Mammography DRLs in Switzerland

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Abstract

The aim of this work is to establish diagnostic reference levels (DRLs) in Mammography in Switzerland. The first part of this study consisted in collecting data from enough centres as to be representative from the country. In total 31 centres including 5 University hospitals, several canton hospitals, and large private clinics, overall covering all linguistic parts of Switzerland participated in the data collection. For this purpose, we prepared and sent out a questionnaire to the corresponding medical physicists asking for technical information necessary for our study (manufacturer and model of the device, kV, mAs, mean glandular dose (MGD)…). The questionnaire was sent to all 31 centres, and we received information from 36 mammography units (6 different manufacturers represented) and 24762 acquisitions. For most of the centres, the data was extracted from the dose management system (DMS) those not having the unit connected to the DMS weren't keen to participate. The data collected was sorted according to the following categories: examination type (2D or 3D), projection (craniocaudal (CC) or mediolateral oblique (MLO)) and 8 different categories of compressed breast thickness (CBT) ranging from a 20mm till 100mm in 10mm width intervals. The analysis showed that the data obtained is representative of the practice in Switzerland, most frequently used units are represented in this study. The main results revealed that the MGD is larger for a 3D acquisition than for 2D. Moreover, the MGD increases as the CBT increases. The 75th percentile of the MGD values obtained are comprised between 0.81mGy – 2.96mGy for 2D, both projections (CC/MLO) and CBT between 20mm and 100mm and between 1.22mGy - 4.04mGy for 3D, both projections (CC/MLO) and CBT between 20mm and 100mm. Finally, diagnostic reference values (DRLs) can be proposed as a function of the examination type (2D/3D), projection (CC/MLO) and CBT. The proposed values compare well to those obtained in the literature and performed with the same methodology.

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Abbreviations

DRL: Diagnostic Reference Level

DMS: Dose Management Software

CBT: Compressed Breast Thickness

2D: Planar (2 Dimensions) mammography examination

3D: Tomosynthesis (3 Dimensions) mammography examinations

CC: Craniocaudal projection

MLO: Mediolateral Oblique projection

MGD: Mean Glandular Dose

RDSR: Radiation Dose Structured Report

Introduction

Breast cancer is a very frequent cancer among women. In 2020, it was the most common cancer worldwide but was only the fifth on the list of the most common causes of cancer death. Indeed, early diagnostics and screening via mammography examinations help to reduce cancer mortality [1].

In Switzerland, the incidence of breast cancer is of 112 in 100'000 inhabitants and the mortality rate is 20 in 100'000 inhabitants. Mammography is the basic examination of the breasts that can detect breast tissue changes, diagnose and manage patients with breast disorders. On top of the diagnostic mammography following a suspicious breast tissue modification or appearance, a screening programme in Switzerland gives women over 50 the opportunity to have a mammography every two years.

In 2018, screening mammograms represented 0.97% of X-ray examinations in Switzerland, which corresponds to 0.3% of the dose contribution of the X-ray modalities, and diagnostic mammography examinations represented 1.74% of the X-ray examinations, corresponding to 0.6% of the total dose of the X-ray modalities [2].

The breast tissue is known to be a very radiosensitive organ [3-5]. Thus, it is very important to optimize its exposure during diagnostic and screening mammograms. Unlike other diagnostic examinations, for mammography, there are maximum values of MGD set per PMMA thickness, with their equivalent breast thickness [6]. In any case, the application of the principles of justification and optimization guarantees adequate protection of the patient. The concept of DRLs is recognized internationally as an important tool to optimize patient's exposure [7]. Comparing institutional values with national or international DRLs is a good way to get an overview of the practice. DRLs should not be seen as a limitation, but as an indication, and allow to lead to optimisations when necessary. According to ICRP 135 [7] a DRL value is defined as the 75th percentile of the distribution of the median values of the participating institutes obtained by the survey. Thus, the DRLs are representative values of the practices for a given examination.

In Switzerland, even though DRLs exists for almost all modalities [8], yet no DRL has been established for mammography. In Europe, several countries have not yet established DRLs for mammography as for example Belgium, Portugal, etc [9]. Others have already DRLs values available. Others have even updated their values recently, such as France [10].

In order to establish national reference levels in Switzerland, we carried out a survey in as many Swiss centres performing mammography examinations (diagnostics and screening) as possible, including university hospitals, canton hospitals and private clinics, to obtain a representative overview of the practices. We collected mammography data from these centres, as well as information about the facilities. We managed to collect data for planar (2D) and tomosynthesis (3D) mammography examinations with a wide variety of parameters, such as different CBT, patient ages, projections, and manufacturers allowing us to propose national DRLs.

Methods

Data collection

The data collection was organized by contacting the medical physicists from the 5 University hospitals in Switzerland and those working in the different cantonal hospitals and large private clinics to cover all linguistic parts of Switzerland. The number of institutes with their corresponding number of mammography units in each canton is shown in Table 1 together with the number of institutes and units that participated in the study.

The data was collected for 2D and 3D mammography examinations and comprises the data from the screening program when active in the different centres.

Table 1 Cantons with their corresponding number of institutes and mammography units and number of those included in the study, classified by linguistic region (D=German-speaking, F=French-speaking, I=Italian-speaking).

Canton	Linguistic region	Number of institutes	Number of mammography units	Number of institutes in the study	Number of mammography units in the study	% of institutes in the study	% of mammography units in the study
Aargau	D	12	15	1	1	8	7
Appenzell Ausserrhoden	D	2	2	0	0	0	0
Basel-Land	D	4	4	1	1	25	25
Basel-Stadt	D	4	6	1	2	25	33
Bern	D / F	19	24	2	2	11	8
Glarus	D	1	1	0	0	0	0
Graubünden	D	4	4	1	1	25	25
Luzern	D	7	11	5	6	71	55
Obwalden	D	1	1	1	1	100	100
Nidwalden	D	1	1	0	0	0	0
Schaffhausen	D	1	3	0	0	0	0
Schwyz	D	3	3	0	0	0	0
Solothurn	D	5	6	0	0	0	0
St. Gallen	D	10	16	5	5	50	31
Thurgau	D	3	3	0	0	0	0
Uri	D	1	1	1	1	100	100
Zug	D	3	3	1	1	33	33
Zürich	D	32	37	4	6	13	16
Fribourg	D / F	7	9	0	0	0	0
Genève	F	19	22	1	1	5	5
Jura	F	2	2	0	0	0	0
Neuchâtel	F	6	7	0	0	0	0
Vaud	F	31	40	3	4	10	10
Valais	D / F	13	15	0	0	0	0
Ticino	I	15	16	4	4	27	25
Total		**206**	**252**	**31**	**36**	**15**	**14**

Questionnaire

The questionnaire for data collection was sent to the medical physicists in early October 2021. Data was collected till March 2022. The complete questionnaire is available in the annex.

The first part of the questionnaire consisted of general questions about the mammography unit (manufacturer and model of the system) and the centre (name of the institute, contact details of the respondent). One questionnaire per unit had to be provided. Instructions for correctly completing the questionnaire were also provided.

Requirements for the data were the following:

- only data from female patients were gathered;
- It was aimed at a minimum of 20 acquisitions per each category of compressed breast thickness interval (8 categories, from 20 to 100 millimetres, and 10mm intervals), projection (CC and MLO) and for 2D and 3D separately;
- if 20 acquisitions were not possible, we asked to provide as much data as possible per category;
- The data provided had to be the most recent consecutive data.

The second part of the questionnaire was the one that had to be filled in with the data. For each acquisition provided, we requested the following information:

- Patient's birth date or age;
- Date of examination;
- Laterality (R/L);
- Projection (CC/MLO);
- Anode material;
- Filter Material;
- Tube voltage (kVp);
- Tube current-time product (mAs);
- Compression force (N)
- Compressed Breast Thickness (CBT);
- Entrance skin dose (ESD);
- Mean Glandular Dose (MGD).

However, not all centres were able to provide all the required data. Therefore, values as the tube voltage, the tube current-time product and compression force were not used for the analysis.

Data Analysis

Before collecting the data and analysing it, many points were discussed to define what would be the criteria to establish the DRLs. Most of them will be discussed in this section.

The breast is composed of a glandular and adipose tissues, each of them in different proportions specific to each person and that will change with, among others, the age of the patient. The proportion of glandular/adipose tissue is defined by the glandularity. Breast density has an influence on the delivered dose [11]. Therefore, some studies conducted on DRLs in mammography, present results according to age categories in addition to other categories (2D/3D), projections, CBT, etc. [12]. Even though, it may be wiser to consider the glandularity instead of age, glandularity was not easily accessible nor exportable via the DMS and therefore it was not considered in the study.

Another parameter influencing the dose is the CBT [12-13]. A large CBT will require a higher dose than a small CBT. The required dose also depends on the projection (CC or MLO) and the examination type (2D or 3D). Therefore, the questionnaire specifically requested 20 acquisitions per each 10 mm thickness interval and per projection, for 2D and 3D.

At the end, the analysis was performed with data arranged according to the following categories:

- 2D/3D
- Projections CC/MLO
- CBT

About the dosimetric quantity to use for establishing DRL, the ICRP 135 [7] gives 3 different possibilities: Entrance-surface air kerma ($K_{a,e}$), Incident air kerma ($K_{a,i}$), MGD but suggests to use MGD, as also proposed by other publications [9,11]. We therefore used MGD as dosimetric quantity for this study. Moreover, not all other quantities were available in the extraction of the Radiation Dose Structured Report (RDSR) of the different systems.

Data was received from 31 centres, for a total of 36 devices. The total number of acquisitions collected is 24’762, of which 14’925 are 2D mammography data, and 9’837 are 3D data. The details of the data received can be found in Table 2 for 2D and Table 3 for 3D. The tables show the data for each mammography unit and their corresponding centre, for 2D (Table 2) and 3D (Table 3), for both CC and MLO projections and for each 10 mm CBT interval. More data was gathered for 2D since not all available systems perform 3D examinations. Not all centres were able to provide the 20 requested acquisitions in all categories, especially for the extreme categories of CBT.

An initial analysis was performed with all the data, independently of the manufacturer. But the influence of the manufacturer was also analyzed.

Table 2 - Number of acquisitions provided by each centre for each device, for 2D, for both CC/MLO projections, and 10 mm CBT intervals.

Centre number	Installation number	Installation	2D																
			CC								MLO								Tot 2D
			20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	
1	1	Hologic - 3Dimensions	20	20	20	20	20	20	19	3	20	20	20	20	20	20	20	15	297
2	2	Siemens - Mammomat Inspiration	20	20	20	20	20	20	20	10	20	20	20	20	20	20	20	20	310
	3	IMS Giotto - Giotto Class	20	20	20	20	20	20	19	2	20	20	20	20	20	20	20	5	286
	4	General Electric - Senographe Essential	17	20	20	20	20	20	13	4	19	20	20	20	20	20	20	3	276
3	5	Siemens - Mammomat Revelation	17	53	133	310	278	95	15	1	11	22	94	229	238	143	40	17	1696
4	6	Siemens - Mammomat Inspiration	8	10	10	10	9	12	7	7	12	10	10	10	11	8	13	13	160
5	7	Philips - Microdose Mammography L30	11	8	12	13	8	9	9	7	9	12	8	7	12	11	11	13	160
6	8	Siemens - Mammomat Inspiration	16	13	13	13	16	12	11	0	4	7	7	7	4	8	9	3	143
7	9	Philips - Microdose L50	8	8	12	9	10	11	8	7	12	12	8	11	10	9	12	13	160
8	10	Philips - Mammo Diagnost DR	11	8	13	8	10	10	8	1	9	12	7	12	10	10	12	0	141
9	11	IMS Giotto - Giotto Class	20	20	20	20	20	20	20	14	20	20	20	20	20	20	20	20	314
10	12	IMS Giotto - Giotto Class	20	20	20	20	20	20	18	2	20	20	20	20	20	20	20	20	300
11	13	IMS Giotto - Giotto Class	20	20	20	20	20	20	20	5	20	20	20	20	20	20	20	12	297
12	14	IMS Giotto - Giotto Class	20	20	20	20	20	20	20	8	20	20	20	20	20	20	20	20	308
13	15	Siemens - Mammomat Inspiration	20	20	20	20	20	20	20	5	20	20	20	20	20	20	20	20	305
14	16	Fujifilm - Amulet FDR 2000AWS	20	20	20	20	20	20	20	0	20	20	20	20	20	20	20	15	295
15	17	Fujifilm - Amulet FDR 2000AWS	20	20	20	20	20	20	12	0	20	20	19	20	20	20	19	4	274
16	18	Hologic - Selenia Dimensions	6	30	67	65	68	34	5	1	48	37	41	48	34	33	16	2	535
	19	Fujifilm - Amulet FDR 3000AWS	0	1	17	16	25	15	22	15	4	31	31	47	45	23	4	2	298
17	20	Hologic - Selenia Dimensions	1	0	2	1	1	0	0	0	13	58	94	125	114	72	22	6	509
18	21	Siemens - Mammomat Revelation	84	223	429	511	455	271	67	16	0	8	14	23	15	15	1	3	2135
19	22	Siemens - Mammomat Inspiration	20	20	20	20	20	20	20	20	20	20	20	20	9	1	0	0	250
20	23	Hologic - Selenia Dimensions	8	20	20	20	20	20	9	1	0	2	1	8	18	7	4	0	158
21	24	Siemens - Mammomat Inspiration	20	20	20	20	20	20	10	3	20	20	20	20	20	20	9	5	267
22	25	Siemens - Mammomat Inspiration	20	20	20	20	20	20	20	11	20	19	20	20	20	20	20	20	310
23	26	Siemens - Mammomat Revelation	20	20	20	20	20	20	20	9	0	0	0	0	0	0	0	0	149
24	27	Siemens - Mammomat Inspiration	20	20	20	20	20	0	20	6	0	0	0	0	0	0	0	0	126
25	28	Hologic - Selenia Dimensions	2	10	20	20	19	20	7	2	3	17	20	20	20	20	7	4	211
26	29	Hologic - Selenia Dimensions	20	20	20	20	20	20	20	20	16	20	20	20	20	20	20	16	312
27	30	Siemens - Mammomat Inspiration	20	20	20	20	20	20	19	4	0	0	0	0	0	0	0	0	143
28	31	Siemens - Mammomat Inspiration	20	20	20	20	20	20	20	20	0	0	0	0	0	0	0	0	160
29	32	Siemens - Mammomat Inspiration	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	320
30	33	General Electric - Senographe Essential	1	6	19	44	38	13	2	2	2	3	18	35	40	21	5	1	250
	34	Hologic - Selenia Dimensions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	35	Hologic - 3Dimensions	5	54	62	123	107	40	20	3	9	49	60	107	111	61	32	3	846
	36	Hologic - Selenia Dimensions	32	108	206	324	318	104	13	0	37	107	181	238	336	163	45	12	2224
Total			**607**	**952**	**1435**	**1887**	**1782**	**1046**	**573**	**229**	**488**	**706**	**913**	**1247**	**1327**	**905**	**521**	**307**	**14925**

Table 3 - Number of acquisitions provided by each centre for each device, for 3D, for both CC/MLO projections, and 10 mm CBT intervals.

Centre number	Installation number	Installation	3D																
			CC								MLO								Tot 3D
			20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	
1	1	Hologic - 3Dimensions	20	20	20	20	20	20	20	8	20	20	20	20	20	20	20	20	308
2	2	Siemens - Mammomat Inspiration	1	5	19	20	20	10	1	0	0	11	12	20	20	17	6	2	164
	3	IMS Giotto - Giotto Class	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	General Electric - Senographe Essential	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5	Siemens - Mammomat Revelation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	6	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	7	Philips - Microdose Mammography L30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	8	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	9	Philips - Microdose L50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	10	Philips - Mammo Diagnost DR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	11	IMS Giotto - Giotto Class	17	20	20	20	20	20	20	15	4	17	20	20	20	20	20	10	283
10	12	IMS Giotto - Giotto Class	20	20	20	20	20	20	20	2	20	20	20	20	20	20	7	5	274
11	13	IMS Giotto - Giotto Class	20	20	20	20	20	20	7	2	20	20	20	20	20	20	12	3	264
12	14	IMS Giotto - Giotto Class	20	20	20	20	20	20	20	18	20	20	20	20	20	20	20	16	314
13	15	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	16	Fujifilm - Amulet FDR 2000AWS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	17	Fujifilm - Amulet FDR 2000AWS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	18	Hologic - Selenia Dimensions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	Fujifilm - Amulet FDR 3000AWS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	20	Hologic - Selenia Dimensions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	21	Siemens - Mammomat Revelation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	22	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	20	20	20	20	20	20	18	3	141
20	23	Hologic - Selenia Dimensions	0	0	0	0	0	0	0	0	0	1	3	9	14	6	6	0	39
21	24	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	25	Siemens - Mammomat Inspiration	20	20	20	20	20	20	18	1	1	5	9	16	20	5	2	0	197
23	26	Siemens - Mammomat Revelation	0	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20	160
24	27	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	28	Hologic - Selenia Dimensions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	29	Hologic - Selenia Dimensions	0	0	0	0	0	0	0	0	19	20	20	20	20	20	20	20	159
27	30	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	20	20	20	20	20	20	20	9	149
28	31	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	20	20	20	20	20	20	20	20	160
29	32	Siemens - Mammomat Inspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	33	General Electric - Senographe Essential	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	34	Hologic - Selenia Dimensions	31	23	27	28	30	28	4	1	27	23	24	34	29	28	15	1	353
31	35	Hologic - 3Dimensions	84	358	679	1010	628	231	44	5	96	357	590	887	721	354	103	31	6178
	36	Hologic - Selenia Dimensions	13	49	76	89	79	34	3	0	16	45	64	83	73	46	23	1	694
Total			**246**	**555**	**921**	**1267**	**877**	**423**	**157**	**52**	**323**	**639**	**902**	**1249**	**1077**	**656**	**332**	**161**	**9837**

Results and discussion

Our first step was to evaluate whether the mammography units for which we collected the data were representative of the models used in Switzerland. The results are shown in Table 4.

Table 4 - Number of mammography units installed in Switzerland for each model, and number of devices considered in the study, by differentiating between devices that can perform 3D examinations (in bold) and those that cannot.

Mammography units	Number of units	Number of units in the study		% of units in the study	
		2D	3D	2D	3D
Hologic Selenia Dimensions / 3Dimensions	**75**	9	6	12	8
Siemens Mammomat Inspiration	44	11	5	25	11
Siemens Mammomat Revelation	21	3	1	14	5
GE Senographe Essential (Care)	19	2	0	11	0
Philips MicroDose L30	19	1	0	5	0
IMS Giotto (SDL / 3DL / Class)	17	5	4	29	24
Philips MicroDose L50 SI	16	1	0	6	0
GE Senographe Pristina	10	0	0	0	0
Philips Mammo Diagnost DR	8	1	0	13	0
Fuji Amulet Innovality (FDR MS-3500)	6	0	0	0	0
Fuji Amulet (FDR MS-1000 /-2000 /-2500)	4	3	0	75	0
Planmed Nuance	3	0	0	0	0
Hologic Selenia	3	0	0	0	0
SIEMENS MAMMOMAT 3000	2	0	0	0	0
GE Senographe Crystal	2	0	0	0	0
Siemens Mammomat Fusion	1	0	0	0	0
MAMMOMAT	1	0	0	0	0
Planmed -SOPHIE	1	0	0	0	0

In total, we analyzed data from 14% of the mammography units installed in Switzerland (see Table 1). These mammography units cover 50% of the models existing in the country, and moreover represent more than 87% of the most frequent models, which are the models for which 10 units or more are installed in Switzerland. Regarding the devices that can perform 3D examinations, we collected data from 4 models of units out of the 7 existing in Switzerland.

Analysis by pooling the data in CBT intervals

A general analysis by pooling all the data from all mammography units was carried out to have an overview. The graphs obtained with this analysis are shown in Figure 1 for the 2D and Figure 2 for the 3D. These graphs show the data from all units combined for each category of CBT. Data is represented by boxplots giving the information of the minimum, first quartile, median, third quartile and maximum. The extreme values, outliers, are represented by circles above and below the box. The mean values are represented by a triangle.

The minimum and the maximum are defined as:

$$\min = Q1 - 1.5 \cdot IQR$$

$$\max = Q3 + 1.5 \cdot IQR$$

Where $Q1$ and $Q3$ are the first and the third quartile, respectively, and IQR is the interquartile range ($Q3 - Q1$). All values below the minimum and above the maximum are outliers.

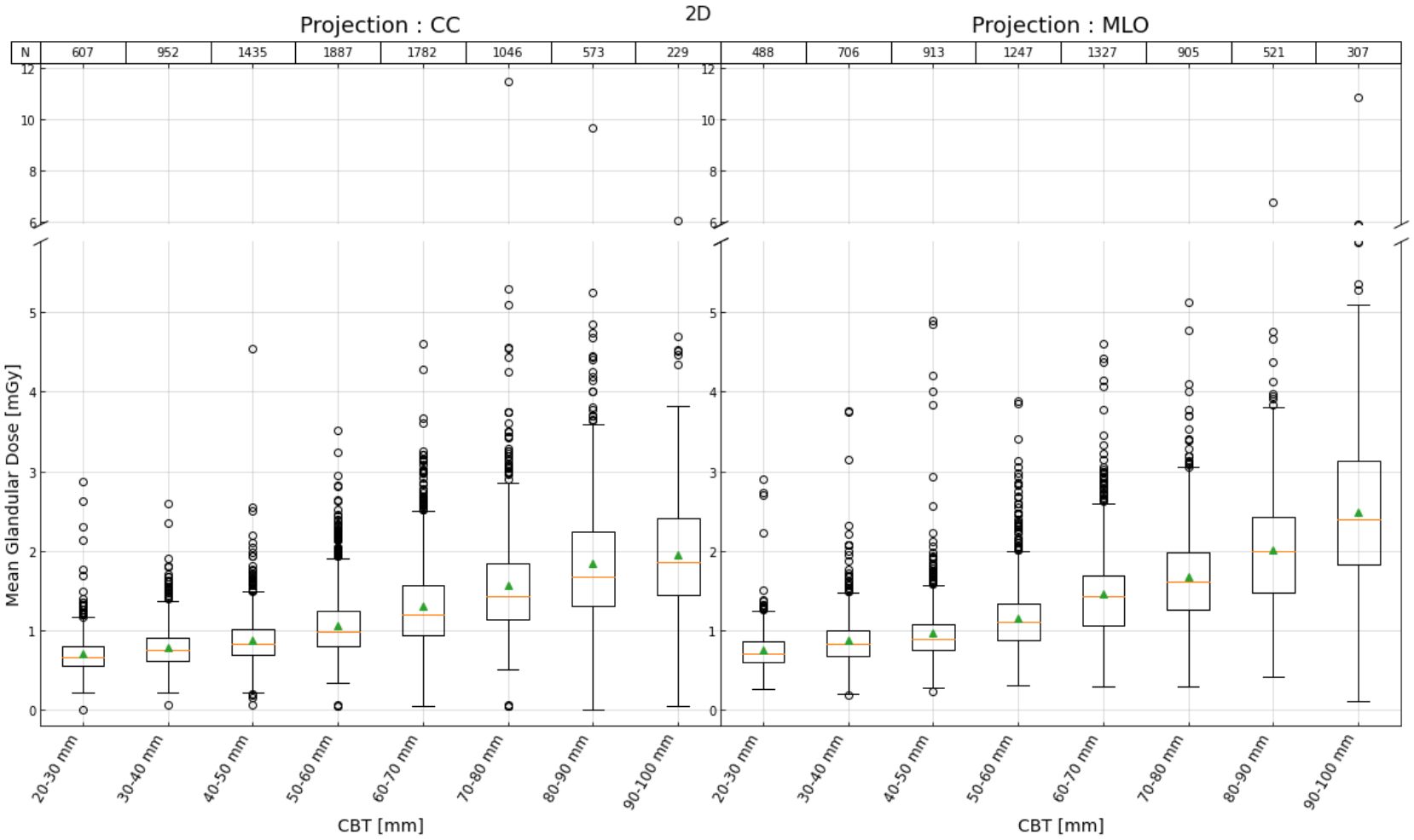

Figure 1 - Mean glandular dose boxplots for all mammography units for 2D examinations, CC and MLO projections, for all CBT intervals.

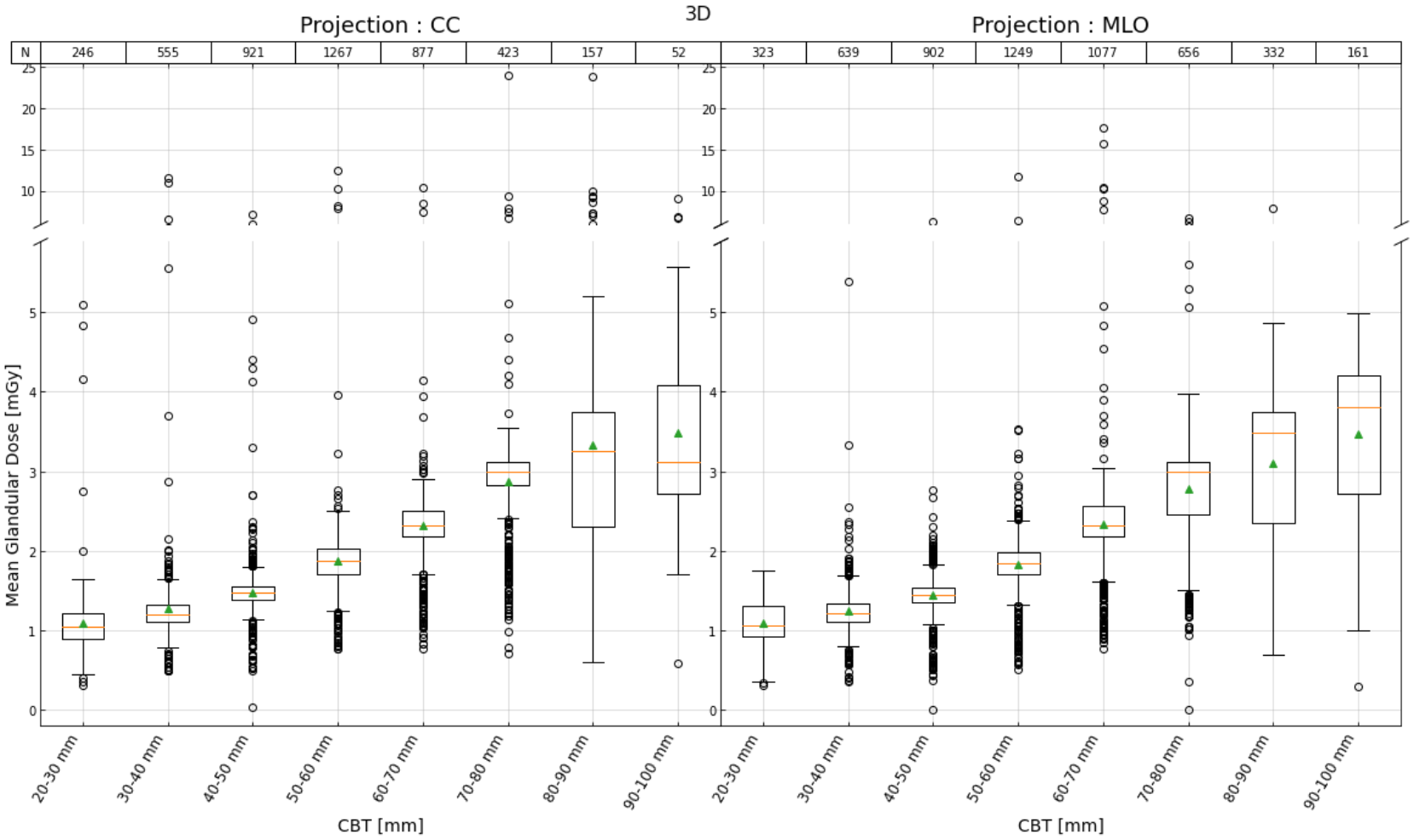

Figure 2 - Mean glandular dose boxplots for all mammography units, for 3D examinations, CC and MLO projections, for all CBT intervals.

The data shows, as expected, that the MGD increases as the CBT increases, whether for 2D or 3D and whatever the projection. These first results illustrate the importance of analysing the data for different categories of CBT. Values for the MLO projection are slightly higher than for CC projection. Furthermore, the values for 3D are larger than for 2D as well described in the literature [13]. The analysis with the pooled data is highly dependent on very few devices because they provide the majority of the acquisitions (see Table 2 and 3). For 3D, more than 50% of the acquisitions come from a single device. This limits the possibility for drawing general conclusions from the pooled data, because it is no more representative of all institutes. Therefore, the ICRP135 approach described below is more appropriate.

Global analysis with medians

According to ICRP 135 [7], a DRL value is defined as the 75th percentile of the distribution of the medians of the datasets obtained by means of a survey. To calculate this value, the medians of the acquisitions from each mammography unit were calculated. For each unit, a median is therefore obtained for 2D/3D, for each projection (CC/MLO) and for each CBT interval. The distributions of the median values are shown as boxplots in Figure 3 and Table 5 for 2D and Figure 4 and Table 6 for 3D. The 75th percentile of the MGD values obtained for 2D and CBT between 20mm and 100mm are comprised between 0.81mGy – 2.55mGy for CC and between 0.83mGy - 2.96mGy for MLO. For 3D, the values are comprised between 1.22mGy – 3.66mGy for CC and 1.33mGy – 4.04mGy for MLO. For 3D values are higher than for 2D. Values also change with respect to the projection, with higher values for MLO than for CC.

Table 5 - Results for the data of the medians of each mammography unit for 2D examinations, CC/MLO projections and for all CBT intervals. "Std" is the standard deviation of the set of data.

	2D															
	CC								MLO							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Mean	0.72	0.80	0.89	1.10	1.29	1.55	1.75	2.07	0.73	0.83	0.93	1.11	1.40	1.65	1.92	2.44
Median	0.69	0.78	0.89	1.08	1.24	1.55	1.79	1.98	0.73	0.82	0.92	1.11	1.44	1.58	1.97	2.50
75th perc.	0.81	0.90	1.03	1.31	1.54	1.86	2.21	2.55	0.83	0.90	1.03	1.28	1.64	2.12	2.23	2.96
Std	0.25	0.21	0.22	0.30	0.42	0.41	0.55	0.94	0.19	0.24	0.27	0.31	0.44	0.52	0.56	0.81

Table 6 - Results for the data of the medians of each mammography unit for 3D examinations, CC/MLO projections and for all CBT intervals. "Std" is the standard deviation of the set of data.

	3D															
	CC								MLO							
	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Mean	1.04	1.15	1.33	1.61	1.88	2.31	2.75	3.15	1.13	1.25	1.36	1.60	1.88	2.22	2.71	3.22
Median	1.04	1.18	1.38	1.60	1.71	1.98	2.56	3.24	1.14	1.22	1.46	1.76	1.77	2.00	2.49	2.97
75th perc.	1.22	1.22	1.47	1.85	2.35	3.03	3.51	3.66	1.33	1.42	1.52	1.89	2.34	3.04	3.57	4.04
Std	0.21	0.21	0.18	0.25	0.42	0.64	0.77	0.96	0.27	0.22	0.28	0.35	0.44	0.63	0.69	0.73

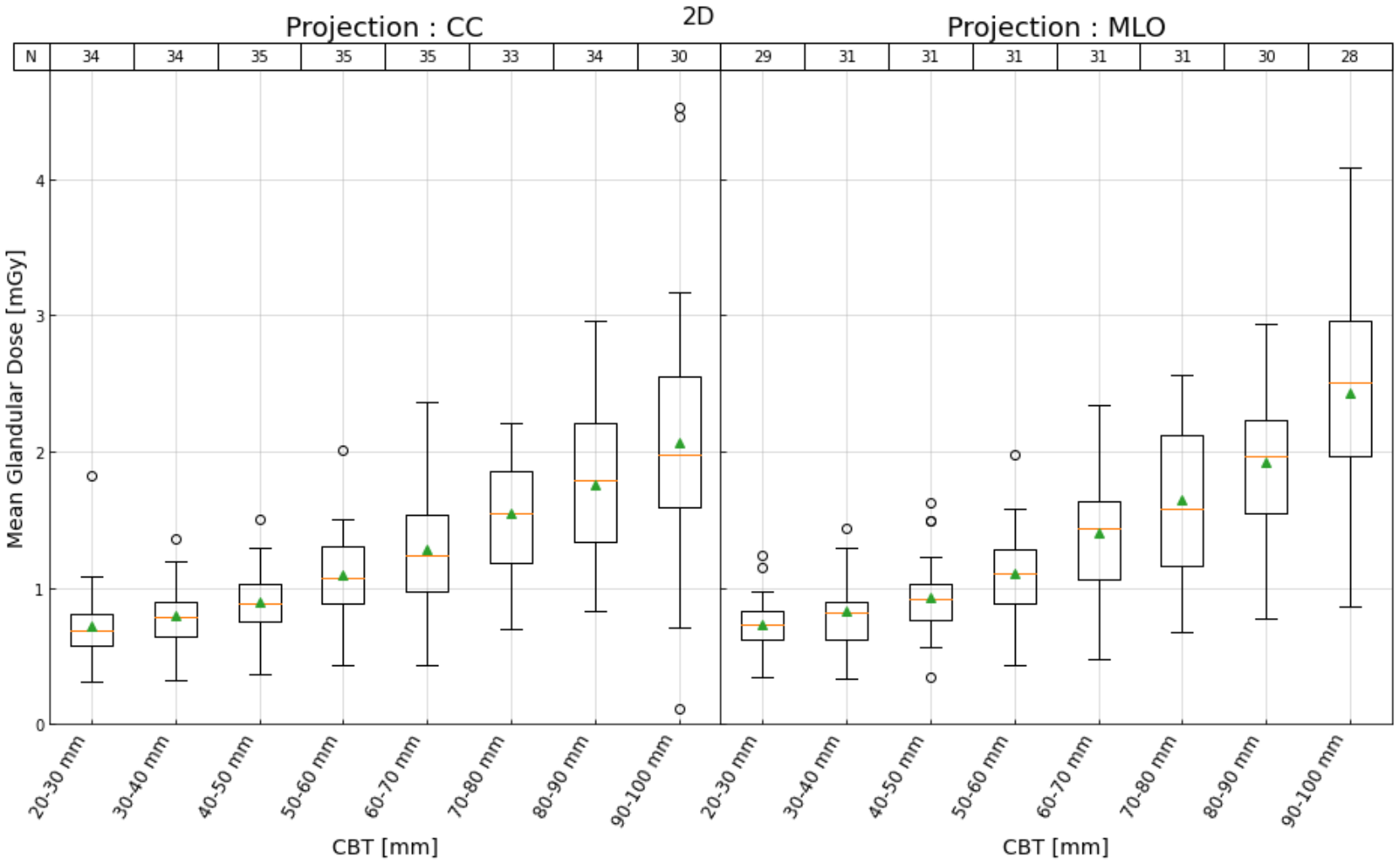

Figure 3 - Boxplots of median values of MGD of all mammography units, for 2D examinations, CC and MLO projections, for all CBT intervals.

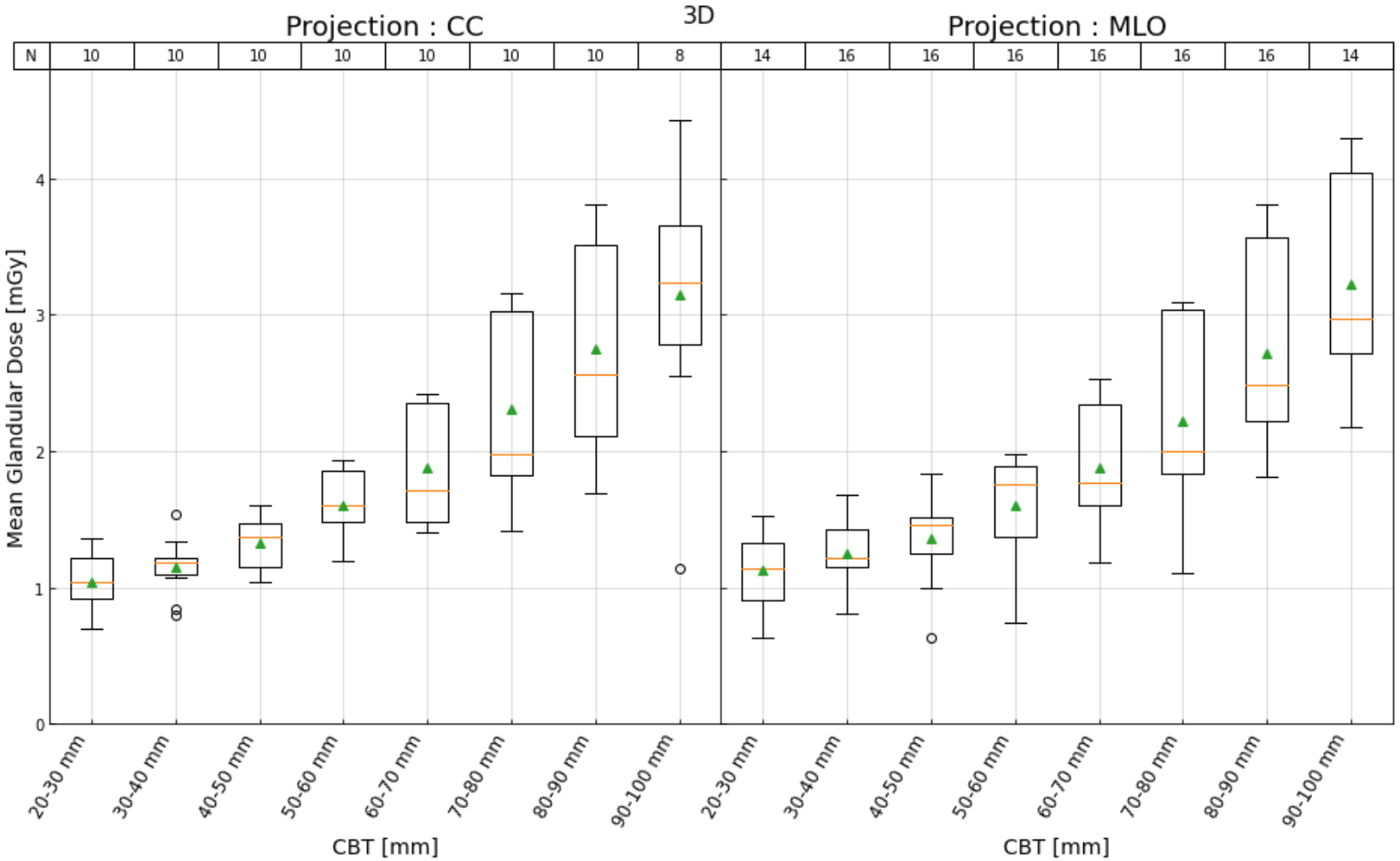

Figure 4 - Boxplots of median values of MGD of all mammography units, for 3D examinations, CC and MLO projections, for all CBT intervals.

The advantage of considering the medians of each mammography unit is that they all have the same weight in the final results. It is important that each unit has an equivalent weight compared to the others, otherwise the institutes that have provided more data will have a greater impact on the final results, which will no longer be representative of all the centres. We therefore consider this method as the appropriate one to propose DRLs.

In the questionnaire, the number of acquisitions required for each category of CBT was 20. However, as already mentioned, not all institutes were able to send at least 20 acquisitions per category and per mammography unit as shown in Tables 2 and 3, especially for extreme CBT categories (e.g. 90-100 mm). The calculation of median could be compromised when having a very low number of data sets available. It was therefore a question of establishing a threshold for a minimum number of acquisitions provided for the dataset to be considered. For this purpose, several threshold values were tested in order to choose the most optimal one: 20 acquisitions minimum (as initially required), 15 acquisitions, 10 acquisitions, or no threshold. To assess the impact of the choice of the threshold value, the percentage differences between the 75th percentile of the MGD values relative to values when no threshold is applied were calculated. Results are presented in Table 7 for 2D and Table 8 for 3D. They show small differences according to the value of the threshold applied, in most cases. Thus, even if it is a debatable point, we have considered that the most optimal is not to apply a threshold at all.

Table 7 - Results of the 75th percentile of the MGD for the data of the medians of each mammography unit with several threshold values for 2D acquisitions, CC/MLO projections and for all CBT intervals. "Std" is the standard deviation of the set of data.

		2D															
		CC								MLO							
CBTs		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Threshold=20	MGD [mGy]	0.80	0.90	1.03	1.32	1.57	2.03	1.89	2.16	0.82	0.91	1.08	1.30	1.67	2.14	2.26	2.97
	Std	0.11	0.18	0.19	0.23	0.37	0.36	0.45	0.43	0.12	0.21	0.22	0.28	0.38	0.42	0.44	0.54
	N	21	26	27	28	28	26	16	4	16	21	22	25	23	23	17	7
% diff 0-20		1.23	0.00	0.00	-0.76	-1.95	-9.14	14.48	15.29	1.20	-1.11	-4.85	-1.56	-1.83	-0.94	-1.35	-0.34
Threshold=15	MGD [mGy]	0.80	0.90	1.03	1.33	1.62	2.01	1.97	1.95	0.84	0.96	1.07	1.30	1.67	2.13	2.25	2.97
	Std	0.14	0.18	0.20	0.28	0.37	0.36	0.52	0.42	0.15	0.22	0.21	0.28	0.38	0.43	0.41	0.58
	N	24	26	29	29	30	27	21	6	18	23	24	25	25	24	19	11
% diff 0-15		1.23	0.00	0.00	-1.53	-5.19	-8.06	10.86	23.53	-1.20	-6.67	-3.88	-1.56	-1.83	-0.47	-0.90	-0.34
Threshold=10	MGD [mGy]	0.79	0.90	1.02	1.32	1.57	1.89	2.18	2.14	0.82	0.90	1.05	1.27	1.66	2.12	2.22	2.96
	Std	0.14	0.18	0.22	0.29	0.40	0.40	0.53	0.48	0.17	0.24	0.21	0.30	0.44	0.46	0.53	0.77
	N	26	29	34	32	32	32	26	9	22	27	26	28	29	26	23	16
% diff 0-10		2.47	0.00	0.97	-0.76	-1.95	-1.61	1.36	16.08	1.20	0.00	-1.94	0.78	-1.22	0.00	0.45	0.00
Threshold=0	MGD [mGy]	0.81	0.90	1.03	1.31	1.54	1.86	2.21	2.55	0.83	0.90	1.03	1.28	1.64	2.12	2.23	2.96
	Std	0.25	0.21	0.22	0.30	0.42	0.41	0.55	0.94	0.19	0.24	0.27	0.31	0.44	0.52	0.56	0.81
	N	34	34	35	35	35	33	34	30	29	31	31	31	31	31	30	28

Table 8 - Results of the 75th percentile of the MGD for the data of the medians of each mammography unit with several threshold values for 3D acquisitions, CC/MLO projections and for all CBT intervals. "Std" is the standard deviation of the set of data.

CBTs		3D															
		CC								MLO							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Threshold=20	MGD [mGy]	1.20	1.22	1.47	1.85	2.35	3.04	3.74		1.33	1.35	1.52	1.90	2.35	3.04	3.66	4.20
	Std	0.17	0.22	0.19	0.25	0.42	0.66	0.78		0.28	0.22	0.30	0.36	0.44	0.61	0.68	0.71
	N	7	9	9	10	10	9	5	0	10	12	13	14	15	13	9	5
% diff 0-20		**1.64**	**0.00**	**0.00**	**0.00**	**0.00**	**-0.33**	**-6.55**	**100.00**	**0.00**	**4.93**	**0.00**	**-0.53**	**-0.43**	**0.00**	**-2.52**	**-3.96**
Threshold=15	MGD [mGy]	1.19	1.22	1.47	1.85	2.35	3.04	3.48	3.05	1.31	1.33	1.52	1.89	2.35	3.04	3.65	4.18
	Std	0.20	0.22	0.18	0.25	0.42	0.66	0.73	0.12	0.26	0.22	0.30	0.35	0.44	0.60	0.65	0.68
	N	8	9	10	10	10	9	6	2	12	13	13	15	15	14	11	6
% diff 0-15		**2.46**	**0.00**	**0.00**	**0.00**	**0.00**	**-0.33**	**0.85**	**16.67**	**1.50**	**6.34**	**0.00**	**0.00**	**-0.43**	**0.00**	**-2.24**	**-3.47**
Threshold=10	MGD [mGy]	1.17	1.22	1.47	1.85	2.35	3.03	3.48	3.05	1.31	1.40	1.51	1.89	2.34	3.04	3.64	4.16
	Std	0.19	0.22	0.18	0.25	0.42	0.64	0.73	0.12	0.26	0.22	0.29	0.35	0.44	0.60	0.70	0.73
	N	9	9	10	10	10	10	6	2	12	14	14	15	16	14	12	7
% diff 0-10		**4.10**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.85**	**16.67**	**1.50**	**1.41**	**0.66**	**0.00**	**0.00**	**0.00**	**-1.96**	**-2.97**
Threshold=0	MGD [mGy]	1.22	1.22	1.47	1.85	2.35	3.03	3.51	3.66	1.33	1.42	1.52	1.89	2.34	3.04	3.57	4.04
	Std	0.21	0.21	0.18	0.25	0.42	0.64	0.77	0.96	0.27	0.22	0.28	0.35	0.44	0.63	0.69	0.73
	N	10	10	10	10	10	10	10	8	14	16	16	16	16	16	16	14

Following the data collection, it was noted that the amount of data collected for 3D exams was much lower than the amount received for 2D exams. This observation is consistent with the proportion of institutes performing 3D examinations, which is not equivalent to the proportion of institutes performing 2D examinations. Adding to this that most institutes were unable to provide the 20 acquisitions requested per mammography unit, little data is available in certain CBT intervals to carry out the calculations. One of the solutions investigated to overcome this problem was to widen the CBT intervals to include more data per interval. Indeed, choosing a larger interval thickness allows more data to be included in the statistics, but the results will therefore be less adapted to each CBT.

To assess the impact of the size of the intervals, the percentages of difference between the 75th percentile of the MGD values for the different interval thickness were calculated with respect to the values for a 10 mm interval thickness, see Table 9.

Table 9 - Results of the 75th percentile of the MGD for the data of the medians of each mammography unit with several CBT interval sizes for 3D acquisitions, CC/MLO projections and for all CBT intervals. "Std" is the standard deviation of the set of data.

		3D															
		CC								MLO							
CBTs		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Int. 10mm	MGD [mGy]	1.22	1.22	1.47	1.85	2.35	3.03	3.51	3.66	1.33	1.42	1.52	1.89	2.34	3.04	3.57	4.04
	Std	0.21	0.21	0.18	0.25	0.42	0.64	0.77	0.96	0.27	0.22	0.28	0.35	0.44	0.63	0.69	0.73
	N	10	10	10	10	10	10	10	8	14	16	16	16	16	16	16	14
% diff 20-10mm		0.81	0.81	7.55	-16.35	7.48	-19.29	0.85	-3.39	2.21	-4.41	9.52	-12.50	9.30	-17.83	2.19	-10.68
Int. 20mm	MGD [mGy]	1.23		1.59		2.54		3.54		1.36		1.68		2.58		3.65	
	Std	0.18		0.19		0.46		0.77		0.24		0.31		0.53		0.73	
	N	10		10		10		10		16		16		16		16	
% diff 40-10mm		17.57	17.57	0.68	-25.00	8.20	-18.36	-37.11	-42.97	13.64	7.79	1.30	-22.73	13.33	-12.59	-32.22	-49.63
Int. 40mm	MGD [mGy]	1.48				2.56				1.54				2.70			
	Std	0.22				0.47				0.26				0.65			
	N	10				10				16				16			
% diff 80-10mm		31.84	31.84	17.88	-3.35	-31.28	-69.27	-96.09	-104.47	30.37	25.65	20.42	1.05	-22.51	-59.16	-86.91	-111.52
Int. 80mm	MGD [mGy]	1.79								1.91							
	Std	0.22								0.31							
	N	10								16							

When the interval thickness is increased from 10 to 20 mm, the 75th percentile of the MGD values vary between -19.3% and 9.5%. When the interval thickness is increased from 10 to 40mm, the percentage differences vary between -49.6% and 17.6%. Finally, if the interval thickness is increased from 10 to 80mm (i.e. all CBTs included), the DRL values vary from -111.5 to 31.8%. This alternating sign is expected because the MGD values are always increasing from CBT interval to CBT interval, as seen in Figures 3 and 4. This steady increase is in fact a good indicator that the data is robust enough to use 10 mm intervals. Since the standard deviation is of the same order for an interval of 80mm as for an interval of 10mm and the difference among dose values increase when increasing the interval size, it is more reasonable to stick to the 10mm interval as a category for the MGD calculation.

Global analysis with medians for a single CBT value

We also analysed the data like many other countries to establish their DRLs, i.e. by pooling all the data for all CBTs combined, but for 2D and 3D, and CC and MLO projections separately. We calculated the median and 75th percentile for all pooled data for each category, and a mean value of CBT. The results are presented in Table 10.

Table 10 - Results for all data pooled for 2D/3D and CC/MLO projections and for a mean CBT value. "Std" is the standard deviation of the set of data.

		2D		3D	
		CC	MLO	CC	MLO
MGD [mGy]	Median	1.10	1.18	1.61	1.75
	75th perc.	1.29	1.42	1.79	1.91
	95th perc.	1.55	1.84	1.94	2.10
	std	0.26	0.34	0.22	0.31
mean CBT [mm]		56	58	54	56

As expected, the results for the median and the 75th percentile are higher for 3D than for 2D [13]. The values obtained are also slightly higher for the MLO projection than for the CC in agreement with the results of the other methods.

Analysis per manufacturer

As illustrated in the literature, there is link between the manufacturer and the behavior of the MGD [14]. We also studied this point. In Figure 5, the median values of the MGD have been plotted as a function the CBT for each one of the manufacturers. Results show that the MGD can be up to 3 times larger when using a device from GE instead a Philips. Nevertheless, the comparison it is not adequate for some specific manufacturers as for example the one from Philips. Indeed, they are the only devices that work as a scanning device, where almost no scatter dose is produced.

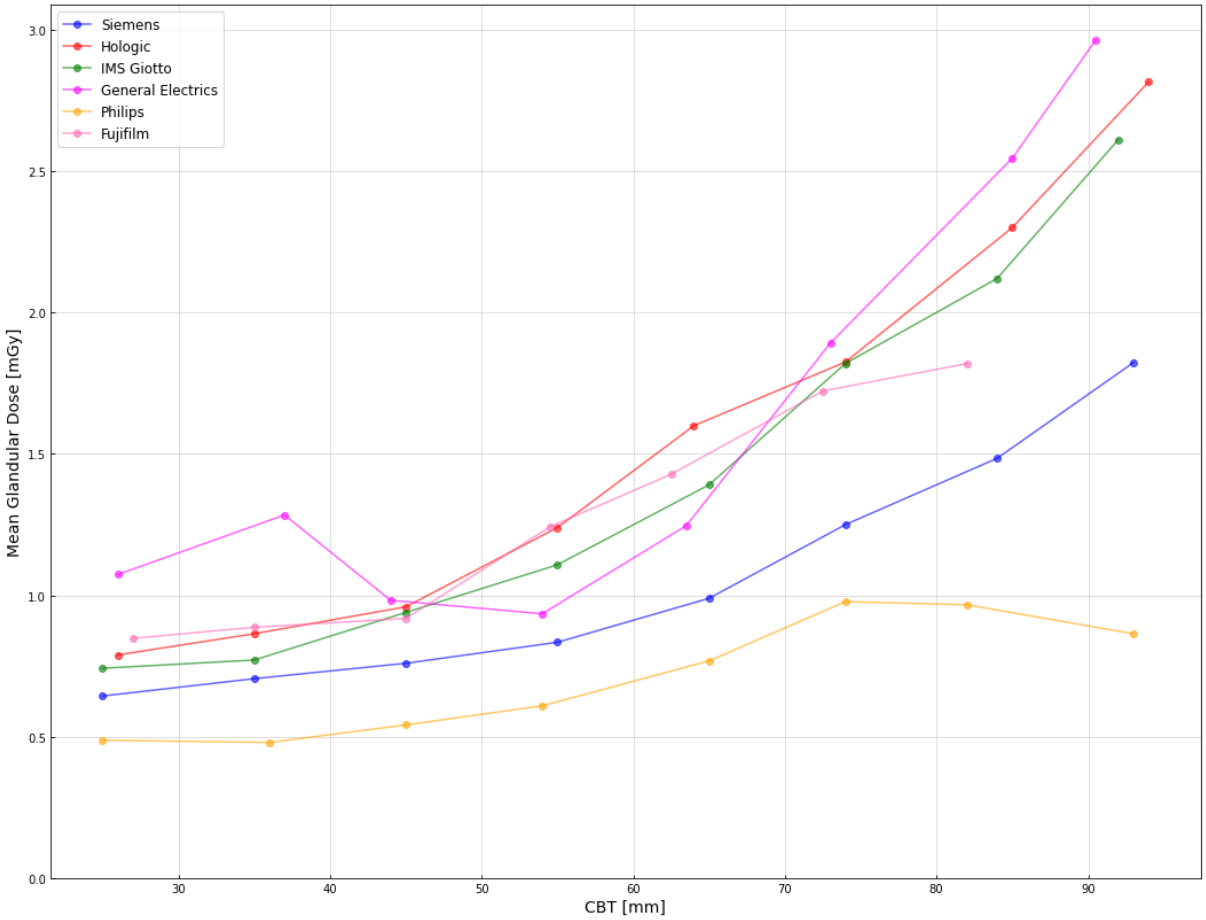

Figure 5 - Median MGD values as a function of the mean CBT values for the different mammography manufacturers in the study.

DRLs proposal

Following the above presented results and according to ICRP 135 [7], a DRL value can be defined as the 75th percentile of the distribution of the medians of the datasets obtained by means of a survey. The 75th percentile of the distribution of the medians from each mammography unit is presented in Table 11 for 2D/3D, for each projection (CC/MLO) and for each CBT interval. These results, obtained in the "Global analysis with medians section", represent the proposed DRLs for Switzerland.

Table 11 – Proposed DRLs values for mammography examinations in Switzerland (MGD per acquisition).

		CC								MLO							
		20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
2D	MGD [mGy]	0.81	0.90	1.03	1.31	1.54	1.86	2.21	2.55	0.83	0.90	1.03	1.28	1.64	2.12	2.23	2.96
3D		1.22	1.22	1.47	1.85	2.35	3.03	3.51	3.66	1.33	1.42	1.52	1.89	2.34	3.04	3.57	4.04

We have chosen to compare our results with recent results from other countries. The comparison should be made very carefully since different methodologies have been used by the different countries, some made their DRLs using patient survey, like us, and some using PMMA phantoms [8, 14-15]. Therefore, we have chosen to compare our results with those countries that applied the same methodology (i.e. patient survey).

Most countries have set their DRLs values for an average CBT value, some separating for CC and MLO projections. To compare our work with their results, we can therefore use the values from Table 10, obtained by pooling the data for 2D and 3D separately, for CC and MLO projections, for a mean CBT value. France is one of these countries, results published by IRSN [10] were separated for 2D and 3D, but all projections combined and the value of the 75th percentile of the MGD was chosen. They obtained a DRL value of 1.7mGy for 2D for a mean CBT of 56mm, and 2.3mGy for 3D for a mean CBT of 57mm. In our case, we have two different values considering the projection, for 2D 1.29mGy for a CBT of 56mm and 1.42mGy for a CBT of 58mm for CC and MLO respectively and for 3D 1.79mGy for a CBT of 54mm and 1.91mGy for a CBT of 56mm for CC and MLO respectively. The values of the French report and ours, when obtained using the same method, are very similar. Slightly higher values have been obtained in Ghana for the 2D, with a DRL set at 75th percentile with a MGD of 2mGy for a CBT 60±5mm [16].

Some other countries have, like us, chosen to separate their results by CBT intervals. To compare our values with theirs, we can use the data from Table 11, our proposed DRLs. Values for New South Wales (2D) are divided in the same CBT categories. Moreover, they have values also available separately for the different detector technologies [17]. When comparing their values for all detector technologies combined, they are slightly higher, with values from 0.97mGy till 2.89mGy for the same CBT categories than ours. Scottish DRLs are proposed for only some of the CBT categories and both projections combined [14]. Their values are again slightly higher than ours.

Turkish results were separated for 2D and 3D, by CC and MLO projections, and by 10mm intervals of CBT from 20mm to 100mm, but also by age, in two categories (40-49 and 50-64) [12]. As mentioned in the section data analysis, breast density (glandularity) is changing with age, therefore it has an influence on the delivered dose. Even though glandularity will be the

key parameter, it is not easily accessible nor exportable via the DMS. The values they obtained are much higher than ours for each category with MGD values up to 4mGy.

In conclusion, our results are in good agreement with those of other countries that have proceeded with a similar method.

Conclusion

To propose DRL values for mammography examinations performed in Switzerland we followed the recommendations established by the International Commission on Radiological Protection [7]. To this end, we performed a survey allowing us to collect data from 36 mammography units installed all over the country. The data, categorized into different categories such as examination type (2D or 3D), projection (CC or MLO) and 8 different CBT categories of 10mm width, ranging from 20mm till 100mm was analysed with different methods. The analysis showed that the data obtained is representative of the practice in Switzerland since most frequent devices are represented. The same conclusions could be drawn from all methods used: the MGD is larger for a 3D acquisition than for 2D, it increases as the CBT increases and has higher values for MLO than CC. Finally, dose reference values (DRLs) can be proposed as a function of the examination type (2D/3D), projection (CC/MLO) and CBT. The proposed values compare well to those obtained in the literature.

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Annex: questionnaire sent to the participating institutes

Establishment of SWISS DRLs in mammography

Dear colleague, this questionnaire aims at collecting data for mammography in order to be able to establish national diagnostics reference levels for mammography examinations in Switzerland. Only with your input, this work can be a success. Thank you in adavance for your help!
Rest assured that the data will be processed anonymously

Contact person for this project:

Marta Sans Merce
e-mail: marta.sansmerce@hcuge.ch
Tél. 079 553 35 06

Informations about you:

Institute:

Your name:
Your e-mail:
Your telephone:
Your role (radiologist, medical physicist,…):

Concerning you mammograph:

Brand:
Model:

IMPORTANT: please only provide data for female patients !!!

IMPORTANT: these will be the Compression Breast Thickness (CBT) categories and the number of datasets required per CBT category

CBT [mm]	Number of data set required
20-29	*20*
30-39	*20*
40-49	*20*
50-59	*20*
60-69	*20*
70-79	*20*
80-89	*20*
90-99	*20*

This page should be filled with at leat 20 most recent and consecutive acquisitions per category of Compressed Breast Thickness (CBT) performed in 2D mammography mode per installation

Patient birth date	Date of exam	laterality L/R	projection CC / MLO	anode material	filter material	kV [kV]	mAs [mAs]	Compression force [N]	CBT [mm]	Entrance dose [mGy]	Mean glandular dose [mGy]

This page should be filled with at leat 20 most recent and consecutive acquisitions per category of Compressed Breast Thickness (CBT) performed in 3D mammography mode (tomosynthesis) per installation

Patient birth date	Date of exam	laterality L/R	projection CC / MLO	anode material	filter material	kV [kV]	mAs [mAs]	Compression force [N]	CBT [mm]	Entrance dose [mGy]	Mean glandular dose [mGy]