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Technical note

Dose management software implementation in mammography

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ABSTRACT

Purpose: This work aimed to evaluate the use of a dose management software (DMS) in mammography and analyse the clinical practice in terms of radiation exposure in screening and diagnostic mammography.
Methods: Mean glandular dose (MGD) from approximately 10,000 images were collected and analysed taking into account anode/filter combination, projection, compressed breast thickness (CBT) and compression force. Causes of increased MGD were investigated and actions were taken when malpractice was detected.
Results: MGD values for craniocaudal (CC) and mediolateral oblique (MLO) exposures for different CBT were defined. The average MGD for CBT of 60–69 mm was 1.84 mGy for CC images and 1.85 mGy for MLO images for screening examinations, while for diagnostic examinations the MGD was 1.95 mGy for CC and 2.01 mGy for MLO images. As no national diagnostic reference levels (DRLs) for mammography exist in Switzerland, typical mean glandular dose (MGD) values were defined as a first step towards their establishment for both screening and diagnostic examinations.
Conclusions: The use of DMS facilitated immensely the analysis of all clinical and technical parameters, the evaluation of radiation dose received by the patients, as well as the overall evaluation of radiographers' performance. The DMS disclosed the role of the medical physicist in dose management and optimization.

1. Introduction

Numerous breast disorders such as hyperplasia, fibrosis, adenosis, cysts or other conditions are detected with mammography [1]. Breast cancer is the most frequent type of cancer accounting for 25% of all cancer cases and 15% of all cancer deaths among women [2,3]. Despite the technological advances in breast imaging, mammography remains the basic breast examination used to detect changes in the breast tissue, diagnose and generally manage patients with breast disorders [4].

Mammography examination applies low energy X-ray radiation to image the breast. This is done to healthy women without any clinical symptoms (screening mammography) or to women with certain clinical symptoms (diagnostic mammography). Taking into consideration that breast tissue is more sensitive to radiation than other soft tissues, it is evident that the X-ray machine and examination technical parameters should ensure the image provide the necessary for diagnosis information with the lowest possible radiation dose [5–8]. Screening mammography is of particular interest in terms of radiation protection as asymptomatic individuals are exposed to radiation.

The new European Basic Safety Standards (BSS) [9] and the International BSS [10] emphasize the need for patient dose optimization in all radiological practices including the exposure of asymptomatic individuals. International Commission on Radiological Protection (ICRP) proposed the use of diagnostic reference levels (DRLs) in 1996 [11] as a means of optimization of X-ray examinations. The establishment and active use of DRL has now become mandatory [12]. In mammography, DRLs can be expressed in terms of entrance surface air kerma free-in-air, entrance skin dose or mean glandular dose (MGD) estimated using a standard Poly(methyl methacrylate) (PMMA) phantom [5–8,13]. The latest ICRP publication on the use of DRLs in medical imaging [14] recommends the MGD as DRL quantity to reflect the influence of different anode/filter combinations and breast thickness on radiation dose, which is not possible with the other two quantities (entrance surface air kerma free-in-air or entrance skin dose). Moreover, according to ICRP 135, DRL values should cover screening programs for asymptomatic individuals as well as diagnostic mammograms [14]. In its previous report 103 ICRP suggested the use of different DRL values for screening programs and diagnostic examination [15]; however, in the more recent recommendations 135, the use of the same values for diagnostic and screening examinations is proposed [14].

The European BSS also clearly state that medical X-ray equipment must have a means to inform the practitioner of the relevant parameters

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for assessing the patient dose and even more important to have the capacity to transfer this information to the record of the examination [9]. Finally, the European BSS introduce new requirements in relation to exposure of asymptomatic individuals, which either shall be part of an approved health-screening programme or shall require specific documented justification for that individual by the practitioner, in consultation with the referrer, following guidelines from relevant medical scientific societies and competent authorities [12].

All the above point to the urgent need of continuous patient dose monitoring and establishment of DRLs in mammography locally, regionally and nationally. Due to the large number of mammograms performed daily both for screening and diagnostic purposes, patient dose collection can be a time consuming, complex task. The last years, manufacturers have introduced sophisticated software to the health market to assist staff on this task. Manufacturers claim that patient dose data can be easily and quickly archived using information from Digital Imaging and Communication in Medicine (DICOM) files or from Picture Archiving and Communication System (PACS) of hospital and further analysed [16–22]. The application of dose management software (DMS) is extensive in CT compared to mammography where the implementation of software seems to be rare. Ten and authors 2015 [23] reported the use of an in-house developed web-application, while Baek and authors 2018 used a commercial software to perform their analysis addressing the importance of collecting data of all patients without the need for data cleaning [24].

Recently a DMS was installed in our hospital and was connected to the mammography system. The aim of this study was to analyse radiation exposure in mammography using the DMS and examine how this software can be integrated to improve clinical practice.

2. Material and methods

2.1. Patient data collection

The study was performed in a general service 325-bed hospital (Spital Zentrum Oberwallis). The collection of data started in September 2017 and finished in September 2018. The hospital has a fully digital X-ray mammography machine Selenia Dimensions (Hologic Inc., Bedford, MA, USA) installed in 2016 with the possibility of conventional mammography and tomosynthesis. The anode material is tungsten (W) and most used filters are rhodium (Rh, 0.050 mm), silver (Ag, 0.050 mm) and aluminium (0.70 mm nominal, used for tomosynthesis images). Compression force may reach 300 Newton (N_T). The system is operated using automatic exposure control (AEC). The AEC maintains constant detector signal level independent of operating mode (conventional mammography or magnification), breast thickness and radiographic technique. Thus, for large breast thickness, where the image contrast to noise ratio is expected to decrease, the mAs is increased.

Two thousand four hundred and twenty eight (2428) patients undergoing screening or diagnostic mammography were included in the analysis. Male patients as well as special views such as spot compression, magnification or images from stereotactic biopsies were excluded from the study (143 patients).

2.2. Patient dosimetry

The MGD is automatically displayed for each projection by the mammography system. For our manufacturer, MGD estimation is calculated according to the following equation:

$$MGD = K \times DgN,$$

where K is the incident air-kerma (IAK) at the breast upper surface and DgN is the normalized glandular dose per unit IAK [25]. DgN depends on the anode/filter combination and glandularity [25]. Breast composition of 50% glandular and 50% adipose tissue is assumed for the calculation of the MGD [25].

In addition to the weekly image quality control (performed by a qualified radiographer) and annual quality control tests (performed by the mammography manufacturer) as specifically stated in the Swiss Radiation Protection Ordinance, the radiological equipment is audited annually by an external auditor or auditor team. The external audit is performed under the responsibility of a medical physicist and the quality control of the physical and technical aspects of mammography screening is based on the European [7] and national guidelines [26,27].

Although the obvious assumption is that data extracted from the DICOM report was correct, we decided to validate it. Thus, displayed data from a sample of examinations was first manually recorded and then compared with the data stored in the DICOM metadata in the PACS system as well as in the DMS.

2.3. Dose management software

Data collection and initial basic statistical analysis was realized using the DMS (DOSE, v.17.11, Qaelum NV, Belgium). The mammography unit exports all data to the conventional PACS (Intellispace v. 4.4.516.1, Philips, Netherlands) which is connected to the DMS. Patient clinical data, technical parameters (kV, anode/filter combination, etc.), compressed breast thickness (CBT) and MGD values are transferred from the mammography machine to the PACS and DMS. Table 1 includes the DICOM tags that were used for analysis. Moreover, for each examination the system maintains the name of the radiographer that performed the examination as well as the name of the examination (screening, diagnostic, etc.). The system offers also the possibility to compare radiation doses with the European Guidelines [7].

The study was done retrospectively and data were analysed using univariate and multivariate logistic regression analyses or/and independent Student's t-tests. Statistical analysis was accomplished using either the software package MedCalc Statistical Software version 18.10.2 (MedCalc Software bvba, Ostend, Belgium; http://www.medcalc.org; 2018) or the MS Excel (version 2010, Microsoft).

2.4. Screening program

All women between 50 and 69 years of age living in Swiss cantons (regions) that participate to the screening program are entitled to a mammography examination every two years. For women over 70 years old, the screening program could continue after personal request until the age of 74 [26]. From January 2019, the age range is extended for women between 50 and 74 years old. In principle, no exclusion criteria exist. However, there are cases when a diagnostic examination or a

Table 1
Digital Imaging and Communication in Medicine (DICOM) tags that record patient characteristics, exposure parameters and radiation dose values used by the mammography machine are shown below.

DICOM tag	Attribute
Patient characteristics	
(0010,0040)	Patient gender
(0010,1010)	Patient age
(0018,11A0)	Body Part Thickness (CBT)
Exposure parameters	
(0018,0060)	kVp
(0018,1152)	Exposure (mAs)
(0018,7050)	Filter material
(0018,1191)	Anode target material
(0018,11A2)	Compression Force
(0018,5101)	View Position
Radiation dose quantity	
(0040,0316)	Mean Glandular Dose

different screening program must be performed. These cases are: i) women with an already diagnosed cancer, ii) women in high risk, iii) women with breast implant or iv) women with dense mammary tissue [26]. The screening mammography examination includes one craniocaudal (CC) and mediolateral oblique (MLO) projection for each breast [10]. In special cases, such as breast implant, other projections may be applied.

Screening examinations can only be performed with digital mammography systems and by radiographers specially trained in screening mammography [26].

2.5. Breast compression

Compression force in our hospital is recommended to start at 100 N_T and to be increased as much as the patient withstands the pain. A questionnaire needs to be fulfilled by the patient before the examination to take into account her specific needs for pain management (present breast pain, discharge, implants, earlier breast operation, etc.). In such cases, the patient may not support the pain, so the compression force needs to be reduced.

2.6. Diagnostic reference levels

As Switzerland does not currently have national or regional DRLs in mammography, typical values in mammography were established during this study as a first step towards the optimisation. According to the latest ICRP publication 135 [14], *typical values* are defined as the median of the MGD distribution. MGD depends on the size of the breast and its composition as well as the projections. Typical values for a standard two-projection mammogram with CC and MLO projections were determined for different breast thickness. Furthermore, differences in radiation doses for diagnostic and screening mammography were examined to decide if typical values should be different for the two categories [14,15].

3. Results

First, we confirmed that data transfer from the mammography unit to the DMS database was correctly performed. In some cases, where data was missing from the DMS, we identified that the input data was not filled in during the examination. One such example was image laterality; but this did not affect data reliability.

The analysis involved 1523 screening and 905 diagnostic mammography examinations. The sample was analysed using various DMS tools for 9780 mammograms (6292 screening mammograms and 3488 diagnostic mammograms). The distribution of patient age is shown in Fig. 1 (1a is related to screening and 1b diagnostic examinations). The graphs show that the screening program is strictly followed and there is only a small number of patients returning for a screening exam after the age of 70 years. On the other hand, patient distribution in diagnostic examinations is larger with a substantial number of patients in the age range of 20–50 years for reasons described in the materials and methods section. Due to the high number of younger patients being examined (310 out of 905 patients, 34.2%) careful investigation of this sample was attempted.

Fig. 2 presents the number of images taken per patient (Fig. 2a for screening mammography and 2b for diagnostic mammography). In screening mammography, the majority of patients (88.4%) underwent 2 images per breast resulting in a total of 4 images. There was a small percent (10%) that underwent 5 mammograms due to either patient movement or wrong positioning. Surprisingly, there was a small but existing percentage of patients (1.4%) that had 6 to 10 mammograms (approximately 20 patients, 133 images). Further investigation showed that main reason for this was the large breast volume and thickness that required more images per breast to include all breast tissue. As far as Fig. 2b is concerned, the distribution for diagnostic mammograms

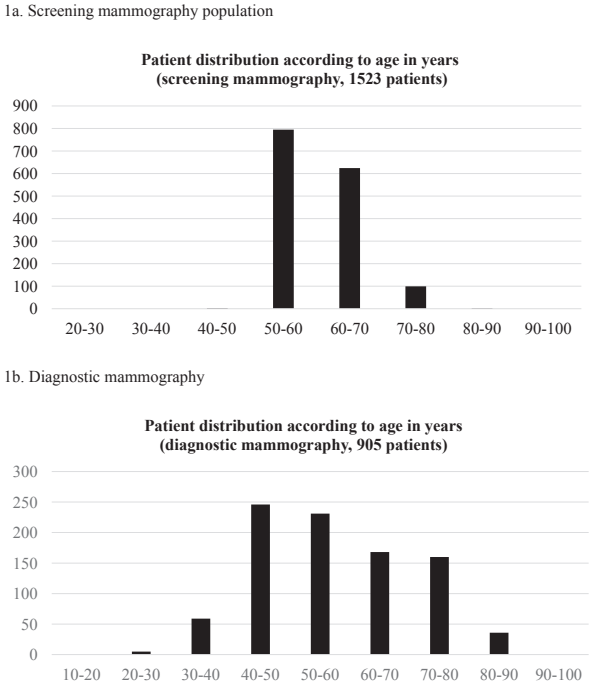


Fig. 1. Number of patients undergoing screening examination is presented according to age (in years).

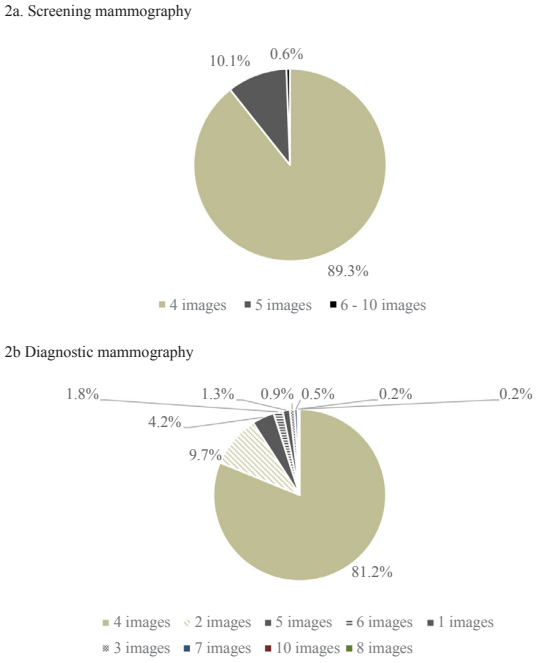


Fig. 2. Number of images per patient are shown below.

seems to be more spread due to additional incidents (mediolateral views, or magnification CC and MLO views) but small number of patients had 6 or more images (20 out of 905 patients, 2,2%, 28 images in total).

Anode/filter combination is chosen automatically by the system depending on CBT. For CBT less than 70 mm or larger CBTs due to implants, the W/Rh combination is chosen. The W/Ag combination is used either for CBT larger than 70 mm or magnification views. Fig. 3 shows the automatic analysis performed by the DMS regarding the anode/filter combination use for screening examinations. W/Rh

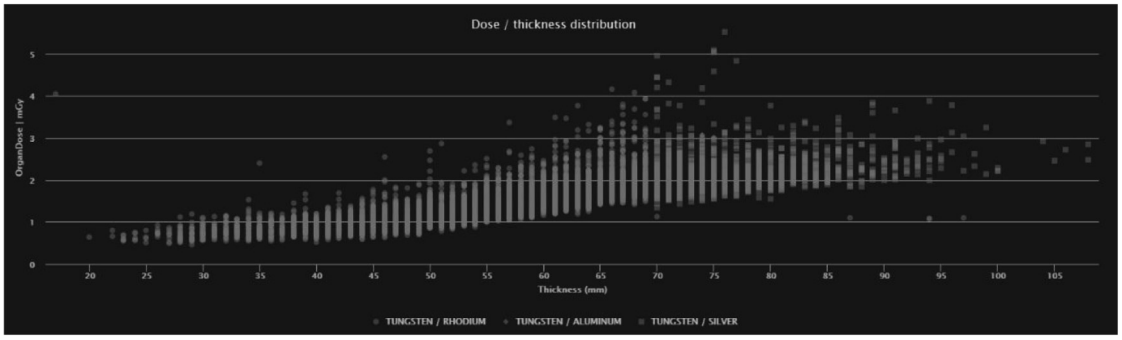


Fig. 3. Anode/filter combination analysis for screening mammography is presented. The dots represent the W/Rh combination for compressed breast thickness (CBT) less than 70 mm or larger CBTs with to implants. W/Ag combination is depicted with squares and is used either for CBT larger than 70 mm or magnification views.

combination is depicted with dots and W/Ag combination is depicted with squares. In case of tomosynthesis, the mammography units employs the W/Al combination (depicted by default with rhombus in Fig. 3), the analysis of which is out of the scope of this study. The DMS allowed us to validate that the system employs systematically the correct anode/filter combination. Four cases with breast thickness over 70 mm and low radiation doses are depicted in Fig. 3 with dots. The DMS offers the possibility to investigate these cases by simply clicking to the dots and having direct access to the particular patient files. It was found that all these cases were patients with breast implants and W/Rh combination was correctly chosen. In Fig. 3, some outliers (radiation doses over 4 mGy) were also identified and analysed. These were either cases where very low compression force was applied or breast was very dense. These cases were used as examples to further improve mammography quality of the department.

Fig. 4 shows the distribution of CBT for CC and MLO projections. It appears that for both projections, the most frequent CBT values are in the range of 60–69 mm substantially higher than the CBT for which DRLs are usually set [7,13].

Table 2 presents the distribution of examinations separately for screening and for diagnostic mammography for various CBT ranges. It must be noted that eight images with breast tissue thickness smaller than 20 mm and larger than 110 mm were excluded from further statistical analysis. Table 2 shows that screening MGD had a wide range of values starting from 0.46 mGy to 5.52 mGy (max/min ratio: 12). Most of the patients were in the range of 50 mm to 79 mm (1551 images at 50–59 mm, 1875 images at 60–69 mm and 1117 images at 70–79 mm). For the range of 51–80 mm of CBT, radiation dose increased by approximately 25% for every 10 mm of breast thickness. For diagnostic images, the distribution did not differ much as shown in Table 2 (MGD range: 0.40 mGy to 9.82 mGy, max/min ratio: 3.2). Statistical comparison between the two samples showed statistically significant

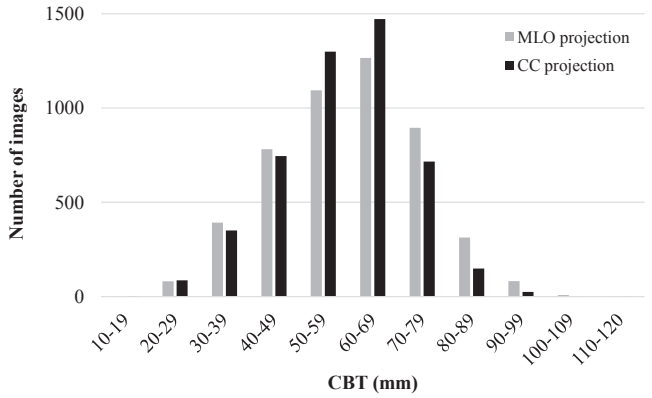


Fig. 4. Compressed breast thickness (CBT in mm) distribution for CC and MLO projections is presented below.

difference for CBT subcategories between 30 and 89 mm (p-value $<$ 0.05). For extreme categories, the non-significant differences could be attributed to the small size of sample. The most frequent CBT range for both groups was 60–69 mm. Mean MGD was 1.84 mGy for screening and 2.01 mGy for diagnostic examinations for CC projection. Correspondingly, for MLO projections mean MGD was 1.85 mGy for screening and 1.95 mGy for diagnostic examinations. The DMS facilitated the quick collection of high amount of patient data allowing us to perform extensive statistical analysis for different CBT ranges that would be practically impossible with manual collection. The analysis showed that radiation doses differed between different CBT ranges pointing to the direction of specifying DLRs for various CBTs. Data point to the direction of setting DRLs separately for screening and diagnostic examinations as there was a small but statistically significant difference between the two groups.

Further analysis for patients younger than 50 years old that undergo diagnostic mammography showed that MGD was higher (1.8 ± 0.80 mGy, mean MGD ± 1 standard deviation) than that of older patients (1.6 ± 0.41 mGy, p-value $<$ 0.001). No differences were found for the mean compression force applied to the two groups or the mean breast thickness. Thus, higher MGD values were related to denser breast of younger patients. Unfortunately, until now breast glandularity cannot be taken into account in clinics for further optimisation.

Fig. 5a,b are taken directly from the DMS system and show the comparison of mean MGD with European dose levels for screening (Fig. 5a) and for diagnostic mammography (Fig. 5b). As stated in the European Guidelines [7], acceptable dose level (ACC) is the maximum mean MGD to equivalent breast, while achievable dose level (ACH) is the recommended level where the systems should be operated. As specifically stated in the guidelines: “The achievable level reflects the state of the art for a particular parameter”. As the European guidelines specify ACC and ACH values for specific CBTs (distinct values between 20 mm and 70 mm), the DMS extrapolates the corresponding values for intermediate breast thicknesses. As very clearly shown, local (hospital) mean MDG values are much lower than both ACC and ACH pointing to the need for updating the European guidelines reference values as new low dose X-ray machine technology enters the medical market. Moreover, it should be addressed that the European guidelines acceptable and achievable levels are determined by calculations based on the European formalism using Dance's et al. conversion coefficients [8]. The Hologic systems provide MGD values based on calculations that use different breast model and conversion coefficients. No corrections were attempted in this article as the European values are used in Switzerland as target and maximum permissible values for dose optimization.

The compression of breast is extremely important in mammography as it facilitates immobilisation of the breast that limits motion artefacts and reduces breast thickness, which limits scatter effects and makes breast thickness approximately uniform. Mean compression force was 105 ± 25.4 N for screening and 102 ± 27.6 N for diagnostic

Table 2
The distribution of Mean Glandular Dose (MGD) in mGy for various compressions breast thicknesses (CBTs) in mm is shown below. N is the number of mammograms in each subcategory of CBT. The table presents the results for craniocaudal (CC) and mediolateral oblique (MLO) projections separately for screening and diagnostic mammography.

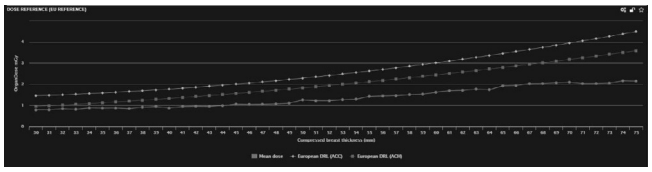
Screening mammography CC projection (3105 images)									
CBT (mm)	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109
N	39	177	429	845	**1004**	505	92	14	0
Min	0.51	0.57	0.63	0.83	**1.16**	1.34	1.55	1.08	
Max	1.12	1.67	2.55	2.87	**4.16**	5.09	3.35	2.93	
Mean	0.71	0.91	1.05	1.39	**1.84**	2.11	2.29	2.24	
Median	0.69	0.88	1.02	1.33	**1.77**	1.98	2.21	2.37	
SD	0.13	0.18	0.24	0.31	**0.39**	0.51	0.37	0.58	
75th	0.79	1.03	1.18	1.56	**2.02**	2.24	2.54	2.51	
MLO projection (3186 images)									
CBT (mm)	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109
N	41	198	473	706	**871**	612	223	54	8
Min	0.46	0.55	0.52	0.78	**1.20**	1.13	1.10	1.10	2.21
Max	1.19	2.40	1.96	3.37	**4.08**	5.52	3.84	3.88	2.92
Mean	0.69	0.83	0.98	1.36	**1.85**	2.10	2.31	2.51	2.52
Median	0.67	0.79	0.95	1.31	**1.76**	2.01	2.22	2.44	2.47
SD	0.14	0.20	0.22	0.31	**0.41**	0.40	0.39	0.46	0.28
75th	0.75	0.92	1.10	1.51	**2.00**	2.25	2.48	2.66	2.79
Diagnostic mammography CC projection (1744 images)									
CBT (mm)	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109
N	47	174	320	454	**471**	208	58	11	1
Min	0.40	0.58	0.67	0.86	**1.07**	0.93	0.87	0.80	0.98
Max	2.39	1.60	3.62	3.95	**4.24**	5.02	9.82	3.33	0.98
Mean	0.78	0.98	1.16	1.52	**2.01**	2.33	2.48	2.41	0.98
Median	0.77	0.96	1.11	1.42	**1.89**	2.22	2.31	2.76	0.98
SD	0.28	0.20	0.33	0.45	**0.51**	0.58	1.22	0.88	
75th	0.85	1.11	1.33	1.70	**2.25**	2.63	2.66	3.07	0.98
MLO projection (1737 images)									
CBT (mm)	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100–109
N	42	196	309	392	**395**	285	90	28	0
Min	0.42	0.51	0.59	0.84	**1.19**	0.92	0.99	0.81	
Max	1.26	2.70	2.85	2.85	**4.82**	7.01	4.15	3.43	
Mean	0.75	0.91	1.05	1.48	**1.95**	2.25	2.47	2.50	
Median	0.72	0.86	0.99	1.40	**1.85**	2.10	2.38	2.60	
SD	0.18	0.23	0.29	0.39	**0.50**	0.67	0.56	0.69	
75th	0.83	1.04	1.18	1.69	**2.21**	2.36	2.73	2.91	

examinations, as required by the medical practice (100 N). Although the difference is small between screening and diagnostic examinations, it is statistically significant (p-value < 0.001) This can be explained by the fact that women with operated breast may complain for greater pain during compression of the operated side [28].

Fig. 6 shows the distribution of compression force (N) plotted against CBT both for CC and MLO projections. Mean compression force for CC projection was found significantly lower than the one applied for MLO projection (CC: 98.9 ± 23.8 N vs MLO: 109.3 ± 27.5, T-test p-value < 0.001). It is evident from the graph that there is a substantial number of patients for which the compression force was much less than the recommended value and a smaller but still existing number with much higher amount of compression than the highest limiting value [7].

As far as breast compression is concerned, it is very important, to obtain consistency to ensure high standards of image quality throughout screening programmes [29]. To do so, a more thorough investigation on radiographers' performance was conducted. The MGD was analysed against the compression force for each radiographer (Fig. 7). To perform screening mammography examinations, radiographers need to follow additional training. Striped diagonal bars depict radiographers that have followed this training while solid bars represent radiographers that are allowed to perform only diagnostic examinations. Only diagnostic CC projection images for breast thickness between 60 and 69 mm were included in the analysis. The overall results did not show any statistically significant differences in terms of MGD or compression force between the group of radiographers that are allowed to perform screening examinations and those that are not allowed (T-test, p-value > 0.05). ANOVA test was used to test any differences among all radiographers. While compression force showed to be significantly different among all, radiation dose did not differ significantly (ANOVA, p-value < 0.001, Scheffé test for all pairwise comparisons), indicating that other factors may play a more important role for breast exposure than the compression force. As expected and verified with the DMS for radiographers that are allowed to perform screening examinations, their practice did not differ for diagnostic or screening examinations. All radiographers were informed of the finding and corrective actions were taken in order to avoid big variability in breast compression between staff performing mammograms.

5a. Screening mammography



5b Diagnostic mammography

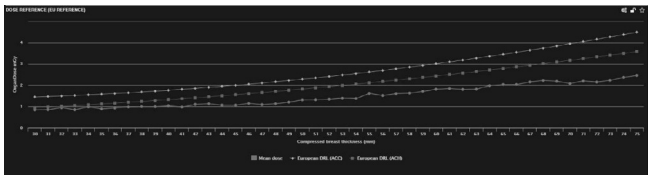


Fig. 5. The figure shows the comparison of mean MGD (y-axis, measured in mGy) with European DRLs for screening (Fig. 5a) and for diagnostic mammography (Fig. 5b). Acceptable MGD values are depicted with rhombus, achievable MGD values with squares and hospital mean MGD values with dots.

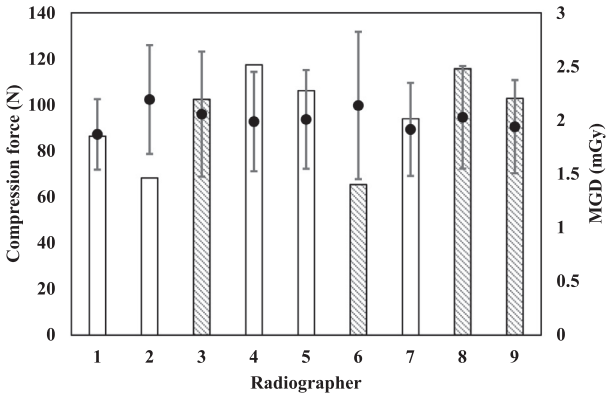


Fig. 7. Mean compression force (N) in bars and MGD (mGy) in dots per radiographer are shown for diagnostic craniocaudal (CC) projections for breast thickness 60–69 mm. The error bars represent the standard deviation of the mean. Radiographers 3, 6, 8 and 9 are allowed to perform screening examinations (striped diagonal bars). Two radiographers that performed less than 10 examinations during the study period were excluded from the study.

4. Discussion

The routine use of the DMS facilitated the quick and extensive analysis for this big number of data, which was not possible previously. Collection and analysis before DMS was still possible of course but due to manual cumbersome work, this would include a small number of patients with limited data per patient. This had to be done by the radiographer or the medical physicist, both of them engaged with routine work in the radiology department. The DMS offered a user-friendly interface and its tools proved helpful also to track unexpected variations from routine procedures. Examples of such unexpected incidences were the additional number of images in a small number of patients undergoing screening mammography that in principle should receive 4 images (2 per breast). Some of these patients received 5, 6 or even 10 images resulting in more than double radiation dose than routine screening imaging. These patients would be practically impossible to identify without the use of DMS. Further investigation showed that extra images were taken mainly because of large breasts that could not fit into one image. However, cases of wrong positioning were also identified; these were discussed in detail with the radiographers that performed the mammograms to the particular patients and corrective actions were taken to eliminate such incidents in the future.

A systematic review on DRLs in digital mammography by Suleiman and authors 2015 [30] revealed that methodologies to establish DRLs vary substantially at an international level. The most common method

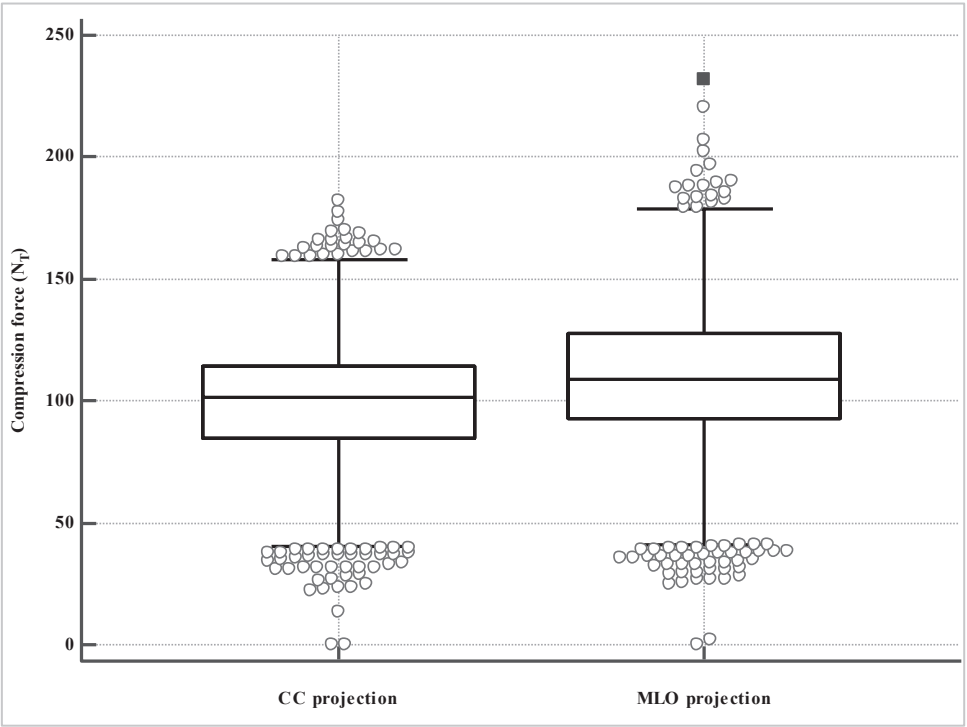


Fig. 6. The figure shows the compression force (N_T) in the y –axis in relation to the compressed breast thickness (CBT) for both diagnostic and screening examinations together.

Table 3
Typical MGD values for various CBT ranges for screening and diagnostic mammography. The European DRLs specified in terms of acceptable and achievable dose are also shown for comparison purposes [7]. Most typical CBT range was between 60 and 69 mm.

3a. Screening mammography

	MGD typical value (mGy)		European DRLs (MGD, mGy)	
CBT range (mm)	CC	MLO	Acceptable level	Achievable level
20–29	0.7	0.7	< 1.0	< 0.6
30–39	0.9	0.8	< 1.5	< 1.0
40–49	1.1	1.0	< 2.0	< 1.6
50–59	1.4	1.4	< 2.5	< 2.0
60–69	**1.8**	**1.9**	**< 3.0**	**< 2.4**
70–79	2.1	2.1	< 4.5	< 3.6
80–89	2.3	2.3		
90–99	2.3	2.5	< 6.5	< 5.1

3b. Diagnostic mammography

	MGD typical value (mGy)		European DRLs (MGD, mGy)	
CBT range (mm)	CC	MLO	Acceptable level	Achievable level
20–29	0.7	0.8	< 1.0	< 0.6
30–39	1.0	0.9	< 1.5	< 1.0
40–49	1.2	1.1	< 2.0	< 1.6
50–59	1.5	1.5	< 2.5	< 2.0
60–69	**2.0**	**2.0**	**< 3.0**	**< 2.4**
70–79	2.3	2.3	< 4.5	< 3.6
80–89	2.5	2.5		
90–99	2.5	2.5	< 6.5	< 5.1

is the use of MGD conversion coefficients for CBT ranges between 45 and 55 and 55–65 mm. Furthermore, Suleiman and authors further report that the 75th and 95th percentiles of the distribution are used as definition of the DRLs by some authors, while others a reference value defined by the authors may be used for DRL [30]. In other publications, the DRL quantity used was the MGD for only MLO projections [31]. The authors attempted to define typical values following ICRP report 135 recommendations [14]. The recommendations are as followed:

- MGD should be the quantity for DRL definition due to the large variability of other metrics,
- approximately 50 patient measurements or more are recommended because of variation in compressed breast thickness,
- DRLs could be established for different breast thicknesses as this is a better approach to refine the DRL process for mammography and
- DRLs should take into account the projection.

Based on the above recommendations, typical values for different CBT values both for screening and for diagnostic mammography were defined using the patient sample from the DMS software (Table 3). These values are rounded values of the mean MGD for a total sample of 2400 patients (much higher than the 50 patient sample recommendation of ICRP 135). Table 3 presents the typical values for screening and diagnostic mammography along with the European DRLs. Our typical values were found much lower not only from the acceptable European values but also from the achievable European values. Differences in typical values between screening and diagnostic mammography were found small but statistically significant, thus the use of both values was decided for best dose optimisation.

This study has its limitations. First, breast density with 50% glandularity is assumed for the calculation of the MGD of all women, as the mammography unit does not provide this information. When different breast density is taken into account, some differenced in MGD are expected [32]. Our DMS will be capable of extracting this information from DICOM data, once the mammography unit manufacturer provides it. Thus, in the future, when this information will be available, a more detailed analysis should be conducted. The second limitation concerns the definition of DRLs. As the study is based on one single centre, only typical values could be established as recommended by ICRP 135. This is a first and important step towards the establishment of local and later, national DRLs in Switzerland as currently national DRLs are not defined. Later, when DMS will be extensively used for mammography, the establishment and regular revision of DRLs will be effortless. Finally, although the study is based on one centre, it allowed us to explore the use of a DMS in mammography, detect abnormalities and work on clinical practice optimisation.

The DMS easily and quickly collect data for all patients and enable a basic statistical overview for radiation doses. The DMS in general provide pre-defined figures and tables according to what each DMS manufacturer considers important. Some filters can be applied to offer a more detailed view on the data. For further higher level analysis that DMS tools cannot provide, data need to be extracted and the analysis has to be done with other software programmes outside the DMS environment. Examples are comparison of means with T-tests and other statistical test, as these features are not currently available by the DMS. The DMS has substantially contributed to the evolvement of the medical physicist's role in dose management in our hospital. Automatic data collection has replaced manual collection of a limited amount of data. Medical physicists may provide now a more thorough and critical analysis of data, confirming the importance of medical physicists' role in patient dose management.

5. Conclusions

The use of the DMS facilitated immensely the analysis of all clinical and technical parameters, the evaluation of radiation dose received by the patients, as well the overall evaluation of radiographers' performance. When and where needed, corrective actions were taken to ensure consistency in high standards of image quality. Typical values both for screening and diagnostic mammography and for various compressed breast thicknesses were defined. The DMS offer the possibility to re-evaluate the practice with big number of data and detect abnormal cases or erroneous behaviours that otherwise could go undetected. DMS are powerful tools for data collection and analysis revealing the essential role of the medical physicist in dose management and optimization.

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