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IOP Publishing J. Radiol. Prot. 42 (2022) 021510 https://doi.org/10.1088/1361-6498/ac5294

Journal of Radiological Protection

OPEN ACCESS

RECEIVED
25 October 2021

REVISED
27 January 2022

ACCEPTED FOR PUBLICATION
7 February 2022

PUBLISHED
9 March 2022

PAPER

Typical doses and typical values for fluoroscopic diagnostic and interventional procedures

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Keywords: dosimetry, typical doses, typical values, diagnostic reference level, interventional radiology, fluoroscopy, dosimetric comparison

Abstract

To implement typical doses (TD) and typical values (TV) for fluoroscopic diagnostic and interventional procedures. A total of 3811 fluoroscopic procedures performed within 34 months on three devices were included in this retrospective study. Dose-, patient- and procedure-related information were extracted using the institutional dose management system (DMS). TD/TV were defined as median dose and calculated for the five most frequent procedures per device for dose area product (DAP), cumulative air kerma (CAK) and fluoroscopy time (FT). National diagnostic reference levels and other single facility studies were compared to our results. Additionally, the five procedures with the highest doses of each device were analysed. To evaluate the data coverage of the DMS compared to the picture archiving and communication system (PACS), procedure lists were extracted from the PACS and compared to the procedure information extracted from the DMS. TD/TV for 15 procedures were implemented. Among all devices, TD for DAP ranged between 0.6 Gycm^2 for port catheter control ($n = 64$) and 145.9 Gycm^2 for transarterial chemoembolisation ($n = 84$). TD for CAK ranged between 5 mGy for port catheter control and 1397 mGy for aneurysm treatment ($n = 129$) and TV for FT ranged between 0.3 min for upper cavography ($n = 67$) and 51.4 min for aneurysm treatment. TD for DAP and CAK were lower or within the range of other single facility studies. The five procedures with the highest median DAP per device were identified, 6 of 15 procedures were also found to be among the most frequent procedures. Data coverage of the DMS compared to the PACS ranged between 71% (device 2, stroke treatment) and 78% (device 1, lower limb angiography) for the most common procedure per device. Thus, in 22%–29% of cases dose data of the performed procedure was not transferred into the DMS. We implemented TD/TV for fluoroscopic diagnostic and interventional procedures which enable a comprehensive dose analysis and comparison with previously published values.

1. Introduction

Interventional radiology has grown over the last decades, as it often represents a less invasive alternative to surgery [1–3]. However, a drawback of fluoroscopic guided interventional procedures is the radiation exposure [2, 4]. Radiation protection optimisation is mandatory to protect patients and operators.

As a tool for radiation protection optimisation in interventional radiology, the European Council Directive 2013/59 Euratom requests to establish diagnostic reference levels (DRLs) [5]. For individual institutions the International Commission on Radiological Protection (ICRP) advises to use the term 'typical doses' (TD)/typical values (TV) on a single facility level [6]. DRLs and TD/TV do not represent cut-off values to determine good or bad radiological practice [6]. They rather guide radiation exposure application and help to identify radiation dose outliers or groups of procedures with potential for radiation protection optimisation [1, 6].

The German Federal Office for Radiation Protection publishes national DRLs for several examinations, which includes a limited number of interventional and fluoroscopic procedures [7, 8]. However, individual facilities are requested to implement TD/TV to address special characteristics of radiological departments [6, 9–11].

In computed tomography, implementation of DRLs is relatively easy due to the standardised dose output parameters, i.e. volumetric computed tomography dose index and dose length product. For fluoroscopic procedures, however, implementing comprehensive DRLs is more challenging [6, 12]: The ICRP advises to define DRLs and TD for dose area product (DAP) and cumulative air kerma (CAK) and DRLs and TV for fluoroscopy time (FT) and number of frames taken during the procedure. DAP serves as a surrogate parameter for stochastic radiation damage (e.g. malignant tumors), whereas CAK serves as a surrogate parameter for deterministic effects (e.g. skin reactions) [6].

The aim of this study was to systematically collect and analyse dose data from diagnostic fluoroscopic examinations and interventional procedures and to implement TD and TV for the five most common examinations performed on each institutional device. Furthermore, we strived to identify examinations with particularly high radiation exposure and to compare our fluoroscopic dose data to published DRLs and other single facility studies.

2. Materials and methods

This retrospective study was approved by the local ethics committee. The requirement for written informed consent was waived. All interventional angiographic procedures and fluoroscopic diagnostic examinations performed between June 2015 and April 2018 on three institutional radiological devices were included.

The three radiological devices were:

- Device 1: Allura Xper FD20, a monoplane flat detector angiography system (Philips Healthcare, Best, Netherlands). The device is used for general interventions, e.g. diagnostic abdominal angiography, percutaneous transluminal angioplasty (PTA) of the extremities and transarterial chemoembolisation (TACE).
- Device 2: Allura Xper FD20 biplane, a biplanar flat detector angiography system (Philips Healthcare, Best, the Netherlands). Device 2 is used for neuroradiological procedures (e.g. diagnostic cerebral angiography or interventional thrombectomy).
- Device 3: Luminos Agile FLC, a digital fluoroscopy system (Siemens Healthineers, Forchheim, Germany). Device 3 is used for diagnostic fluoroscopic examinations (e.g. gastrointestinal follow-through examinations or catheter position control).

2.1 Data acquisition

A dose management system (DMS) (Dosetrack, Sectra, Linköping, Sweden) was used to process and export procedure-specific information. Anonymised patient ID, age, sex, accession number, exam description, DAP ($Gycm^2$), CAK (mGy, at the patient reference entrance point) and FT (seconds, later transformed to minutes) were used for analysis. In interventional radiology the ICRP recommends to assess DRLs and TD/TV for all available dose quantities, so if a procedure exceeds comparable values it is easier to identify the source of the radiation exposure [6]. The DMS was introduced in March 2018 in our institute. Data of procedures performed before the DMS was established was retrospectively transmitted to the DMS from the picture archiving and communication system (PACS). Later we identified this as a source for doubled exported data.

2.2 Evaluation of data transmission

To evaluate the completeness of retrospective data transfer from the PACS to the DMS, procedure lists were exported from PACS to Excel (Microsoft Office 2016, Redmond, Washington, USA) for the study period for all three devices. The sample size of the most common procedure per device as recorded in the PACS were compared to the sample size recorded in the DMS.

2.3 Data analysis

Procedures were identified by their protocol name. Procedures performed on phantoms and pediatric patients were excluded from the study (device 1/device 2/device 3, $n = 43/110/43$). For biplane procedures on device 2, an entire data set was stored separately for each flat panel detector for every procedure. These were combined for analysis in this study ($n = 1540$). Further, all incomplete datasets with a DAP $= 0$ $Gycm^2$ and procedures that were exported twice (device 1/device 2/device 3, $n = 93/3307/0$) were excluded. The

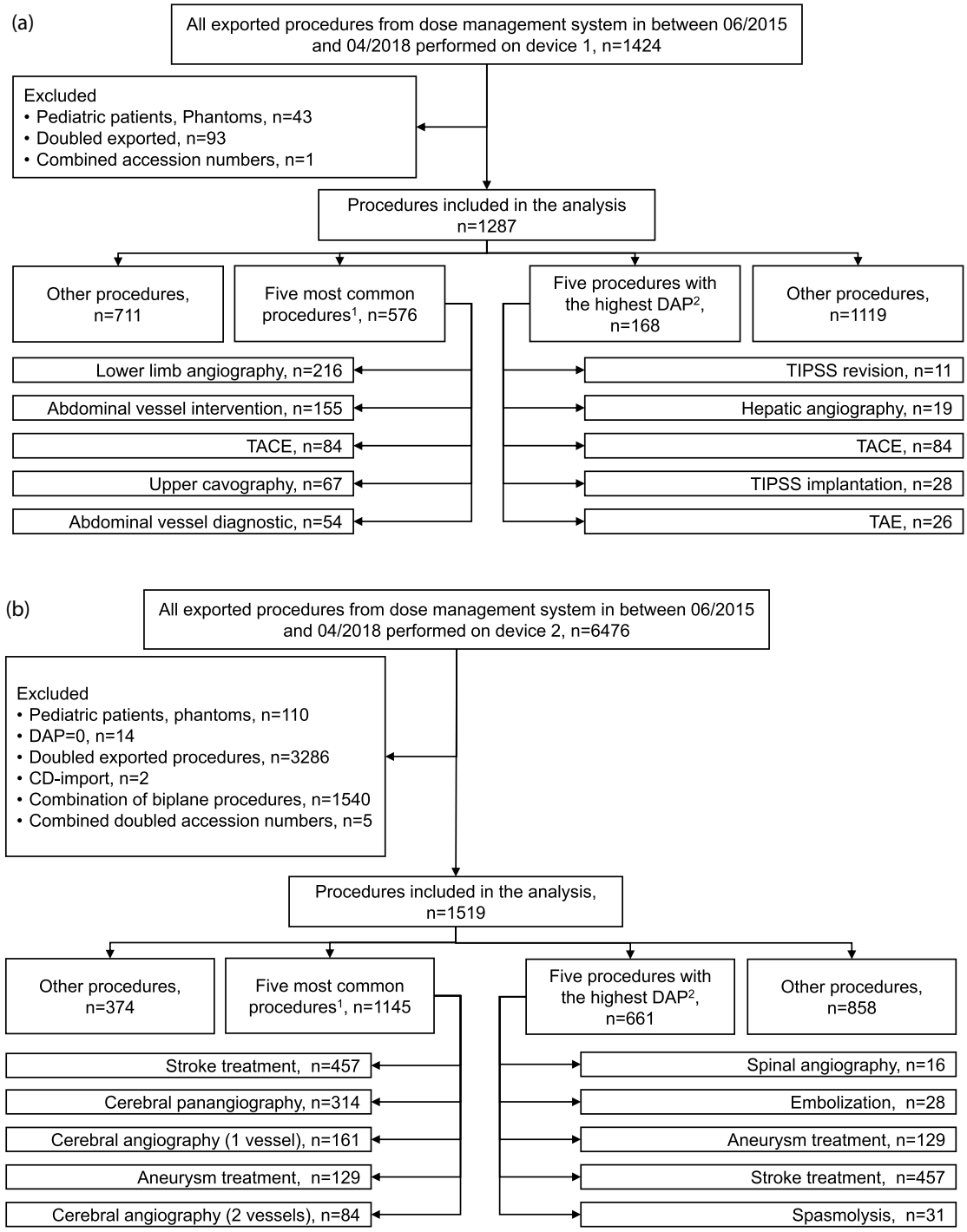

Figure 1. (a) Flowchart of data acquisition for device 1 (general radiological device). Superscripts: 1—five most common procedures (ranked by sample size), 2—five most dose intensive procedures (ranked by median DAP), TACE = transarterial chemoembolisation, TIPSS = transjugular intrahepatic portosystemic stent–shunt, TAE = transarterial embolisation. (b) Flowchart of data acquisition for device 2 (neuroradiological device). Superscripts: 1—five most common procedures (ranked by sample size), 2—five most dose intensive procedures (ranked by median DAP).(c) Flowchart of data acquisition for device 3 (fluoroscopic device). Superscripts: 1—five most common procedures (ranked by sample size), 2—five most dose intensive procedures (ranked by median DAP).

latter occurred intermittently due to a miscommunication between the modality and the DMS. Additionally, as previously mentioned, on device 2 (biplane device) every flat panel detector stored a data set for the same procedure and transferred it to the DMS which leads to an even higher number of doubled exported procedures for this device.

Data was subsequently grouped according to the radiological procedures. The catalogue for grouping procedures was pre-determined and procedures were manually assigned to each group. Grouping of procedures was necessary for a number of reasons, first to subsume different protocol names under the same

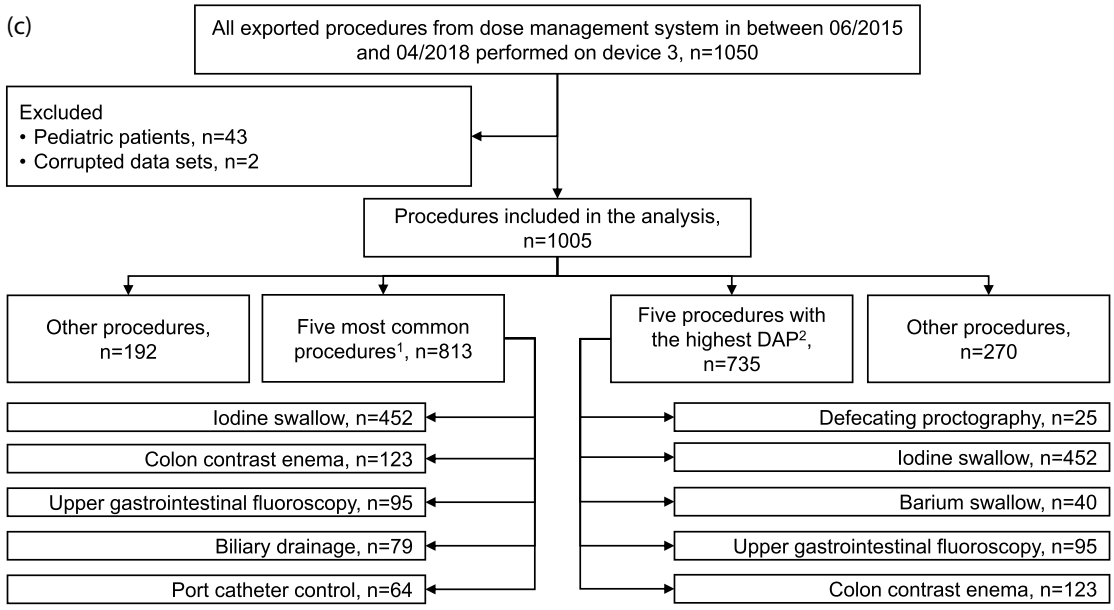

Figure 1. (Continued).

clinical indications, e.g. for stroke treatment, different protocol names were found which encoded multiple procedures of the same general procedure in a different order (e.g. thrombolysis followed by stent-retriever based thrombectomy or vice versa). Second, grouping of protocol names was performed to exclude information unlikely to be related to dose exposure (e.g. when the procedure was performed on the left leg or right leg) and third when the encoded protocol name has changed over time (e.g. to correct a spelling error). The five most frequent procedures were identified for the calculation of TD/TV. Additionally, the five procedures with the highest median DAP per device were identified (figures 1(a)–(c)). Here, a minimum number of ten procedures was used as a cut-off for inclusion in this study. Grouping of procedures and data analysis was performed by two of the coauthors in consensus (*JT*, 7th year medical student and *AS*, medical physicist with 5 years of experience) with consultation of a senior radiologist (*JB* with 8 years of experience in radiology) and neuroradiologist (*CR* with 9 years of experience in radiology and neuroradiology).

2.4 Calculation of typical doses

The ICRP distinguishes between obtaining national, regional and local DRLs and introduced the term 'typical dose/typical value' for single facilities [6]. Our results represent TD and TV which equal the *median value* of the distribution of dose parameters [6, 13]. TD were established for DAP in $Gycm^2$ and for CAK in mGy and TV for FT in min for the five most common procedures on each device.

Basic statistical analysis contained evaluation of mean, standard deviation, minimum, maximum, 25th percentile (25th P), median and 75th percentile (75th P). TD/TV were defined as median values according to ICRP report 135 [6] and calculated for the five most common procedures.

3. Results

3.1 Study cohort

In total, 8950 entries were registered in the DMS during the study period (device 1/device 2/device 3, $n = 1424/6476/1050$). After reviewing the data, 3811 examinations were included in the analysis (device 1/device 2/device 3, $n = 1287/1519/1005$; figures 1(a)–(c)). The five most common procedures per device included 2534 examinations (device 1/device 2/device 3, $n = 576/1145/813$). These included 1255 male (50%) and 1279 female patients (50%). Mean age was 62.8 ± 15.8 years (range 18–107 years). The five procedures with the highest dose per device included 1564 examinations (device 1/device 2/device 3, $n = 168/661/735$; 742 men, 822 women, mean age 64.5 ± 16.0 years (18–107 years)).

Table 1. TDs and 25th and 75th P in parenthesis for the single plane angiographic modality (device 1) for DAP, CAK and TVs for FT. TACE = transarterial chemoembolisation. *N* = sample size.

Procedure	*N*	DAP (Gycm^2)	CAK (mGy)	FT (min)
Lower limb angiography	216	16.0 (8.0; 40.7)	74 (39; 165)	14.4 (8.3; 22.3)
Abdominal vessel intervention	155	114.4 (57.4; 222.8)	635 (358; 1249)	19.4 (11.9; 28.7)
TACE	84	145.9 (82.4; 236.8)	942 (600; 1587)	24.5 (18.9; 34.6)
Upper cavography	67	5.2 (2.8; 11.0)	14 (8; 26)	0.3 (0.1; 0.6)
Abdominal vessel diagnostic	54	122.0 (66.1; 288.6)	521 (253; 1098)	14.9 (7.4; 29.4)

Table 2. TDs and 25th and 75th P in parenthesis for the biplane angiographic modality (device 2) for DAP, CAK and TVs for FT. *N* = sample size.

Procedure	*N*	DAP (Gycm^2)	CAK (mGy)	FT (min)
Stroke treatment	457	102.9 (64.0; 151.9)	653 (381; 1032)	25.8 (15.6; 40.3)
Cerebral panangiography	314	79.2 (62.8; 100.6)	404 (299; 525)	9.0 (5.7; 15.3)
Cerebral angiography (one vessel)	161	30.8 (20.8; 61.1)	195 (136; 340)	5.3 (3.3; 13.8)
Aneurysm treatment	129	132.8 (99.1; 186.8)	1 397 (944; 1906)	51.4 (35.9; 70.0)
Cerebral angiography (two vessels)	84	48.5 (36.4; 71.4)	253 (177; 379)	6.1 (3.6; 10.4)

Table 3. TD and 25th and 75th P in parenthesis for the fluoroscopic diagnostic modality (device 3) for DAP, CAK and TVs for FT. *N* = sample size.

Procedure	*N*	DAP (Gycm^2)	CAK (mGy)	FT (min)
Iodine swallow	452	6.4 (2.4; 13.7)	31 (12; 70)	0.6 (0.4; 1.0)
Colon contrast enema	123	4.1 (2.2; 8.9)	15 (7; 33)	0.9 (0.5; 1.4)
Upper gastrointestinal fluoroscopy	95	4.1 (1.7; 8.7)	16 (6; 37)	0.8 (0.5; 1.2)
Biliary drainage	79	1.4 (1.0; 3.1)	7 (3; 14)	0.7 (0.5; 1.0)
Port catheter control	64	0.6 (0.3; 1.4)	5 (3; 15)	0.5 (0.2; 0.7)

3.2 Evaluation of data transmission

For the most common procedures on device 1 (lower limb angiography) $n = 276$ entries were found in the PACS within the study period, while $n = 216$ corresponding entries were found in the DMS. Hence, 78% of the procedures as found in the PACS had corresponding data in the DMS on device 1. Data transmission for the most common procedure on device 2 (stroke treatment) was 71% from PACS ($n = 647$ entries) to the DMS ($n = 457$). On device 3 the data transmission for the most common procedure (iodine swallow) was about 73% from PACS ($n = 597$ entries) to the DMS ($n = 452$ entries). Lacking examinations were distributed throughout the included time range of 34 months.

3.3 Dose data

On device 1, the average value for DAP was 84.9 ± 128.5 (range 0.01–970.9) Gycm^2, 443 ± 685 (0–5235) mGy for CAK and 16.1 ± 14.1 (0.0–88.3) min for FT. On device 2, the average DAP was 92.2 ± 84.3 (0.02–764.0) Gycm^2, 651 ± 741 (range 0–5744) mGy for CAK and 22.6 ± 25.0 (0.1–227.2) min for FT. On device 3, the average DAP was 8.9 ± 14.3 (0.01–161.6) Gycm^2, 46 ± 79 (0–791) mGy for CAK and 0.9 ± 0.7 (0.0–5.7) min for FT.

3.4 Typical doses and typical values for the most frequent procedures

Tables 1–3 present the five most frequent procedures performed on each device and the respective TDs and TVs.

3.5 Comparison of our results to national DRLs and other single facility studies

Table 4 presents a comparison of our results and national DRLs. Since national DRLs are defined as the 75th P we provide data of median values (TD, TV) and 75th P of our results. For the comparison with other single facility studies we used our TD and TV (50th P).

In comparison to national DRLs, our 75th P for DAP undercut comparable values or was positioned within the range of DRLs except for our 75th P for cerebral angiography (one vessel, 61.1 Gycm^2). Here the French national DRL is 30.0 Gycm^2, which is 51% lower than our result. For colon contrast enema, our 75th P (8.9 Gycm^2) is 61% lower than the comparable German national DRL (30 Gycm^2).

Our 75th P for CAK undercuts comparable national DRLs in four out of seven comparisons. The comparisons ranged from our 75th P for aneurysm treatment (1906 mGy) being 31% lower than the

Table 4. Comparison of the 75th P from our results and TDs/TVs (both 50th percentile; 50th P) with other published national DRLs (#) or multicentric studies (+) which propose national DRL (set as the 75th P). DAP in Gycm^2, CAK in mGy, FT in min, TACE = transarterial chemoembolisation, I = PTA iliac, II = PTA–stent iliac, III = PTA upper leg and knee, IV = PTA lower leg and foot, V = PTA lower limb, VI = lower limb angiography, VII = thrombectomy, VIII = coiling of aneurysms, IX = embolisation of aneurysms, X = biliary drainage control (T-tube cholangiography), XI = biliary drainage control and intervention.

Procedure		TD/TV 50th P	75th P	Germany # [7, 8] + [14]	United Kingdom# [15]	Austria# [16]	Switzerland# [17]	Italy# [18]	France+ [9]	Spain# [19]	Bulgaria+ [20]
Lower limb angiography	DAP Gycm^2	16.0	40.7	90.0^{I}/40.0^{III}/ 25.0^{IV}	56.0 ^{VI}	100.0^{II}	200.0 ^{VI}/200.0^{I}/ 350.0^{V}	—	75.0^{VI}	78.0^{VI}/170.0^{II}	45.0^{VI}
	CAK mGy	74	165	—	—	—	—	—	150^{VI}	—	—
	FT min	14.4	22.3	—	5.9^{VI}	—	10.0^{VI}/20.0^{I}/14.0^{V}	—	6.0^{VI}	4.0^{VI}/21.4^{II}	1.9–3.0^{VI}
TACE	DAP Gycm^2	145.9	236.8	230.0	—	—	300.0	400.0	250.0	303.00	—
	CAK mGy	942	1 587	—	—	—	—	—	990	—	—
	FT min	24.5	34.6	—	—	—	20.0	20.0	28.0	26.3	—
Abdominal vessel diagnostic	DAP Gycm^2	122.0	288.6	—	—	—	300.0	—	—	—	—
	FT min	14.9	29.4	—	—	—	20.0	—	—	—	—
Stroke treatment	DAP Gycm^2	102.9	151.9	180.0^{VII}	—	190.0^{VII}	—	—	—	—	—
Cerebral panangiography	DAP Gycm^2	79.2	100.6	—	—	—	150.0	115.0	105.0	—	—
	CAK mGy	404	525	—	—	—	—	—	730	—	—
	FT min	9.0	15.3	—	—	—	15.0	10.0	13.0	—	—
Cerebral angiography (one vessel)	DAP Gycm^2	30.8	61.1	—	—	—	—	—	30.0	—	—
	CAK mGy	195	340	—	—	—	—	—	220	—	—
	FT min	5.3	13.8	—	—	—	—	—	4.0	—	—
Aneurysm treatment	DAP Gycm^2	132.8	186.8	250.0^{VIII}	—	—	—	180.0^{IX}	190.0^{IX}	—	—
	CAK mGy	1 397	1 906	—	—	—	—	—	2770^{IX}	—	—
	FT min	51.4	70.0	—	—	—	—	42.9^{IX}	58.0^{IX}	—	—

(Continued.)

Table 4. (Continued.)

Procedure		TD/TV 50th P	75th P	Germany [#] [7, 8] [+] [14]	United Kingdom[#] [15]	Austria[#] [16]	Switzerland[#] [17]	Italy[#] [18]	France[+] [9]	Spain[#] [19]	Bulgaria[+] [20]
Cerebral angiography (two vessels)	DAP Gycm^2	48.5	71.4	—	—	—	—	—	75.0	—	—
	CAK mGy	253	379	—	—	—	—	—	470	—	—
	FT min	6.1	10.4	—	—	—	—	—	7.0	—	—
Colon contrast enema	DAP Gycm^2	4.1	8.9	30.0	—	20.0	—	—	—	—	—
Biliary drainage	DAP Gycm^2	1.4[x]	3.1[X]	14.0[XI]	5.0[X]	—	—	45.0[XI]	35.0[XI]	30.0[XI]	—
	CAK mGy	7	14	—	—	—	—	—	260	—	—
	FT min	0.7	1.0	—	1.8	—	—	—	16.0	17.3	—

Table 5. Comparison of our TDs and TVs to other median values of dose quantities from single facility studies. *N* = sample size, PTA = percutaneous transluminal angioplasty, TACE = transarterial chemoembolisation, I = angiography, II = PTA, III = biliary drainage control (T-tube cholangiography), IV = biliary drainage control and intervention (T-tube cholangiography and removal).

Procedures	*N*	DAP ($Gycm^2$) median values	CAK (mGy) median values	FT (min) median values
Lower limb angiography				
This study	216	16.0	74	14.4
Rana [21][I]	9	10.1	—	4.2
Rana [21][II]	11	15.5	—	29.2
Heilmaier [22][II]	73	43.0	590	—
Erskine [23]	123	9.2	—	10.3
Pitton [24]	60	79.0	—	—
Abdominal vessel intervention				
This study	155	114.4	635	19.4
Heilmaier [22]	36	190.9	1 720	—
TACE				
This study	84	145.6	942	24.5
Heilmaier [22]	21	183.4	1 720	—
Erskine [23]	52	208.7	—	30.0
Bundy [25]	395	304.5	1 428	15.6
Kloeckner [26]	92	295.4	—	—
Abdominal vessel diagnostic				
This study	54	122.0	521	14.9
Rana [21][I]	8	107.9	—	15.4
Heilmaier [22][I]	21	95.2	350	—
Bundy [25][I]	524	232.9	1 194	12.2
Cerebral panangiography				
This study	314	79.2	404	9.0
Erskine [23]	257	63.8	—	6.3
D'Ercole [11]	100	131.4	—	8.5
Aneurysm treatment				
This study	129	132.8	1 397	51.4
Rana [21]	54	267.2	—	53.4
Erskine [23]	91	118.2	—	32.0
D'Ercole [11]	72	349.3	—	33.7
Iodine swallow				
This study	452	6.4	31	0.6
Erskine [23]	> 400	23.6	—	1.0
Colon contrast enema				
This study	123	4.1	15	0.9
Erskine [23]	161	34.8	—	3.3
Biliary drainage				
This study[III]	79	1.4	7	0.7
Heilmaier [22][IV]	61	10.8	60	—
Bundy [25][III]	101	4.4	26	3.9
Kloeckner [26][III]	165	83.6	—	—
Port catheter control				
This study	64	0.6	5	0.5
Heilmaier [22]	16	1.2	10	—

comparable French national DRL (2770 mGy) to our result for TACE (1587 mGy) exceeding the comparable French national DRL (990 mGy) by 60%.

The 75th P of our results for FT exceed comparable values in seven out of eight comparisons. The comparisons ranged from our 75th P for biliary drainage (1.0 min) being 45% lower than the comparable British national DRL (1.8 min) to our result for lower limb angiography (22.3 min) exceeding the comparable Spanish national DRL (4.0 min) by 560%.

Additionally, we compared our TD and TV to other median values from single facility studies (table 5). These studies used the 75th P to implement TD, but also published their median values for the dose quantities which we used for the comparison. Our TD for DAP and CAK were generally lower or within the range of published median values (table 5). Our TV for FT were lower or within the range of published median values except for cerebral panangiography. Here our TV (9.0 min) is 43% higher than the comparable value from Erskine *et al* (6.3 min) and 6% higher than the comparable value from D'Ercole *et al* (8.5 min).

Table 6. Median values and 25th, 75th P in parenthesis for DAP, CAK and FT for procedures with high doses for the single plane angiographic modality (device 1, general radiology). TIPSS = transjugular intrahepatic portosystemic stent–shunt, TAE = transarterial embolisation, TACE = transarterial chemoembolisation, *N* = sample size.

Procedure	*N*	DAP (Gycm^2)	CAK (mGy)	FT (min)
TIPSS revision	11	164.8 (74.1; 391.5)	609 (363; 1239)	18.7 (16.0; 40.8)
Hepatic angiography	19	147.8 (96.9; 209.9)	827 (481; 1078)	17.0 (11.5; 26.8)
TACE	84	145.9 (82.4; 237.7)	942 (600; 1587)	24.5 (18.9; 34.6)
TIPSS implantation	28	136.8 (80.7; 197.0)	477 (312; 723)	25.3 (18.8; 33.8)
TAE	26	136.1 (79.3; 237.2)	868 (555; 1570)	23.1 (14.7; 39.5)

Table 7. Median values and 25th, 75th P in parenthesis for DAP, CAK and FT for procedures with high doses for the biplane angiographic modality (device 2, neuroradiology). *N* = sample size.

Procedure	*N*	DAP (Gycm^2)	CAK (mGy)	FT (min)
Spinal angiography	16	417.6 (221.7; 530.8)	2 848 (1333; 3 165)	24.3 (19.9; 33.6)
Embolisation	28	193.3 (114.6; 237.6)	1 421 (919; 2179)	43.4 (27.3; 78.5)
Aneurysm treatment	129	132.8 (99.1; 186.8)	1 397 (944; 1906)	51.4 (35.9; 70.0)
Stroke treatment	457	102.9 (64.0; 151.9)	653 (381; 1032)	25.8 (15.6; 40.3)
Spasmolysis	31	97.2 (79.2; 110.2)	434 (373; 558)	6.4 (4.0; 23.0)

Table 8. Median values and 25th, 75th P in parenthesis for DAP, CAK and FT for procedures with high doses for the fluoroscopic diagnostic modality (device 3, fluoroscopy). *N* = sample size.

Procedure	*N*	DAP (Gycm^2)	CAK (mGy)	FT (min)
Defecating proctography	25	7.5 (4.3; 24.3)	30 (23; 126)	1.0 (0.4; 1.6)
Iodine swallow	452	6.4 (2.4; 13.8)	31 (12; 70)	0.6 (0.4; 1.0)
Barium swallow	40	6.1 (1.4; 16.1)	38 (7; 88)	0.9 (0.4; 1.3)
Upper gastrointestinal fluoroscopy	95	4.1 (1.7; 8.7)	16 (6; 37)	0.8 (0.5; 1.2)
Colon contrast enema	123	4.1 (2.2; 8.9)	15 (7; 33)	0.9 (0.5; 1.4)

3.6 Procedures with the highest DAP values

Tables 6–8 present the procedures with the highest median DAP values performed on each device and the respective dose data for all dose quantities.

40% of the most frequent procedures, which were found to be dose-intensive included TACE (device 1), aneurysm treatment, stroke treatment (device 2), iodine swallow, upper gastrointestinal fluoroscopy and colon contrast enema (device 3).

4. Discussion

This study aimed to obtain TD and TV for the most frequent diagnostic and interventional fluoroscopic procedures. We established TD and TV for the five most common procedures performed on each device for DAP, CAK and FT and additionally identified the five most dose intensive procedures per device.

We observed a wide distribution of dose parameters for diagnostic and therapeutic interventions. This wide range has been previously reported for dose application in interventional radiology [12, 20, 22, 27, 28]. Mainly, procedure protocol, patient physique (height, weight), disease severity, operator skill and equipment contribute to variations in dose values [6, 12, 29]. Additionally, existing research identifies analysis-related issues such as inconsistencies in procedure names and grouping to cause this wide spread when comparing DRLs to previously published values [6, 11, 12, 22, 24, 29, 30]. In the report of the EUCLID-project the authors promote a common lexicon to avoid these inconsistencies and simplify comparisons [12]. To enable a comprehensive comparison, we included as much available information for the previously published values as possible and subgrouped some procedures, e.g. biliary drainage (tables 4 and 5). Thus, for biliary drainage only the British national DRL is suitable for a comparison. It is the only national DRL which includes just a diagnostic biliary drainage control and therefore is consistent to our institutional inclusion criteria for the procedure 'biliary drainage'. Of note, we found a wide spread of applied dose not only for interventional, but also for diagnostic procedures.

4.1 Comparison to published national DRLs

We found a large difference between our 75th P and previously published national DRLs and our TD/TV and other single facility studies. Though TD/TV and national DRLs are defined differently, the ICRP encourages

comparisons [6]. However, in this study we used the 75th P of our results for the comparison with national DRLs to enable a consistent comparison. Additionally, the International Atomic Energy Agency supports comparisons among facilities as their report describes an increased awareness for radiation doses correlating with operators' technique [1].

If single facility values exceed national DRLs, investigation should be performed [5, 6]. Our 75th P results exceeded national DRLs in one out of nine comparisons for DAP, in three out of seven comparisons for CAK and in seven out of eight comparisons for FT. The largest discrepancy for CAK was observed for TACE (1587 mGy) and the comparable French national DRL (990 mGy). For the TACE procedure the French national DRL is the only comparable national DRL. In comparison of our result for CAK for TACE with other single facility studies, our result undercuts previously published single facility results. As a potential reasons for this inconsistency, we assume the basic study method which differs for national DRLs and single facility studies, e.g. the sample sizes. In comparison to the study setup to implement national DRLs, our study represents a quite small sample size for some procedures which could bias our results. However, the sample sizes are according to the ICRP sufficient to implement DRLs [6]. So, we perceive this comparison and acknowledge it as a chance for further optimisation.

Regarding the FT results, only one of our 75th P values undercuts the comparable national DRL (biliary drainage). Here another reason for this wide range might be that there are different imaging methods in interventional radiology. The impact of the imaging method (acquisition or fluoroscopy mode) varies for FT, DAP and CAK: The dose intensive acquisition mode increases DAP and CAK but not the FT. In contrast, the fluoroscopic mode increases the FT but has very little impact on the overall dose compared to the acquisition mode [24]. Thus, DAP and CAK seem much more suitable as DRL parameters whereas FT should play a minor role. At our facility, operators strive to use the fluoroscopic mode whenever possible to reduce radiation exposure for the patient, which may explain high FT values in some procedures. This is reflected in CAK and DAP being below previously published DRLs for these procedures.

Not every country which published national DRLs uses the same parameters to define DRLs. Germany [7, 8, 14] for example only has national DRLs for DAP, whereas France [9] set national DRLs for all three dose quantities which also limits the possibilities for a thorough comparison due to limited reference values.

4.2 Comparison to single facility studies

We compared our TD and TV to previously published single facility studies. These studies used the 75th P to implement TD instead of the median value. The ICRP introduced the term TD/TV for single facility studies in 2017. Besides Bundy *et al* [25] and Rana *et al* [21] (both published in 2018), all other publications were published before or in 2017. It is unclear why Bundy *et al* and Rana *et al* still used the 75th P instead of the median value. To enable a comparison, we used the also published median values provided in the single facility studies for DAP, CAK and FT. In comparison to other single facility studies, the presented DAP and CAK values are below or within the range of previously published values. Median DAP values for lower limb angiography published by Rana *et al* were 37% lower than the values found in our institution. However, according to the ICRP, at least 30 examinations should be used as a sample size when analyzing dose data to implement DRL [6]. Rana *et al* reported dose data for only nine cases, which limits comparability [21].

Various previous studies reported median FT values lower than the locally established TV [11, 21, 23, 25]. However, as previously mentioned, FT is a poor indicator for radiation damage and less important as DRL.

4.3 Procedures associated with high radiation doses

By identifying procedures associated with high radiation doses, we aimed to create consciousness about procedures, on which we may need to focus our dose optimisation efforts. The importance of this analysis is reflected by the fact that six procedures identified as dose intensive are also among the 15 most frequent procedures. Of note, high DAP values of certain procedures may be the result of the interventional complexity. Our department is part of a tertiary care and teaching hospital. Due to the status as a maximum care facility, the complexity of cases is higher compared to smaller hospitals [11]. Additionally, due to the teaching environment, junior physicians are also carrying out procedures and experience of the interventionalist correlates with dose application [9, 31].

In our study, we report TD and TV for interventional radiology, which can be used to monitor and analyse dose application to the patient. Besides the radiation exposure to the patient, the staff is also exposed, especially from scattered radiation [32]. It has to be noted that TD and TV are not targeted to estimate radiation exposure to the interventionalists or surrounding staff, especially as they do not inherit the frequency of performed procedures. Nevertheless, dose optimisation enabled by TD and TV is not only beneficial for the patient but can also reduce radiation exposure of the interventionalists.

4.4 Evaluation of data transmission from the PACS to the DMS

We observed smaller sample sizes registered in the DMS than in the PACS for the most common procedures per device, which is the result of a miscommunication between the PACS and the DMS. The DMS was introduced in 2018 in our institute and the data of the study period was partly retrospectively transferred from the PACS to the DMS. Unfortunately, some radiation dose structured reports (RDSR) were not available in the PACS and could therefore not be transferred to the DMS. These missing RDSR led to a smaller sample size recorded in the DMS.

4.5 Limitations

Our study has limitations. First, regrouping was necessary in this study and though it was done very carefully, manually editing is always a risk to compromise the data [12].

Second, there was no information on patient weight included in this study due to its inconsistent recording. Different publications describe that dose metrics are far more associated to procedure complexity than patient habitus [1, 6, 33]. Furthermore, Schegerer *et al* indicated that a standard patient could be assumed when averaging a defined number of examinations [10]. However, to improve dose analysis, patient weight should be constantly recorded in the future.

Third, the level of complexity of an intervention was not considered in the analysis. The ICRP [6] recommends subdividing procedures into different levels of complexity [9, 11, 19, 34], which was not available retrospectively and should be evaluated in a future, prospective study.

Fourth, a proportion of examinations has not been transmitted to the DMS. A potential reason for this might be that if a procedure has been performed a dose report and images are generated: The images are crucial for the radiologists work and if they are missing the image data is immediately transferred again. If the dose data is missing and is unrecognised for some time, the transfer to the DMS might not be possible because the modalities have limited storage capacities. However, since no systematic error in the data transmission was observed, a change in the frequency distribution of the procedures or TD is not to be expected.

Fifth, we compared our results (75th P and TD/TV) to national DRLs and other single facility studies and added as many details as possible for the procedures to enable a comprehensible comparison. Though the comparison was performed carefully the inclusion criteria of procedures may be different. However, the ICRP encourages comparisons and gives guidance on how to determine DRLs and TD/TV [6].

5. Conclusion

We systematically collected and analysed institutional dose data from interventional and diagnostic fluoroscopic procedures to generate TD and TV. Though comparisons with national DRLs are complex this study identified some procedures which could benefit from a thorough look into, to optimise radiation exposure. In comparison to other single facility studies our TD for DAP and CAK were lower or positioned withing the range of previously published values. Additionally, procedures with the highest radiation doses were analysed separately. Our results may help to optimise the institutional fluoroscopic dose application in the future.

Acknowledgment

All authors declare that they have no conflict of interest.

Ethical statement

Human rights

This study was approved by the local ethics committee. The requirement for written informed consent was waived. All procedures referred to in this study were in accordance with the Helsinki Declaration of 1964 and its following amendments.

Animal rights

This study did not include any animal experiments by any of the authors.

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