Original Article

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Establishing Local Diagnostic Reference Levels for CT Angiography Examinations

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Abstract:

Objective: Computed tomography angiography (CTA) examinations are performed to diagnose blood vessel anomalies. However, this examination results in a significant radiation dose being received by the patient. Local diagnostic reference levels (DRLs) are necessary for determining the extent of radiation dose during examinations. Therefore, the main objective of this study is to establish local DRL values for CTA examinations.

Material and Methods: In this study, a total of 213 participants underwent CTA examination; wherein: 67 underwent computed tomography (CT) cerebral angiography (CTCA), 80 underwent CT pulmonary angiography (CTPA), 40 underwent CT lower limb angiography with aortogram (CTLLA), and 26 underwent CT upper limb angiography (CTULA). Body mass index along with the circumference of the body were calculated. A number of dose descriptors; such as computed tomography dose index volume (CTDIvol) and dose length product (DLP), were collected, and DLP was used to calculate the effective dose, using the conversion factor.

Results: For the angiography phase, CTCA, CTPA, CTLLA, and CTULA had median CTDIvol values of: 31.62, 6.38, 12.16, and 10.12 mGy, respectively. Median DLP and effective dose for CTCA were: 1388.64 mGy*cm & 4.30 mSv, CTPA were 243 mGy*cm & 3.41 mSv, CTLLA were 1855.86 mGy*cm & 12.06 mSv, and CTULA were 945.98 mGy*cm & 2.93 mSv, respectively.

Conclusion: The estimated local DRLs were lower than the international standard for the angiographic phase; however, the dose exceeded the international standard when the entire examination was considered. This study revealed the need for dose optimization in CTA examinations.

Keywords: CT cerebral angiography, CT lower limb angiography with aortogram, CT pulmonary angiography, CT upper limb angiography, diagnostic reference levels

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Introduction

Recent advances in computed tomography (CT) technology have both revolutionized and enabled the creation of high-quality three-dimensional images, resulting in better diagnosis and treatment[1,2]. Hardware advancements have also enabled high-speed acquisition with greater volume coverage, allowing efficient subject care in a shorter time span. However, with regards to diagnostic reference levels (DRLs) these are still under investigation; especially with respect to Computed Tomography Angiogaphy (CTA) as they entail large amounts of radiation[3,4].

CT angiography is a non-invasive examination useful for diagnosis of vascular occlusion; replacing conventional invasive catheter angiography[5,6]. CTA has seen a rapid rise in application, resulting in concerns regarding radiation dose due to its multiphase acquisition and large volume coverage[7,8]. According to the linear non-threshold model, the risk of radiation-induced cancer is evident even in low doses of less than 100 mSv[9,10]. The optimization process has become the main focus, with DRLs being recognized as a standard for dose monitoring by numerous international organizations; including the European Union and International Commission on Radiation Protection (ICRP)[11–14].

DRLs are a simple yet important optimization tool to identify X-ray examinations with relatively high radiation doses. DRLs do not recommend an absolute upper threshold for X-ray examinations, but rather identify the upper limit of the radiation dose for good clinical practice[15]. DRLs can be defined at a local, national, and regional level, they can also be defined for specific clinical purposes. As CTA examinations are performed for specific clinical purposes, with relatively high radiation doses, the main objective of this present study was to establish Local DRL (LDRLs) values for CTA examinations.

Material and Methods

Patient selection

Approval for this prospective study was acquired from the Institutional Ethics Committee (IEC-545/2018). Patients aged 18 years and above, who were referred for CT cerebral angiography (CTCA), CT pulmonary angiography (CTPA), CT lower limb angiography with aortogram (CTLLA) and CT upper limb angiography (CTULA), were screened for consideration of the inclusion criteria. Participants with fractured extremities and amputated limbs were excluded from CT lower limb and upper limb angiography analysis. Additionally, participants with cervical collars were excluded from CT cerebral angiography. Written informed consent was collected from all the participants.

Data collection

A total of 213 subjects having undergone CT angiography examinations were included in the study; in which CTCA had 67 subjects, CTPA had 80 subjects, CTLLA had 40 subjects, and CTULA had 26 subjects out of 40 subjects (For CTULA, due to fewer referrals, only 26 subject's data was collected during the data collection period). The subjects demographic data including height and weight were collected to measure body mass index (BMI). The body circumference of the subjects was recorded prior to the scanning examination; including head and shoulder circumferences being measured at the level of the glabella and the jugular notch, respectively. For CTCA examinations, the shoulder circumference for CTPA, hip circumference at the level of the anterior superior iliac spine for CTLLA, and head and shoulder circumference for CTULA was measured. CT angiographic examinations were performed using the standard protocol in a 128-slice Philips Incisive CT scanner, which included three phases: the pre-contrast or plain phase, the post contrast angiographic phase, and the delayed phase. The scan parameters are shown in Table 1.

Table 1 Scanning parameters for computed tomography angiography examinations

Scanning phase	Rotation time (sec)	Pitch	Slice thickness (mm)	idose	Collimation	DRI	mA	mAs	Scan length (mm)
CT cerebral angiography									
Pre-contrast/plain	0.5	0.7	5	2	64*0.625 mm	NA	402.94±16.19	289.18±1.98	388.92±52.24
Angiography	0.5	0.8	0.8	3	64*0.625 mm	NA	483.01±36.67	234.96±24.94	364.41±52.15
Delay	0.4	0.8	1	4	64*0.625 mm	NA	458.78±75.97	240.30±25.41	376.75±31.41
CT pulmonary angiography									
Pre-contrast/Plain	0.5	0.8	5	3	64*0.625 mm	15	138.58±59.65	81.50±30.06	327.39±34.82
Angiography	0.4	1	0.9	3	64*0.625 mm	16	212.81±71.66	84.53±28.53	310.60±33.42
Delay	0.4	1	1	3	64*0.625 mm	16	212.78±75.57	85.23±29.64	323.59±33.75
CT lower limb angiography									
Pre-contrast/plain	0.5	1	5	3	64*0.625 mm	20	208.39±41.37	102.79±13.14	1206.44±368.34
Angiography	0.5	0.8	1	3	64*0.625 mm	16	234.65±19.90	149.05±0.22	1430.76±140.89
Delay	0.5	0.8	3	3	64*0.625 mm	17	136.15±40.13	85.90±24.62	1264.89±193.68
CT upper limb angiography									
Pre-contrast/plain	0.5	1.1	5	3	64*0.625 mm	20	253.08±57.79	114.96±26.19	877.70±66.65
Angiography	0.4	1	1	4	64*0.625 mm	21	317.27±70.31	128.62±26.61	848.34±91.82
Delay	0.4	1	3	3	64*0.625 mm	21	320.77±66.86	127.85±26.72	862.38±77.04

DRI=dose right index, NA=not applicable,
(DRI or dose right index is a Philips iCT nomenclature given for automatic tube current selection; based on body size. It has an index number of 1–44 that correlates to image quality; for example, if the DRI is increased by 1, then the mAs will increase by 12%, and noise will decease by 6% and vice versa.)
mA=milliampere, mAs=milliampere-seconds

Data; such as dose right index (DRI), mA, mAs, scan length, scan time, computed tomography dose index volume (CTDIvol), and dose length product (DLP) were collected after the scan for all three phases of CT angiographic examinations. DLP was further used to calculate the effective dose (E), by multiplying the DLP with the k-value. A k-value of 0.0031 was used for CTCA and CTULA; as the area of coverage was the head and neck, and for CTPA a k-value of the chest 0.014 was used[16]. For CTLLA a k-value of 0.0065 was used, which was derived by averaging the value of the chest and lower limb. This was because the area of coverage included the chest for the aortogram[16,17].

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS), version 16. Descriptive statistics were performed to establish the local DRLs. The demographic data, BMI, and scan parameters were reported in mean and standard deviation. In terms of dose descriptors, CTDIvol, DLP and effective dose; wherein, the guidelines suggest the use of median to report local DRL, thus the median with 25th and 75th quartile was reported in this study[18].

Results

Descriptive statistics were performed on 213 subjects: 143 males and 70 females. The mean age of the subjects was 53.97±14.83 years. Table 2 shows various CTA descriptive data for subject-specific characteristics.

According to the results it was noted that when considering a single phase, the CTDIvol, DLP, and effective dose was highest in the plain phase for CTCA, and in the delayed phase for CTPA. However, for the individual angiography phase, highest CTDIvol, DLP, and effective dose was noted for CTLLA and CTULA. In terms of total CTDIvol, CTCA the results projected a highest median value of 104.75 mGy; whereas, the lowest median value of 19.16 mGy was noted in CTPA. For the total DLP, the highest median value of 4693.76 mGy*cm was noted in CTCA, while the lowest total in DLP; 775.48 mGy*cm, was noted in CTPA. Furthermore, the highest total effective dose of 24.37 mSv was noted in CTLLA, while the lowest total effective dose of 8.46 mSv was noted in CTULA. Table 3 represents the median value, with 25th and 75th quartile values for CTDIvol, DLP, and effective dose of all the CT angiographic examinations, for different phases acquired during the examination.

Table 2 Descriptive statistics of patient parameters

CT angiography	n	Gender	Age (years)(range)	Body circumference (cm)	BMI
CTCA	67	M: 42 F: 25	57.94±14.66 (19-85 years)	H: 22.42±1.08 S: 40.52±3.24	23.80±3.14
CTPA	80	M: 48 F: 32	51.43±16.48 (19-87 years)	S: 39.39±3.00	22.91±4.59
CTLLA	40	M: 35 F: 5	59.13±13 (22-87 years)	Hp: 36.65±3.49	22.04±2.97
CTULA	26	M: 18 F: 8	47.38±15.20 (24-73 years)	H: 22.54±0.64 S: 39.08±2.89	22.92±3.84

CTCA=computed tomography cerebral angiography, CTPA=computed tomography pulmonary angiography, CTLLA=computed tomography lower limb angiography with aortogram, CTULA=computed tomography upper limb angiography, BMI=body mass index, M=male, F=female, H=head, S=shoulder, Hp=hip, CT=computed tomography

Table 3 Local DRLs for CT angiography examinations

CTA	$CTDI_{vol}$ (mGy) Median (25^{th} and 75^{th} quartile)				DLP (mGy*cm) Median (25^{th} and 75^{th} quartile)				Effective dose (mSv) Median (25^{th} and 75^{th} quartile)			
	Pre-contrast	Angiography phase	Delayed phase	Total	Pre-contrast	Angiography phase	Delayed phase	Total	Pre-contrast	Angiography phase	Delayed phase	Total
CTCA	40.80 (40.80, 40.81)	31.62 (31.18, 32.60)	32.33 (31.85, 33.52)	104.75 (104.01, 107.12)	1861.94 (1780.34, 1943.22)	1388.64 (1310.7, 1459.59)	1433.05 (1345.14, 1587.47)	4693.76 (4430.24, 4889.97)	5.77 (5.52, 6.02)	4.30 (4.06, 4.52)	4.44 (4.17, 4.92)	14.55 (13.73, 15.16)
CTPA	6.03 (4.88, 7.94)	6.38 (5.32, 8.29)	6.47 (5.32, 8.40)	19.16 (15.83, 24.22)	234.76 (181.86, 318.16)	243.81 (193.71, 309.85)	262.22 (199.91, 319.88)	775.48 (580.34, 909.48)	3.28 (2.54, 4.45)	3.41 (2.71, 4.34)	3.67 (2.79, 4.48)	10.86 (8.12, 12.73)
CTLLA	8.24 (8.09, 8.44)	12.16 (12.16, 12.16)	6.46 (5.90, 7.42)	26.66 (25.65, 27.83)	1134.04 (641.92, 1279.54)	1855.86 (1696.17, 1944.14)	863.20 (754.08, 982.74)	3748.59 (3141.33, 4061.68)	7.37 (4.17, 8.31)	12.06 (11.02, 12.63)	5.61 (4.97, 6.38)	24.37 (20.67, 26.40)
CTULA	9.23 (7.83, 10.65)	10.12 (8.85, 12.11)	10.03 (8.82, 12.11)	29.06 (22.79, 34.96)	860.16 (670.76, 1099)	945.98 (770.69, 1122.98)	941.79 (766.69, 1115.94)	2728.03 (2082.53, 3342.17)	2.66 (2.08, 3.40)	2.93 (2.38, 3.48)	2.92 (2.37, 3.46)	8.46 (6.45, 10.36)

CTA=computed tomography angiography, CTCA=computed tomography cerebral angiography, CTPA=computed tomography pulmonary angiography, CTLLA=computed tomography lower limb angiography with aortogram, CTULA=Computed tomography upper limb angiography

Discussion

This study reported on the radiation doses, in terms of CTDIvol, DLP, and effective dose for all the different phases acquired during CT angiography examinations. According to the institute protocol, CTA examinations are usually performed in three phases; namely: the pre-contrast or plain phase, angiography phase, and the delayed phase. This is the first study, to our knowledge, to report the doses separately for all the phases acquired. Along with the individual phase dose report, a total dose report (sum of all the phases) is also reported. Therefore, the local DRLs for the angiography phase as well as the total dose have been established.

Establishing DRLs to identify radiation dose trends in CT examination is a very important task before the optimization process. There are several studies available on local DRLs or national DRLs, based on routine CT examinations; such as the head, chest, and abdomen[19,20]. However, there are still limited resources in DRLs for CTA examinations. In this present study, it has attempted to establish local DRLs for the most commonly performed CTA examinations in our institute. For CT cerebral angiography, the median local DRLs in terms of CTDIvol for the angiography phase was 31.62 mGy and the DLP was 1388.64 mGy*cm. The CTDIvol values obtained from this study were lower than that of studies found in the literature[21–25]. However, in a study conducted by Pyong-Kon Cho et al.[4] their value was lower than this present study. In terms of dose descriptor DLP, this study's values were lower than that of the previous studies[4,21,22,25]. In conrast, in the study conducted by Alkhorauef et al.[23], and Treier et al.[24] they reported lower DLP values than this present study (Table 4). The discrepancy in the results may be due to the number of phases acquired, which was not mentioned, while in this study it has mentioned the radiation dose value for each phase.

Studies on CT pulmonary angiography have either excluded multiphase studies, or have no number of phases being mentioned. Therefore, it was concluded that the DRLs were only established from the angiographic phase. The results of this present study shows the median CTDIvol value for the angiography phase being 6.38 mGy, with the median DLP being 243.81 mGy*cm. The results of the present study value are lower than the international studies[7,15,24,26–28] and European recommendations[29]. A similar trend was noted in terms of the DLP value as well. The values of the international studies were higher than the value of this present study for the angiography phase; however, when the total dose was considered (CTDIvol: 19.16 mGy and DLP: 775.48) the values of this present study were higher (Table 4).

In cases of CT lower limb angiography, with aortograms, there are limited studies showing established DRLs. In the study of Dina Husseiny Salama et al[30]., they reported higher values for CTDIvol, and lower values for DLP, than this present study (Table 4). However, there are studies on CT lower limb angiography and CT aortogram separately. Treier et al.[24] and Christoph Aberle et al.[31] study reported CTDIvol and DLP for CT lower limb angiography and CT aortogram, respectively. Combining both the study to generate DRLs for comparison would also not be feasible, due to the scan range. For example, in the case of CT lower limb angiography, the scan ranges from the iliac crest and below, and for the aortogram the scan ranges from the jugular notch to the symphysis pubis. In both, the studied pelvis is being exposed, and due to this reason the comparison is not made. There was no study found in the literature for CT upper limb angiography.

In this present study, it was noted that the highest CTDIvol value was for CTCA examinations, and the

Table 4 Comparison of computed tomography angiography radiation dose with international studies

Angiography	Authors	CTDIvol (mGy)		DLP (mGy*cm)	
		Mean	3rd Quartile	Mean	3rd Quartile
CTCA	Present study	31.62	32.60	1388.64	1459.59
	Pyong-Kon Cho et al.[4]	24.59	26.7	1379.53	1816.53
	Geoffrey Korir et al.[21]	43	50	4076	1015
	Moon Chan Kim et al.[22]	32.9	42.7	1502	1854
	Alkhorayef et al.[23]	70.8	–	1082	–
	Treier et al.[24]	–	65	–	1000
	Ngaile et al.[25]	37	39	1711.17	2325
CTPA	Present study	6.38	8.29	243.81	309.85
	Foley[15]	9.9	12.5	324	432
	European Union[29]	–	15	–	552
	Klosterkemper et al.[28]	8.8	–	–	–
	Treier et al.[24]	–	15	–	467
	MacGregor et al.[27]	–	16	–	579
	Harun et al.[26]	–	9	–	329
	Kanal et al.[7]	–	18	–	557
CTLLA	Present study	12.16	12.16	1855.86	1944.14
	Dina Husseiny Salama et al.[30]	29.5	36.7	1103.5	1317.8

CTCA=computed tomography cerebral angiography, CTPA=computed tomography pulmonary angiography, CTLLA=computed tomography lower limb angiography with aortogram, CTDIvol=computed tomography dose index volume, DLP=dose length product

lowest was for CTPA (Table 3). This is predominantly due to the tube current setting used for each phase: CTCA examinations use higher tube current settings; whereas, CTPA uses lower tube current settings (Table 1). In the case of DLP, the highest value was noted for CTCA examinations and the lower value was noted in CTPA. Although DLP is influenced by scan length, DLP itself is the product of CTDIvol and scan length[24]. Therefore, the DLP value of CTCA is higher when compared to CTLLA, even though the scan length is highest in CTLLA. For effective doses, the highest value was noted for CTLLA examinations, while the lowest was noted for CTULA. This is predominantly due to the conversion factor used for calculating effective doses. For CTCA examinations, the conversion factor was lowest as compared to other examinations considered in this study; therefore, the effective dose was lower; even though the DLP was highest for CTCA examinations. Similarly, for CTULA, this study used the same conversion factor as for CTCA examinations; thus, the effective dose was lowest in CTULA examinations. The highest conversion factor was used for CTPA examinations; however, due to the lowest DLP value, the effective dose was lower.

Justification in radiation protection is controversial, yet important. Deciding on the number of acquisitions is justification rather than optimization[31]. Deciding on the area coverage also can be put under the jurisdiction of justification. It is purely the decision of the radiologist to decide the number of acquisitions and area coverage. From this present study, the amount of dose reduction could be predicted if the phase acquired is justified. It should also be noted that up to 35% of the dose can be reduced, if one phase for any CT angiography examination is eliminated.

This study has several limitations. Firstly, the study was performed in a single center and with a single CT scanner. Although, the sample size for CTCA, CTPA, and CTLLA was enough to establish DRLs; according to the recommendation by the International Commission on Radiation Protection Report 135 that states that: "at least 30 subjects are required for establishing DRLs"[18]. However, recommending the DRLs for CT angiography examination might not be enough, due to this being a single-center study. This study collected data for CTLLA and CTULA, for establishing local DRLs; however, no international data was available to compare the results. Furthermore, the sample size for CTULA was limited for establishing local DRLs.

Conclusion

In this present study, the local diagnostic reference levels for CT angiography examination were established for CT cerebral angiography, pulmonary angiography, and lower limb with aortogram. This study reported local DRLs for the angiography phase and total dose separately. When only the angiography phases was compared, our DRL was lower than the international studies. However, when the total dose was considered, the value of this present study was higher than that of the international studies for CT cerebral angiography and CT pulmonary angiography. Therefore, it is recommend that further studies should be conducted to explore the various techniques and technical factors to reduce the radiation dose, with optimized image quality for CTA. This would enhance clinical diagnosis and patient care.

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Conflict of interest

The authors have no conflicts of interest to declare.

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