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REVIEW **Open Access**

Diagnostic reference levels in interventional neuroradiology: a scoping review

Marvin Grech[1*], Francis Zarb[1], Reuben Grech[2], Neville Calleja[2] and Paul Bezzina[1]

Abstract

Objectives To review the literature on diagnostic reference levels (DRLs) in interventional neuroradiology (INR), summarise reported dose values, and examine the methodologies used for their establishment.

Materials and methods A scoping review was conducted using SCOPUS, Web of Science, PubMed, and ProQuest. Studies reporting DRLs for INR diagnostic procedures (cerebral angiography, (CA)) and therapeutic procedures (stroke thrombectomy, (ST); aneurysm coiling, (AC); arteriovenous malformation/fistula (AVM/AVF) embolisation) were included. Extracted data comprised dose metrics, sample size, percentile definition, procedure classification, and statistical approaches used for DRL derivation.

Results Thirty-nine studies reported DRLs for air kerma–area product (P_{KA}), fluoroscopy time (FT), and reference air kerma (RAK). Most studies defined DRLs using the 75th percentile, although variations were observed in percentile selection, procedure grouping, and inclusion criteria. Considerable heterogeneity in sample sizes and data collection methods was identified. Reported DRLs varied widely: for CA, P_{KA} 41–256.65 Gycm^2, FT 6–20 min, and RAK 289–921 mGy; for ST, P_{KA} 110–225.1 Gycm^2, FT 30–45 min, and RAK 730–1590 mGy; for AC, P_{KA} 52.1–487.4 Gycm^2, FT 16–90 min, and RAK 505–4750 mGy; and for AVM/AVF embolisation, P_{KA} 206.4–550 Gycm^2, FT 59–135 min, and RAK 2350–6000 mGy.

Conclusion DRLs in INR show substantial variability, partly driven by methodological inconsistencies. Greater standardisation of DRL derivation and reporting is needed to support harmonisation and optimisation.

Key Points

Question *How does the lack of international consensus on interventional neuroradiology (INR) diagnostic reference levels (DRLs), alongside inconsistent reporting, hinder benchmarking, optimisation, and radiation protection?*

Findings *DRLs are reported for major INR procedures, but vary widely across studies and procedure types.*

Clinical relevance *Differences in dose metrics, procedure classification, and data collection hinder comparison and benchmarking between centres. Standardised methods and harmonised reporting are crucial for effective dose optimisation and radiation protection in INR. Consistency in deriving DRLs would enable reliable benchmarking and support future registry-based initiatives.*

Keywords Interventional neuroradiology, Air kerma-area product, Reference air kerma, Fluoroscopy time, Diagnostic reference levels

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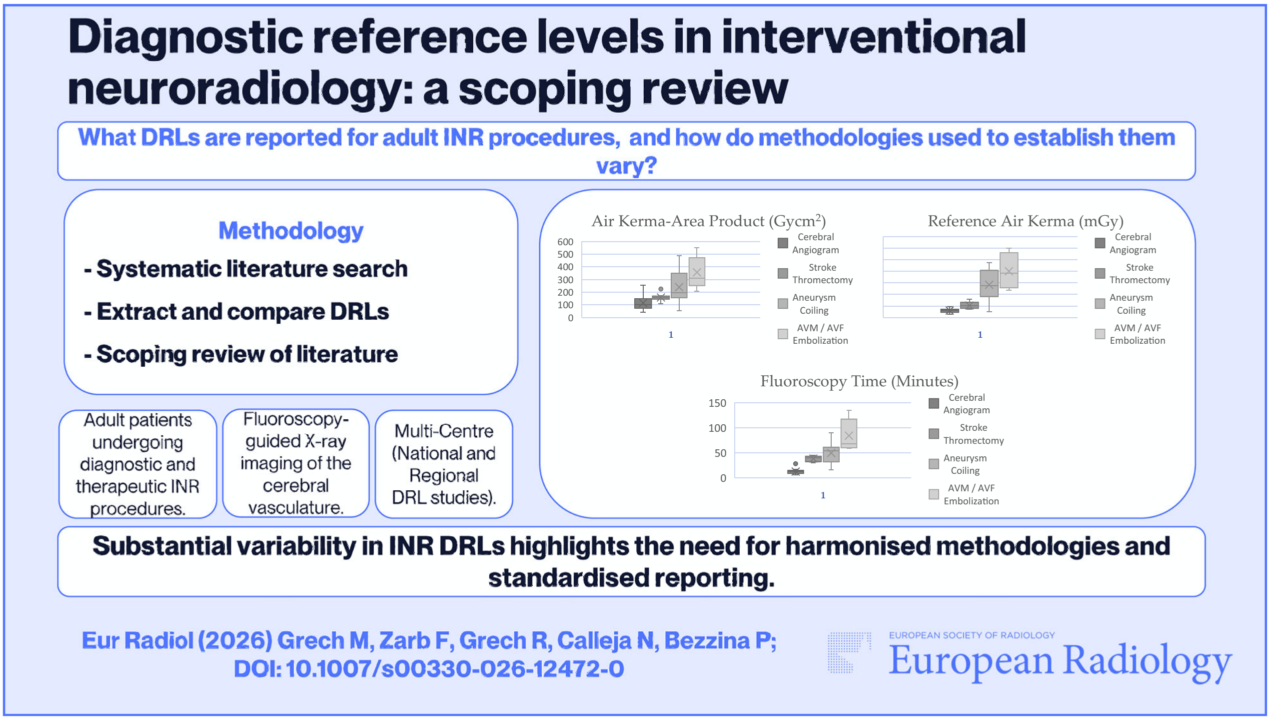
Graphical Abstract



Diagnostic reference levels in interventional neuroradiology: a scoping review

What DRLs are reported for adult INR procedures, and how do methodologies used to establish them vary?

Methodology

- **Systematic literature search**
- **Extract and compare DRLs**
- **Scoping review of literature**

Adult patients undergoing diagnostic and therapeutic INR procedures.

Fluoroscopy-guided X-ray imaging of the cerebral vasculature.

Multi-Centre (National and Regional DRL studies).

Substantial variability in INR DRLs highlights the need for harmonised methodologies and standardised reporting.

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Introduction

Interventional radiology (IR) has grown over the last decade, with the increase in average life expectancy and technological development, and it often represents a less invasive procedure alternative to surgery [1–4]. The number of IR procedures has increased in the last decade, and these results included only procedures involving imaging tests performed during IR in this period [5], with the actual number of procedures performed now expected to be larger.

When compared to other diagnostic radiographic examinations, IR examinations require higher radiation doses and longer exposure times. When one considers IR's increased use and high radiation dose, radiation protection and patient dose management are crucial, and efforts to optimise the IR procedures and establishment of diagnostic reference levels (DRLs) during IR procedures are therefore needed [5].

DRLs are a method of investigation of dose levels utilised as a tool to support and monitor optimisation of radiation protection in the medical exposure of patients for diagnostic and interventional procedures [6, 7]. The International Commission on Radiological Protection (ICRP) recommended that DRLs be set at the 75th percentile of the distribution of median values for DRL quantities for specific examinations at individual facilities across a country [6].

New IR systems have dose monitoring devices that track total air kerma-area product (P_{KA}), reference air kerma (RAK) at the interventional reference point, fluoroscopy time (FT), and total number of images (NI) recorded during digital acquisition, digital subtraction angiography, or cine runs [7]. All these quantities are considered as appropriate primary or secondary diagnostic reference quantities for IR procedures [8].

Variations exist in the way national DRLs are established, as not all countries may be using the same parameters to define their DRLs. The majority have national DRLs based only on P_{KA}, whereas the minority have all three quantities. This limits the possibilities for a thorough comparison due to limited DRL harmonisation [9].

The purpose of this scoping review was to explore the literature for established DRLs in adult interventional neuroradiology (INR) procedures, including both diagnostic and therapeutic applications. The review aims to identify any variations in DRL values, parameters used and evaluate the methodologies applied in their establishment.

The scientific value of this work lies in providing the first comprehensive scoping review dedicated exclusively to DRLs in INR. While individual studies and national

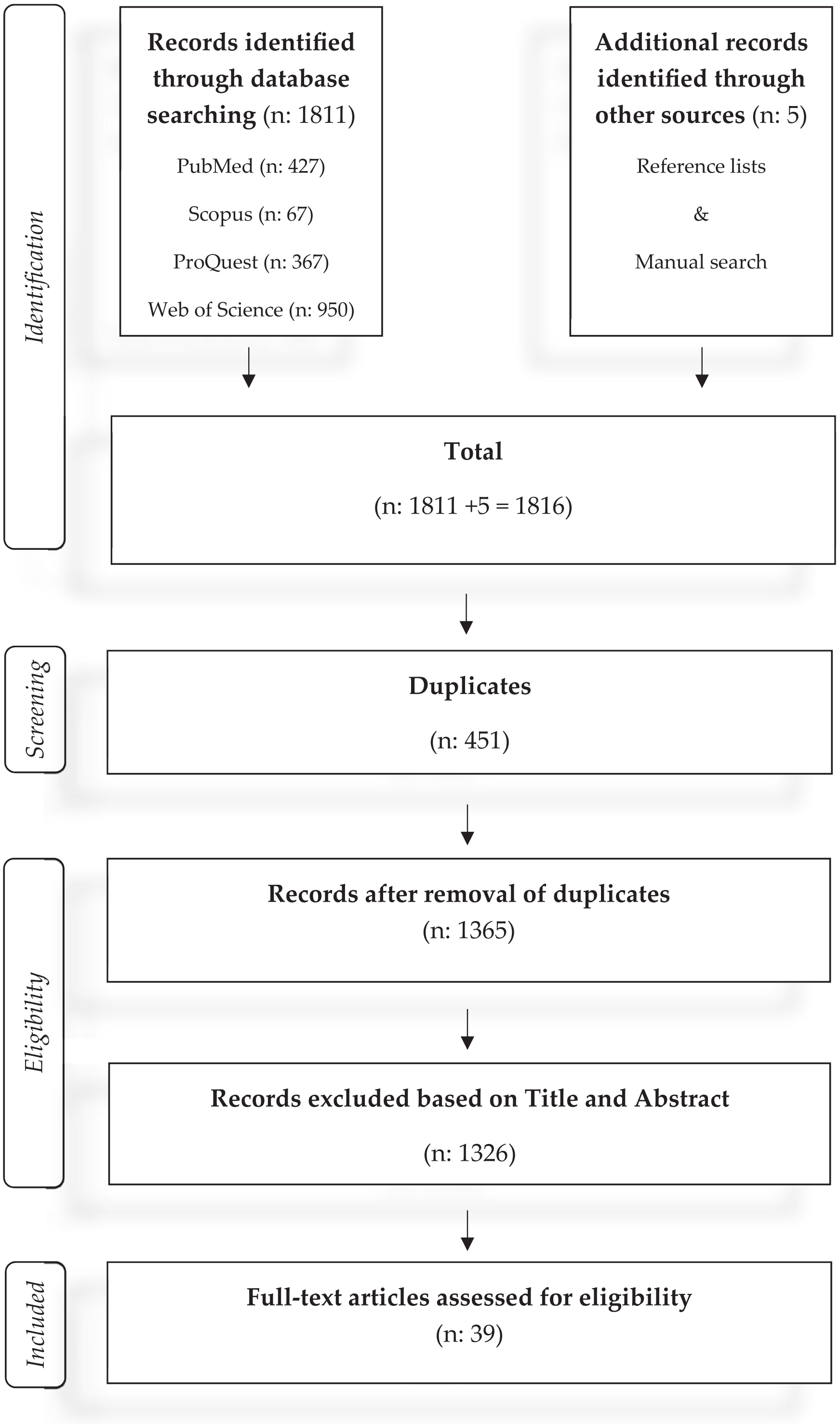

Fig. 1 Systematic literature search flowchart

reports exist, no prior review has systematically mapped the global literature, synthesised DRL data across the main INR procedures, and examined methodological variations in DRL establishment.

DRLs are typically established at the national level, reflecting local clinical practices, patient demographics, and equipment configurations. While such national DRLs are essential for internal benchmarking, direct international comparisons may be of limited relevance unless methodologies, including procedural definitions, dose indices, and data collection protocols, are standardised.

In addition to mapping existing DRLs, this review undertakes a critical synthesis of the methodological approaches used in their establishment. Given the substantial heterogeneity observed across studies, the review also aims to provide concrete, evidence-informed recommendations to support future harmonisation of DRLs in INR at national and international levels.

Materials and methods

Ethical approval was not required since this was a review of published literature.

An extensive electronic literature search on DRLs for INR diagnostic procedures (cerebral angiography) and therapeutic procedures (stroke thrombectomy, aneurysm coiling, arteriovenous malformations (AVM) and/or arteriovenous fistulas (AVF) embolisations) was carried out using databases such as 'Scopus', 'Web of Science', 'PubMed', and 'ProQuest' for any publications between 1998 to 2023. To enhance the sensitivity of the search, free text and subject headings (MeSH) were utilised. Five main keywords used for the search were: 'interventional neuroradiology', 'air kerma-area product', 'reference air kerma', 'fluoroscopy time', and 'DRLs'. Boolean combinations are provided as Supplementary Material Table 1.

Supplementary Material Table 2 presents the eligibility criteria for selected papers. Eligible publications were classified according to their major topic, which drove the formation of sections and subsections within this literature review. Figure 1 presents the flow of the systematic literature search, which ended up with a total of 39 papers being identified during the period 1998 to 2023.

Two independent reviewers (the researcher, an interventional radiographer with 27 years of experience, and a neuro-interventional radiologist with 25 years of experience) screened titles and abstracts against predefined inclusion and exclusion criteria (Supplementary Material Table 2). Full-text articles were then assessed for eligibility. Discrepancies between reviewers were resolved through discussion, with a third reviewer (an academic in radiography with more than 30 years of experience and with a special interest in interventional radiography) consulted when consensus could not be reached.

A scoping review methodology was chosen over a systematic review or meta-analysis due to the heterogeneity of the available literature. Studies varied widely in procedural classifications, dose indices reported, patient populations, and data collection methods, precluding the application of uniform inclusion criteria necessary for quantitative synthesis. The scoping review approach provided the flexibility to capture the breadth of available evidence, summarise DRL values across diverse contexts, and identify methodological gaps, thereby laying the groundwork for future systematic reviews when greater standardisation in reporting has been achieved.

Data from eligible studies were systematically extracted into a pre-designed spreadsheet capturing: study design, country, patient population, procedure type, dose indices reported (P_{KA}, RAK, FT) and methodological details such as collection techniques and equipment used.

DRL comparisons between studies were performed using the Kruskal–Wallis test to determine whether there is a statistically significant difference between the medians of P_{KA}, FT, and RAK [10]. The post hoc Dunn's test was conducted when the results of the Kruskal–Wallis tests were statistically significant, and this test determined exactly which groups are different. All statistical tests were carried out at a significance level (α) of 0.05.

Results

Characteristics of included DRL studies

From the 39 studies selected, 22 were prospective and 17 were retrospective studies, with all studies conducted using patient participants. Only one study also reported the use of phantoms.

Recorded DRLs as per literature findings

The procedures for which DRLs were established in the literature were: cerebral angiography, stroke thrombectomy, aneurysm coiling, and AVM/AVF embolisation.

Cerebral angiography

Table 1 shows the DRLs (3rd quartile values) for P_{KA}, FT, and RAK for all diagnostic cerebral angiography procedures, with those studies having their DRLs above the weighted mean shaded grey.

The lowest P_{KA} reported was 41 Gycm^2 [11] while the highest level was 256.65 Gycm^2 [12]. The ranges for FT varied from a minimum of 6 min [13] to a maximum of 28 min [14]. The minimum RAK was 289 mGy [15] and the maximum was 921.1 mGy [16].

Stroke thrombectomy

Table 2 shows the DRLs (3rd quartile values) for P_{KA}, FT, and RAK for all stroke thrombectomy procedures, with those studies having their DRLs above the weighted mean shaded grey.

Table 1 Cerebral angiography DRLs (3rd quartile values)

Author	**Year**	**Country**	**Institutions (*N*)**	**Sample size (*N*)**	**P_{KA} (DRL) (Gy/cm^2)**	**FT (DRL) (minutes)**	**RAK (DRL) (mGy)**
McParland et al [44]	1998	Saudi Arabia	1	28	82.5		
Brambilla et al [45]	2004	Italy		188	**198**	**17.5**	
Verdun et al [25]	2005	Switzerland	5	91	**124**		
Aroua et al [36]	2007	Switzerland	5	91	**125**	**15**	
Bleeser et al [29]	2008	Belgium	14	616	71		
Vano et al [46]	2008	Europe	3	72	**107**	**12**	
Trueb et al [26]	2009	Switzerland	20	32	**160**	8	
Alexander et al [34]	2010	USA	1		**102.4**		
Sandborg et al [47]	2010	Sweden	1	226	72		
Kien et al [48]	2011	France	9		**229**	**14**	
D'Ercole et al [22]	2012	Italy	1	100	**180.4**	**12.3**	
Zotova et al [11]	2012	Bulgaria	5	67	41	**12.2**	379
Soderman et al [23]	2013	Sweden	1	174	76	9	
Chun et al [38]	2014	South Korea	1	439	**154.2**	**14**	
Erskine et al [37]	2014	Australia	1	257	82.6	6.25	
Ihn et al [16]	2016	South Korea	23	490	**144.2**	**12.2**	**921.1**
Etard et al [27]	2017	France	34	695	87.5	10.3	628
Hassan et al [17]	2017	France	1	398	59.7	7.5	450
Sailer et al [49]	2017	Netherlands	1	112	44.5		
Acton et al [28]	2018	Ireland	1	189	96		
Rana et al [33]	2018	India	1	226	**121.97**		
Choi et al [35]	2019	South Korea	1	540	94.1	**13.8**	**690**
Rizk et al [13]	2019	Lebanon	6	310	83	6	**693**
Malan et al [15]	2020	South Africa	1	61	55	**14**	289
Ihn et al [18]	2021	South Korea	22	429	101.6	**13.3**	**711.3**
Papanastasiou et al [30]	2021	Greece	1	60	70.2	9.2	494
Opitz et al [12]	2022	Germany	1	71	**256.65**	**17.18**	
Tristram et al [9]	2022	Germany	1	314	100.6	**15.3**	525
Slave et al [14]	2023	South Africa	1	26	**209.3**	**28.4**	**868.5**
				Weighted mean	102.64	11.73	654.74

Bold values above the weighted mean

Table 2 Stroke thrombectomy 3rd quartile values

Author	**Year**	**Country**	**Institutions (*N*)**	**Sample size (*N*)**	**P_{KA} (DRL) (Gy/cm^2)**	**FT (DRL) (minutes)**	**RAK (DRL) (mGy)**
Hassan et al [17]	2017	France	1	73	110	30	1018
Acton et al [28]	2018	Ireland	1	10	**172**		
Farah et al [32]	2018	France	1	319	162	**42**	854
Guenego et al [19]	2019	International	5	520	148		730
Schegerer et al [31]	2019	Germany			158	35	
Pace et al [50]	2020	Malta	1	122	144.7		
Ihn et al [18]	2021	South Korea	22	326	**225.1**	**44.7**	**1590**
Tristram et al [9]	2022	Germany	1	457	151.9	40.3	**1032**
				Weighted mean	163.57	41.34	1012.57

Bold values above the weighted mean

Table 3 Aneurysm coiling 3rd quartile values

Author	Year	Country	Institutions (*N*)	Sample size (*N*)	P_{KA} (DRL) (Gy/cm^2)	FT (DRL) (minutes)	RAK (DRL) (mGy)
Brambilla et al [45]	2004	Italy					**4240**
Verdun et al [25]	2005	Switzerland	5	58	**352**	50	
Aroua et al [36]	2007	Switzerland	5	58	**440**	50	
Miller et al [24]	2009	USA	7	148	**339.4**	**90**	**4750**
Vano et al [51]	2009	Spain	1	325	**386**		**3900**
Alexander et al [34]	2010	USA	1		167.3		
Sandborg et al [47]	2010	Sweden	1	226	157		
Vano et al [51]	2010	Spain	1	383	**392**		3300
Kien et al [48]	2011	France	9		**349**	**58**	
D'Ercole et al [22]	2012	Italy	1	72	**487.4**	46.3	
Soderman et al [23]	2013	Sweden	1	138	196	16	
Chun et al [38]	2014	South Korea	1	111	**272.8**	**61.1**	
Erskine et al [37]	2014	Australia	1	91	152.9	32	
Borota et al [52]	2016	Sweden	1	35	97.39	**83.05**	1980
Ihn et al [16]	2016	South Korea	23	371	**271**	**64.7**	**4471.3**
Etard et al [27]	2017	France	19	427	186.5	**58**	2763
Hassan et al [17]	2017	France	1	71	111.9	34.8	1368
Acton et al [28]	2018	Ireland	1	109	123		
Rana et al [33]	2018	India	1	54	**370.78**		
Choi et al [35]	2019	South Korea	1	173	206.2	**60**	
Rizk et al [13]	2019	Lebanon	3	117	190	27	2422
Schegerer et al [31]	2019	Germany			192	54	
Malan et al [15]	2020	South Africa	1	55	63	25	505
Peter et al [21]	2020	South Africa	1	30	52.1	17.8	
Ihn et al [18]	2021	South Korea	22	327	199.9	**57.3**	**3458.7**
Tristram et al [9]	2022	Germany	1	129	186.8	**70**	1906
Slave et al [14]	2023	South Africa	1	15	**275**	34.1	1744
				Weighted mean	254.06	54.51	3309.89

Bold values above the weighted mean

The P_{KA} range was from a minimum of 110 Gycm^2 [17] to a maximum of 225.1 Gycm^2 [18]. The lowest FT range was 30 min [17], while the highest was almost 45 min [18]. The DRL in RAK ranged from 730 mGy [19] to 1590 mGy [18].

Aneurysm coiling

Table 3 presents the DRLs (3rd quartile values) from 26 studies for P_{KA}, FT, and RAK, for all aneurysm coiling procedures, with those studies having their DRLs above the weighted mean shaded grey. One study by Forbrig et al [20] was not included in the comparative DRL Table 3, as aneurysm coiling procedures were stratified into four distinct categories. This categorisation limited the ability to directly compare their reported DRLs with those from other studies, which typically present aggregated data for aneurysm coiling as a single category. The lowest P_{KA} was 52.1 Gycm^2 [21], whereas the highest was 487.4 Gycm^2 [22]. The lowest FT reported was that of 16 min [23] while the highest was 90 min [24]. The highest RAK was 4750 mGy [24], while the lowest was 505 mGy [15].

AVM/AVF embolisation

As per previous procedures, Table 4, shows the DRLs (3rd quartile values) for P_{KA}, FT, and RAK for all AVM/AVF embolisation procedures with those studies having their DRLs above the weighted mean shaded grey.

The lowest P_{KA} was 206.4 Gy/cm^2 [17] and the highest 550 Gy/cm^2 [24]. The lowest FT was approximately 59 min [12], while the highest was 135 min [24]. The RAK range was 2350 mGy [17] to 6000 mGy [24].

Table 4 AVM/AVF embolisation 3rd quartile values

Author	Year	Country	Institutions	Sample size	P_{KA} (DRL)	FT (DRL)	RAK (DRL)
			(*N*)	(*N*)	(Gy/cm^2)	(minutes)	(mGy)
Miller et al [24]	2009	USA	7	134	**550**	**135**	**6000**
Sandborg et al [47]	2010	Sweden	1	226	225		
Kien et al [48]	2011	France	9		**435**	61	
Etard et al [27]	2017	France	13	239	280.5	67.8	3224
Hassan et al [17]	2017	France	1	33	206.4		2350
Acton et al [28]	2018	Ireland	1	6	310		
Rana et al [33]	2018	India	1	7	288.54		
Ihn et al [18]	2021	South Korea	22	78	**412.3**	**99.3**	**4447.8**
Opitz et al [12]	2022	Germany	1	111	**507.33**	58.57	
				Weighted mean	348.63	86.37	4130.20

Bold values above the weighted mean

Discussion

Although formal quality assessment was not conducted, a qualitative appraisal of the included sources revealed considerable variation in methodological transparency, sample sizes, and national endorsement. DRLs derived from national surveys or endorsed by regulatory/professional bodies were considered more reliable and broadly applicable. Conversely, single-centre studies or those lacking detail on dose index definitions were less robust. The completeness of reported dose indices also varied, with some sources reporting only P_{KA}, while others included RAK and FT, limiting cross-study comparability.

Variations in patient doses were revealed in published studies between the contributing hospitals and at times even the same hospital for the same procedure [12, 13, 15, 25–28]. These variations in patient doses were attributed to the procedure complexity, patient morphology, type of equipment, imaging techniques and protocols, different dose reduction technologies, operators' skills and experience, and standardised method of data collection [12, 13, 15, 25–28].

As DRLs are generally defined at the national level, variations in methodology limit the direct comparability of values between countries. Without standardised approaches to parameter selection, data collection, and analysis, observed differences may reflect methodological divergence rather than genuine practice variation.

Procedure complexity

The complexity of an interventional procedure greatly impacts the amount of radiation administered [2]. Ideally, interventional procedures should have DRLs based on their difficulty level as suggested by ICRP 2017 [27]. Several reviewed studies have proposed local DRLs based on complexity for INR procedures, such as cerebral angiography, intracranial aneurysm embolisation, and arteriovenous malformations [22, 29–31]. The complexity demonstrates the ability to identify factors for INR procedures, categorising them as easy, medium, or complicated, and assigning DRL values accordingly [6]. Quantifying procedure complexity requires extensive clinical data, which is not always available, especially in retrospective research [27]. However, dividing the patients into complexity categories has further reduced the number of patients in each category, resulting in weakening the strength of the corresponding comparisons [30]. It may be the case that more complex procedures would require a longer FT, which may result in a higher $P_{KA.}$ The rating of complexity for this review was worked out based on the dose administered in $P_{KA,}$ FT, and RAK. Detailed $P_{KA,}$ FT and RAK for each procedure type from different authors are illustrated in Figs. 2–4.

The Kruskal–Wallis test indicated that for P_{KA}, FT and RAK (Figs. 2–4), there is a significant difference in the P_{KA}, FT and RAK between the different groups ($p < 0.001$). Since the results were statistically significant, post hoc Dunn's test using a Bonferroni corrected alpha of 0.0083 was conducted. This test indicated that the mean ranks of P_{KA}, FT and RAK for the following pairs are significantly different between them ($p < 0.05$).

Aneurysm coiling (45.23 Gycm^2) gives almost double the dose, and AVM/AVF embolisation (61.67 Gycm^2) gives almost triple the dose in terms of P_{KA} when compared to cerebral angiography (21.45 Gycm^2). This was also noted when AVM/AVF embolisation gave almost double the dose when compared to stroke thrombectomy (34.38 Gycm^2). From these results, AVM/AVF embolisation is indicated as the most complex procedure.

Cerebral angiography FT (11.29 min) was 3 times lower when compared to FT in aneurysm coiling (35.3 min) and 4 times lower when compared to the AVM/AVF embolisation (46.2 min). This shows that the more FT was required, the more complex the procedure.

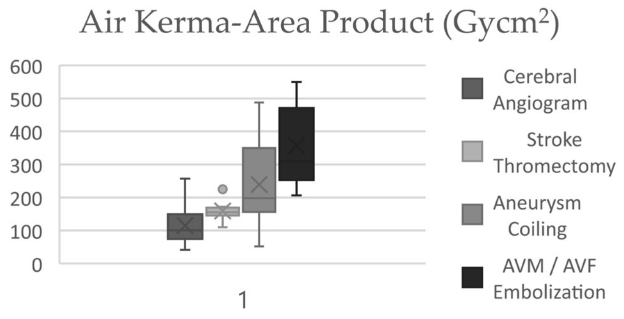

Fig. 2 Box-and-whisker plot showing P_{KA} (Gycm^2) variations amongst the procedures ($p < 0.001$)

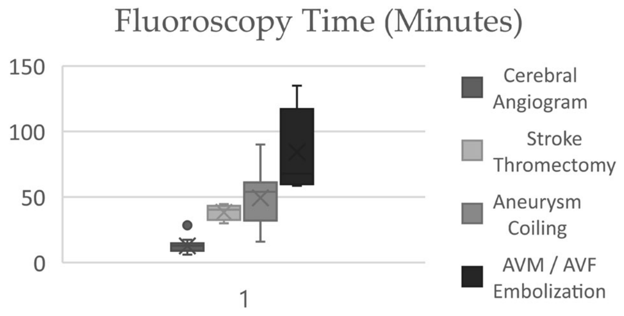

Fig. 3 Box-and-whisker plot showing FT (minutes) variations amongst the procedures ($p < 0.001$)

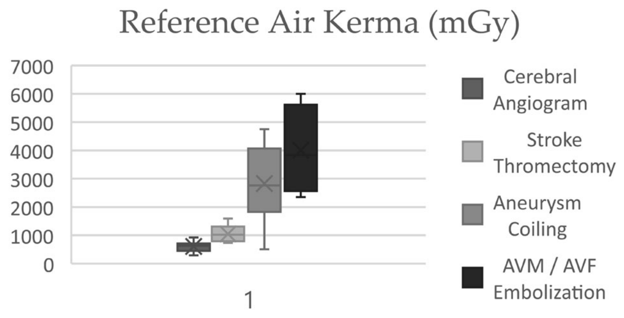

Fig. 4 Box-and-whisker plot showing RAK (mGy) variations amongst the procedures ($p < 0.001$)

When comparing RAK data of cerebral angiography (7 mGy) with aneurysm coiling (14.4 mGy) and AVM/AVF embolisation (27.5 mGy), this was almost double and triple that of the diagnostic procedure. From the mentioned results, aneurysm coiling and AVM/AVF embolisations have higher radiation doses due to being more complicated procedures.

Based on the indications from the findings of K_{PA}, FT, and RAK measures in the reviewed literature, a rate from 1 to 4 was assigned according to the procedure complexity, where 1 indicates the least complex and 4 being the most complex: cerebral angiography—1; stroke/mechanical thrombectomy—2; aneurysm coiling—3, and AVM/AVF embolisation—4.

Patient morphology

The difference in dose is influenced by several variables, including but not limited to patient factors, lesions, or pathological factors [14].

Adult DRLs are frequently specified for people of average size [28]. However, patients' gender did not influence the radiation dose to the patients during cerebral angiography. Studies did not consider the impact of patient morphology on the dose because the process takes place at the level of the head, which is not affected by gender [24, 32]. Nevertheless, collecting patient's body mass index, which may be a better predictor of dose than gender, was still important for neuro-interventions, as the initial access route may be from the femoral artery moving the catheter across the abdominal and thoracic areas, where the patient's anatomy and thickness may result in higher doses in men compared to women [32].

When compared to anterior circulation aneurysms, posterior cerebral circulation aneurysms are more difficult to treat due to unfavourable anatomy, a more frequent requirement for assist devices such as embolisation devices, balloon remodelling, and stents, which have a higher complication risk [28]. Separate DRLs were proposed for anterior and posterior circulation coiling procedures since aneurysm location is the main factor affecting radiation exposure during coiling procedures; however, this evaluation could not be performed from the reviewed studies evaluated as the location of the coils was not indicated [28].

Type of equipment

Higher P_{KA} may result from older equipment due to image intensifier deterioration becoming less sensitive to x-ray photons. To keep the same image quality, radiation exposures with older intensifiers must be increased [13, 23, 33]. The detectors used for IR have advanced over time [13, 33]. Flat panel detectors and pulsed fluoroscopy are now standard features on IR equipment [13, 23, 33].

Over the years, results demonstrated a gradual decrease in reported P_{KA}, owing to the implementation of digital technology, continuous optimisation of hardware and software for data acquisition and image generation, advancements in radiation protection systems integrated into x-ray equipment, improvement in fluoroscopy image quality and the possibility of storing the last image of a fluoroscopy series reducing the number of acquisitions. All these factors could explain radiation dose reductions [13, 23, 27, 33, 34].

Two types of equipment were encountered in the literature: conventional, that is, the Image Intensifier, and

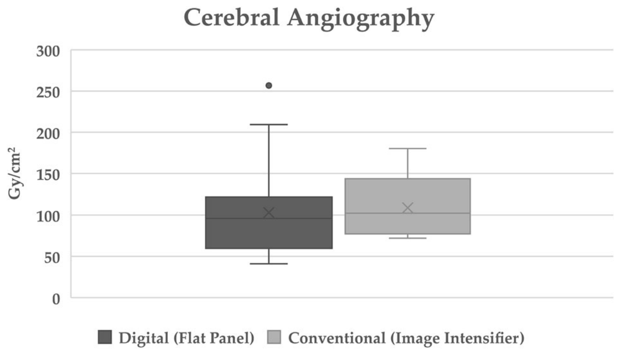

Fig. 5 Comparison of median values of P_{KA} (Gy/cm^2) in cerebral angiography ($p = 0.57$)

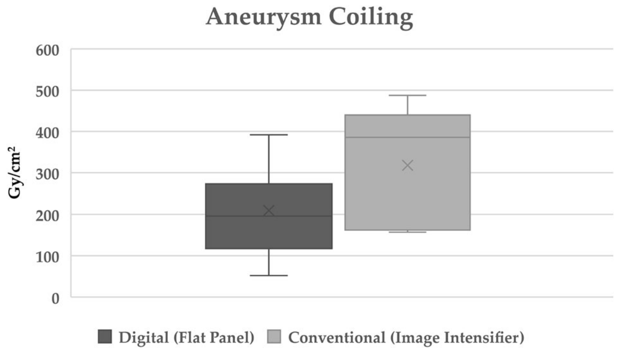

Fig. 6 Comparison of median values of P_{KA} (Gy/cm^2) in aneurysm coiling ($p = 0.20$)

digital, a Flat Panel detector. The radiation dose provided by these two categories of equipment was compared using the Mann–Whitney test.

Differences of the median in the two types of equipment in both cerebral angiography ($n = 24$) and aneurysm coiling ($n = 22$) did not achieve statistical significance ($p > 0.05$). This could have been due to the small population sample size, as it may have been too small to demonstrate any significant variation in the values (Figs. 5 and 6).

Variations in radiation dose indicated that, although not statistically significant, with the use of modern digital equipment, less radiation dose was administered when compared to conventional equipment.

Imaging techniques and protocols

Variations in DRLs can be attributed to a variety of reasons, including differences in imaging techniques and protocols used between centres [22]. A considerable dose variance is produced by differences in the number of frames, projections, and exposure parameters utilised in the procedures [22].

Interventional neuroradiologists attempt to use low pulse rate fluoroscopy whenever possible to reduce radiation exposure for the patient. The use of high FT values in some procedures may be explained using higher fluoroscopic rates [9, 11].

Different work practices may have an impact on the administered dose. Automated exposure algorithms, determined to be the most significant factor in influencing patient dose, may be used to manage fluoroscopy interventional procedures [16, 18].

Different dose reduction technologies

Roadmap fluoroscopy is one advanced technological method that allows for the visualisation of anatomic structures using image subtraction at peak intravenous contrast opacification, resulting in a significant reduction in the amount of image frames enabling dose savings [35]. Lower frame rates that give acceptable image quality could be used to reduce the radiation exposure by reducing the number of frames [35].

Neuro-interventional radiologists skills and experience

Significant variation was demonstrated in P_{KA}, FT, and the number of images obtained during cerebral angiography procedures conducted by experienced radiologists [36]. Lack of expertise among young radiology trainees is a primary cause of dose variability [36]. First-year training fellows are more likely to utilise more FT during the procedure than experienced operators and ascribed significant dose increases in teaching hospitals [36].

Standardised method of data collection

Since there is no broad agreement on adequate dosimetric quantities for radiation dose estimation, and because multiple dose metrics are used in published studies, comparing radiation doses at different sites becomes challenging [13, 23, 33]. Due to the lack of a standardised technique for collecting and reporting radiation exposure during neuro-interventional treatments, it was suggested that, to be able to compare practices in accordance with radiation safety rules, a multicentric database with standardised data as well as uniform neuro-interventional nomenclature is required [17].

Methodological synthesis and implications for DRL harmonisation

A critical examination of the included studies highlighted substantial variability in how DRLs were defined, calculated, and reported. Differences were observed in the selection of dose indices (e.g., P_{KA} alone versus full reporting of P_{KA}, RAK, and FT), inconsistencies in procedural categorisation (such as grouping initial and follow-up angiography together or combining coiling with diagnostic runs), and a lack of clarity regarding whether CBCT and ancillary acquisitions were included in DRL calculations. These methodological inconsistencies complicate interpretation and limit the reliability of cross-study comparisons, as reported differences may reflect variations in reporting practices rather than true differences in clinical performance or patient risk.

Furthermore, the heterogeneity in data collection approaches, ranging from manual extraction to automated system logs without standardised definitions, underscores the absence of a unified methodological framework. The lack of consistent reporting of patient morphology, equipment characteristics, fluoroscopic frame rates, and procedural complexity further restricts the ability to stratify and benchmark DRLs meaningfully. These findings emphasise the need for greater methodological alignment across institutions and countries to ensure that DRLs can fulfil their intended role as optimisation and benchmarking tools.

To support such harmonisation, several methodological priorities emerge from this synthesis. These include the adoption of a core set of dose indices, agreement on standardised procedural taxonomies, consistent inclusion or exclusion rules for CBCT and additional imaging runs, mandatory reporting of complexity and key patient and equipment factors, and the development of standardised data dictionaries and collection templates. Together, these measures would enhance DRL comparability, improve transparency, and enable robust regional or international analyses.

High P_{KA} is usually associated with high RAK [14]. The link between P_{KA} and FT was weaker, which was similar to earlier findings [30, 37]. No single dose parameter may be extrapolated solely to infer radiation exposure; instead, during radiation exposure optimisation, as many parameters as possible should be considered. This is supported by the ICRP's recommendations [6].

The following examples from the literature reviewed listed below confirm the lack of standardisation in data collection methods for DRL establishment.

Initial diagnostic angiography and follow-up angiographies were not separated as different categories [17]. While initial diagnostic angiography generally refers to the examination of four or more cerebral vessels, follow-up angiography will normally study two or three arteries, with the exception of AVM/AVF, resulting in a reduced radiation dose, and so their DRLs should be separate [17].

When diagnostic cerebral angiographies and endovascular coil embolisations were conducted in the same session, patient data were separated into two groups [38]. To date, this was the only published report with such segregated data [38]. Previous studies may have included these procedures under the coiling embolisation group, which may have increased the reported DRL for embolisation procedures [22, 24, 25, 36]. This was also reported by Papanastasiou et al [30], who explained that since comparable data were not included as independent entries in the system dose reports, their study did not provide a separate analysis of the doses delivered to patients by cone beam CT (CBCT) acquisitions conducted as part of the procedure. CBCT is only conducted during cerebral Angiograms, and CBCT dose data is put into system dose reports as part of the procedure [30].

This highlights the importance of a harmonised way of categorising interventional procedures. If the same procedure varies in the way it is conducted, then DRLs cannot be compared.

Although published after the predefined inclusion period, the recent study by Lopes et al [39] contributes significantly to the evolving landscape of DRLs in INR. This multicentre European study provides updated and procedure-specific DRLs for key INR procedures, including mechanical thrombectomy and aneurysm coiling, based on a large and diverse dataset. The findings not only offer contemporary benchmarks for radiation exposure but also highlight variation in practices across centres, reinforcing the need for harmonised methodologies in DRL establishment. Furthermore, the study exemplifies the importance of coordinated data collection and reporting standards at the European level, which may serve as a model for future regional or global DRL development initiatives.

Continental comparisons (e.g., between Europe ($n = 26$), Asia ($n = 7$), the Americas ($n = 2$), Australia ($n = 1$), and Africa ($n = 3$)) were not feasible due to the predominance of European studies and the limited number of comparable studies from other regions, highlighting a gap in globally representative DRL data.

While there is no unified international guideline specific to INR, relevant recommendations from ICRP [6, 40, 41] and European Commission documents guide radiation protection practices [42, 43], including the use of DRLs. Several national bodies have developed procedure-specific DRLs for INR, but these vary significantly in methodology and scope, underscoring the need for harmonised international guidance.

This scoping review demonstrates that, although DRLs have been reported for several INR procedures, including CA, ST, AC, and AVM/AVF embolisation, substantial variability persists in both reported dose values and underlying methodologies. DRL coverage remains limited or inconsistent for less frequently performed procedures, such as tumour embolisation, as well as for paediatric neuro-interventions. Furthermore, only a minority of studies consistently report all three key dose indicators (PKA, RAK, and FT), which significantly hampers standardisation and meaningful cross-country comparison.

These findings highlight an urgent need for methodological harmonisation in future DRL development for INR. Central to this effort is the adoption of a harmonised minimum dataset that mandates the routine reporting of PKA, RAK, and FT as core dose indices, alongside standardised procedural classifications that clearly distinguish between diagnostic and follow-up angiography, standalone vs combined therapeutic procedures, and the use of CBCT. In parallel, structured reporting of key variables known to influence patient dose, such as patient morphology, procedural complexity, frame rates, and angiography system generation, should be implemented to improve data interpretability and comparability. To support sustainable harmonisation, future work should prioritise multicentre and multinational collaborations and the development of registries underpinned by predefined data dictionaries, enabling consistent data collection and facilitating European or international DRL initiatives. Finally, regular review and updating of DRLs are essential to ensure alignment with ongoing advances in technology, evolving interventional techniques, and optimisation strategies in neuro-interventional practice.

Conclusion

This work is original in its scope, covering both diagnostic and therapeutic INR procedures and including studies from multiple continents over a 25-year period. It presents DRL distributions, highlighting variability and outliers not previously consolidated in this field. It also offers methodological insights by identifying key differences in dose indices, procedural categorisation, and data collection approaches, all of which affect international harmonisation. By mapping these gaps and variations, the review provides a reference framework to support future DRL development, standardisation, and policy making in INR radiation protection.

Abbreviations

AC	Aneurysm coiling
AVF	Arteriovenous fistulas
AVM	Arteriovenous malformations
CA	Cerebral angiography
CBCT	Cone beam computerised tomography
DRLs	Diagnostic reference levels
FT	Fluoroscopy time
$Gycm^2$	Gray-centimetres squared
ICRP	International Commission on Radiological Protection
INR	Interventional neuroradiology
IR	Interventional radiology
mGy	Milligray
min	Minutes
P_{KA}	Air kerma area product
RAK	Reference air kerma
ST	Stroke thrombectomy

Supplementary information

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Methodology

- Scoping literature review

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