
	Children (5 years)	282	2.6	57	1.7	2.2	3.1
Helical	Adults	421	2.9	96	2.1	2.6	3.2
	Children (5 years)	236	2.6	54	1.6	2.4	3.1
Chest	Adults	457	7.7	63	4.5	6.9	9.5
	Children (5 years)	239	7.1	108	3.0	5.1	8.6
Abdomen	Adults	445	10.0	50	6.4	9.2	13.0
	Children (5 years)	229	7.7	102	4.0	6.2	9.8

examinations that used 120 kV (Table 1). Notably, this study indicated that a lower voltage was associated with a lower dose. In some cases with small children, lower voltage worked well, whereas in other cases, especially with larger children, this approach might not be effective.

For chest and abdominal examinations, the mean effective doses using scanners from Western manufacturers were significantly lower than those from Japanese scanners (*t*-test, $p < 0.05$), except for in the paediatric chest examinations. Because the utilization rate of low voltage in Western-manufactured CT scanners was higher than that in Japanese-manufactured

scanners (Figure 1), we suspect that this was the reason for the mean effective doses when using CT scanners by Western manufacturers being significantly lower than those of Japanese scanners.

Matsunaga *et al*¹⁰ reported that the CTDI_{vol} using IR was significantly lower than that using FBP in adult head, chest and abdominal examinations and in paediatric abdominal examinations. However, in this study, there was no statistically significant difference in any of the mean effective doses between facilities according to the different reconstruction algorithms used. Hence, the reconstruction algorithm used does not appear

Table 10. Mean effective doses estimated in this study for each anatomical region compared with the mean effective doses reported in other countries

Country		UK	Healthcare level I	Japan	Australia	Syria	Korea	USA	This study
Year		2003	2008	2008	2008	2009	2013	2013	2014
Head	Adults	1.5	2.4	2.6		1.2	1.7	2.0	2.9
	Children (5 years)	1.5			1.2	1.2		2.0	2.6
Chest	Adults	5.1	7.8	5.4		5.4	9.9	9.0	7.7
	Children (5 years)	3.6			5.6	4.3		3.0	7.1
Abdomen	Adults	5.3	12.4	5.7		7.7	12.6	10.0	10.0
	Children (5 years)				6.3	6.6		4.0	7.7

In the USA, effective doses are median values.

Paediatric age in Syria and USA is <15 years.

to have an actual impact on the effective dose when taking the average effects of the whole body into consideration.

The mean effective doses of each anatomical region in this study were within the values indicated by Mettler et al;²⁷ however, our data were relatively high compared with the values reported in other countries^{9,15–20} (Table 10). In particular, for head CT in Japan, the effective dose values were noticeably higher than those in other countries.^{9,15–20} Although the main point of CT is that the clinical benefits should outweigh the small absolute risks, the radiation doses from CT scans ought to be kept as low as possible. In this study, we found that the tube current–time products (mAs) in Japan were higher than those in other countries^{21,23} and that they impact on the effective dose. Each facility should reconsider the CT parameters for head examinations using the results of this study as a means to optimize the diagnostic radiation dose. Moreover, Fukushima et al²⁸ suggested that education on using a dedicated scan protocol for paediatric head CT is needed for radiographers in Japan, as currently, the examination protocol for adult head CT is adopted for paediatric head CT as well, with no particular consideration, in many facilities. However, it should be noted that we calculated the effective doses using the International Commission on Radiological Protection (ICRP) publication 103 weighting factors³ in the present study, whereas the studies from the UK¹⁵ and Syria¹⁸ were calculated using the ICRP 60 weighting factors.²⁹ Huda et al³⁰ reported that the use of ICRP 103 weighting factors increased the effective doses in the head by approximately 11%.

The accuracy of the effective dose calculation relies on the calculation method used. In this study, the mean tube currents

were entered into an ImPACT spreadsheet, and the effective dose values were calculated. Tube current modulation has been widely applied in all types of protocols, except those for the whole head and in calcium score acquisitions.^{22,28} Kawaguchi et al³¹ reported that the differences between the effective doses estimated using the mean tube current values and those estimated using longitudinal modulated tube current values were small, suggesting that the effective dose was estimated with sufficient accuracy in the present study.

CONCLUSION

Our results indicate that the mean effective doses for adult head, chest and abdominal CT examinations are 2.9, 7.7 and 10.0 mSv, respectively, whereas the corresponding mean effective doses for paediatric CT examinations are 2.6, 7.1 and 7.7 mSv, respectively. The estimated effective doses for head examinations in this study were higher than those reported in other countries.

This study also showed that the tube current product and pitch factor are major influences on the effective dose. Hence, the CT parameters should be selected carefully to ensure that the patient dose is kept minimal, consistent with the clinical purpose.

Facilities using CT scanners from Western manufacturers more frequently use low tube voltage techniques, thus reducing patient radiation doses, particularly for the body region.

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