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A SURVEY OF SHORT-TERM AND LONG-TERM STABILITY OF TUBE PARAMETERS IN A MAMMOGRAPHY UNIT

by

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In order to set up a successful mammography screening program in the Republic of Srpska, a Siemens Mammomat 1000 X-ray machine was selected for analysis as the said mammography system is widely used in clinical practice. The variations in tube parameters (specific air kerma, high-voltage accuracy and reproducibility, linearity between exposure and dose exposure time) were monitored over a five-year period, from 2008 to 2012. In addition, due to observed daily fluctuations for chosen parameters, a series of measurements were performed three times a day within a single-month period (mainly October 2012). The goal of such an experimental set up is to assess short-term and long-term stability of tube parameters in the given mammography unit and to make a comparison between them. The present paper shows how an early detection of significant parameter fluctuations can help eliminate irregularities and optimize the performance of mammography systems.

Key words: mammography, air kerma, quality control

INTRODUCTION

Breast screening programs operate in many countries with mammographic X-ray units subject to stringent quality control tests [1]. Dosimetry measurements of the X-ray unit normally include workplace monitoring, *i. e.*, measuring the $H^*(10)$ ambient dose equivalent by means of a portable instrument, as well as quality control (QC) testing of the device itself. QC includes a series of measurements of X-ray tube parameters such as high voltage, exposure time and specific air kerma values by means of a multimeter device and appropriate QC phantoms [2].

In our previous paper [3], results of technical parameters for 31 mammography units were presented. All the measurements were performed within a single calendar year. Large fluctuations in dose among different measuring sites were detected which was clearly unacceptable, not only from the standpoint of mammography screening, but in clinical mammography as well. In this paper, in order to set up a successful mammography screening program in the Republic of Srpska, an X-ray machine, model Siemens Mammomat 1000, was selected for analysis as a typical model in clinical practice.

Screening practices took place at the Banja Luka Clinical Center. Several parameters derived from exposure measurements (such as specific air kerma, high voltage accuracy and reproducibility, linearity between exposure and dose, exposure time) were used for evaluation. The variations in tube parameters of a single mammography unit were measured over a five-year period (2008-2012), except for a total of a few weeks of inactivity due to maintenance or upgrade service.

According to available literature, long-term stability has been widely observed [1], whilst short-term stability has been investigated to a considerably smaller extent. The present paper provides a brief insight into trends observed by parameters of a typical mammography unit over a five-year period of its life cycle.

MATERIALS AND METHODS

A Siemens Mammomat 1000 was selected for analysis as this model is widely used in clinical practice. The unit was installed in 2000.

Measurements of tube parameters were basically performed on two time scales: daily and annual. The annual tests (including the 2008-2012 period) are carried out as a compulsory part of legally prescribed

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radiation protection practice. The annual measurements were performed roughly at the same time of a day, in the same season, in approximately identical microclimatic conditions (*i. e.*, without significant alterations in X-ray room temperature and humidity); thus, it can be concluded that the measurement conditions were kept quite constant over the five-year period. On the other hand, the daily monitoring of the same set of parameters was introduced for the sole purpose of experiment and performed during 25 consecutive workdays, mainly in October 2012. Each daily measurement consisted of three parameter acquisitions: immediately after turning the unit on, after three hours of activity, and at the end of the work shift (after six hours of activity).

QC procedures to be performed for each screening mammography unit are defined according to the European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis. They include the following [4]:

- specific air kerma at 28 kV and 20 mAs, expressed in Gy/mAs,
- linearity K_a/P_{It} *vs*. high voltage squared, its tolerance limits being expressed by percentage values (voltage range between 24 kV and 34 kV, with 5% tolerance),
- reproducibility of exposure, *i. e.*, five consecutive measurements of high voltage, exposure time and air kerma at 28 kV and 20 mAs, where the three measurements must not exceed 5% deviation from the mean value,
- exposure-to-dose linearity at 28 kV and It values between 10 mAs and 160 mAs, with 5% tolerance, and
- high voltage accuracy (10% tolerance range).

These parameters were measured using Barracuda multimeter (by RTI Electronics, Sweden) and ACR mammographic accreditation phantom (by Fluke Biomedical RMS, Cleveland, OH).

RESULTS

Results obtained by daily and annual measurements are shown in respective tables in the following order:

- table 1 displays the values of all the observed parameters measured three times a day for 25 consecutive workdays, and
- table 2 shows the values obtained by yearly measurements during five consecutive years.

For the sake of clarity, some parameters are plotted with measured values represented as points, whereas the underlying time trends are displayed as lines connecting the single points.

Specific kerma value. On a daily basis, specific air kerma values range from 77.0 µGy/mAs to 90.7 µGy/mAs, with a mean value of 80.4 µGy/mAs. More significant fluctuations in air kerma values may always be observed between the first and the third measured daily value (fig. 1).

The annual survey of specific air kerma values for the period 2008-2012 shows values ranging from 69.8 µGy/mAs to 94.2 µGy/mAs, with an upward trend over the entire observed period (fig. 2).

Linearity of specific air kerma value vs. high voltage squared. This linearity trend is almost maintained constant over time when observed on a daily basis during the 25-day period in consideration, and has a value of 0.99. Its behaviour throughout the 2008-2012 period is resumed in tab. 2.

High-voltage reproducibility. Daily measurements of high-voltage reproducibility show deviations ranging from 0.02% to 0.42%, which is still within tolerance limits. In turn, fluctuations in reproducibility measurements over the given five-year period are shown in fig. 3.

Air kerma reproducibility. Regarding kerma reproducibility, the deviations are comprised between 0.02% and 0.91%, their daily mean value being

Table 1. Measured values of mammography X-ray tube parameters within a 25-day period

	Min	Max	Mean	SD	Median
Specific air kerma value K_a/P_{It} [µGymA^{-1}s^{-1}]	77.0	90.7	80.4	2.56	80.9
Voltage reproducibility deviation [%]	0.02	0.42	0.12	0.10	0.11
Kerma reproducibility deviation [%]	0.02	0.91	0.16	0.19	0.17
High-voltage accuracy deviation [%]	1.30	6.50	2.35	1.13	2.10

Table 2. Results of annual measurements of mammography tube parameters over a five-year period. The unusually high deviation in voltage accuracy values detected in 2008 (14.50%) was successively remediated through service maintenance

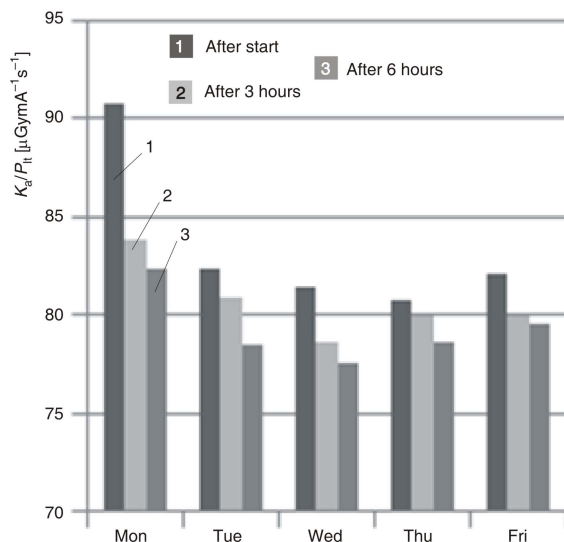| Parameter	Year				
	2008	2009	2010	2011	2012
Specific air kerma value K_a/P_{It} [µGymA^{-1}s^{-1}]	69.8	74.0	72.2	76.5	94.2
Linearity of specific air kerma value *vs*. high-voltage squared $K_a/P_{It} = f(U_0^2)$	0.999	0.995	0.999	0.955	0.997
Voltage reproducibility deviation [%]	0.02	0.30	0.29	0.51	0.10
Air kerma reproducibility deviation [%]	0.47	0.19	0.17	0.26	0.05
Exposure-to-dose linearity $D = f(It)$	1.000	1.000	0.999	0.990	0.999
Voltage accuracy deviation [%]	14.50	2.74	2.10	1.92	2.43

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Figure 1. Daily fluctuations in specific air kerma values obtained during the first week of daily measurements
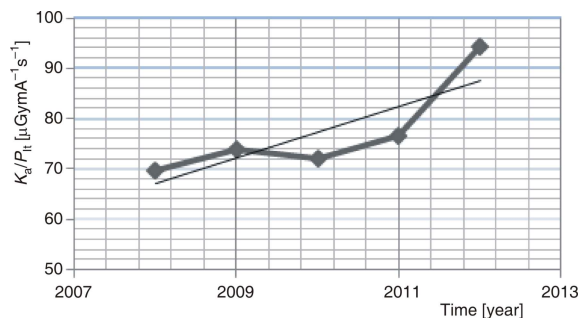

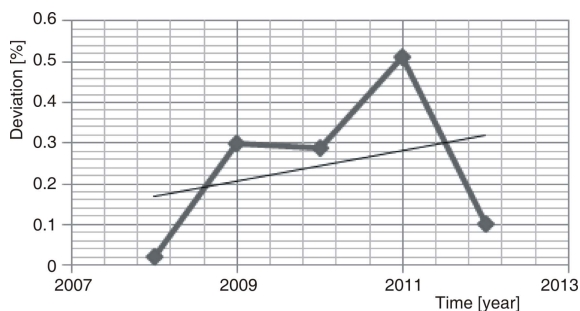**Figure 2. Annual specific air kerma values over a five-year period**

Figure 3. Fluctuations in deviation values of high-voltage reproducibility over five consecutive year

0.16%. Therefore, the variations in this parameter are kept within legally prescribed limits.

Exposure-to-dose linearity. The link between exposure parameters and dose is linear and constant over time, either on a daily basis or for prolonged time periods (from 2008 to 2012). Its value is practically always 1.

High-voltage accuracy. Daily deviations from high-voltage accuracy range between 1.3% and 6.5%

with a mean value of 2.1%, which is still within tolerance limits. If the entire five-year period is considered, the deviations from high-voltage have been reduced relative to the initial deviation value measured, and have been brought back within the tolerance limits.

DISCUSSION AND CONCLUSIONS

A series of QC measurements of the given mammography unit performed in October and the beginning of November 2012, consisting of three daily samplings, have shown stability in values of several tube parameters. For instance, it was found that the linearity of air kerma against high-voltage squared (or the dose against each of the exposure parameters), are constant on a daily basis. On the other hand, observable daily fluctuations are found in some parameters depending on the exact sampling time [5, 6]. While examining specific air kerma values on a daily level, the highest dose values are encountered in the first morning measurement – immediately after starting the machine – whereas later in the day their value decreases. On the contrary, deviations in high-voltage and air kerma reproducibility, as well as the deviation in high-voltage accuracy, are smallest immediately after starting the machine; during the work shift their values gradually increase. Nevertheless, all those deviations are always kept within the prescribed tolerance limits.

Speaking in long-terms, the annual values of specific air kerma show an increasing trend. The linear response of specific air kerma to high-voltage squared as well as the linearity between exposure and dose, have remained constant over time. The deviations in kerma and voltage accuracy and reproducibility assume different values over course of time.

During the life cycle of any X-ray unit, besides the normal process of generating diagnostic radiological images, different unwanted events occur that may compromise the unit's functionality. Among those are interruptions in power supply, voltage variations, mechanical defects of unit components due to aging, inappropriate handling, *etc*. However, the aging of the X-ray tube is perhaps the key factor for inducing significant fluctuations in those parameters over time [6, 7]. To restore the unit to an up-and-running state, certain service interventions have to be performed occasionally by the manufacturer.

By conducting routine annual QC tests of mammography X-ray units it becomes possible to detect deviations of parameters outside the range of normal values. It then becomes possible to directly influence the quality of mammography procedures in at least two ways:

– early detection of significant parameter deviations makes it possible to eliminate irregularities possibly arisen during the machine's functioning. This would result in an improved overall quality of mammography images, and

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– unnecessary patient exposure (either due to increased air kerma values or to excess of stray radiation) may be efficiently reduced.

Mammography examination is particularly delicate mainly because of (1) high radiosensitivity of the breast and (2) requirement for both high space and contrast resolution. These facts are of special concern in mammography screening, where the asymptomatic target population undergoes mammography, so the expected average size of a lesion is even smaller than in clinical mammography. Unlike the units used solely for clinical mammography, which are being tested on an annual basis, those involved with screening are subject to more stringent semi-annual QC tests [2]. The goal of parameter monitoring and intercomparison is to reduce their fluctuations to a minimum, thus eliminating significant variations in image quality or patient doses for the same type of imaging procedures. Minimising these fluctuations would result in improved image quality, with a simultaneous reduction in patient doses and, consequently, in reduced risk of inducing secondary cancers. Moreover, comparison of patient doses among different mammography units could bring about the establishment of dose reference levels for all X-ray mammography units within the framework of the national healthcare system [8, 9].

New legislation also requires daily and weekly QC tests of mammography units to be introduced into practice. Continuous monitoring of weekly and monthly fluctuations in the measured parameters might cast a new light on the causes of long-term variations in mammography unit performance.

ACKNOWLEDGEMENT

AUTHOR CONTRIBUTIONS

Experiments were carried out by J. Ž. Praskalo and B. V. Kočić. Theoretical analysis was carried out by J. Dj. Davidović, M. M. Živković, and S. M. Pejović. All of the authors have further analysed and discussed the results. The manuscript was written by J. Ž. Praskalo and J. Dj. Davidović. The figures were prepared by J. Ž. Praskalo.

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КРАТКОРОЧНО И ДУГОРОЧНО ПРАЋЕЊЕ СТАБИЛНОСТИ ПАРАМЕТАРА МАМОГРАФСКОГ РЕНДГЕН УРЕЂАЈА

У циљу успешног успостављања мамографског скрининг програма у Републици Српској, анализиран је мамограф Siemens Mammomat 1000, као најчешће заступљен мамографски уређај у клиничкој пракси. Варијације врдности параметара рендгенске цеви (специфична вредност керме, поузданост и поновљивост високог напона, линеарност експозиција-доза и време експозиције) посматране су у периоду од пет година, од 2008. до 2012. године. Поред тога, због уочених дневних флуктуација изабраних параметара, три пута дневно вршена су мерења током месец дана (углавном у октобру 2012). Циљеви тако постављеног експеримента су процена краткорочне и дугорочне стабилности параметара цеви у испитиваној мамографској јединици као и њихово поређење. Овај рад показује да рано откривање значајних флуктуација у параметрима може помоћи у отклањању неправилности и оптимизацији рада на мамо-уређајима.

Кључне речи: мамографија, керма у ваздуху, контрола квалитета