TECHNICAL NOTE

Proposed local diagnostic reference levels in angiography and interventional neuroradiology and a preliminary analysis according to the complexity of the procedures

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Received 15 April 2010; received in revised form 23 September 2010; accepted 14 October 2010

Available online 11 November 2010

KEYWORDS

Cerebral angiography;
Cerebral embolisation;
Diagnostic reference
levels;
KAP (kerma-area
product)

Abstract The aim of this study was to propose local diagnostic reference levels (DRL) for exposure to radiation during diagnostic procedures and neuroradiological interventions such as cerebral angiography and embolisation of cerebral aneurysms (intra-cranial aneurysms and arteriovenous malformations). Hospitals should adopt the national DRLs for use locally or establish their own DRLs based on local practice, if sufficient local data are available.

For this purpose we studied a sample of 113 cerebral angiography procedures and 82 embolisations of cerebral aneurysms. The data recorded included the kerma-area product (KAP), the fluoroscopy time and the number of frames for each procedure: third quartiles from the total dosimetric databank were calculated and proposed as provisional local DRL. Since the complexity of a procedure must be taken into account when evaluating the radiation dose, in the case of embolisation of aneurysms (intra-cranial), in this initial phase we assessed whether the complexity of the embolisation procedure is related to the size of the aneurysm and/or its site. We, therefore, re-calculated the DRL for only intra-cranial aneurysms, leaving aside the arteriovenous malformations. Considering that the DRL calculated for all the

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therapeutic procedures are similar to those calculated considering only intra-cranial aneurysms, at the moment we propose, besides the DRL for cerebral angiography, a single DRL for all interventional procedures, even when the clinical pictures are very different. Local preliminary DRLs were proposed as follows: 180 Gy cm², 12 min and 317 frames for cerebral angiography and 487 Gy cm², 46 min and 717 frames for interventional procedures (intra-cranial aneurysms and arteriovenous malformations).

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Introduction

The EURATOM Directive 97/43 [1] on medical exposure states the need to establish and use diagnostic reference levels (DRL), defined as "dose levels in medical radio-diagnostic practices... for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied". DRL are values of doses accepted for radiographic examinations [2–6] and their application is generally accepted for some diagnostic procedures with fluoroscopy, such as barium enemas and barium meals [7,8]. Over the years, DRL have been proposed in the field of cardiology for invasive diagnostic and therapeutic procedures such as coronary angiography, percutaneous transluminal coronary angioplasty (PTCA), and electrophysiology procedures [9–11]. In particular, European DRL for PTCA procedures have been proposed, with these levels differing according to the complexity of the procedure [10].

Here we propose local DRL for two types of neuroradiological procedures, one diagnostic (cerebral angiography) and one therapeutic (cerebral embolisation). Cerebral angiography refers to investigation of head and brain arteries, whereas cerebral embolisation is therapeutic obliteration (coiling) of intra-cranial aneurysms and arteriovenous malformations (AVM). Selective investigations in the case of cerebral aneurysms are carried out on four axes (internal carotid and vertebral arteries), whereas those for AVM involve six axes (internal carotid, external carotid and vertebral arteries).

The praxis suggested by the European Guidelines [12] is to consider as DRL the 75th percentile of the distribution, established by a dosimetric survey, of dose (KAP) or other parameters such as fluoroscopy time and number of frames. DRL are not restrictive limits, nor are they dose limits or threshold levels that define the competent performance of the operator or the equipment [6], but rather guideline levels to good practice, whose establishment and application in interventional neuroradiology must be flexible because of the complexity of the procedures. DRL are not applicable to individual patients. Comparison with DRL shall be made using mean values of a patient sample only. The main objective of DRL is their use in a dynamic and continuous process of optimization. In order to be able to define DRL it is recommended that more than 50 cases are analysed [13,14]. It should be noted that the DRL are typically established after a survey between different centres and not only from a single Hospital. Following the UK recommendations, as presented by Marshall [15], establishing national DRLs would require

a minimum of 20 centres and at least 10 patients for each examination room, thus 200 patients minimum. Hospitals should adopt the national DRLs for use locally or establish their own DRLs based on local practice, if sufficient local data are available. The aim of this study was to propose local diagnostic reference levels (DRL) for exposure to radiation during diagnostic procedures and neuroradiological interventions such as cerebral angiography and embolisation of cerebral aneurysms (intra-cranial aneurysms and arteriovenous malformations). This study is based on data from 113 cerebral angiography procedures and 82 cerebral embolisation procedures carried out at the Department of Radiology of the *Fondazione I.R.C.C.S. Policlinico San Matteo*.

Material and methods

Description of the pathologies and their classification

Cerebral aneurysms are circumscribed dilations of intra-cranial arteries and are generally saccular. They have a proximal neck and a distal base, this latter usually with a more fragile wall that is more likely to rupture. Cerebral aneurysms occur more frequently in adults than in children and more commonly in women than in men; they can present at any age but are more common between the fourth and seventh decades of life. Aneurysms can be treated via direct surgical craniotomy or by embolisation. The choice of treatment, most suitable for the individual patient, is determined by the neurosurgeon and the neuroradiologist during the diagnostic angiographic examination. Angiography enables the aneurysmal sac to be visualised as well as any areas of thrombosis within it, and shows the position and size of the neck and its relationship to other vessels, in particular the artery of origin. Angiography is considered the gold standard for the diagnosis and follow-up of vascular malformations within the brain and, specifically, for aneurysms and AVM. The choice of treatment depends on the type of aneurysm, its site, its size and the clinical condition of the patient.

Endovascular treatment (coiling) is carried out by the controlled deployment of coils of various shapes and sizes within the aneurysmal sac in order to reduce or block the supply of blood into the aneurysm. The coils, delivered with the help of a microcatheter and released within the sac, become modelled there in such a way that they fill all the space within the aneurysm, causing its obliteration and excluding it from the arterial blood circulation (Fig. 1).

Intra-cranial aneurysms are classified according to their shape, size and anatomical site, with these characteristics

Figure 1 Endovascular coiling of ruptured intra-cranial aneurysm. Panel A: drawing of a platinum coil after deployment. Panel B: a cerebral angiogram of a saccular aneurysm of the apex of the carotid siphon. Panel C: the microcatheter within the sac of the aneurysm. Panel D: obliteration of the aneurysmal sac with a group of coils.

being very important when evaluating the appropriate treatment.

The various types of intra-cranial aneurysm are described in [Table 1](#).

Most intra-cranial aneurysms are saccular, while dissecting, fusiform, mycotic, traumatic and Charcot-Bouchard's aneurysms are less common.

Saccular intra-cranial aneurysms are generally classified on the basis of the maximum diameter of the sac into three groups: "small" (aneurysmal sac less than 10 mm), "large" (the maximum diameter of the sac ranges between 10 and 25 mm) and "giant" (an aneurysmal sac with a diameter greater than 25 mm). Small and large aneurysms were considered in this study, since there was only one case of a giant aneurysm. The strategy regarding giant aneurysms, in particular, has changed: embolisation with coils can cause a significant change in the physiology of the aneurysm, transforming it into a heavy, traumatic mass of metal. Nowadays, the often preferred strategy is that of occlusion – if possible – of the feeding vessel with detachable balloons or with flow-diverter stents which occlude the neck of the aneurysm without having to fill the sac itself with coils.

Aneurysms are also classified according to their site: it is essential to determine whether the aneurysm is intradural or extradural, since these two types of aneurysms have different clinical and therapeutic implications. The origin of the ophthalmic artery provides a reliable angiographic reference point for distinguishing extradural aneurysms from intradural ones ([Fig. 2](#)).

The most frequent site of cerebral aneurysms is the circle of Willis and in particular, the anterior circle (involved in 85% of cases), at the junction of the anterior communicating artery and the anterior cerebral artery, at the origin of the posterior communicating artery from the internal carotid artery and at the bifurcation of the middle cerebral artery; as far as regards the posterior circle (involved in 15% of cases), the sites most commonly affected are the junction between the basilar artery and the superior cerebellar artery or anterior inferior cerebellar artery and at the origin of the posterior inferior cerebellar artery where it comes off the vertebral artery.

Patient dose values

We extracted a sample of 113 cerebral angiography procedures (in 100 patients: 61 women and 39 males) and 82 procedures of embolisation of cerebral aneurysms (in 72 patients: 46 women and 26 males; mean age 56.3 years, age range 23–79 years). The 82 embolisation procedures were performed for 72 intra-cranial aneurysms and 10 AVM. The angiographic system used was a monoplane Philips Allura 15 with a rotational programme; the system is equipped with an image intensifier with a field of view (FOV, Φ) 38, 31, 25, 20 or 17 cm in diameter. Enlargements with FOV of 17 and 20 are often used in cerebral embolisation procedures to have a high resolution during the placement of the Guglielmi coils. The total filtration is 3 mm Al in the digital image acquisition mode and varies in the three pulsed fluoroscopy modes: LOW (12.5 images/s – total filtration: 4 mm Al + 0.1 mm Cu), NORMAL (12.5

Table 1 Classification of cerebral aneurysms.

Saccular	Small round aneurysm, with a neck
Fusiform	Dilation of the whole wall of the vessel, usually as a result of diffuse atherosclerosis; rarely ruptures
Traumatic	Aneurysm which usually results from stretching of the artery, but which can also be caused by a direct lesion. Such aneurysms are more common in the extracranial carotid circulation, epiaortic and extradural vessels
Mycotic	Aneurysm resulting from an infection in which septic emboli lead to the development of arteritis
Charcot-Bouchard	Microscopic aneurysm due to hypertension, usually occurring in the lenticulostriate and perforating arteries of the basal ganglia or brainstem
Dissecting	Forms when the blood passes between the walls of the artery, separating the tunica intima from the muscle layer. Can be traumatic or of a variety of other aetiologies (e.g. Marfan's syndrome)

images/s – total filtration: 3 mm Al), and HIGH (25 images/s – total filtration: 4 mm Al + 0.1 mm Cu). Fluoroscopy mode mostly used is the NORMAL mode. In the fluoroscopy mode (NORMAL mode), the maximum dose rate (FOV 17) was 32 mGy/min; after technical intervention was reduced

to 23 mGy/min. The dose per image in the radiography mode was 3 mGy/frame for FOV 17.

The system includes an appropriately calibrated transmission chamber (KERMAX – plus-Air Kerma Product Meter Scanditronix, Schwarzenbruck). The patient dose (KAP

Figure 2 Cerebral circulation and the circle of Willis.

values) presented in this report are corrected for the KAP calibration. The KAP values were not corrected by the attenuation of the table and the mattress (attenuation measured 10%).

The other factors analysed besides the KAP were fluoroscopy time and number of frames for each procedure (both diagnostic and therapeutic) and the degree of correlation between these variables and the KAP. Third quartiles from the total dosimetric databank were calculated and proposed as provisional local DRL for KAP, fluoroscopy time and number of images.

Statistical analysis

Data are described by mean and SD if continuous and as counts and percent if categorical. Variables measuring the radiation exposure were dichotomised according to whether the exceeded or not predefined cut-offs for the DRL ($>486.11 \text{ Gy cm}^2$ for total KAP; $>46.15 \text{ min}$ for fluoroscopy time, >664.75 for number of frames). The association between exceeding DRL and location (easy/difficult access) and dimension (small/large) of the aneurysms was assessed by means of the Fisher's exact test. Odds ratio (OR) and 95% confidence intervals (95%CI) were computed with a logistic model, to measure the strength of any association. Given that it was hypothesised that a putative association between exceeding the DRL and dimension of the aneurysm would be affected by the location of the latter, prior subgroup analysis by location was programmed.

All tests were two-sided; p -values <0.05 are considered statistically significant. Stata 11 (StataCorp, College Station, TX, USA) was used for computations.

Results

We checked the correlation between KAP and the fluoroscopy time and the number of cine frames. Pearson's correlation test was used to assess whether the KAP is linearly related to the fluoroscopy time and the number of images. A p -value <0.0001 was considered statistically significant. In the case of cerebral angiography there was a good

correlation between KAP_{TOT} and fluoroscopy time ($n = 113$, $r = 0.7349$, $p < 0.0001$, $r^2 = 0.5401$) and a weaker correlation between KAP and the number of frames ($n = 113$, $r = 0.6416$, $p < 0.0001$, $r^2 = 0.4117$). In the case of cerebral embolisation there was a poor correlation between KAP and fluoroscopy time ($n = 82$, $r = 0.6790$, $p < 0.0001$, $r^2 = 0.4610$) and a good correlation between KAP and number of images ($n = 82$, $r = 0.7343$, $p < 0.0001$, $r^2 = 0.5392$).

The number of patients in each category and the range, median, mean and standard deviation (SD), 75th percentile and 10th percentile of KAP, fluoroscopy time and number of frames for diagnostic and therapeutic procedures are given in Table 2a.

Figures 3 and 4 show values of KAP, histograms for cerebral angiography (113 procedures) and cerebral embolisation (82 procedures).

In both cases the distribution is skewed and asymmetrical with a main peak, a tail and a few extreme values. These histograms are typical of what is expected for examinations involving fluoroscopy.

When evaluating the patient dose it is important to take into account the complexity of the individual lesion and the ability of the interventional neuroradiologist to perform fine manipulation of the catheter in the region of interest also affects the total exposure time, which is directly proportional to the patient radiation dose. In the case of aneurysm embolisation (intra-cranial aneurysms), in this first phase we evaluated whether the complexity of the procedure was related to the size of the aneurysm and its location. For this purpose we re-calculated the DRL only for the intra-cranial aneurysms, excluding the AVM, and analysed the possible causes of exceeding the DRL, hypothesising that greater exposure could be related to the complexity of the intervention. Operator-dependency and variability due to the learning curve were not taken into consideration since all the procedures were carried out by the same person with more than 10 years' experience and an annual case burden of more than 50 procedures. With regards to the operator and the dependence of dose data on this variable, Verdun et al. [16] found, in the diagnostic procedures that they evaluated,

Table 2a KAP, fluoroscopy time and number of frames for diagnostic and interventional procedures.

Procedure	Sample size		KAP (Gy cm ²)	Fluoroscopy time (min)	Number of frames
Diagnostic (113 procedures)					
Cerebral angiography	100 patients	Mean ± SD	142.10 ± 75.51	9.89 ± 8.27	242 ± 117
		Median	131.37	8.5	220
		3rd quartile	180.415	12.3	316.75
		Range	33–522.87	1.0–48	14–584
		10th percentile	56	2.92	118.60
Interventional (82 procedures)					
Cerebral embolisation (embolisation for aneurysm or AVM)	72 patients	Mean ± SD	382.8 ± 176.21	37.22 ± 16.73	574 ± 295
		Median	351.92	34.60	558.50
		3rd quartile	487.42	46.30	717
		Range	120.93–943.689	7.5–92.3	150–1956
		10th percentile	192.53	16.96	256.20

Figure 3 Histogram of total KAP values for cerebral angiography.

Figure 4 Histogram of total KAP values for cerebral embolisation.

“the largest variability was observed for cerebral examinations in spite of the fact that these examinations were systematically performed by “senior” radiologists”, that is, radiologists with more than 5 years’ experience”. Aroua et al. [17] observed a great variability among the parameters for this type of procedure, which is “usually performed by senior radiologists and hence the high doses are due less to a lack of training than to the complexity of the case”.

The number of patients undergoing cerebral aneurysm embolisation, the range, median, mean and SD values, 3rd quartile and 10th percentile of KAP, fluoroscopy time and number of frames are given in Table 2b. This table shows the values of exposure parameters for the embolisation procedures of cerebral aneurysms according to the degree of complexity.

The procedures were classified on the basis of the size of the aneurismal sac (small and large) as well as according to the location of the aneurysm, assigning an index of complexity of 0 to procedures carried out on aneurysms in the apex of the basilar artery and the siphon of the interior carotid artery, and an index of complexity of 1 for those located in the following anatomical districts: anterior communicating artery, posterior communicating artery, posterior circle, posterior inferior cerebellar artery – anterior inferior cerebellar artery and the pericallosal/callosomarginal artery bifurcation. For each group we determined the degree of correlation between the parameters described above (size and position of the aneurysm) and analysed when the DRL for KAP, fluoroscopy time and number of frames were exceeded. Access to the aneurysm was defined as easy for 37 (51%) of the procedures and difficult for the remaining 35. Twenty-two (31%) of the aneurysms were large and 50 were small. The mean KAP was 364 Gy cm² (SD = 162), the mean fluoroscopy time was 36 min (SD = 16) and the number of frames per procedure was 533 (SD = 245). For each of the considered

Table 2b KAP, fluoroscopy time and number of frames for cerebral embolisation.

Procedure	Sample size		KAP (Gy cm ²)	Fluoroscopy time (min)	Number of frames
Interventional (72 procedures)					
Cerebral embolisation (embolisation for aneurysm)	64 patients	Mean ± SD	369.54 ± 162.29	35.86 ± 15.64	533 ± 245
		Median	349.305	33.65	528
		3rd quartile	486.11	46.15	664.75
		Range	120.93–940.383	7.5–75	150–1326
		10th percentile	120.93	8	150
Interventional (37 procedures)					
Cerebral embolisation (index of complexity 0)	35 patients	Mean ± SD	396.78 ± 165.30	39.33 ± 16.92	597 ± 267
		Median	388.89	40.9	608
		3rd quartile	468.06	51,10	775
		Range	135.72–940.38	7.5–75	188–1326
		10th percentile	219.41	18.92	298
Interventional (35 procedures)					
Cerebral embolisation (index of complexity 1)	34 patients	Mean ± SD	340.73 ± 156.23	32.19 ± 13.43	466 ± 201
		Median	293.19	33	472
		3rd quartile	491.12	40.15	580
		Range	120.93–797.35	13.6–63.1	150–901
		10th percentile	191.75	16.28	244

parameters, 18 (25%) procedures were classified as having exceeded the DRL (total KAP $>486.11 \text{ Gy cm}^2$, fluoroscopy time $>46.15 \text{ min}$ and number of frames >664.75). In five instances (7%) over-exposure was recorded for all three parameters, in nine cases (13%) for two parameters and in 21 cases (29%) for one of them; thus, 37 procedure (51%) could have been considered to have been performed without exceeding the DRL. The association between exceeding the DRL and location and/or size of the aneurysm is summarised in Table 3. As shown, the percentage of examinations in which the DRL were exceeded was similar for aneurysms with easy and difficult access; this percentage was higher (although not significantly so) for large aneurysms than for small aneurysms, with a two-fold increase in odds of exceeding the DRL (36% vs 20%, OR 2.3). This behaviour was confirmed after stratification by location. However, the percentage of procedures in which the DRL for both fluoroscopy time and number of frames was smaller (although not significantly so) for locations with difficult access, with a two-fold and three-fold decreases in the odds of exceeding the DRL (17% vs 32%, OR 0.4 and 35% vs 14%, OR = 0.3, respectively), while it was slightly higher for larger aneurysms than for smaller ones. When stratifying for location, for large aneurysms the time was exceeded more frequently for those with easy access than those for which the access was difficult. Conversely, the number of frames was less frequently exceeded for larger aneurysms with easy access and more frequently for larger aneurysms to which access was difficult. Finally when considering exceeding the DRL as a whole, this was significantly less likely for aneurysms in difficult locations, with a three-fold decrease in the odds of exceeding the DRL (34% vs 62%, OR 0.3) and more frequent (but not significantly so) for larger aneurysms, with a more than two-fold increase in the odds of exceeding the DRL (64% vs 42%, OR = 2.4). After stratification by location, larger aneurysms tended to be associated with a higher odds ratio of exceeding the DRL.

Discussion

Tables 4 and 5 present comparisons between our results and those published in the literature. In particular, Table 5 reports the results related to all the cerebral embolisation procedures (intra-cranial aneurysms and AVM) in order to be able to compare the published data. What is intended by cerebral embolisation, as specified by the various authors, is described below the table. The sample size (number of patients) is also shown in tables, in order to give an impression of the significance of the data.

For cerebral angiography procedures, the mean fluoroscopy time and the mean number of frames were lower in our patients than in the other studies: indeed, the number of frames was more than double in some other studies. The associated KAP can be up to 523 Gy cm^2 with an average of 142 Gy cm^2 . For this type of examination, Brambilla et al. [19] reported a range of KAP from 19 to 401 Gy cm^2 , with an average of 158 Gy cm^2 and Aroua et al. [17] reported a range from 8 to 996 Gy cm^2 , with an average of 121 Gy cm^2 .

It appears from Table 2a that the fluoroscopy time is about three times longer for cerebral embolisation than

Table 3 Association between values over the DRL and characteristics of the aneurysms (location and size).

Aneurysm	Total KAP over DRL			Time over DRL			Number of frames over DRL			Any value over DRL		
	N (%)	OR (95%CI)	p-value ^a	N (%)	OR (95%CI)	p-value ^a	N (%)	OR (95%CI)	p-value ^a	N (%)	OR (95%CI)	p-value ^a
Overall												
Location			1.00			0.18			0.06			0.021
Easy access	9 (24%)	—		12 (32%)	—		13 (35%)	—		23 (62%)	—	
Difficult access	9 (26%)	1.08 (0.37–3.13)		6 (17%)	0.43 (0.14–1.32)		5 (14%)	0.31 (0.10–0.98)		12 (34%)	0.32 (0.12–0.83)	
Size			0.13			0.39			0.77			0.13
Small	10 (20%)	—		11 (22%)	—		12 (24%)	—		21 (42%)	—	
Large	8 (36%)	2.29 (0.75–6.94)		7 (32%)	1.65 (0.54–5.07)		6 (27%)	1.19 (0.38–3.72)		14 (64%)	2.42 (0.86–6.80)	
Stratified by location												
Easy access (N = 37)			0.14			0.73			0.31			0.51
Small	3 (14%)	—		6 (29%)	—		9 (43%)	—		12 (57%)	—	
Large	6 (34%)	3.6 (0.73–17.60)		6 (37%)	1.50 (0.37–5.60)		4 (25%)	0.44 (0.11–1.84)		11 (69%)	1.65 (0.42–6.46)	
Difficult access (N = 35)			0.63			1.00			0.19			0.39
Small	7 (24%)	—		5 (17%)	—		3 (10%)	—		9 (31%)	—	
Large	2 (33%)	1.57 (0.23–10.50)		1 (17%)	0.96 (0.09–10.1)		2 (33%)	4.33 (0.54–35.5)		3 (50%)	2.22 (0.37–12.2)	

^a Fisher's exact test.

Table 4 Cerebral angiography: comparison with the literature data.

Reference	N. of patients		Fluoroscopy time (min)	KAP (Gy cm ²)	N. of frames
This study	100	Mean	9.89	142.10	242
		Median	8.50	131.37	220
		3rd quartile	12.30	180	317
		Range	1–48	33–523	14–584
Verdun et al. [16]	91	Mean	—	107	—
		Median	—	—	—
		3rd quartile	—	124	—
		Range	—	—	—
Aroua et al. [17]	91	Mean	12.6	121	679
		Median	—	—	—
		3rd quartile	15	125	480
		Range	2–85	8–996	32–5486
McParland [18]	28	Mean	12.1	74.1	—
		Median	9.9	69.6	—
		3rd quartile	14.2	82.5	—
		Range	2.9–36	21.4–196	—
Brambilla et al. [19]	188	Mean	13.7	158	—
		Median	—	152	—
		3rd quartile	17.5 ^a	198	—
		Range	—	19–401	—
Bor et al. [20]	27	Mean	10.6	91.5	481
		Median	—	—	—
		3rd quartile	—	—	—
		Range	1.7–33	29.2–217.1	149–1088
Vano et al. [21]	13	Mean	—	68.2	—
		Median	—	73.1	—
		3rd quartile	—	82.8	—
		Range	—	16.3–136	—
Papageorgiou et al. [22]	33	Mean	9.8	128	254
		Median	9.6	104	247
		3rd quartile	—	—	—
		Range	1.9–24.4	33–261	143–432
Vano et al. [23]	72	Mean	—	—	—
		Median	—	—	—
		3rd quartile	12	107	550
		Range	—	—	—

^a established from the mean value.

for cerebral angiography. The average KAP related to cerebral embolisation was 382 Gy cm², values of as high as 944 Gy cm² have been recorded. Our KAP values are comparable to those reported in the literature.

In order to be able to compare the doses between populations, the KAP must be normalised as a function of differences in size of the patients. This normalisation is not necessary for fluoroscopy time or number of frames, because these are not influenced by body size. However, in the specific case of cerebral procedures, Miller et al. [25] showed that some parts of the body, such as the head, “where size ranges relatively little with body weight in adults, size correction and weight banding yielded values similar to the uncorrected values”.

For cerebral angiography the 75th percentiles of both fluoroscopy time and number of frames in our study were lower than the proposed values; the KAP value was much higher than proposed but lower than that suggested at a local level by Brambilla et al. [19]. Vano et al. [14] proposed

values of 120 Gy cm² for KAP, 15 min for fluoroscopy time and 500 for the number of frames as preliminary European DRL for cerebral angiography. They suggested that local data should be collected from at least 50 patients and the mean value calculated for a comparison with the proposed levels. In our study the mean calculated values were 142 Gy cm², 9.9 min and 242 for KAP, fluoroscopy time and number of frames, respectively. In Switzerland, Aroua et al. [17] proposed national DRL for cerebral angiography of 125 Gy cm² for KAP, 15 min for the fluoroscopy time and 480 for the number of frames. According to the indications of Vano et al. [14], if we limit ourselves to comparing our mean values with those reported above, it can be seen that the fluoroscopy time and number of frames in our study were lower, whereas our KAP values were 14% higher, presumably due to the type of fluoroscopy used with different instruments (different filtration, continuous or pulsed and probably, in our case, a non-optimized value for the dose per image in radiography mode).

Table 5 Cerebral embolisation: comparison with published data.

Reference	N. of patients		Fluoroscopy time (min)	KAP (Gy cm ²)	N. of frames
This study	72	Mean	37.22	382.18	574
		Median	34.60	351.91	558
		3rd quartile	46.30	487	717
		Range	7.5–92.3	120.93–943.68	150–1956
Verdun et al. [16]	58	Mean	—	335	—
		Median	—	—	—
		3rd quartile	—	352	—
		Range	—	—	—
Aroua et al. [17]	52	Mean	36.5	335	760
		Median	—	—	—
		3rd quartile	50	440	800
		Range	3.3–134	24–1345	60–3348
McParland [18]	5	Mean	34.1	105	—
		Median	25.5	85.4	—
		3rd quartile	—	—	—
		Range	15.2–55.8	57.2–201	—
Brambilla et al. [19]	25	Mean	9.9	329	—
		Median	—	263	—
		3rd quartile	12.7 ^a	338	—
		Range	—	65–1221	—
Bor et al. [20]	21	Mean	48.4	215.7	1250
		Median	—	—	—
		3rd quartile	—	—	—
		Range	5.3–140	100.2–394	526–1912
Miller et al. [24]	356	Mean	87.1	319.87	1053
		Median	—	—	—
		3rd quartile	—	—	—
		Range	2.6–313.7	3.98–1351.11	71–2654

This study: intra-cranial aneurysms, AVM.

Verdun et al. [16]: cerebral embolisation – AVM, arteriovenous fistulae, intra-cranial aneurysms, tumours or haemorrhagic lesions.

Aroua et al. [17]: AVM, arteriovenous fistulae, intra-cranial aneurysms, tumours or haemorrhagic lesions.

McParland [18]: cerebral embolisation.

Brambilla et al. [19]: embolisations and placement of stents.

Bor et al. [20]: cerebral AVM, aneurysms and other intra-cranial vascular pathologies.

Miller et al. [24]: neuroembolization head, AVM, aneurysms and tumours.

^a Established from the mean value.

For cerebral embolisation 75th percentiles of our KAP values, fluoroscopy times and numbers of frames were comparable to those proposed by Aroua et al. [17] as Swiss national DRL. Miller et al. [25] recently proposed DRL, not corrected for body size, in the USA, for certain interventional radiology procedures including cerebral embolisation, divided into those for AVM, aneurysms and tumours. They proposed the following DRL for AVM – 550 Gy cm² (75th percentile 505 Gy cm²) for the KAP, 135 min for fluoroscopy time and 1500 for the number of images – while the corresponding proposals for aneurysms were 360 Gy cm² (75th percentile 341 Gy cm²), 90 min and 1350.

The differences between proposed DRL can be large for a variety of reasons including differences in the definition of the type of examination and in the techniques used between centres, the complexity of the procedures (in our series the procedures were carried out in a University Hospital, in which the proportion of complex procedures may be relatively high and there is a certain number of junior radiologists undergoing training), and the series

examined. The variability of the KAP as a function of the number of frames and the fluoroscopy time depends of various factors, such as the size of the fields and the angle of incidence.

We analysed how size of the aneurysmal sac and the site of the aneurysm could affect the complexity of the procedure and, in particular, the likelihood of exceeding the DRL. We found that DRL are exceeded significantly less frequently for aneurysms considered to be of difficult access, and more frequently, but not significantly so, for large aneurysms. Depending on their location, large aneurysms tend to be associated with a greater probability of exceeding the DRL. One factor that it seems must be taken into account with this type of procedure is the psychological approach of the operator to the single case. We re-calculated the DRL according to the size of the aneurysmal sac: for small aneurysms the calculated DRL for the KAP, fluoroscopy time and number of frames were 449.59 Gy cm², 43.2 min and 661, respectively; for large aneurysms the corresponding DRL were 505.47 Gy cm², 53.8 min and 720. In spite of the limited

statistics, it appears that the DRL for small aneurysms were lower than those for large aneurysms. The DRL obtained depending on anatomical site were 473.06 Gy cm², 51.03 min and 786 for those defined as having an index of complexity 0 and 493.94 Gy cm², 44.45 min and 661 for those designated as having an index of complexity of 1. In spite of these differences and considering that the DRL calculated for all the therapeutic procedures are similar to those calculated considering only intra-cranial aneurysms, we propose retaining a single set of DRL and, at the moment, it would seem justified to use a the DRL for embolisation procedures, even in the presence of very different clinical pictures.

Table 2a also shows the values for the 10th percentile. An International Atomic Energy Agency study recommended the 10th percentile as an 'action level' below which an investigation is needed on how to the practice is being implemented. "If mean values are greater than DRL, the entrance dose rate at the image intensifier and the dose/image should be investigated first by comparing the current values with those obtained during the acceptance test. As a second step, the examination protocol should be verified" [23].

If the mean dose at the local institution is less than the 10th percentile for the same procedure in the population used to define diagnostic reference levels, evaluation of image quality should be preferred [10]. Our values, for both types of procedure, are above the 10th percentile.

We are currently evaluating with the neuroradiologist the feasibility of defining a more complete index of complexity for the therapeutic procedures (distinct indices of complexity for AVM and intra-cranial aneurysms), as already done in the field of cardiology (e.g. for PTCA procedures). The index of complexity could take into account the age and gender of the patient, the size of the aneurysmal sac or AVM, the number of embolisations, the number and type of coils used, etc. The degree of correlation between the index of complexity and the KAP, fluoroscopy time and number of frames, will then be evaluated.

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