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Research article

Diagnostic Reference Levels for conventional radiography and fluoroscopy in Austria: Results and updated National Diagnostic Reference Levels derived from a nationwide survey

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ABSTRACT

Objective: Evaluation and updating of Austrian National Diagnostic Reference Levels (NDRLs).
Methods: A nationwide survey on common conventional radiography and fluoroscopy examinations was conducted. In line with Austrian radiation protection standards, all relevant Austrian hospitals and radiology offices/centers were asked to report a minimum sample of 10 representative dose-area product (DAP) values together with patient weight and fluoroscopy time, if applicable. Examinations included for conventional radiography were skull, chest, abdomen, pelvis, lumbar spine and bedside chest x-ray, for fluoroscopy barium enema (single and double contrast) and swallowing (video). Participants were invited via e-mail, followed up by reminders to increase participation rates. Plausibility checks were performed to increase data quality. 3rd quartiles of facility median and mean DAP were calculated and compared to Austrian and international NDRLs.
Results: 59% of invited facilities submitted DAP data, 43% submitted additional data on patient weight and 41% on fluoroscopy time. DAP case numbers varied from 1005 to 2121 for conventional radiography and from 182 to 1380 for fluoroscopy. Average patient weight was 75 kg for conventional radiography and 77 kg for fluoroscopy.
Conclusion: 3rd quartiles derived from the survey are substantially lower than the old Austrian NDRLs (valid till early 2018). Since 3rd quartiles correspond well to European NDRLs, the update would be in accordance with European DRL harmonisation efforts.

1. Introduction

Dose optimisation is an important principle in radiation protection and can be met effectively by the concept of diagnostic reference levels (DRLs) for standardized procedures [1]. Several publications from the International Commission on Radiological Protection (ICRP) were released defining the concept of DRLs, the latest in 2017 with the new ICRP 135 [1–3].

The European Council Directive 2013/59/Euratom defines DRLs as “dose levels in medical radiodiagnostics or interventional radiology practices (…) for typical examinations for groups of standard-sized patients for broadly defined types of equipment” [4]. DRLs can only be effective if they are updated regularly to keep pace with changes in medical practice and developments of imaging technologies. The European Commission Directive therefore calls on member states of the European Union to ensure that their national diagnostic reference levels (NDRLs) are regularly reviewed and used [4]. Since DRLs are set at the 3rd quartile of the dose distribution of standard examination types, the introduction of new DRLs automatically exerts pressure on the quarter of providers with the highest radiation levels (for a given examination type) to engage in optimization.

As Austrian NDRLs were mostly based on data collected in 2000 there was an urgent need to update NDRLs based on current data. For this reason, in 2017 a nationwide study was conducted to collect dose values for different types of radiological examinations, the results of which formed the basis for the determination of the new Austrian NDRLs. This paper presents the results of this nationwide survey and illustrates the main findings from the process of updating Austrian

Abbreviations: AP, anterior-posterior; DAP, dose area product; DRL, diagnostic reference levels; HTML, hypertext markup language; ICRP, International Commission on Radiological Protection; IQR, interquartile range; IQV, interquartile value; KAP, kerma area product; LAT, lateral; NDRL, national diagnostic reference levels; PA, posterior-anterior

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NDRLs for conventional radiography and fluoroscopy.

2. Material and methods

2.1. Survey design and data entry form

This nationwide survey has been conducted in line with similar international studies to provide recommendations for updating the existing Austrian NDRLs for common conventional radiography and fluoroscopy examinations [5,6]. An ethics board approval was granted for the project. Detailed instructions were sent to each facility regarding data entry, quality assurance and patient inclusion. In line with Austrian radiation protection standards, all relevant Austrian hospitals and radiology offices/centers were asked to report a minimum sample of 10 representative quality assured dose area product (DAP or KAP, Kerma Area Product) values for each facility. The facilities were advised to enter only DAP values for standard examinations which represent their standard procedures and exclude cases where any complications occurred. If several x-ray rooms were used, dose data was asked to be collected for every room separately. However, the minimum of 10 examinations was defined as the sum for all x-ray rooms in which the respective examination was performed, in case it has not been possible to collect a minimum of 10 examinations per room. Corresponding patient weight and fluoroscopy time were optional to report. The survey was carried out by using a HTML based online data entry form. This offers the opportunity to identify each individual data entry and to create reports and retrospectively trace and analyse the data entry (e.g. time stamps, facility and room, persons entering data). Though rarely used by the facilities, data could alternatively be provided in offline form using a standardized data collection sheet available online for download if the HTML based online data entry form did not work properly on their internet browser. All relevant facilities were invited via e-mail, followed up by e-mail reminders and if necessary telephone calls to non-responding facilities to increase response rates. The data collection period lasted from May 2017 to September 2017.

2.2. Examinations

The main aim of the study was to update existing Austrian NDRLs, which were the starting point of defining relevant examinations [7]. In addition, NDRLs from other countries like Germany, Switzerland and the UK were included and discussed with a multidisciplinary expert group consisting of radiologists, medical physicists and radiographers. Examinations of extremities were excluded because of their minor contribution to both, individual and collective dose. Conventional radiography examinations evaluated were skull AP/PA, skull LAT, chest PA, chest LAT, abdomen AP/PA, pelvis AP, lumbar spine AP, lumbar spine LAT and bedside chest x-ray, which is only conducted in hospitals.

Fluoroscopy examinations evaluated were swallowing (video) and barium enema (single contrast also with water-soluble contrast agents, and double contrast). Barium small bowel was excluded because of its low frequency in daily practice. Swallowing (video) is a common examination in Austria and is still widely present in clinical routine. The examination barium enema (single contrast) is primarily conducted in hospitals e.g. for evaluation of a postoperative leak after colon surgery. For this reason, due to the risk of perforation, the examination is performed only with single contrast (water-soluble contrast agent, without addition of air or CO_2).

2.3. Data analysis and plausibility checks

According to ICRP 135 quartiles were calculated based on the median DAP values of the facilities for each examination [1]. Alternatively, quartile calculation was additionally performed based on the mean values (Table 3) to better allow comparison with NDRLs having been derived previously based on quartiles of averages.

During the data collection phase, a questions and answers hotline was installed, and participating facilities could directly call experts to assist in case of questions regarding data collection and entry. This was extensively used by the professionals in the first weeks of the data collection phase. Pop up warning messages were integrated into the data entry forms indicating implausible entered data. In that case the software would have prompted the user to check unit and/or dose entered. To verify sufficient data quality, monitoring during the survey was performed and facilities entering implausible dose values were contacted directly. After the survey period, final plausibility checks were undertaken scanning for systematic or single value outliers followed by direct feedback to participating facilities asking them to review and correct their data entries if necessary. In most cases the errors could be identified as errors in units or unit conversion. In extremely rare cases where the reason for implausible dose values could not be clarified and the data corrected, the data was discarded.

2.4. Statistical analysis

Statistical analyses were conducted with the statistical software package R (Version 3.3.1; The R Foundation, Free Software Foundation, Boston, MA) and Microsoft Excel (Version 2016, Microsoft, Redmond, WA). Median, mean, maximum, minimum, quartiles of radiation doses, and interquartile values (IQV) were calculated for each of the examinations. IQV were defined as the ratio of 3rd and 1st quartile. All these parameters were calculated based on both, the facility mean and median values, respectively. Quantile discrepancies between chest PA and bedside chest x-ray were analysed using a robust quantile test with bootstrap ($n = 1000$) confidence intervals using the R WRS2 Version 0.9–2 package. The α-inflation for multiple testing was accounted for applying the Benjamini-Hochberg-Correction [8] for the quantile test.

3. Results

Overall response rates are shown in Table 1. In total 59% of invited facilities (67% of invited hospitals and 51% of invited radiology offices, respectively) submitted DAP data. After plausibility checking, 15,305 DAP data sets for conventional radiography and 2079 for fluoroscopy were analysed. Case numbers presented in Table 2 varied from 1005 to 2121 for conventional radiography and from 182 to 1380 for fluoroscopy. Most data were collected for chest PA and fewest for barium enema with single contrast. With 43% of the DAP data additional weight data was submitted.

Results on mean weight, 1st, 2nd (median) and 3rd quartile values as well as minimal and maximal DAP in cGy·cm^2 (equalling μGy·m^2) are shown in Table 3; fluoroscopy time in minutes in Table 4. All DAP and fluoroscopy time values have been calculated based on *mean* and *median* facility values, respectively. In Tables 3 and 4 both are shown separated by a slash.

For *conventional radiography* interquartile values ranged between 1.8 and 2.0. Lowest DAP values were recorded for chest PA with 1.0 cGy·cm^2, highest for abdomen AP/PA with 1050 cGy·cm^2. Mean weight was 75 kg and varied from 73 (skull x-rays) to 76 kg (lumbar spine x-ray).

For *fluoroscopy* interquartile values were found between 1.4 and 4.2. Lowest DAP values were derived for swallowing (video) with 30 cGy·cm^2, highest for Barium enema (double contrast) with 6117

Table 1
Response rates.

	hospitals	offices	total
total participants	105	79	184
total invited	157	155	312
response rate [%]	**67**	**51**	**59**

Table 2
Numbers (N) of patient data available for analysis and responding facilities.

Examination types	N DAP	N weight	responding facilities		
			hospitals	offices	total
	Conventional radiography				
skull AP/PA	1313	460	71	59	130
skull LAT	1241	416	72	54	126
chest PA	2121	1033	99	79	178
chest LAT	1995	941	93	78	171
abdomen AP/PA	1583	684	92	62	154
pelvis AP	1989	919	97	78	175
lumbar spine AP	2031	966	97	78	175
lumbar spine LAT	2027	938	98	77	175
bedside chest	1005	368	85	0	85
	Fluoroscopy				
barium enema (single contrast)	182	38	18	1	19
barium enema (double contrast)	517	112	25	36	61
swallowing (video)	1380	608	51	46	97

cGy·cm^2. Mean weight was 77 kg, ranging from 75 kg for Barium enema (double contrast) to 79 kg for barium enema (single contrast). Fluoroscopy time values (Table 4) were submitted for 41% of the DAP values. Minimum fluoroscopy time was reported for swallowing (video, 0.1 min) and maximum for barium enema (double contrast, 7 min).

4. Discussion

A response rate of approximately 60% is generally regarded as exceptionally high [5,6,9,10], especially as all relevant hospitals and radiology offices/centers in Austria were included into the survey. Quality of data submitted was good in general, however errors from DAP unit conversion frequently occurred (in approximately 10% of the DAP data sets). All data entries were monitored and checked for outliers and uncommon or even implausible values during and after the survey period. All these possible or actual errors were followed up directly with the participating facilities and corrected manually. According to ICRP 135 the interquartile range serves as an indicator of dispersion of the data [1]. All conventional radiography examinations exhibit an interquartile range (IQR, 3rd minus 1st quartile value) with a magnitude of approximately 50% of the value of the 3rd quartile. IQVs between 1.8 and 2.0 are similar to the results by Hart, Hillier and Shrimpton [5] and Roch, Celier, Dessaud and Etard [11]. DAP-values and fluoroscopy time for barium enema (double contrast) and swallowing (video) are comparable to the results of Hart, Hillier and Shrimpton [5]. The frequency of skull x-rays, abdomen x-rays and barium enema (double contrast) is decreasing, most likely due to the more frequent use of computed tomography [12]. Consequently, case numbers for these examination types were lower in this study and future evaluation of frequency as well as relevance in daily routine is recommended. Bedside chest x-ray and barium enema (single contrast) are primarily conducted in hospitals, subsequently fewer case numbers for these examination types were recorded.

4.1. Comparison with DRLs from other countries

Table 5 compares the 3rd quartiles of mean DAP values with Austrian NDRLs based on an Austrian study from the year 2002 (revised 2005) by Nowotny [13] and in place until February 2018 (DRL_{old}) [7], German [14] and Swiss [15] NDRLs, and UK values [5].

The results for *conventional radiography* of this survey are on average 35% (facility mean) lower than DRL_{old}. They compare well with other countries NDRLs as they are on average 4% lower than the German DRLs from 2016, and 13% lower than the older Swiss DRLs from 2011.

Results for *fluoroscopy examinations* also indicate a change in practice since the last definition of NDRLs. Values for barium enema (double contrast) are nearly half of the DRL_{old}, for swallowing 27% less. The 3rd quartiles from this study are higher than the NDRLs from the UK for these two examinations. For barium enema (single contrast) Austrian results are 40% lower than the German NDRL, respectively.

4.2. Bedside chest vs standard chest PA examination

Exposure techniques used for bedside chest, and general chest PA x-rays differ considerably resulting in significantly different mean patient doses ($p < 0.01$, robust quantile test, WRS 2 Packages R). Fig. 1 shows DAP histograms for these examinations. Therefore, bedside chest examinations are not pooled together with upright chest examinations but need to be treated as a different examination type.

4.3. Diagnostic reference levels

Results presented provided the data basis for updating Austrian NDRL. However, in the attempt of European harmonisation [16], also recent NDRLs from other European countries were considered in the definition of actual Austrian values, as well as an input from an expert group consisting of physicians, medical physicists and radiographers responsible for medical radiation protection in clinical routine. For setting the DRL the 3rd quartiles calculated mainly based on the facility mean values were used. However, values were generally rounded upwards. Only in case of pelvis AP a value between 3rd quartile based on mean and median was selected since this value was numerically identical to the DRL for abdomen reducing the actual number of different values.

For skull AP/PA the slightly higher German NDRL (60 cGy·cm^2) was

Table 3
Patient weight and quartiles, interquartile values (IQV), minimum and maximum values of facility mean and median DAP.

Examination types	mean weight [kg]	calculation basis: facility mean / median DAP [cGy·cm^2]					
		1st Quartile	Median	3rd Quartile	IQV	Minimum	Maximum
Conventional radiography							
skull AP/PA	73.0	28.4 / 27.7	36.1 / 34.2	50.1 / 48.7	1.8 / 1.8	12.1 / 11.1	276.4 / 276.4
skull LAT	73.1	28.8 / 27.6	38.5 / 36.2	53.0 / 49.0	1.8 / 1.8	12.5 / 12.5	148.0 / 148.0
chest PA	75.4	7.3 / 6.5	10.0 / 9.1	13.9 / 12.8	1.9 / 2.0	1.0 / 0.9	47.8 / 44.5
chest LAT	75.2	24.1 / 20.9	33.3 / 30.1	49.5 / 41.8	2.0 / 2.0	4.6 / 5.0	205.5 / 193.4
abdomen AP/PA	74.0	102.8 / 92.1	156.1 / 128.3	209.9 / 184.0	2.0 / 2.0	28.6 / 23.2	1050.2 / 971.0
pelvis AP	74.8	113.7 / 97.5	164.8 / 142.4	212.1 / 193.8	1.9 / 2.0	49.5 / 38.2	781.4 / 647.0
lumbar spine AP	75.9	99.8 / 85.5	136.2 / 120.7	195.2 / 175.6	2.0 / 2.0	40.8 / 34.1	591.1 / 536.0
lumbar spine LAT	75.7	178.5 / 160.6	234.3 / 206.5	316.6 / 309.5	1.8 / 1.9	88.8 / 70.8	921.7 / 774.9
bedside chest	74.7	11.1 / 10.4	15.0 / 15.1	21.5 / 20.1	1.9 / 1.9	1.5 / 1.2	103.8 / 100.2
Fluoroscopy							
barium enema (single contrast)	78.9	1112.2 / 873.9	1382.9 / 1122.3	1814.1 / 1261.5	1.6 / 1.4	450.1 / 399.6	2969.6 / 2772.6
barium enema (double contrast)	74.9	1088.0 / 1021.9	1810.6 / 1571.0	2501.4 / 2047.3	2.3 / 2.0	219.5 / 117.0	6117.4 / 5920.9
swallowing (video)	76.2	226.8 / 164.1	411.1 / 333.1	944.3 / 606.1	4.2 / 3.7	30.4 / 28.9	3403.1 / 3819.0

Table 4
Number (N) of fluoroscopy time values, quartiles, interquartile values (IQV), minimum and maximum values of facility mean and median fluoroscopy time.

examination types	N	calculation basis: facility mean / median time [minutes]					
		1st Quartile	Median	3rd Quartile	Interquartile Value	Minimum	Maximum
barium enema (single contrast)	121	1.0 / 1.0	1.4 / 1.2	1.6 / 1.4	1.6 / 1.4	0.8 / 0.6	3.1 / 3.0
barium enema (double contrast)	208	1.6 / 1.4	2.0 / 1.8	3.3 / 3.0	2.1 / 2.1	0.3 / 0.2	6.8 / 6.8
swallowing (video)	531	0.8 / 0.6	1.2 / 1.1	1.7 / 1.6	2.1 / 2.7	0.2 / 0.1	5.9 / 5.3

Table 5
Comparison of the 3rd quartiles from this study with published data; [a] patient entry field: 30 × 15 cm^2, [b] chest AP.

Examination types	DAP [cGy·cm^2]				
	3rd Quartile (basis: facility mean)	NDRL Austria (DRL_{old})	NDRL Germany	NDRL Switzerland	NDRL UK
Conventional radiography					
skull AP/PA	50.1	100	60	65	na
skull LAT	53.0	100	50	50	na
chest PA	13.9	28	15	15	10
chest LAT	49.5	100	40	60	na
abdomen AP/PA	209.9	300	230	na	250
pelvis AP	212.1	300	250	250	220
lumbar spine AP	195.2	200	200	235[a]	150
lumbar spine LAT	316.6	400	350	415	250
bedside chest	21.5	na	na	na	15[b]
Fluoroscopy					
barium enema (single contrast)	1814.1	na	3000	na	na
barium enema (double contrast)	2501.4	4600	na	na	2100
swallowing (video)	944.3	1300	na	na	750

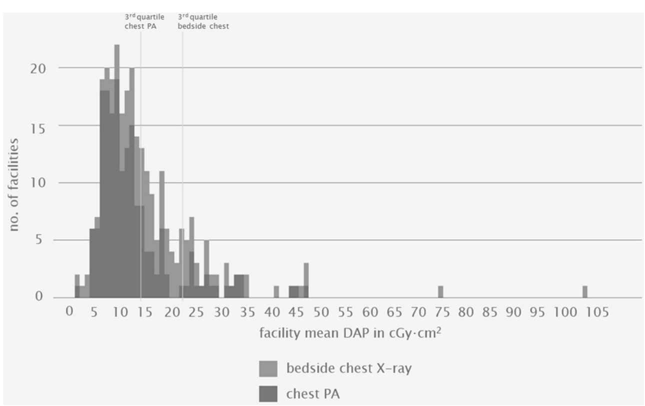

Fig. 1. Histograms of bedside chest x-ray and chest PA. 3rd quartiles shown based on facility mean DAP.

adopted, for skull LAT the identical German and Swiss DRL (both 50 cGy·cm^2). For chest PA the German and Swiss value (15 cGy·cm^2) comparing closely to the 3rd quartiles (14 / 13 cGy·cm^2, based either on mean or median, respectively) was recommended as NDRL by the expert group. In case of chest LAT (3rd quartiles 50 / 42 cGy·cm^2) the value selected corresponds to the average of the German (40 cGy·cm^2) and the Swiss value (60 cGy·cm^2), respectively.

In the case of lumbar spine LAT, the 3rd quartile (317 / 310 cGy·cm^2) was considerably lower than the German NDRL and particularly lower as the Swiss NDRL. Therefore, the expert group recommended a NDRL based on the rounded 3rd quartile. Lumbar spine AP corresponded to the German NDRL (200 cGy·cm^2) which was thus adopted.

The idea to define a separate NDRL for bedside chest x-ray was not followed by the expert group. Arguments against doing so where that Germany and Switzerland also have not established a comparable NDRL, frequency and dose of this examination is comparatively low, and only hospitals would be affected.

Barium enema (single contrast) is new in the list of DRLs for Austria and its relevance was discussed above. For this reason and as the 3rd quartile (1814 / 1262 cGy·cm^2) was considerably lower than the German NDRL, the expert group recommended a DRL based on the generously upwards rounded 3rd quartile.

For barium enema (double contrast; 2501 / 2047 cGy·cm^2) and swallowing (video; 944 / 606 cGy·cm^2) rounded values very close to the 3rd quartiles calculated based on the facility mean were adopted. The UK NDRLs from 2010 for these two examination types were lower than the results of this study. Therefore, the 3rd quartiles were not rounded upwards.

The values adopted as Austrian NDRLs for conventional radiography and fluoroscopy examinations are shown in Table 6. These values have been implemented in the Austrian Medical Radiation Protection Directive in February 2018 [17].

4.4. Limitations of this study

For conventional radiography on average 11% of the data delivering facilities (9% of the hospitals and 13% of the offices) were not able to provide the full amount of 10 DAP values for all their examination types

Table 6
Updated Austrian NDRLs for conventional radiography and fluoroscopy.

examination types	DAP [cGy·cm^2]
conventional radiography	
skull AP/PA	60
skull LAT	50
chest PA	15
chest LAT	50
abdomen AP/PA	210
pelvis AP	210
lumbar spine AP	200
lumbar spine LAT	320
fluoroscopy	
barium enema (single contrast)	2000
barium enema (double contrast)	2500
swallowing (video)	940

in the short survey period. Yet, all these data were included into the analyses. The ratio behind this decision was that even if these institutions provided not the desired minimum number of 10 values, these data are valuable because most of these were offices and hospitals small in size with lower patient frequencies. For fluoroscopy, the percentage of facilities which could not report 10 DAP values was higher with on average 25% (23% hospitals, 30% offices) reflecting the lower frequency of these examinations.

In addition, the lower response rate for non-hospital-based examinations may also influence data quality because only offices interested in radiation protection may have participated in the survey, and offices with for example lower equipment standard may not have provided data. Since the response rate for hospitals was higher, this might also be true for these facilities but to a smaller extent.

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Conflict of interest

None.

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