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Assessment of Patient Dose from CT Examinations in selected Hospitals in Abuja and Environs

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ABSTRACT
The computed tomography scanners were assessed using polymethyl methacrylate(PTW chamber type 30009, Freiburg, Germany) computed tomography phantoms, dose index for head and body were estimated(CTDIw) in this study and comparison made with corresponding console displayed doses(CTDIvol) together with their Dose Length Product(DLP). The study was performed on a Philips and Siemens Somatom Emotion computed tomography (CT) scanner systems. Dose measurements were made using 100 mm long pencil ion chamber connected to an electrometer with cylindrical CT dosimetry phantoms; head phantom (16-cm in diameter) and body phantom (32-cm in diameter) using scan technique of 120kVp,90kVp,110kVp and 130kVp with slice thickness of 3mm,5mm, 6mm and current-time products of 300mAs,200mAs,250mAs and 80 mAs were selected for charges of head and body phantoms for Philips CT simulator and Siemens 6 slice Somatom Emotion for the scan in axial mode, with a computed tomography dose index ($CTDI_{vol}$) console display of 19.03mGy and 10.8mGy at periphery and centre of the phantom and the estimated dose ($CTDI_w$) measurements of 19.13mGy and 12.12mGy for head and body phantom examination respectively for Philips CT simulator and computed tomography dose index ($CTDI_{vol}$) console display of 10.2mGy and 2.15mGy at periphery and centre of the phantom and the estimated dose ($CTDI_w$) measurements of 10.33mGy and 4.31mGy for head and body phantom examination for Siemens 6 slice Somatom Emotion respectively. Also, average DLP for head and body were recorded as 836mGy.cm and 335mGy.cm for Philips CT and 395 mGy.cm, 12.17 mGy.cm for head and body for Siemens 6 slice Somatom Emotion. With estimated doses for head of Philips CT simulator and Siemens 6 slice Somatom Emotion tomography deviations of 161.37%, 187.51 %, 119.55%, 384.03%, 432.43% and 306.58% and estimated displayed doses for body deviation of 106.27%,89.77%,9.24%,480.05%,433.64% and 155.22% for Philips CT simulator and Siemens 6 slice Somatom Emotion tomography compared with Shrimpton et al 1991,Breiki et al 2006 and Hidajat 1998 which were within the acceptable limits by International Diagnostic Reference Levels.

***KEYWORDS**: Patient dose, Computed tomography, Dose index, Dose Length Product, Quality control*

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I. INTRODUCTION

Computed tomography (CT) scan has emerged as a powerful tool for effective radiological diagnosis in a variety of diseases since it allows high-resolution three-dimensional images to be acquired in a short period of time. Computed tomography is very important in patient diagnoses and has been used in a variety of medical imaging procedures because of its unique ability to offer clear images of bone, muscle, blood vessels, and different types of tissue [1]. Where other imaging techniques are much more limited in the types of images they can provide. It can also be used to plan certain surgeries, guide biopsies, measure bone mineral density, detect injuries to internal organs, and has proven to be a valuable tool for the diagnosis and treatment of many musculoskeletal disorders. Computed tomography imaging is even used for the diagnosis and treatment of certain vascular diseases. Probably the most important aspect of computed tomography however, is its role in cancer treatment. It allows physicians to accurately detect and locate different types of cancers and plays an important part in radiation treatment planning process. Computed tomography is also used in combination with positron emission tomography systems, creating a hybrid technology to maximize patient imaging techniques. The importance of computed tomography technology is without doubt a vital aspect for the diagnosis and treatment of patients, and with new advancements in computed tomography continuing to develop; patient care will continue improving [1].Computed tomography has being recognized as administering high radiation dose to the patient, when compared to other diagnostic imaging modalities and this has raised concern over patient radiation doses[2].The expanding use of computed tomography (CT) worldwide has resulted in this modality becoming the major source of the population in exposure to X-rays, contributing to 40% of the resulting collective dose in the UK in 1997[3]. Indeed, data from 1991 to 1996 show that globally, CT was responsible for 34% of the annual collective dose from medical exposures, following new biological information on harm due to radiation and modified risk estimates, from recommendations of the International Commission on Radiological Protection (ICRP) revised in publication 60, [4] ,[5] and new quantities and concepts were introduced. However, computed tomography procedures consist of exposures from multiple rotation of the radiation source and the total dose to the irradiated volume is the accumulated dose from the adjacent scans [6]. It is therefore pertinent to carry out a quality control on computed tomography to provide adequate confidence that a diagnostic facility will produce consistently high quality images with minimum exposure of the patients and personnel.

II. MATERIALS AND METHODS

The PTW pencil ion chamber model type 30009, Freiburg Germany was connected to an electrometer with a cable placed in the central hole of the head phantom (PMMA cylindrical acrylic head PTW chamber type 30009, Freiburg, Germany). Two horizontal lasers in the CT room were adjusted to be visible on the mid-line of the ion chamber and a vertical laser was also set to be visible at the middle of the phantom. This was done to properly align the phantom and the chamber on the couch. The cable connecting the ion chamber and the electrometer was tapped on the couch to prevent dislodging of the ion chamber from the phantom. The CT room was locked for radiation protection reasons. A topogram of the head phantom was taken and the required volume was selected. Parameters such as tube potential, tube current and slice thickness were selected while other parameters were kept constant for the examination. A tube potential of 120kVp, 90kVp, 110kVp and 130kVp with slice thickness of 3mm, 5mm and 6mm and current-time products of 300mAs, 200mAs, 250mAs and 80 mAs were selected for charges of head and body phantoms for Philips CT simulator and Siemens 6 slice Somatom Emotion for the scan in axial mode. Computed tomography dose index quality assurance measurements were taken three times at each point (one in centre and four points on peripheral of a phantom) at the periphery sites of 12, 3, 6 and 9 O'clock as well which was also represented as P1, P2, P3, P4 and C respectively to gain better statistics. The procedure was repeated with different values of tube current-time product but with all other parameters constant. Different values were chosen to provide range of data that can be analyzed to check the validity of the dose measuring techniques. After the head phantom measurements were done, the procedure was repeated for the CT body phantom. Charges were measured and recorded in each scan. The charges measured and recorded from the electrometer in charge mode, corrected for temperature and pressure using barometer (Pressure indicator D PI 800) and Thermometer (Digital, China) for pressure and temperature correction to estimate computed tomography dose index to that of computed tomography dose index console display values and compare results obtained using some mathematical expressions:

$$k_{TP} = \frac{(273.2+T)P_0}{(273.2+T_0)P} \quad (1)$$

$$C_{PMMA,100,c} = \frac{10}{NT} M_c N_{PKL,Q_o} k_Q k_{TP} \quad (2)$$

$$C_{PMMA,100,P} = \frac{10}{NT} M_P N_{PKL,Q_o} k_Q k_{TP} \quad (3)$$

$$C_w = \frac{1}{3}(C_{PMMA,100,c} + 2C_{PMMA,100,P}) \quad (4)$$

Where:
T is nominal slice thickness
N is number of tomographic slices simultaneously exposed (so that the nominal width of the irradiating beam is NT)
k_{TP} is the correction factor for temperature and pressure
T is temperature measured in the study room
P is the pressure in the room
T_0 is temperature at reference condition
P_0 is air pressure at reference condition
N_{PKL}, Q_o is the dosimeter calibration coefficient in terms of the air kerma length product
k_Q is the factor which corrects for differences in the response of the dosimeter at the calibration quality and at the measurement quality Q of the clinical X-ray beam.
M_c and M_p is the mean dosimeter readings from the central chamber bore of the standard phantom and the mean dosimeter readings in the peripheral chamber bores.

III. DISCUSSION

Results for the head and body phantom measurements are presented in Tables 1 and 2 respectively. Charge readings in tables are for single tube rotation for single slice. Scan protocols for the head phantom study were set at head scan CT techniques of 120 kVp and 300 mAs to mimic clinical conditions for an adult patient. The estimated dose ($CTDI_w$) from measurements taken in this study was 19.13 mGy and the corresponding console displayed dose (CTDIvol) was 19.03 mGy. A deviation of 0.53% was realized between the estimated and console displayed doses. Estimated dose from measurements taken in the body phantom was 12.12 mGy, and this was at abdominal scan CT techniques of 90 kVp and 200 mAs. The console displayed dose for the body examination was 10.8 mGy, hence deviation of 12.12% was realized between the estimated and console doses for Philips CT.

For Siemens Somatom Emotion CT in Tables 3 and 4, scan protocols for the head phantom at 110kVp,250mAs,gave an estimated dose of 10.33mGy with corresponding console displayed dose of 10.2 mGy and at CT technique of 130kVp and 80mAs,the estimated dose of 4.31mGy and console display of 2.15 mGy for body was achieved. A deviation of 1.27% and 100.47% was realized between the estimated and console displayed doses. There were deviations in estimated and console display on the CT because; the $CTDI_w$ approximates the average dose over a single slice in order to account for variation in dose values between the centre and the periphery of the slice. Whereas, the $CTDI_{vol}$ determine the radiation dose in one tube rotation in multidetector scanners and allows for variations in exposure.

From the results obtained from Tables 1 to 4, the estimated $CTDI_w$ values for the CT head and body phantoms from this study can be compared with study by [7]. In their CT head and body phantom study, they compared $CTDI_{vol}$ from Ion Chamber technique with that displayed on the CT system console. At scan protocol of 120kVp and 150mAs, they reported dose measurements of 44.3 mGy from the Ion Chamber technique with a corresponding console displayed value of 42.4 mGy for the head phantom examination at $CTDI_{vol}$ deviation of 4.5%. When scan protocol was set at 120 kVp and 100 mAs for pelvic examination in their study, the dose measured was 20.08 mGy against a console displayed value of 19.49 mGy which yielded a deviation of 3.1%.

The measured doses for the head phantom examination can also be compared with a study by [8] for adult patients undergoing CT examination in six CT facilities. They reported a diagnostic reference levels ($CTDI_{vol}$) of 39.0 – 58.6 mGy for routine head scans and 14.9 - 24.2 mGy for pelvic scans in their study in Ghana. $CTDI_{vol}$ for tube current-time products from 140 – 200 mAs and fixed tube potential of 130 kVp for this study is below the diagnostic reference level reported by Inkoom et al., in 2014 but tube current-time products from 220 – 300 mAs for the head phantom examination with both techniques in this study can satisfactorily be compared with the diagnostic reference levels reported in [8].

A comparison of average measured $CTDI_w$ in this study with other countries is presented in Table 5. The head phantom dose of 19.13 mGy for Philips CT was observed to be lesser in comparison with doses for other countries by 161.37%, 187.51%, 119.55% and 384.03%, 432.43%, 306.58%, for Siemens CT head phantom dose of 10.33 mGy for [9], [10] and [11] presented in Table 5 and figures 1 and 2.The estimated doses for body phantom for both Philips CT and Siemens CT (with abdominal exposure technique factors) in this study was lesser in comparison for [9], [10] but was slightly higher than [11] for Philips CT at 9.24%.Studies show that for systems with theoretically estimated console doses, accuracy of dose measurement may exceed ±10% [12].

The mean DLP values acquired for head and abdomen, were in the range of 313.3-1341.33 mGy.cm and 87.07-592.1mGy.cm which gave average DLP of 836 mGy.cm for head and average DLP of 336 mGy.cm for body Tables 6 and 7 for Philips CT. Similarly, the mean DLP values acquired for head and abdomen, for Siemens had average DLP of 395 mGy.cm for head and average DLP of 12 mGy.cm for body as shown in Tables 8 and 9. The DLP values obtained for head CT in this work (836 mGy.cm and 395 mGy.cm) were lower than the values of European Diagnostic Reference Levels (1050 mGy.cm) but the DLP value for Philips CT in the study was higher than those of [13], [14] , [15].DLP for abdominal CT (336 mGy.cm and 12 mGy.cm) is comparable to the values reported by values of European Diagnostic Reference Levels (800 mGy.cm) but higher than [14] (Table10 and figures 3 and 4). These differences can be due to difference in exposure factors, scanner type, and technology.

IV. CONCLUSION

The results of the study show that the Patient dose in general, $CTDI_w$ and DLP values in particular are greatly affected by technical parameters applied, technicians experience and CT machine type and technology but the results of this study conforms to standards by regulatory bodies.

V. EXPERIMENTAL RESULTS

***** slice thickness = 5mm and Number of slices = 9*

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT $CTDI_{vol}$ console(mGy)	Estimated $CTDI_w$(mGy)
120	300	P_1	954.0	957.1	958.0	0.954	0.9571	0.958	0.956	19.03	19.13
120	300	P_2	1279	1280	1281	1.279	1.280	1.281	1.280	19.03	19.13
120	300	P_3	1885.0	1886.0	1887.0	1.885	1.886	1.887	1.886	19.03	19.13
120	300	P_4	988.1	987.0	986.0	0.9881	0.987	0.986	0.987	19.03	19.13
120	300	C	498.1	499.0	497.0	0.4981	0.499	0.497	0.498	19.03	19.13

Table 1 Charges recorded for CT head Phantom Examination from PTW Electrometer for Philips CT Simulator

***** slice thickness = 3mm and Number of slices = 8*

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT $CTDI_{vol}$ console(mGy)	Estimated $CTDI_w$(mGy)
90	200	P_1	405.7	403.7	392.0	0.4037	0.4037	0.392	0.400	10.8	12.12
90	200	P_2	378.4	375.4	372.5	0.3754	0.3754	0.3725	0.375	10.8	12.12
90	200	P_3	333.3	316.7	328.5	0.3167	0.3167	0.3285	0.326	10.8	12.12
90	200	P_4	386.2	383.3	375.4	0.3754	0.3754	0.3754	0.382	10.8	12.12
90	200	C	284.5	272.7	312.8	0.3128	0.3128	0.3128	0.290	10.8	12.12

Table 2 Charges recorded for CT body Phantom Examination from PTW Electrometer for Philips CT Simulator

***** slice thickness = 6mm and Number of slices = 18*

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT $CTDI_{vol}$ console(mGy)	Estimated $CTDI_w$(mGy)
110	250	P_1	1616.1	2845.30	1000.1	1.6161	2.8453	1.0001	1.8205	10.2	10.33
110	250	P_2	1860.24	1790.16	1000.20	1.8602	1.7902	1.0002	1.5502	10.2	10.33
110	250	P_3	1000.0	1020	1340	1.000	1.020	1.340	1.120	10.2	10.33
110	250	P_4	1356.4	1704.6	1200.5	1.3564	1.7046	1.2005	1.4205	10.2	10.33
110	250	C	1201.5	1003.0	800.0	1.2015	1.003	0.800	1.0015	10.2	10.33

Table 3 Charges recorded for CT head Phantom Examination from PTW Electrometer for Siemens 6 Slice CT

***** slice thickness = 5mm and Number of slices = 7*

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT $CTDI_{vol}$ console(mGy)	Estimated $CTDI_w$(mGy)
130	80	P_1	150.34	175.61	125.95	0.1503	0.1756	0.1259	0.1506	2.15	4.31
130	80	P_2	270.78	150.00	120.78	0.2708	0.1500	0.1208	0.1805	2.15	4.31
130	80	P_3	249.78	249.94	250.59	0.2498	0.2499	0.2506	0.2501	2.15	4.31
130	80	P_4	290.34	272.88	128.28	0.2903	0.2729	0.1283	0.2305	2.15	4.31
130	80	C	111.20	120.20	159.35	0.1112	0.1202	0.1594	0.1303	2.15	4.31

Table 4 Charges recorded for CT body Phantom Examination from PTW Electrometer for Siemens 6 CT

Examination	[9]	[10]	[11]	This study	
				Philips	Siemens
Head	50	55	42	19.13	10.33
Abdomen	25	23	11	12.12	4.31

Table 5 Comparison of average measured $CTDI_W$ in this study with other studies

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT CTDI$_{vol}$ console(mGy)	Mean DLP(m Gy.cm)
120	300	P_1	954.0	957.1	958.0	0.954	0.9571	0.958	0.956	19.03	313.3
120	300	P_2	1279	1280	1281	1.279	1.280	1.281	1.280	19.03	591.33
120	300	P_3	1885.0	1886.0	1887.0	1.885	1.886	1.887	1.886	19.03	841.3
120	300	P_4	988.1	987.0	986.0	0.9881	0.987	0.986	0.987	19.03	1091.3
120	300	C	498.1	499.0	497.0	0.4981	0.499	0.497	0.498	19.03	1341.33

Table 6 Mean DLP for CT Head Phantom Examination from PTW Electrometer for Philips CT Simulator

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT CTDI$_{vol}$ console (mGy)	Mean DLP(m Gy.cm)
90	200	P	405.7	403.7	392.0	0.4037	0.4037	0.392	0.400	10.8	209.93
90	200	P_2	378.4	375.4	372.5	0.3754	0.3754	0.3725	0.375	10.8	332.77
90	200	P_3	333.3	316.7	328.5	0.3167	0.3167	0.3285	0.326	10.8	455.57
90	200	P_4	386.2	383.3	375.4	0.3754	0.3754	0.3754	0.382	10.8	592.1
90	200	C	284.5	272.7	312.8	0.3128	0.3128	0.3128	0.290	10.8	87.07

Table 7 Mean DLP for CT body Phantom Examination from PTW Electrometer for Philips CT Simulator

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT CTDI$_{vol}$ console(m Gy)	Mean DLP(mGy.cm)
110	250	P_1	1616.1	2845.30	1000.1	1.6161	2.8453	1.0001	1.8205	10.2	395.31
110	250	P_2	1860.24	1790.16	1000.20	1.8602	1.7902	1.0002	1.5502	10.2	395.31
110	250	P_3	1000.0	1020	1340	1.000	1.020	1.340	1.120	10.2	395.31
110	250	P_4	1356.4	1704.6	1200.5	1.3564	1.7046	1.2005	1.4205	10.2	395.31
110	250	C	1201.5	1003.0	800.0	1.2015	1.003	0.800	1.0015	10.2	395.31

Table 8 Mean DLP for CT Head Phantom Examination from PTW Electrometer for Siemens 6 Slice CT

Fixed kVp	mAs	Exams	Recorded Charges (pc)			Recorded charges (nc)			Mean	CT CTDI$_{vol}$ console(mG y)	Mean DLP(mGy. cm)
130	80	P_1	150.34	175.61	125.95	0.1503	0.1756	0.1259	0.1506	2.15	12.17
130	80	P_2	270.78	150.00	120.78	0.2708	0.1500	0.1208	0.1805	2.15	12.17
130	80	P_3	249.78	249.94	250.59	0.2498	0.2499	0.2506	0.2501	2.15	12.17
130	80	P_4	290.34	272.88	128.28	0.2903	0.2729	0.1283	0.2305	2.15	12.17
130	80	C	111.20	120.20	159.35	0.1112	0.1202	0.1594	0.1303	2.15	12.17

Table 9 Mean DLP for CT body Phantom Examination from PTW Electrometer for Siemens 6 Slice CT

Examination	[13]	[14]	[15]	[16]	This study	
					Philips	Siemens
Head	740	587	787	1050	836	395
Abdomen	-	247	-	800	336	12

Table 10 Comparison of DLP values listed for some CT scanners with other studies

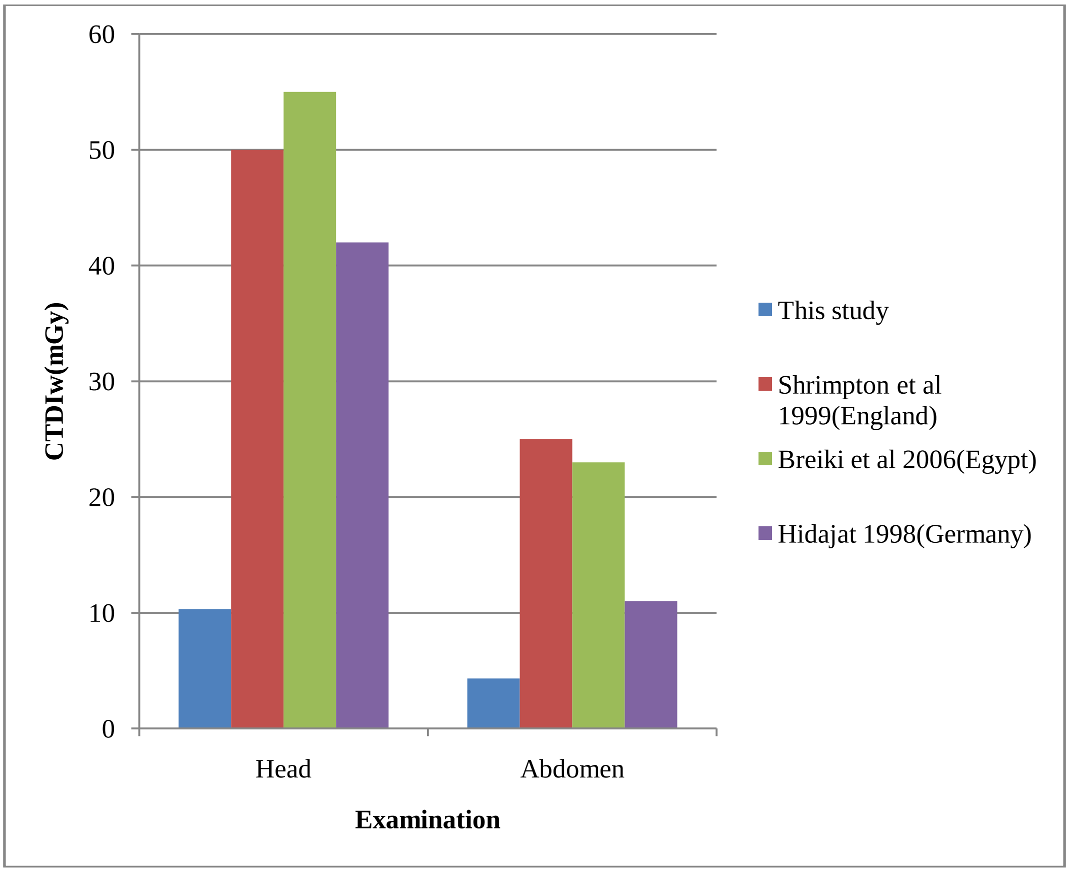

Figure 1: A bar chart showing a comparison of estimated $CTDI_w$ with international Diagnostic reference levels for Philips CT

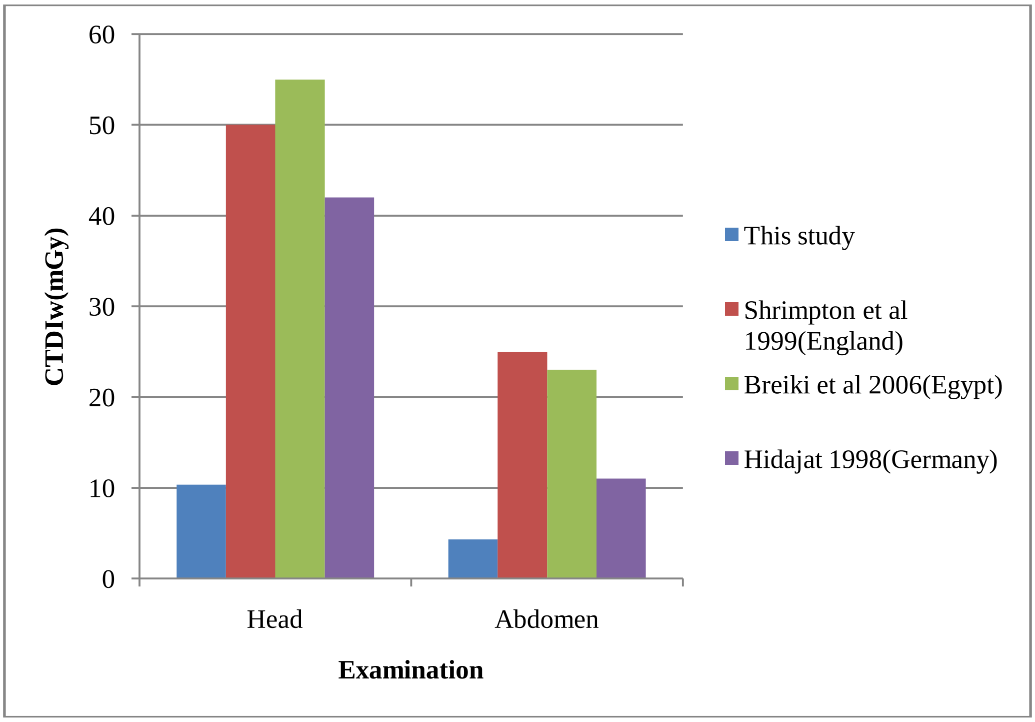

Figure 2: A bar chart showing a comparison of $CTDI_w$ with international Diagnostic reference levels for Siemens 6 slice CT

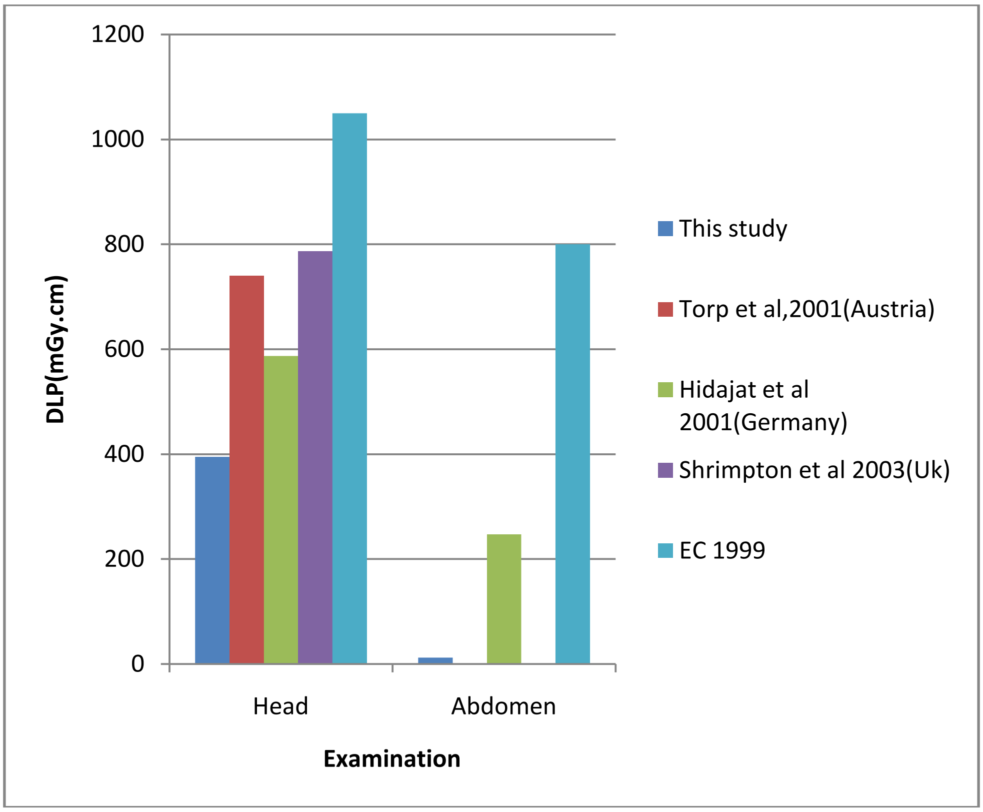

Figure 3: A bar chart showing a comparison of DLP with international Diagnostic reference levels For Philips CT

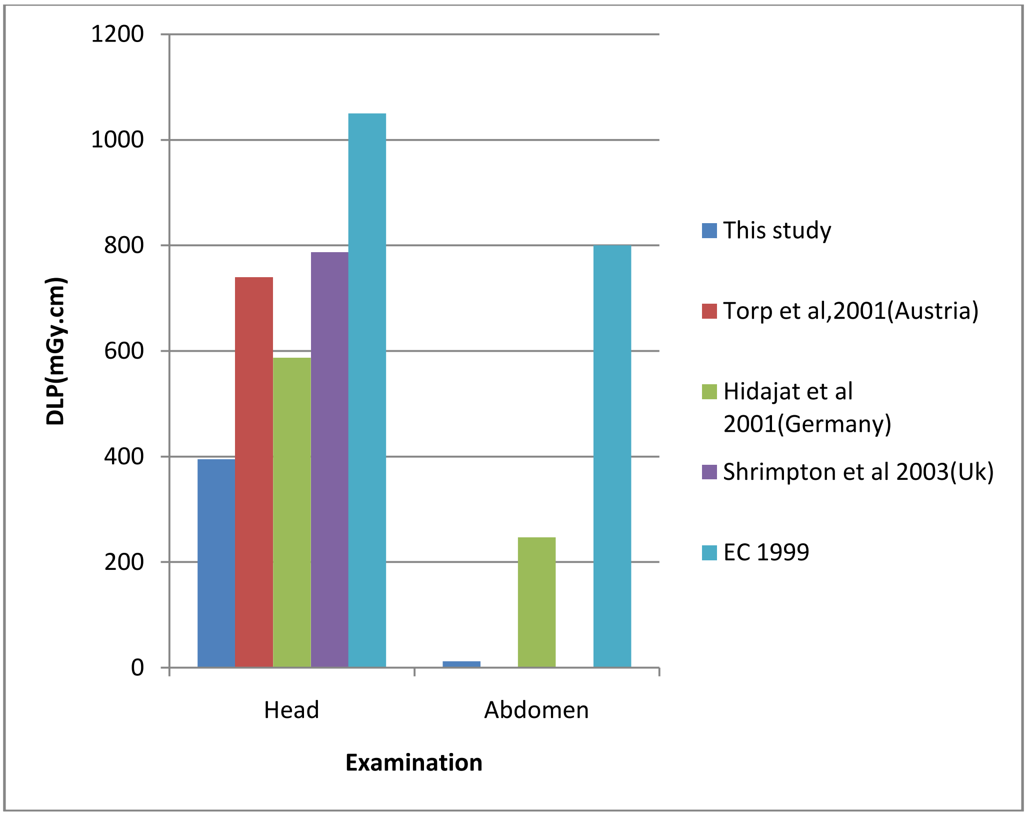

Figure 4: A bar chart showing a comparison of DLP with international Diagnosti reference levels for Siemens 6 slice CT

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