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Analysis of radiation exposure data from common radiological procedures in Dutch hospitals

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ABSTRACT

Introduction: In the Netherlands, Diagnostic Reference Levels (DRLs) have not been based on a national survey as proposed by ICRP. Instead, local exposure data, expert judgment and the international scientific literature were used as sources. This study investigated whether the current DRLs are reasonable for Dutch radiological practice.
Methods: A national project was set up, in which radiography students carried out dose measurements in hospitals supervised by medical physicists. The project ran from 2014 to 2017 and dose values were analysed for a trend over time. In the absence of such a trend, the joint yearly data sets were considered a single data set and were analysed together. In this way the national project mimicked a national survey.
Results: For six out of eleven radiological procedures enough data was collected for further analysis. In the first step of the analysis no trend was found over time for any of these procedures. In the second step the joint analysis lead to suggestions for five new DRL values that are far below the current ones. The new DRLs are based on the 75 percentile values of the distributions of all dose data per procedure.
Conclusion: The results show that the current DRLs are too high for five of the six procedures that have been analysed. For the other five procedures more data needs to be collected. Moreover, the mean weights of the patients are higher than expected. This introduces bias when these are not recorded and the mean weight is assumed to be 77 kg.
Implications for practice: The current checking of doses for compliance with the DRLs needs to be changed. Both the procedure (regarding weights) and the values of the DRLs should be updated.

Introduction

In the Netherlands Diagnostic Reference Levels (DRLs) for radiation exposure were defined most recently in 2012 for 11 common radiological procedures. These procedures include mammography, chest radiography, pelvis radiography, CT pulmonary angiography (CTPA), CT coronary angiography (CTCA), CT abdomen, coronary angiography (CAG) and for children: chest radiography, abdomen radiography, CT head and voiding cystourethrography VCUG.[1] The values of these DRLs have been based on local exposure data, expert judgment by the Netherlands Commission on Radiation Dosimetry (NCS) and the international scientific literature, but not on a nationwide survey. Adherence to DRLs is an indication of good radiological practice, in which radiological protection is considered important. Average dose values for groups of patients subject to the same procedure should generally remain below the DRL.[1]

A study by the National Institute for Public Health and the Environment in the Netherlands (RIVM),[2] based on data from 2013, showed that radiological departments in many hospitals do not compare their dose estimates to the DRLs according to the procedure that was outlined in the national guideline.[1] According to this procedure dose values and weights should be recorded for all procedures except mammography for a minimum of 20 patients.

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Per procedure the 20 (or more) dose estimates (Dose Area Product (DAP) values for plain and fluoroscopic examinations and Computed Tomography Dose Index (CTDIvol) and Dose Length Product (DLP) values for CT-scans) should be plotted on a graph against the weights of the patients. A best regression line then needs to be calculated in order to derive a dose estimate for a standard patient of 77 kg. It is this dose estimate that should be compared to the DRL. For pediatric x-ray procedures DRLs are defined for age groups neonate, 1 year, and 5 year. For pediatric CT procedures DRLs are defined for age groups neonate, 1 year, 5 year, and 10 year.[1]

In many cases hospitals in the Netherlands record dose values and compare the averages to the corresponding DRLs. However, weights of patients are not commonly recorded and some (mainly pediatric) procedures are not performed often enough to follow the guideline and gather dose estimates from at least 20 patients.

To remedy some of these issues a project was set up in which radiography students of the Bachelor programme Medical Imaging and Radiotherapy (MIRT) of three universities of applied sciences carried out the formal DRL comparison procedure in the hospitals during their clinical placements. The aim and first results of this project were published by Bijwaard et al. (2017).[3]

The project was carried out on a yearly basis from 2014. In 2018 an analysis was conducted using the data collected in 2014, 2015, 2016 and 2017. The aim of this analysis was to investigate whether a trend exists in the collected exposure data over time. If a downward trend were found this might indicate that continued attention to exposure levels could lead to dose reduction and increased compliance to DRLs. If no such trend were found this might indicate that radiological procedures were not altered over the years 2014–2017 in a way that affects dose. In that case the combined data from all years 2014–2017 might be considered as a single data set and a statistical analysis of this data set might provide new insights for future DRLs. Here the results of this analysis are reported.

Methods

In each year of data collection (2014–2017) the following procedure was conducted to ensure the reliability and accuracy of the data. Hospitals were contacted by one of the three participating universities of applied sciences and asked to participate voluntarily. Medical physicists and senior radiographers at these hospitals were contacted and asked to provide local supervision over the students and their measurements. Students in three MIRT programs participated in this study as a part of their clinical placement. Participating diagnostic radiography students received training at their university and conducted dose and weight measurements at ‘their’ hospitals for at least 20 patients for one or more procedures. All patient data was rendered anonymous and therefore ethical approval was not needed. Procedure selection was based on the student's experience and the frequency of procedures in the time frame of the student's clinical placement. The entire examination (and not only the dose and weight measurements) was carried out by the student under the supervision of a medical physicist.

For most adult procedures dose values and weights of a minimum of 20 patients were recorded. Selection of patients was based on a convenience sampling approach by collecting data of all patients in daily routine until a minimum of 20 was obtained. Patient weights were collected at the time of the radiological procedure. For x-ray procedures DAP values were recorded and CTDIvol and DLP for CT procedures. Dose measurements were plotted against weights and linear and exponential regressions were calculated using Microsoft Excel 2010 software including the coefficient of determination R^2 and standard error (SE). In this way for adult patients a dose value for a patient weight of 77 kg was estimated. For pediatric patients the arithmetic mean dose value in an age group was compared to the respective DRL. Mammography mean glandular doses (MGD) were measured at PMMA phantom thickness of 3 cm, 5 cm and 7 cm for comparison to the DRL. These methods all follow the national guidelines composed by the National Commission for Radiation Dosimetry (NCS).[1]

In the four years of data collection, a total of 40 hospitals participated in this project (out of the approximately 80 hospitals conglomerates that exist in the Netherlands). However, most hospitals had the students collect dose data from X-ray procedures in adults such as chest X-rays and pelvis X-rays. Some of the procedures, for which DRLs exist, were hardly tested for compliance to the DRLs. In this paper, the arbitrary choice is made to only consider and analyse the procedures for which doses have been recorded at least 100 times. The rationale behind this choice is that this is approximately the sample size needed in a random sampling of a large population with a reliability of 95% and an error margin of 10%. However, it should be noted that in reality the sampling is not random because 100 dose measurements mean that compliance to the DRL has been investigated in 5 settings (with data from 20 patients). This leads to the data set described in Table 1.

All data has been analyzed in two steps. In the first step for each examination average dose values and standard deviations were calculated per examination for all data collected in the same calendar year. From this, plots were made to investigate whether a trend exists over time. One might expect a downward trend in dose values against time, for the following reasons: (1) hospitals might use the results of a previous year as a benchmark that they want to improve upon, (2) increased attention for DRLs (partly due to publications resulting from this project) may lead to increased dose awareness among radiographers, and (3) hospitals might replace old equipment by new equipment with more possibilities to reduce radiation exposure.

If no trend over time were visible in the exposure data, this would indicate that data could be combined. In that case a second step was taken in which the combined data were analysed to derive averages, standard deviations and distribution plots. In this analysis also 75-percentile values were calculated that could be used as an updated value of the DRL. After all, ICRP recommends DRLs to be derived as 75-percentile values from a national dose survey,[4] and in this case the combined data set could be regarded as a national dose survey.

Results

In the first step of the analysis average dose values were derived for each year and for each examination for which at least 100 data had been collected. The results of this analysis are shown in Fig. 1. Note that the yearly data groups are expected to be statistically significantly different from each other for the following reasons: (1) the data come from different hospitals every year and these were not chosen randomly, and (2) the data are organized in sets of 20 data points per DRL checking.

The results show no apparent downward trend for the six procedures with more than 100 patient data (X chest, X pelvis, CT abdomen, CTPA, CTCA and CAG) as shown in Fig. 1. In fact it is for all procedures possible to draw a straight horizontal regression line that would fit all data within their error bars. Hence, we conclude that the data show no significant trend (upward nor downward) over time.

The fact that no trend over time is found indicates that the yearly projects themselves have had no significant influence on radiation doses used, and this allows for the joining of the separate, yearly data sets into one data set that (despite the yearly

Table 1
Overview of all data collected from 2014 to 2017. Data in grey have not been analyzed further for this paper. A cut-off value of at least 100 data per procedure was used.

Examination	Number of hospitals	Number of dose measurements
Chest x-ray	36	2265
Pelvis x-ray	28	1242
CT abdomen	18	691
CTPA	17	576
CTCA	11	384
CAG	7	193
Mammography 3/5/7 cm	3/3/3	5/5/5
Chest x-ray 0/1/5 y	4/4/3	63/63/60
Abdomen x-ray 0/1/5 y	4/3/3	40/55/48
CT head 0/1/5/10 y	-/1/1/1	-/9/10/15
VCUG 0/1/5 y	–/–/3	–/–/61
TOTAL	*40*	*5790*

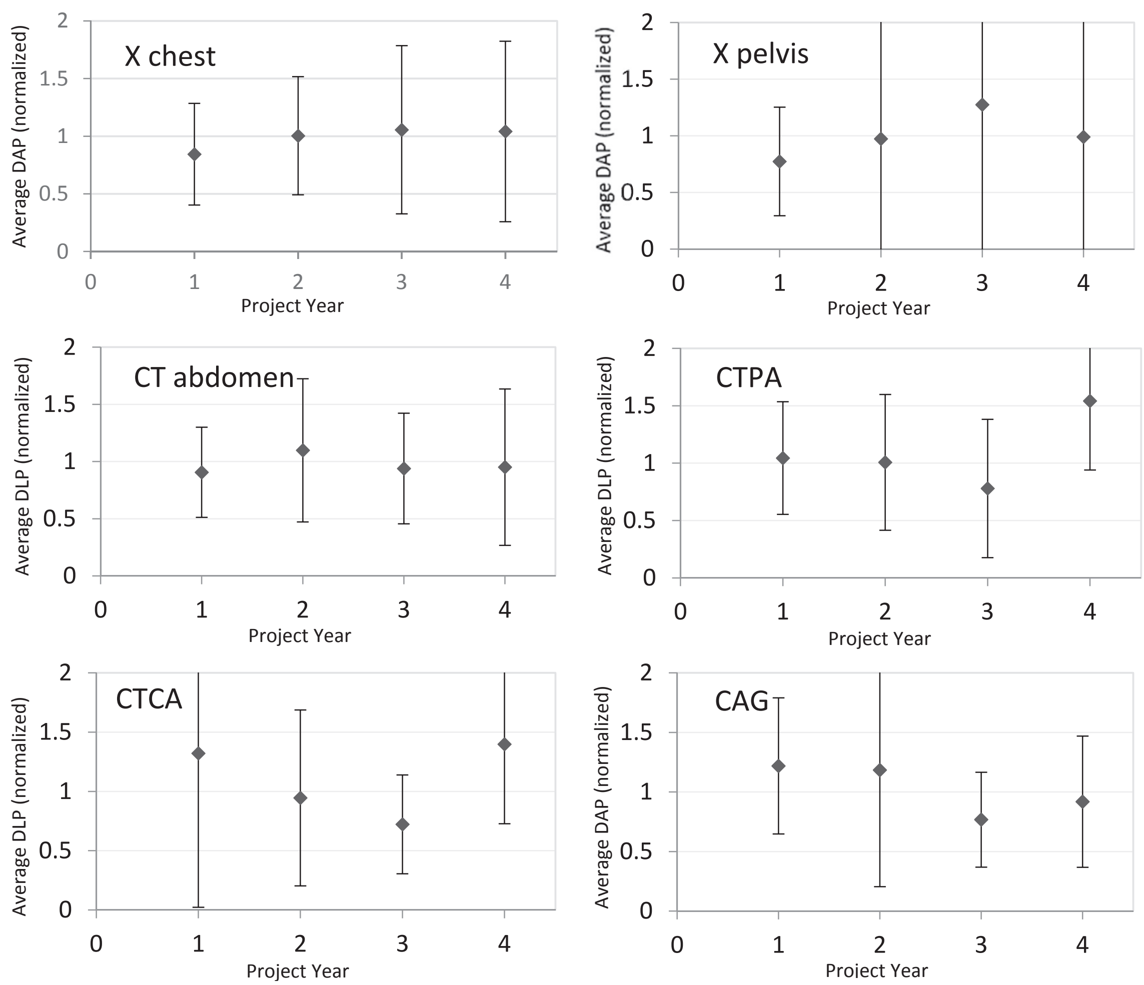

Figure 1. Average dose values per project year (year 1 is 2014), normalised with the average dose for the procedure of all project years together (i.e. the average of all dose data for this procedure), and standard errors for the six procedures with more than 100 patient data. None of the six procedures shows a clear (downward) trend.

differences) can be analysed as a whole. The results of this second step of the analysis are shown in Figs. 2 and 3.

The histograms in Fig. 2 show a very good compliance with the current DRLs. For most procedures the 75 percentile values of their distributions are far below the current DRL (with the exception of CTPA). This indicates that the current DRLs may be too high. ICRP states that national DRLs should be derived from a national survey as the 75th percentile value of the resulting distributions. The distributions in Fig. 2 have been derived from a national project, but not all hospitals supplied data. If these distributions are considered representative for the Netherlands than new DRLs can be calculated. This is shown in Table 2.

In Fig. 3 exponential regression lines of dose values against weight are shown for the six procedures with more than 100 patient data. All regression lines show an upward curvature as more radiation is usually needed with increasing patient size. However, significant scatter can be observed that is at least partly due to different hospitals using different equipment and different

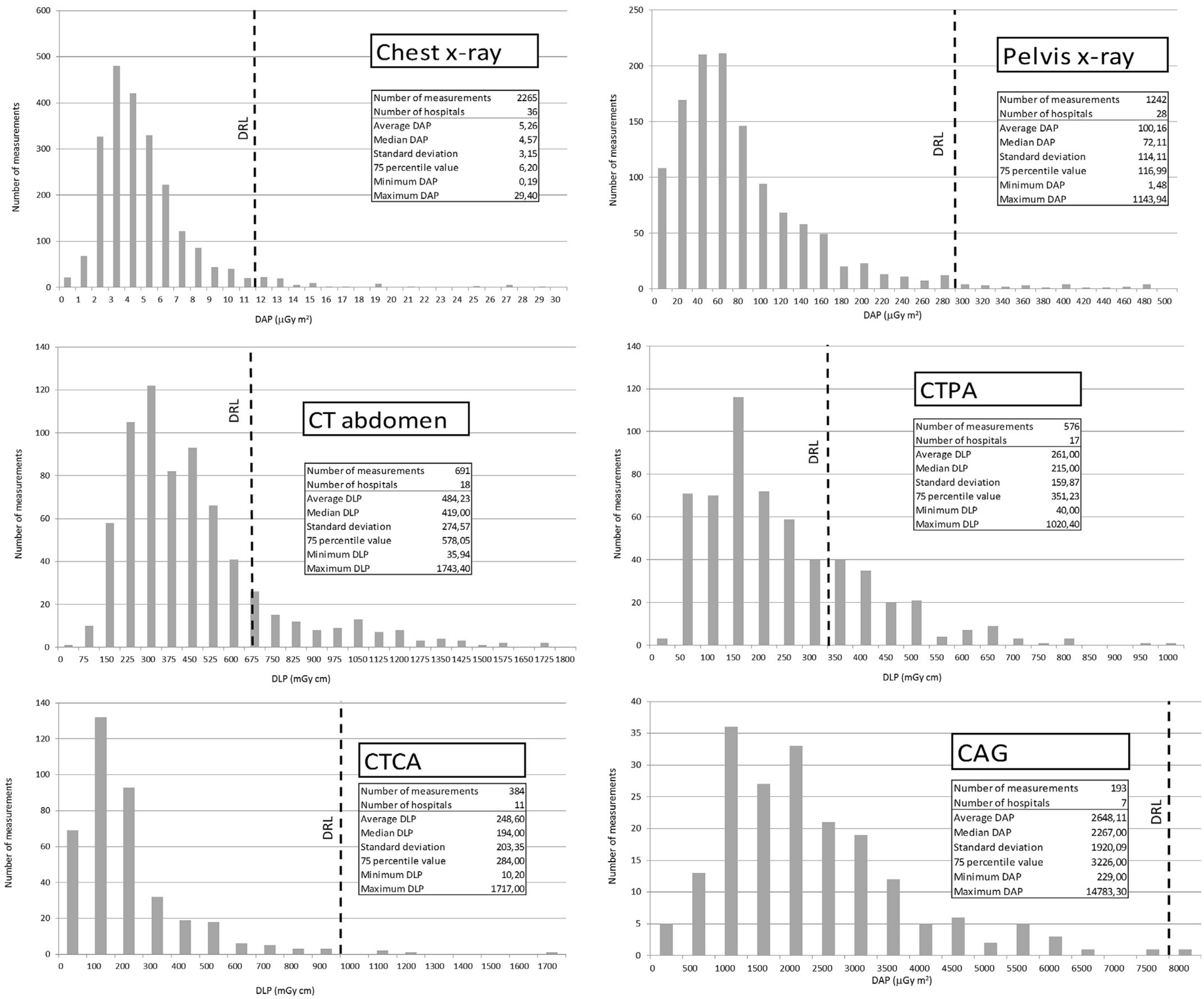

Figure 2. Histograms of all dose measurements performed for the checking of DRL compliance for the six procedures with more than 100 data. Current DRL values are indicated by the dashed lines.

protocols. The regression lines can be compared with the current DRLs and the 75 percentile values from the distributions. For the current DRLs an average weight of 77 kg is assumed. The average weights of the patients are slightly higher than 77 kg and range from 77.9 for chest x-ray to 83.3 kg for CAG.

Discussion

The observed compliance to the current Dutch DRLs is extremely good. The compliance is enhanced by at least two important factors: (1) participation to this study was on a voluntary basis, and (2) the Dutch DRLs are not based on national dose surveys. The first factor may have led to a participation bias: mainly hospitals that were likely confident about their performance may have signed up. Explanation of the second factor requires a more thorough look at the development of the Dutch DRLs. The International Commission on Radiological Protection (ICRP) currently advises to base national DRLs on 75-percentile values of a nationwide dose survey.[4] At the time the Dutch DRLs were developed no such dose surveys existed for the Netherlands. Therefore, the Dutch DRLs were based on local data, results from other countries and expert judgment. The committee that drafted the report about the DRLs expected hospitals to be able to comply with them. From that perspective it is not surprising that compliance to the DRLs is found in nearly all cases.

A factor that may have reduced compliance with DRLs is that in some cases patients were simply asked about their weights instead of performing weight measurements. This may lead to some bias because patients may be inclined to report lower weight. This would lead to higher dose values for apparently lower weights and therefore worse compliance with DRLs. The very good compliance that is observed seems to indicate that the contribution of this factor to bias is small.

In Dutch radiological practice weights are not commonly reported. This complicates checking for DRL compliance because weights are needed to follow the formal procedure. Some hospitals choose not to measure weights, but simply assume that a large sample of patient data will on average not deviate (much) from the mean weight of 77 kg. In that case one only needs to collect dose data for a large sample and compare the mean to the DRL. The mean

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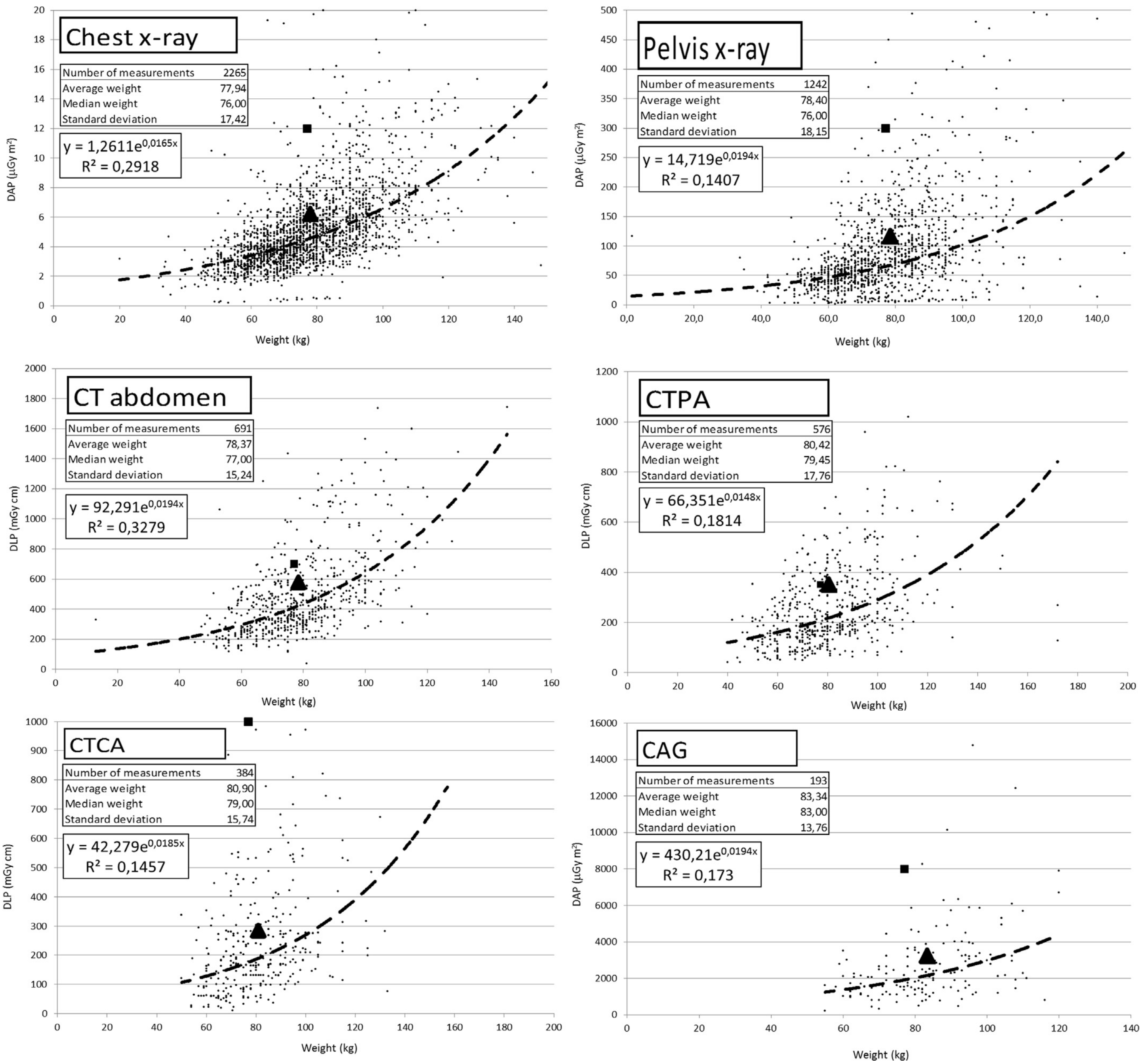

Figure 3. Dose measurements against weight. Exponential regression lines are shown dashed. Current DRLs (for 77 kg) are black squares and 75 percentile values (for average weight) are black triangles.

Table 2
Comparison of current DRLs with 75 percentile values derived in this study and suggestions for new DRLs.

Examination	Current DRL	75 percentile from this study	Suggested new DRL
Chest x-ray	12 µGy·m²	6.20 µGy·m²	6 µGy·m²
Pelvis x-ray	300 µGy·m²	116.99 µGy·m²	120 µGy·m²
CT abdomen	700 mGy·m	578.05 mGy·m	600 mGy·m
CTPA	350 mGy·m	351.23 mGy·m	350 mGy·m
CTCA	1000 mGy·m	284.00 mGy·m	300 mGy·m
CAG	8000 µGy·m²	3226.00 µGy·m²	3500 µGy·m²

weights calculated in this study confirm that this is in general viable. Mean weights range from 77.9 kg for chest x-ray to 83.3 kg for CAG. However, when applying the regression line for CAG, 83.3 kg corresponds to a DAP of 2167 µGy m², whereas 77 kg corresponds to a DAP of 1916 µGy m². The difference in DAP is therefore 2167-1916 = 251 µGy m² which is considerable. Fortunately, this leads in practice to a conservative estimate: if the average DAP is below the DRL for a sample of patients that is on average heavier than 77 kg than it will certainly be below the DRL for a sample that is on average 77 kg. And as indicated earlier: all mean weights are higher than 77 kg.

The current nationwide results provide us with an opportunity to suggest new DRLs (see Table 2). For some procedures dose measurements were obtained from a significant sample of all Dutch hospitals. For example, for chest x-rays DAP values were obtained from 36 hospitals (out of a total of approximately 80 Dutch hospital conglomerates). However, for others this is not the case. For CAG, for example, only 7 hospitals reported data. It is unclear whether this is a representative sample of Dutch hospitals. This is something that needs to be explored further. It should be noted, however, that the current Dutch DRL for CAG is not based at all on a survey among Dutch hospitals. It has been derived from DRLs in Sweden and Switzerland that were published in 2002 and 2007, respectively.[1] In that respect the current approach is still an improvement.

In this study we have not investigated the quality of the obtained images. It is important to note that the optimization principle in radiation protection requires imaging to be at least adequate for diagnostic purposes and radiation doses simultaneously to be as low as reasonably achievable (ALARA). In clinical practice one should therefore not only focus on reducing doses, but also on maintaining image quality.

Conclusions

In the Netherlands DRLs have been compiled in 2012 for 11 common radiological procedures. However, these DRLs have not been based on a national dose survey. From 2014 to 2017 radiography students from three universities of applied sciences have been checking the compliance to the DRLs. Their results have shown very good compliance as has been published earlier.[3] Here, it was shown that the dose data that were collected in yearly national projects, show no trend over time. This indicates that hospitals have probably not used the yearly data to improve their practices. Therefore, it is possible to combine the data from 2014 to 2017 and analyse them together. These combined analyses have been carried out for six of the 11 radiological procedures (i.e. all procedures for adults except mammography), for which dose data from more than 100 patients was available. For these six procedures new DRLs are suggested that in most cases are far below their current values. These new DRLs are calculated as the 75 percentile values from the dose distributions of the combined data from the national project. Apart from that, average weights have been calculated and compared to the value used in the current guidelines (77 kg). This shows that average weights are slightly higher than assumed (77.9−83.3 kg), which can in some cases lead to considerable bias in dose when weights are not measured. However, this will lead an overestimation of dose for an average person (assumed to weigh 77 kg), which can be regarded as a conservative approach.

Conflict of interest

None

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