Original Article

Patient dose in brain perfusion imaging using an 80-slice CT system

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A R T I C L E   I N F O

A B S T R A C T

Background and purpose. – Brain CT Perfusion (CTP) is an X-ray imaging technique for the assessment of brain tissue perfusion, which can be used in several different entities. The aim of this study is the evaluation of the radiation dose to patients during a comprehensive brain CT prescription protocol (CPP) consisting of an unenhanced brain CT, a brain CT angiography and a CTP scan.
Materials and methods. – Eighteen patients were studied using an 80-slice CT system, with an iterative reconstruction algorithm. The volume Computed Tomography Dose Index (CTDI$_{vol}$) and dose length product (DLP) were recorded from the dose report of the system. The calculation of effective dose (ED) was accomplished using the DLP values.
Results. – For the CTP examinations, the CTDI$_{vol}$ ranged from 116.0 to 134.8 mGy, with the mean value 119.5 mGy. The DLP ranged from 463.9 to 539.2 mGy·cm, with the mean value 478 mGy·cm. For the CPP, the total ED ranged from 3.31 to 5.07 mSv, with the mean value 4.37 mSv.
Conclusions. – These values are lower than the values reported in corresponding studies, including studies utilizing CT systems with more slices.

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Introduction

Brain CT perfusion (CTP) is an X-ray imaging technique for the assessment of various cerebrovascular disorders, especially in acute stroke patients [1–4]. Stroke can be either ischemic or hemorrhagic [5,6]. In view of the updated guidelines for the endovascular treatment of ischemic stroke [7], CTP is an essential tool to point out the potentially salvageable ischemic penumbra from the infarct core [6–10], especially when endovascular thrombectomy is going to be applied. According to the guidelines for the management of ischemic stroke, hemorrhage must be precluded by performing an unenhanced brain CT (UN-CT) scan, while in cases where endovascular thrombectomy should be applied, a brain CT angiography (CTA) and a CTP scan will complete the initial evaluation, providing all the necessary information for the endovascular therapy [6,8,9,11,12]. The discrimination of potentially salvageable ischemic penumbra from the infarct core is accomplished by capturing the first pass of a bolus of contrast medium through the vasculature, a procedure that requires consecutive imaging of the identical parenchymatic region [9,12,13]. This area lies at the level of the basal ganglia as it comprises vicarious territories of the anterior, middle and posterior cerebral artery, offering the best spatial selection for stroke assessment [6,14]. CTP has also been used to address possible ischemic areas in cases of vasospasm, following subarachnoid hemorrhage (SAH) or to evaluate the perfusion/aggressiveness of various brain tumors. Furthermore, CTP has been used to verify the absence of brain perfusion, in cases of brain death.

Nevertheless, exposure to X-ray radiation, associated with the consecutive imaging of the CTP, combined with the additional exposure from UN-CT and CTA, and the fact that stroke patients may be submitted to manifold proceedings, declares that the management of the patient X-ray dose commensurate with the medical task of the justification of the procedure, is a necessity [3,14,15]. Overexposure of stroke victims from diagnostic and therapeutic procedures may lead to deterministic effects, such as hair loss and/or skin redness [16–19]. Moreover, although the lens of the eye is in most cases out of the acquisition zone, its proximity suggests the absorption of a certain dose of radiation [14,15]. Numerous studies have reported high dose results, suggesting the need for

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further investigation [14,15,20–23]. The dosimetric quantity used in these studies was the effective dose (ED), as it facilitates the comparison amongst different techniques [24,25].

In this study, the patient doses during a comprehensive brain CT prescription protocol (CPP), carried out in our hospital using an 80-slice CT system and an iterative reconstruction (IR) algorithm, are presented. The dosimetric quantity used was the ED, derived from the dose length product (DLP) utilizing appropriate conversion factors.

Patients and methods

Eighteen patients participated in this study undertaking brain CT imaging for either acute stroke, brain death verification, vasospasm following SAH, or brain tumor. All the brain CT procedures were carried out at the Department of Radiology, at the University Hospital of Patras, between January 2017 and May 2018. The system used was an 80-slice CT scanner (Toshiba Aquilion Prime, Toshiba Medical Systems Corporation), with a maximum beam collimation of 40 mm (e.g. 80×0.5 mm). The utilized algorithm for the specific study was the IR algorithm AIDR 3D Std. The comprehensive prescription protocol (CPP) consists of three types of examinations; an UN-CT, a CTP and a CTA at a tube voltage of 120, 80 and 120 kVp, respectively. The scan range for the UN-CT and CTA was from the skull base to vertex performed in helical scan mode. CTP scanning was performed with the maximum beam collimation of 40 mm (10×4 mm), in axial mode, with the center of the scan length being posed at the plane of the inferior part of the bodies of lateral ventricles, during the dynamic administration of 50 mL of iodinated contrast media with a concentration of 350–370 mg/mL of iodine, intravenously injected at a flow rate of 5 mL/s, followed by 30 mL saline at 5 mL/s. Additionally, CTA scanning was performed with the dynamic administration of 100 mL of iodinated contrast media with a concentration of 350–370 mg/mL of iodine, intravenously injected at a flow rate of 4 mL/s, followed by 30 mL saline at 4 mL/s.

Overall, the technical details for the three types of examinations of the CPP are presented in Table 1. The tube voltage values have been selected as follows: in our department (for the daily routine, besides CPPs), it has been adopted that the diagnosis from the UN-CTs and CTAs are based on clinical images acquired using 120 kVp. Based on this, the same value has been adopted for the UN-CT and CTA of our CPP. In addition, for the CTP, the lowest available tube voltage value of the system, which was 80 kVp, was selected. That is due to the fact that higher attenuation levels for iodine-based contrast agents are achieved at lower X-ray tube voltages, due to the increased possibility of photoelectric effect [26]. The current modulation was inactivated following the instructions of the vendor. The CPP is performed at a constant tube current of 230, 40 and 250 mA, respectively. The gantry rotation time was 0.75, 1.5 and 0.5 s, respectively. The pitch factor, or axial scan spacing, is defined as table distance traveled in one 360º rotation for a helical scan, or the spacing between acquisitions for axial scans, over total collimated width of the x-ray beam i.e. pitch = I/N·T, where N is the number of acquired sections per scan and T is the nominal width of each acquired section. If the table increment is equal to the nominal beam width, the pitch factor p = I/N·T is equal to 1. However, in the CTP protocol of the present study, there is no table motion, therefore the pitch factor value is presented with a dash, whereas the pitch factor values for the UN-CT and CTA, are 0.625 and 0.637, respectively. Thus, the effective mAs (mAs_{eff} = mA s/pitch) values for the UN-CT, CTP and CTA are 276, 60 and 196 mAs, respectively. The selection of beam collimation for the three acquisition modes has been decided having in mind that: narrow beam collimation results in increased image noise, an effect

that is compensated by increasing mAs and/or kVp, which in turn increase the absorbed dose to the patient. Finally, the system was under a periodic quality control program, in order to ensure the correct performance, as well as the reliability and reproducibility of the exposure parameters. The difference between displayed and measured Volume Computed Tomography Dose Index ($CTDI_{vol}$) and DLP was less than 5% in all cases.

The dose report of the system provided data regarding the tube voltage, $CTDI_{vol}$ and DLP. $CTDI_{vol}$ represents the average absorbed radiation dose within the irradiated scan volume, for a similar attenuation 16-cm diameter standardized phantom, while DLP is the product of $CTDI_{vol}$ and the length of the imaged object.

Patients' data such as sex, age and weight were recorded. Patients included 8 women and 10 men. The mean age of all patients was 53.5 y, ranging between 18 and 78 y. The mean weight of all patients was 80.2 kg, ranging between 60 and 100 kg. The patient ED was calculated by multiplying each DLP value with the conversion factor of 0.0021 mSv/mGy·cm [5,22,25].

Results

The mean $CTDI_{vol}$ for the UN-CT was 55.6 mGy, ranging from 54.7 to 60.1 mGy. The mean $CTDI_{vol}$ for the CTA was 35.2 mGy, ranging from 34.7 to 38.2 mGy. The mean $CTDI_{vol}$ for the CTP was 119.5 mGy, ranging from 116 to 134.8 mGy. Furthermore, the mean DLP for the UN-CT was 927.5 mGy·cm, ranging from 473.7 to 1113.9 mGy·cm. The mean DLP for the CTA was 682.1 mGy·cm, ranging from 543.7 to 814 mGy·cm. The mean DLP for the CTP was 478 mGy·cm, ranging from 463.9 to 539.2 mGy·cm.

Finally, the mean ED value for the UN-CT was 1.95 mSv, ranging from 0.99 to 2.34 mSv. The mean ED for the CTA was 1.43 mSv, ranging from 1.14 to 1.70 mSv. The mean ED for the CTP was 1 mSv, ranging from 0.97 to 1.13 mSv, whilst the mean ED for the CPP was 4.37 mSv, ranging from 3.31 to 5.07 mSv. The values for the $CTDI_{vol}$, DLP and ED are presented in Table 2.

Discussion

The results of the present study were compared with the corresponding values reported in the literature and are presented in Table 3 for the UN-CT, CTA and CTP, in terms of $CTDI_{vol}$, DLP and ED.

In particular, for CTP, the mean $CTDI_{vol}$ in our study was 119.5 mGy. Arandjic et al. [15], Hoang et al. [20] and Bricout et al. [22] using 64-slice CT systems, and a tube load of 200, 200 and 180 mAs, respectively, reported higher $CTDI_{vol}$ values, than the mean value of our study. Moreover, Horiguchi et al. [21] also using a 64-slice CT system and a tube load of 80 mAs, reported a comparable $CTDI_{vol}$ value to the mean value of our study. Fang et al. [23], utilizing a 128-slice CT system and a tube load of 100 mAs, reported a lower $CTDI_{vol}$ value than the mean value of our study. As the tube voltage was the same for both studies, a possible explanation for the 2-fold difference is the non-mentioned value of pitch factor, which affects the mAs_{eff} value. Li et al. [27] and Solano et al. [28] utilizing 128-slice CT systems as well, and a tube load of 150 and 80 mAs, respectively, reported higher $CTDI_{vol}$ values, than the mean value of our study. Brix et al. [29] using a 192-slice CT system and a tube load of 250 mAs, reported a $CTDI_{vol}$ value of 196 mGy which is 64% higher than our value, although they used a tube voltage of 70 kVp. Lin et al. [30] using a 256-slice system and a tube load of 80 mAs, reported a $CTDI_{vol}$ value of 128.2 mGy, which is 7% higher than our value. Salomon et al. [31] using a 320-slice system, reported a range of $CTDI_{vol}$ values, with the minimum value of 400 mGy, which is 3.34 fold higher than our value.

Table 1
Scan parameters for the CPP of this study.

Modality	UN-CT	CTA	CTP
Tube voltage (kVp)	120	120	80
Tube current (mA)	230	250	40
Rotation time (s)	0.75	0.5	1.5
Pitch factor	0.625	0.637	–
Effective mAs	276	196	60
Total scan time (s)	10.2	3.8	51.0
Scan type	Helical	Helical	Axial
Scan range (mm)	141	141	40
Anatomical area	Scull base to vertex	Scull base to vertex	Basal ganglia
Beam collimation (mm)	40×0.5 mm	80×0.5 mm	10×4 mm
D-FOV	240.0 (S)	220.3 (S)	220.3 (S)
Slice thickness (mm)	3.0	3.0	10.0
Slice interval (mm)	3.0	3.0	10.0
Time interval (s)	–	–	1.5
Contrast agent	None	100 mL of 350–370 mg/mL iodine contrast at 4 mL/s followed by 30 mL saline at 4 mL/s	50 mL of 350–370 mg/mL iodine contrast at 5 mL/s followed by 30 mL saline at 5 mL/s

Table 2
$CTDI_{vol}$, DLP and ED values for the CPP of this study.

	CTDIvol (mGy)			DLP (mGy·cm)			ED (mSv)			
	UN-CT	CTA	CTP	UN-CT	CTA	CTP	UN-CT	CTA	CTP	CPP
Min	54.7	34.7	116.0	473.7	543.7	463.9	0.99	1.14	0.97	3.31
Max	60.1	38.2	134.8	1113.9	814.0	539.2	2.34	1.70	1.13	5.07
Mean	55.6	35.2	119.5	927.5	682.1	478.0	1.95	1.43	1.00	4.37
SD (±)	1.98	1.16	7.22	137.05	64.77	28.93	0.29	0.13	0.06	0.38
CV (%)	3.56	3.29	6.04	14.77	9.49	6.05	14.87	9.09	6.0	8.69

Table 3
Comparison of $CTDI_{vol}$, DLP and ED mean values in UN-CT, CTA and CTP reported in various studies.

Study	Systemslices	CTDIvol (mGy)			DLP (mGy·cm)			ED (mSv)			
		UN-CT	CTA	CTP	UN-CT	CTA	CTP	UN-CT	CTA	CTP	Total
Loftus et al. [3]	–	–	–	–	1183.2	3128.2	1991.8	–	–	–	–
Mnyusiwalla and Aviv [5][d]	64	–	–	–	1227.8	1565.4	2663.6	2.70	1.60	4.90	12.5[c]
Sabarudin et al. [14][d]	64	–	–	–	–	–	–	–	0.61	2.07	2.68
Arandjic et al. [15][d]	64	–	–	230.0	–	–	2120.0	–	–	4.90	4.90
Hoang et al. [20][d]	64	–	–	531.4	–	–	2125.7	–	–	7.50	7.50
Horiguchi et al. [21][d]	64	–	–	121.0	–	–	965.0	–	–	2.22	2.22
Bricout et al. [22][d]	64	42.6[a]	24.5[a]	204.1[a]	662.0[a]	369.0[a]	1831.0[a]	1.40[a]	0.80[a]	3.90[a]	6.10[a]
Konstas et al. [34]	64	–	–	–	–	–	–	–	–	3.70	3.70
Fang et al. [23][d]	128	–	–	55.5	–	–	859.0	–	–	1.80	1.80
Saake et al. [35][d]	128	–	–	–	–	–	–	1.40	0.50	4.20	6.10
Li et al. [27][d]	128	–	–	184.2	–	–	2172.0	–	–	4.65	4.65
Solano et al. [28][d]	128	–	–	192.0	–	–	1831.0	–	–	4.21	4.21
Brix et al. [29][d]	192	–	–	196.0	–	–	2909.0	–	–	6.40	6.40
Lin et al. [30][d]	256	–	–	128.2	–	–	985.0	–	–	2.06	2.06
Murayama et al. [36][d]	256	–	–	–	–	–	–	–	–	3.50[b]	3.50[b]
Dorn et al. [32][d]	256	–	–	–	–	–	723.8	–	–	1.67	1.67
Shankar et al. [33][d]	320	–	–	–	–	–	1000.0	–	–	–	–
Manniesing et al. [37][d]	320	–	–	–	–	–	–	2.30	2.80	5.00	10.10
Orrison et al. [38][d]	320	–	–	–	–	–	–	–	–	4.30	4.30
Diekmann et al. [39][d]	320	–	–	–	–	–	–	1.62	–	3.61	5.23
Salomon et al. [31][d]	320	–	–	400.0[b]	–	–	2230.0[b]	–	–	5.13[b]	5.13[b]
This study	80	55.6	35.2	119.5	927.5	682.1	478.0	1.95	1.43	1.00	4.37

–: not mentioned.
[a] Median values.
[b] Minimum values.
[c] Includes two additional exams; CT permeability and postcontrast CT.
[d] Iterative reconstruction.

Regarding the DLP, the mean value in our study was 478 mGy·cm. Mnyusiwalla and Aviv [5], Arandjic et al. [15], Hoang et al. [20], Horiguchi et al. [21] and Bricout et al. [22], using 64-slice CT systems, reported values 2-5.6 fold higher. Fang et al. [23], Li et al. [27] and Solano et al. [28], utilizing 128-slice CT systems, reported values 1.8-4.5 fold higher. Brix et al. [29], using an 192-slice CT system, reported a DLP value of 2909 mGy·cm, which is 6.1 fold higher. Lin et al. [30] and Dorn et al. [32], using 256-slice CT systems, reported DLP values 1.5-2.1 fold higher. Shankar et al. [33] and Salomon et al. [31], using 320-slice CT systems, reported
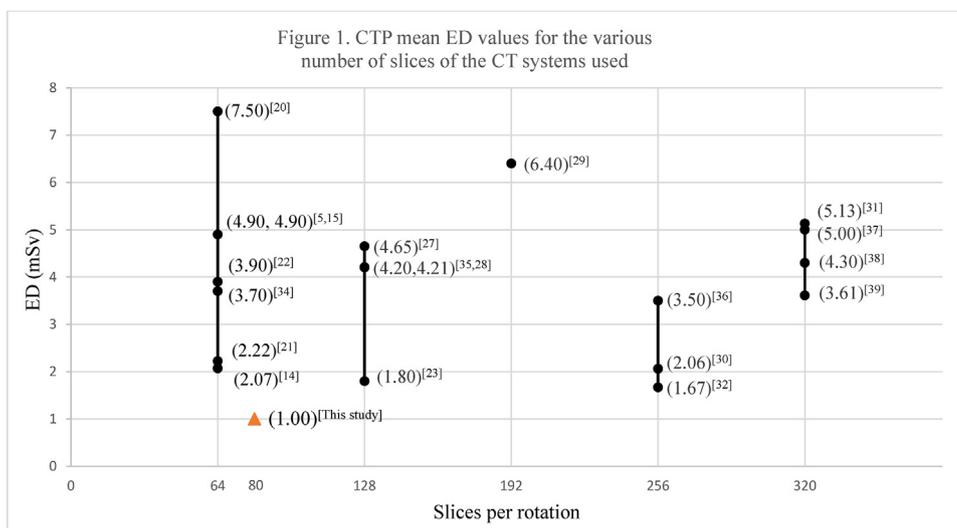
Fig. 1. CTP mean ED values for the various number of slices of the CT systems used.

DLP values 2.1-4.7 fold higher The reported DLP values are higher than our value, mainly due to the extended scan range of the CTP protocol used.

Regarding the ED, the mean value of our study was 1 mSv. Mnyusiwalla and Aviv [5], Sabarudin et al. [14], Arandjic et al. [15], Hoang et al. [20], Horiguchi et al. [21], Bricout et al. [22] and Konstas et al. [34], using 64-slice CT systems, reported values 2.1–7.5 fold higher. Fang et al. [23], Saake et al. [35], Li et al. [27] and Solano et al. [28], utilizing 128-slice CT systems, reported values 1.8–4.7 fold higher. Brix et al. [29], using an 192-slice CT system, reported a value of 6.4 mSv, which is 6.4 fold higher. Lin et al. [30], Murayama et al. [36] and Dorn et al. [32], using 256-slice CT systems, reported values 1.7–3.5 fold higher. Manniesing et al. [37], Orrison et al. [38], Diekmann et al. [39] and Salomon et al. [31], using 320-slice CT systems, reported values 3.6–5.1 fold higher. All these values, along with the number of slices of the CT systems used, are presented in Fig. 1.

For the CPP, the total ED value of our study (4.37 mSv) was compared with the studies that included at least the three types of examinations (UN-CT, CTA, CTP). Mnyusiwalla and Aviv [5], Bricout et al. [22], Saake et al. [35] and Manniesing et al. [37] reported values 1.4–2.9 fold higher than our value, mainly due to the larger dose contribution of the CTP protocols in the total ED (see Table 3). It should be noted that, the value reported by Mnyusiwalla and Aviv [5], corresponded to two additional examinations, CT permeability and postcontrast CT. ED is an indicator that takes into account the difference in biological radiosensitivity of each tissue/organ and reflects the incidence of stochastic effects. However, its application has limitations as its calculation is based on a "standard" human body that does not accurately reflect any one individual [25].

The main limitation of our study was the small group of patients participated ($n = 18$).

The reason for that was twofold. Firstly, between January 2017–June 2017 the sample size was 15 patients ($n = 15$), while between July 2017–May 2018 there was a significant reduction in the number of stroke patients eligible for mechanical thrombectomy who presented in our Department. Moreover, and in accordance to the recent updated guidelines (March 2018), from April 2018, we stopped doing CTP in patients eligible for mechanical thrombectomy (presented in < 6 h). The new recommendation is against the use of any additional imaging beyond CT and CTA or MRI and magnetic resonance angiography (MRA), such as perfusion studies, for selecting those patients [40]. In addition,

since the CTP protocol conducted in our hospital presents a small Standard Deviation value (± 0.06 mSv), it seems that changes should arise mainly from the optimisation of the UN-CT and CTA. The values presented in this study can contribute in the effort for the establishment of national Diagnostic Reference Level (DRL) values. Regarding the limitation of image quality analysis absence, a qualitative and quantitative study will be performed in the future.

In brain CTP examinations, the increase of slices per rotation from 64 to 320, does not mandatorily result in a decrease in patient dose. The proper balanced selection of scan and reconstruction parameters, in combination with the appropriate scan range, results in the reduction of the absorbed dose to the patient. Therefore, the collaboration between the radiologists and the medical radiation physicists of each institution is of paramount importance, for the adoption of an optimum prescription protocol, that will secure the fidelity of the examination and simultaneously the minimization of the radiation dose to the patient.

Conclusion

The patient dose for the comprehensive prescription protocol in brain CT perfusion, carried out in our hospital utilizing an 80-slice CT system, was 4.37 mSv. This value is lower than the values reported in corresponding studies, including studies utilizing CT systems with more slices. The results highlight the necessity and importance of the harmonic collaboration between the radiologists and the medical physicists, leading to the enhanced utilization of the system used.

Disclosure of interest

The authors declare that they have no competing interest.

Appendix A.

The calculation of the ED derived from the following equation: ED = k × DLP, where k is an appropriately selected conversion factor. A reasonable approximation can be obtained using the conversion factor of 0.0021 mSv/mGy·cm [5,22,25], since conversion factor values vary from 0.0019 to 0.0023 mSv/mGy·cm. The conversion factor value used, is applicable to head scans.

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