Comparison in Reading Stability between Calibrated and Non-Calibrated Ionization Chamber

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Abstract: ***Radiation equipment used in medical facilities requires regular calibration to ensure accurate and safe measurements. This research examines the reading stability between calibrated and non - calibrated ionization chambers, focusing on the importance of calibration in maintaining accuracy and safety. The study analyzed five ionization chambers of the same type, comparing their performance on different calibration dates. International bodies recommend calibrating ionization chambers every two to three years. However, some countries lack specific regulations for calibration. This research aims to provide insights into the impact of regular calibration on equipment performance. Implementing effective quality control programs can minimize risks associated with ionizing radiation exposure during medical procedures. The methodology involved assessing the accuracy of tube voltage and time settings, mAs linearity, and reproducibility. The half - value layer (HVL) was also measured to compare different dosimeters reading for X - ray machines. The findings of this research can guide healthcare facilities in developing comprehensive quality control programs, ensuring accurate and safe radiation equipment performance. Regular calibration is essential in maintaining measurement accuracy and minimizing risks during medical procedures. This research found that it is not necessary to calibrate the radiation measurement device annually; comparing it to a calibrated device that functions well is sufficient. However, periodic calibration, if feasible, is preferable. In many countries, including Saudi Arabia, devices are calibrated at the manufacturing country, taking one to two months. In such cases, comparing to a calibrated device may be satisfactory***

Keywords: dosimeters, medical physics, quality control, calibration

1. Introduction

A radiology quality control program is a crucial aspect of any medical facility containing radiation equipment to ensure the accuracy and safety of radiation measurements [1]. The periodic tests conducted by a medical physicist and the use of specialized tools such as phantoms and ionization chambers are essential components of the quality control program [2]. These instruments must be calibrated periodically to maintain their accuracy and sensitivity and ensure their stability under changing conditions of use and storage [2].

One critical test that needs to be checked periodically in the ionization chamber is its accuracy, which can be achieved by using a radiation source producing a known radiation exposure level [2]. The calibration frequency depends on the nature and use of the field in which the devices are used [3]. The periodic time between calibrations should follow national regulations [4]. However, some countries lack specific regulations for the calibration of ionization chambers [3].

International bodies such as the International Commission on Radiation Units and Measurements (ICRU) and the American Association of Physicists in Medicine (AAPM) recommend the calibration of ionization chambers at least once every two years and should not exceed three years [5], [6].

In this research, we analyze the stability of the response of six ionization chambers of the same type on different calibration dates to determine changes in their performance. This study can provide critical insights into the importance of regular calibration in maintaining the accuracy and safety of radiation equipment .

The findings of this research can assist healthcare facilities in developing comprehensive quality control programs that ensure the accurate and safe performance of radiation equipment. Ultimately, implementing sound quality control practices can help minimize the risks associated with exposure to ionizing radiation during medical procedures .

2. Material and Method

2.1 Material

This study was conducted with three x - ray machines in three hospitals by using five x - ray dosimeters were calibrated in different years.

2.1.1 Dosimeter:

X – ray dosimeter and electrometer calibrated for x – ray beam quality.
X – ray solid state dosimeter was used, Unfors RaySafe Xi

and X2 (Unfors RaySafe AB, Billdal, Sweden) has a complete solution for the X - ray room consisting of devices for QA and service of diagnostic X - ray machines and real - time [7]

Table 1: Dosimeres Information

Dosimeter name	Serial Number	model	Date of calibration
2023	249088	X2	3/2023
2022	208247	X2	8/2022
2020	254930	X2	10/2020
2019	186169	X1	10/2019
2015	167738	X1	8/2015

2.1.2 X - ray Machines:

The X - ray machines in King Abdullah Medical City (KAMC), King Abdullah Medical Complex - Jeddah (KAMCJ) and Security Force Hospital (SFH).

Table 2: Information of x - ray machines

Hospital name	KAMC	KAMCJ	SFHM
Manufacture	Carestream	Samsung	Philips
Serial No.	010619	7F235	34375A238471
Model	DXR Evolution plus	RxOnly	12000174
manufacturing year	2019	2019	2011
Max. and Min. kV	150 40	150 50	MAX: 150 MIN: 20
Max. and Min. mA	Large: 630 Small: 10	Large: 640 Small: 10	Large: 377 Small: 10
Max. and Min. mAs	Large: 800 Small: 0.1	Large: 800 Small: 0.1	Large: 800 Small: 0.1
AEC	√	√	√
Filtration	2 mmAl/75	1.1 Al/75	2 mmAl/75
Focal size	Broad Focus: 1.2 Fine Focus: 0.6	1.2 0.6	1.2 0.6

2.2 Method:

2.2.1 kV and time Accuracy

The accuracy of measurement is defined as "the degree of closeness of measurements of a quantity to that quantity's actual (true) value"[8]. Accuracy of tube voltage and time setting were examined for three machines in three hospitals by using five different sensors. Different exposures were recorded for tube voltage and time accuracy. The formula that uses for calculate the accuracy R_x was:

$$R_x = \left|\frac{x_m - x_n}{x_n}\right| \% \qquad (2.1)$$

Where: x_m is the measured value of time [ms] or voltage [kV], current [mA] and x_n is the nominal value of time [ms] or voltage [kV] and [current mA].

2.2.2 mAs Linearity

The linearityis "the average ratios of exposure to the indicated milliampere-seconds product (mR/mAs) obtained at any two consecutive tube current settings" [9]. The Coefficient of Linearity (COL) was checked using the following equation.

$$\frac{|X_1 - X_2|}{|X_1 + X_2|} < 0.1 \qquad (2.2)$$

Where X_1 and X_2 are two successive readings.

2.2.3 Reproducibility

Reproducibility is "difference between the measured and nominal value for high voltage, time, dose output"[10]. Reproducibility of dose, time and high voltage setting-parameters were measured with five sensors, with three exposures were made. The reproducibility P_z was calculated using the formula:

$$P_z = \frac{|Max_R - Min_R|}{|Max_R + Min_R|} \leq 0.05 \qquad (2.3)$$

Where : Max_R is the maximum reading of dose[mGy], time [ms] or voltage [kV] and Min_R is the minimum reading of dose[mGy], time [ms] or voltage [kV].

Another equation used for calculation of the reproducibility P_z as following:

$$P_z = \frac{SD}{Z_{av}} \times 100\% \qquad (2.4)$$

Where: SD is the estimator of standard deviation of a series of measurements dose[mGy], time [ms] or voltage [KV] , Zav is the means value of the parameters measured [dose[mGy], time[ms] or voltage [KV] [9]and [11].

2.2.4 Half Value Layer (HVL)

Half value layer (HVL) of X - ray machine of the three hospitals was measured at 80 kVp, 20 mAs and at SID 100 cm. The HVL were record from the sensor to compare the different.

3. Result

3.1 kVp and time accuracy:

Different exposures were recorded for tube voltage 60, 80, 100 and 120 kVp. The kVp accuracy were calculated using equation (2.1) and the average obtained for each hospital. Table (3) below demonstrated the average kVp accuracy for each hospital at five different calibration year.

Table 3: Mean kVp accuracy values at each calibration year for the three hospitals.

Dosimeter Hospital	2023	2022	2020	2019	2015
KAMCJ	1.274%	1.295%	1.295%	0.426%	0.927%
KAMC	0.804%	0.82%	0.844%	0.569%	0.792%
SFHM	0.805%	0.9017%	1.066%	0.564%	0.5883%

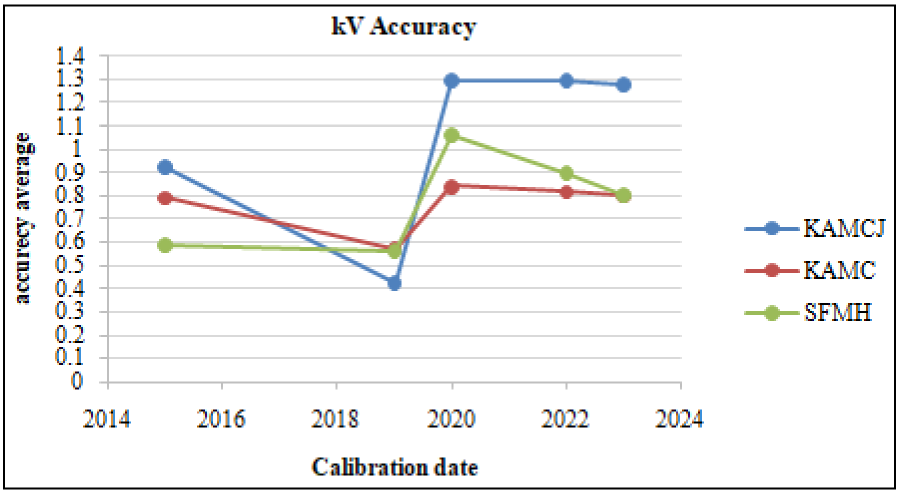

Figure 1: Average kVp accuracy as a function of calibration date for the three hospitals.

3.2 Time accuracy

Exposure time accuracy for the three diagnostic x - ray devices were examined in the three hospitals. The amount measured over the times of 25, 50, 100, 200, and 400 millisecond (msec) and at 80 kVp, 20 mAs and SID = 100 cm. The mean of time accuracy was obtained and shown in table (3) for the three hospitals at each detector.

In Figure (2) was analysis the accuracy of exposure time which shows that KAMC and SFHM have comparable values throughout all calibration years, KAMCJ has varied values. Although, all time exposure accuracy values are within the acceptable level.

Table 4: Time Accuracy values at each calibration year for the three hospitals.

Dosimeter Hospital	2023	2022	2020	2019	2015
KAMCJ	0.411%	0.425%	0.425%	0.4732%	0.5152%
KAMC	0.155%	0.16%	0.155%	0.2926%	0.3822%
SFHM	0.155%	0.155%	0.155%	0.2332%	0.1986%

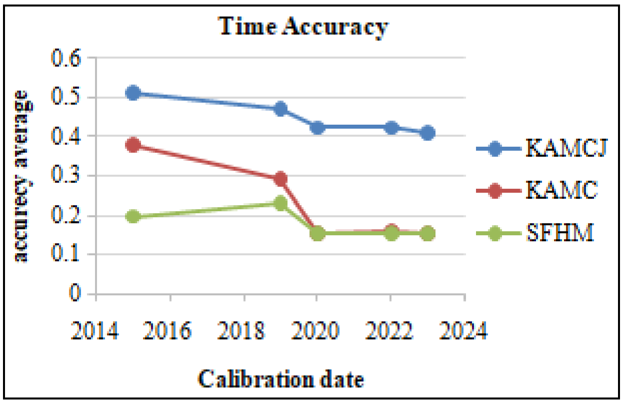

Figure 2: Exposure time accuracy for the three hospitals as a function of calibration date.

3.3 kV and Time reproducibility:

Reproducibility of tubes voltage was set on 80 KVp and 20 mAs on the machine control panel. The Reproducibility measurements calculated using equation (2.4). As demonstrated in Table (5) and plotted in Figure (3), While the reproducibility of exposure time set in a fixed exposure time 100 msec on the X - ray devices. Using equation (2.4), exposure time reproducibility values calculated and, the values are recorded in table (5) and plotted in figure (4).

Table 5: Reproducibility measurements of tube voltage for the three hospitals

Dosimeter	2023		2022		2020		2019		2015	
	kV	Time	kV	Time	kV	Time	kV	Time	kV	Time
KAMCJ	0.0005	0.0002	0.0009	0	0.0009	0	0.0019	0.00027	0.0002	0.00027
KAMC	0.0003	0	0	0	0.0005	0	0.0001	0.00027	0.0007	0.00027
FMH	0.00058	0	0.00067	0	0.00066	0	0.00068	0.00027	0.0013	0.00027

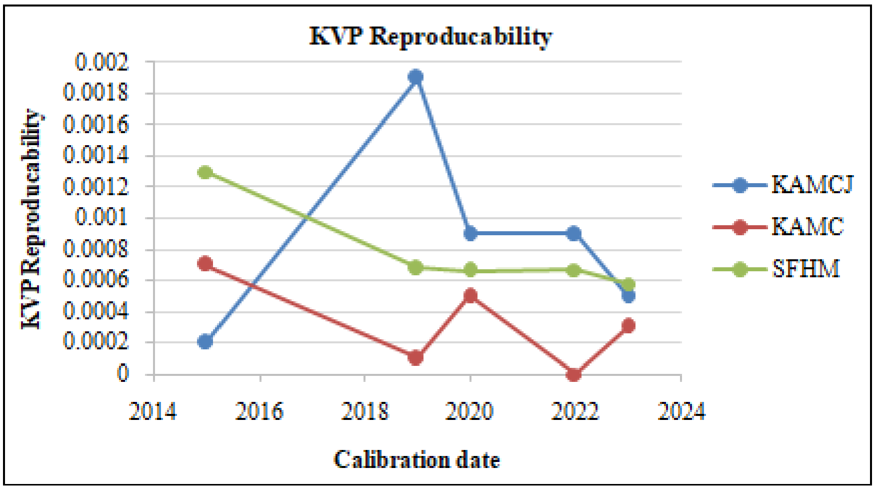

Figure 3: kVp reproducibility as a function of calibration date for the three hospitals.

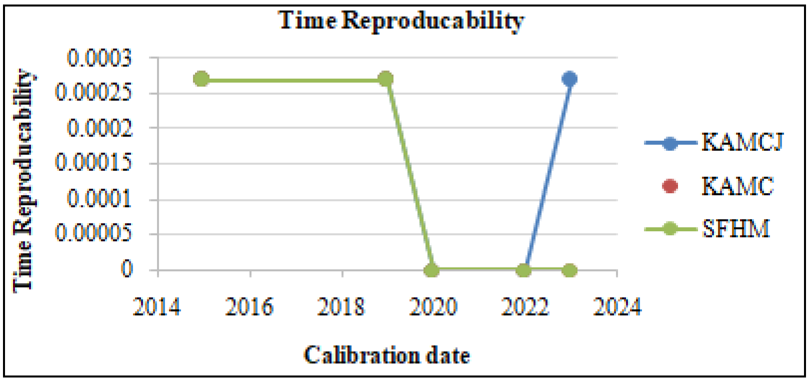

Figure 4: Exposure time reproducibility as a function of calibration date for the three hospitals.

3.4 Dose reproducibility

The reproducibility of mAs tube output obtained in fixed mAs 20 and 80 kV, calculated using equation (2.4). mAs reproducibility values calculated and, the values are recorded in table (6) and plotted in figure (5).

Table 6: mAs reproducibility measurements for the three hospitals.

Dosimeter Hospital	2023	2022	2020	2019	2015
KAMCJ	0.001	0.001	0.0016	0.0006	0.0008
KAMC	0.0006	0	0.0005	0.0003	0.0005
SFHM	0.0009	0.00077	0.00082	0.009	0.0059

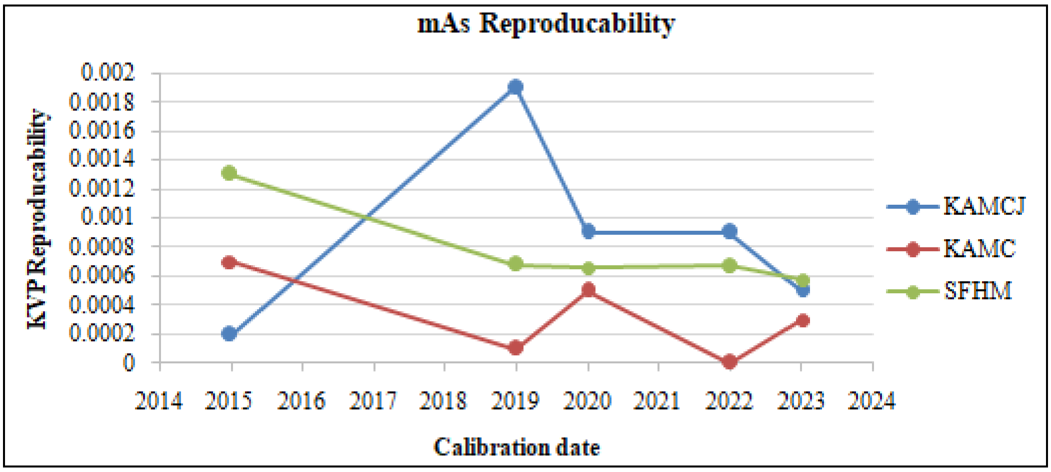

Figure 5: mAs reproducibility measurements as a function of calibration date.

3.5 mAs Linearity

The mAs output linearity has been obtained and recorded in table (7), plotted in figure (6). The coefficient of linearity values has varied between0.01 to 0.003 which is less than the tolerance value.

Table 7: Coefficient of linearity for the three hospitals in each calibration year

Year / Hospital	2023	2022	2020	2019	2015
KAMCJ	0.004	0.003	0.0035	0.005	0.006
KAMC	0.02	0.022	0.003	0.002	0.009
SFHM	0.0051	0.0049	0.0051	0.0219	0.0167

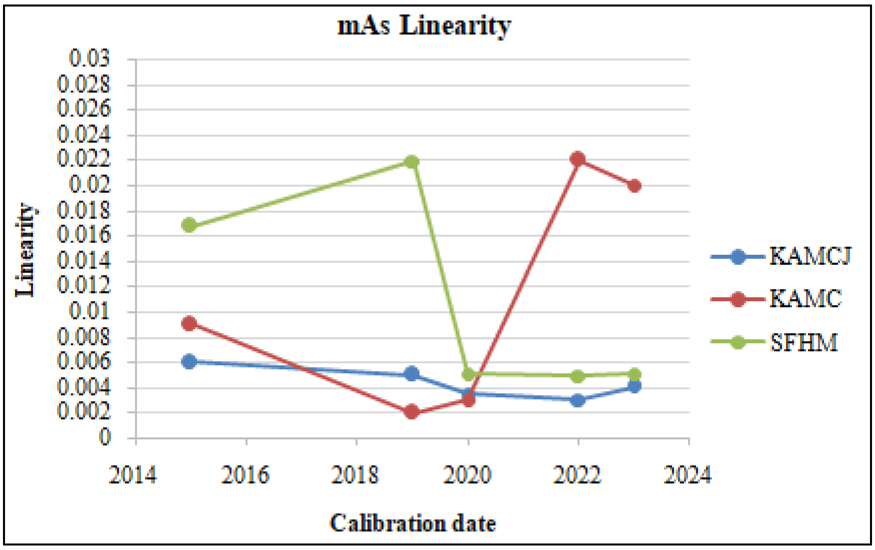

Figure 6: Coefficient of linearity as a function of calibration datefor the three hospitals.

3.6 HVL

HVL measurements of X - ray machine of the three hospitals was measured at 80 kVp, 20 mAs and at SID 100 cm. The HVL values are recorded in table (8) and plotted in figure (7).

Table 8: HVL measurements for the three hospitals

Year / Hospital	2023	2022	2020	2019	2015
KAMCJ	4.67	4.79	4.79	4.5	4.58
KAMC	3.37	3.32	3.26	3.24	3.12
SFHM	3.32	3.28	3.21	3.16	3.13

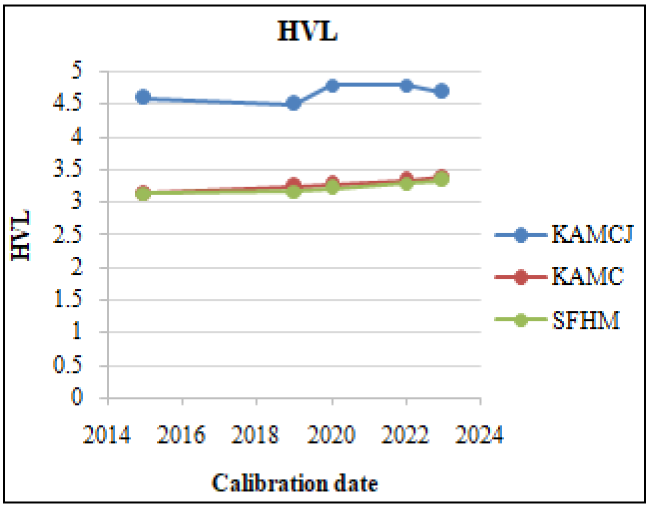

Figure 7: HVL measurements as a function of calibration date.

4. Discussion

The result for the kV accuracy in figure (1) in KAMC, KAMCJ and FMH were studied for wide tube voltages the result was lower than 5% kV accuracy acceptance tolerance limit of AAPM recommendation [12] and [11]. The mean percentage errors were presented as shown in table (3) for KAMC and SFHM have similar kV accuracy values while KAMCJ showed some small differences in 2020, 2022 and 2023. However, the kV accuracy was good at all kV stations. The maximum value of kV accuracy was in KAMCJ at 2022 and 2020 it was equal to 1.295.

Also, the time accuracy in figure (2) is showed good result of accuracy it was lower than 5% kV accuracy acceptance tolerance limit of AAPM recommendation [12] and [11]. The mean percentage errors were presented as shown in table (4) almost similar in 2023, 2022 and 2020 for all hospitals and shown a small differances in 2019 and 2015.

Reproducibility of kV was calcite by COV. It was varied from 0 to 0.0001 which is less than the tolerance value. While for time reproducibility in KAMC and SFMH have same COV values at all calibration years and in KAMCJ also have same values except year 2023. However, all values do not exceed the acceptable level. The mean of COV for all dosimeters shown differences in KAMC and KAMCJ, while in SFHM it was the same COV in all dosimeters.

Also, the result for the dose reproducibility as shown in figure (5) for KAMC, KAMCJ and SFHM were studied by COV for wide dose reproducibility measurements it was within the acceptance tolerance limit of AAPM recommendation [12] and [11]. The mean percentage errors were presented as shown in table (6) for KAMC and KAMCJ have similar dosereproducibility values while SFHM showed some differences in 2019 and 2015.

The result for the mAs linearity in figure (6) in KAMC, KAMCJ and SFHM were studied and the results were lower than 0.1. The mean percentage for linearity were presented as shown in table (7) for KAMCJhad stable coefficient of linearity values in all dosimeters except in 2019 and 2015, while in KAMCJ and SFHM it showed small difference between the dosimeters

The result for the HVL measurements in figure (7) in KAMC, KAMCJ and SFHM were studied from the RaySafe direct it was within the acceptance tolerance limit according to FDA [13]. The measurements were presented as shown in table (8) for KAMC and SFHM have similar HVL values while KAMCJ showed higher in 2020, 2022 and 2023. However, the HVL measurements were good at all years.

5. Conclusion

In this study, kV and time accuracy, mAs linearity, reproducibility for kV, time and dose and HVL were tested using different dosimeters have different calibrattion years. The quality control tests for X – ray machines were good for all dosimeters in all hospitals and were within the tolerance limit.

This research found that it is not necessary to calibrate the radiation measurement device annually; comparing it to a calibrated device that functions well is sufficient. However, periodic calibration, if feasible, is preferable. In many countries, including Saudi Arabia, devices are calibrated at the manufacturing country, taking one to two months. In such cases, comparing to a calibrated device may be satisfactory.

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