Compliance to Diagnostic Reference Levels for radiation exposure in common radiological procedures in Dutch hospitals: A nation-wide survey carried out by medical imaging students

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ABSTRACT

Introduction: In the Netherlands, hospitals have difficulty in implementing the formal procedure of comparing radiation dose values to Diagnostic Reference Levels (DRLs).

Methods: To support the hospitals, train radiography students, and carry out a nationwide dose survey, diagnostic radiography students performed 125 DRL comparisons for nine different procedures in 29 radiology departments. Students were instructed at three Dutch Universities of Applied Sciences with a radiography programme and supervised by medical physicists from the participating hospitals.

Results: After a pilot study in the western part of the country in eight hospitals, this study was enlarged to involve 21 hospitals from all over the Netherlands. The 86 obtained dose comparisons fall below the DRLs in 97% of all cases. This very high compliance may have been enhanced by the voluntary participation of hospitals that are confident about their performance.

Conclusion: The results indicate that the current DRLs that were not based on a national survey, may need to be updated, sometimes to half their current value. For chest and pelvis examinations the DRLs could be lowered from 12 and 300 \( \mu \)Gy \( \cdot \) m\(^2\) to the 75-percentile values found in this study of 5.9 and 188 \( \mu \)Gy \( \cdot \) m\(^2\), respectively.

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Introduction

In the Netherlands Diagnostic Reference Levels (DRLs) for radiation exposure were defined 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. The values of these DRLs have been based on expert judgement and international literature, but not on a nationwide survey. In addition to these DRLs, so-called target values have been set at usually half the value of the DRL. These target values have also been based on expert judgement and they indicate an achievable dose level. 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.²

A study by the National Institute for Public Health and the Environment in the Netherlands³ 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. Per procedure the 20 (or more) dose estimates (DAP values for plain and fluoroscopic examinations and CTDIvol and 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 and to the target dose value. An example is shown in Fig. 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 paediatric) procedures are not performed often enough to follow the guideline and gather dose estimates from at least 20 patients. The Ministry of Health, Welfare and Sports acknowledged that it was difficult for radiological departments to comply with the prescribed procedure and looked for ways to support hospitals. The National Institute for Public Health and the Environment that is formally part of the ministry contacted Inholland University (InhU) of Applied Sciences (Haarlem) and a plan was drafted that involved students of the Bachelor programme Medical Imaging and Radiation Oncology carrying out the formal DRL comparison procedure in the hospitals where they receive their training.

The purpose of this study was to assist hospitals in complying to the DRL-procedure, to gather national dose data (and measure DRL compliance) and to provide a means for medical imaging students to get hands-on experience with DRL-procedures.

Methods

In 2014 a pilot study was conducted in which eight hospitals in the western part of the country voluntarily participated. Medical physicists and senior radiographers at these hospitals were contacted and asked to provide local supervision over the students and their measurements. Students participated in this study as a part of their internship, which takes place in their third year of study. Participating diagnostic radiography students received a training at InhU 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 internship. The entire examination (and not only the dose and weight measurements) was carried out by the student. Linear regression lines were calculated to estimate the dose value at 77 kg which was then compared to the DRLs and target values. The measurement data were undersigned by the responsible medical physicist and sent to the lead institution (InhU) for further processing. At InhU the results were checked by recalculating the estimate by linear regression as well as a fit of an exponential function. The results were shared anonymously with the National Institute for Public Health and the Environment, who published them on its website for medical radiation applications (www.rivm.nl/ims, in Dutch).

For all 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 moment of the radiological procedure. For x-ray procedures DAP values were recorded and CTDIvol and DLP for CT. Dose estimates were plotted against weights and linear and exponential regressions were calculated using Microsoft Excel 2010 software including determination of coefficient $R^2$ and standard error (SE). In this way a dose value for a patient weight of 77 kg was estimated.

For paediatric x-ray procedures DRLs and target values are defined for age groups neonate, 1 year, and 5 year. For paediatric CT procedures DRLs and target values are defined for age groups neonate, 1 year, 5 year, and 10 year. The arithmetic mean dose value in an age group was compared to the respective DRL and target value. Mammography mean glandular doses (MGD) were measured at PMMA phantom thickness of 3 cm, 5 cm and 7 cm for comparison to the DRL and target values.

The 2014 pilot study showed the feasibility of the approach, but only eight out of a total of approximately 80 Dutch hospital conglomerates participated. To obtain a larger sample and a more complete view of Dutch clinical practice, the two other Dutch Universities of Applied Sciences with the same bachelor program were involved in 2015: Fontys University of Applied Sciences (Eindhoven) and Hanze University of Applied Sciences (Groningen). The experiences of the 2014 pilot were shared and in 2015 a nationwide study was set up in the same way as the original pilot. In total 21 hospitals from all over the country participated. Again, participation was on a voluntary basis and under supervision of the local medical physicist. Diagnostic radiography students of the three universities performed dose and weight measurements for procedures in the hospitals where they received their clinical training. Selection of procedures, data collection and data processing was similar to the 2014 study. DRL comparisons were excluded if the number of patients was less than 20.

Results

In the pilot study of 2014 eight hospitals in the western part of the Netherlands participated. Seven of these were willing to share their results. One hospital participated in the study for training purposes, but did not want to make public any results regardless of the outcome. In Fig. 1 a typical example of a comparison of dose values to the DRL is shown for chest examinations in one of the participating hospitals. The DRL comparison procedure requires an estimation of the dose value for a patient of 77 kg. This can either be derived by linear or exponential regression of the collected data. As shown in Fig. 1, the difference between these two is marginal, especially when compared to the DRL of 12 μGy m².

In 2014, dose values for eight different radiological procedures (out of 11 for which national DRLs have been defined) were compared to DRLs (see Table 1). Some procedures were compared in all hospitals and sometimes in more than one x-ray room. Other procedures were compared only sporadically, due to the limited availability of patients. The three procedures for which no comparison to the DRL could be performed were all for children: abdomen examination, CT head and VCLG. The hospitals that participated did not receive enough children during the
measurement campaign to allow for a formal comparison to the DRL. Of the total number of shared DRL comparisons no data was excluded.

In all 37 comparisons of dose values from different procedures, the DRLs were not exceeded. In some instances, large differences (a factor of two to three) between average dose values for the same procedure were recorded. This was even the case between different x-ray rooms of the same hospital. All results of the dose comparisons can be found at the Dutch website: http://www.rivm.nl/Onderwerpen/M/Medische_Stralingstoepassingen/Stralingsbescherming patiënten/Diagnostische_Referentieniveaus/Pilotproject_DRN_toetsing.

When the study was expanded in 2015, 21 Dutch hospitals (approximately 25% of all Dutch hospitals) voluntarily participated in the study. In total, 86 comparisons to the DRLs of nine different procedures were performed according to the national guidelines. An overview of these comparisons is provided in Table 1. This table shows that the distribution of the number of comparisons over the procedures is very heterogeneous: relatively simple procedures such as the different x-rays for adults have been compared many times, whereas more difficult procedures using CT or fluoroscopy and involving children were sometimes not compared at all, as fewer than 20 patients were measured. As in the pilot study, for some procedures comparisons to the DRL were carried out in several x-ray rooms of the same hospital. For chest examinations this leads for example to 36 comparisons in 16 hospitals.

In Fig. 2, the results of the 36 comparisons of chest examinations to the DRL are shown. All derived dose estimates are below the DRL and near the target value (half the DRL). The dose estimates range from 3.2 to 9.2 μGy m², but the variation within one hospital is always less than a factor 2.

In Fig. 3 the results of the 21 comparisons of pelvis examinations to the DRL are shown. All but one derived dose estimates are below the DRL and 14 dose estimates are below the target value (half the DRL). The dose estimates range from 46 to 344 μGy m² (a factor 7.5), but the variation within one hospital is always less than a factor 2.

For procedures involving CT-scans considerably fewer comparisons to the DRLs were carried out. In Fig. 4 the results of the 7 comparisons of DLP values of CT abdomen to the DRL are shown. All derived dose estimates are below the DRL and two are below the target value. The dose estimates range from 275 to 610 mGy cm, or slightly more than a factor 2.5.

In Fig. 5 the results of the 8 comparisons of DLP values of CTPA to the DRL are shown. All derived dose estimates are below the DRL and 6 are below the target value. The dose estimates range from 121 to 310 mGy cm (a factor 2.5).

For the other procedures at most 5 comparisons were carried out. For the paediatric procedures it was difficult to obtain enough data (at least 20 patients for one or more age groups) to perform a valid comparison to the DRL. The results of these comparisons are not shown here, but all results can be found at the Dutch website:

### Table 1

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![Figure 2](image.png)  
Figure 2. DRL comparison results for chest examinations. The dashed line indicates the DRL and the dotted line the target value. Error bars reflect the standard error in the linear regression that was carried out.
Discussion

In Dutch radiology departments medical physicists are usually responsible for dose measurements. In practice radiographers often perform these measurements under supervision of a medical physicist. This study takes this one step further: diagnostic radiography students are trained to perform these measurements (and perform the examination), supervised by the local medical physicist. An important message of this study is that this has turned out to be a viable approach that might be exported to other procedures and other countries. In our view the benefits of using radiography students are: it is an efficient (and cost-effective) way to collect dose data from a large number of hospitals, and it is also (and perhaps more importantly) a means to train students in a task that they are likely to perform once graduated and to make them familiar with the concept of radiation protection in practice. Note that in this way the compliance of student performances to the DRLs is measured. This need not be problem as long as the supervision (by more experienced radiographers and medical physicists) is well taken care of.

This project is an example of task-based learning, which is a well-known approach in linguistics, for example to learn a new language. The task in this case is to perform a formal comparison of patient doses to the national DRL, following the prescribed procedure. During the execution of the task students become familiar with the concept of DRLs and radiation protection in general. They learn how to operate the x-ray equipment. They practice communication skills with real patients. And they experience doing research, collecting data, making regression plots and drawing conclusions. The advantages of task-based learning as opposed to problem-based learning have been described in a clinical setting.

Overall the results show that compliance to the DRLs is very good. In only a few cases DRLs are exceeded. Although compliance to DRLs is indicative of good radiological practice, their exceedance may be justified: complexity of some procedures or an abnormal distribution of patient weights may for instance be valid causes. In any case the exceedance of a DRL should be a reason for further investigation.

The observed compliance to the DRLs is very good (83 out 86 cases or 97% in the nationwide study): in only three cases DRLs are exceeded (and this may be justified). This appears to be true for all nine different procedures, although for some procedures very few comparisons could be carried out. 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 entirely based on dose surveys. The first factor may have led to a participation bias: mainly hospitals that were 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. At the time the Dutch DRLs were developed no such dose surveys existed for the Netherlands. Therefore, the Dutch

DRLs were based on smaller regional surveys, results from other countries and expert judgement. The committee that drafted the report about the DRLs expected hospitals to be able to easily comply with them. Therefore also target values were introduced: in good radiological practice these values should be achievable. 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.

The current nationwide results provide us with an opportunity to derive new DRLs. For some procedures dose measurements were obtained from a significant sample of all Dutch hospitals. For example, for the chest examinations 36 measurements from 16 hospitals were recorded. According to the ICRP we could take the 75-percentile dose value (5.9 μGy m²) as the new DRL. In this case the DRL would become approximately half the current value (12 μGy m²). The same is true for pelvis examinations, for which we have 21 measurements. In that case our 75-percentile dose value is 188 μGy m², whereas the current DRL is 300 μGy m².

For the different paediatric procedures relatively few data were obtained. An important reason for this lies in the relatively short period (internships last usually 4–5 months) in which data could be collected by the students. Many general hospitals do not receive enough children in that period of time to be able to follow the prescribed DRL comparison procedure (requiring at least 20 patients per age group). There may be several solutions to this problem: (1) data collection for these procedures may take place in the context of the longer research project students carry out for their final thesis, or (2) data collection might be done by several students during consecutive internships at the same radiology department. At the same time this problem has been recognized in a broader European context. The EU project PiDRL has drafted a guideline for paediatric DRLs that will be published as a part of the European Radiation Protection series. One of the solutions to the shortage of paediatric data per age category that is suggested in the document is to use a DRL curve for all age (or weight) groups instead of single values per group.

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. In the current study the image quality was at least adequate for diagnostic purposes.

Conclusions

In this study it has been shown that it is feasible to support hospitals with diagnostic radiography students in implementing DRLs in their quality assurance system. Diagnostic radiography students were able to perform comparisons of dose values to the DRLs according to the formal procedure under supervision of medical physicists. In this way the students learnt about radiation protection in medical imaging practice and a nationwide dose survey was carried out at the same time. The results of this survey demonstrate that nearly all participating hospitals comply with the DRLs, although differences in dose values between hospitals may amount to a factor of 3. The former may indicate that the current Dutch DRL values, which are not based on a national dose survey, need to be updated. For this purpose the 75-percentile values of this study may be used for procedures that were checked in a significant number of hospitals. This was not the case for all procedures, for which a DRL has been proposed. Especially for paediatric procedures it was often difficult to obtain enough data. For these procedures the measurement period could be prolonged.

Conflict of interest statement

The authors have no conflict of interest.

Acknowledgments

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