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Research Article

COMPARATIVE ASSESSMENT OF DOSE CALIBRATORS USED IN NUCLEAR MEDICINE

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Abstract: *Dose calibrators are used to measure the amount of radioactive to be given to the patient. It is necessary to determine the correct dose and measure the amount of radioactive material with the least possible error. To minimize these potential errors, quality control (QC) tests should be carried out periodically according to the United States Nuclear Regulatory Authority (NRC). ATOM LAB 400 (serial number:11070208) and 500 (serial number: 15091215) dose calibrators that are actively used in our clinic were used. The aim of this study is to compare with another recently calibrated dose calibrator to verify the dose calibrator that needs to be updated is working properly. QC tests were performed on both dose calibrators. Test results of the currently certified dose calibrator and ATOM LAB 400 dose calibrator whose certificate will be updated were found to be compatible with each other. The tests performed on both dose calibrators remained with the error limits. The calibration certificate of the ATOM LAB 400 calibrator has been updated in accordance with NRC protocol.*

Keywords*: Nuclear Medicine, Dose Calibrator, Quality Control.*

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1. Introduction

Nuclear medicine clinics use radiopharmaceuticals with different half-lives for imaging and treatment. These radiopharmaceuticals may be administered to the patient at different activities by means of syringes of different volumes. The radioactive part of the radiopharmaceutical delivered to the patient emits radiation, such as gamma ray or beta particles. Therefore, each activity planned to be given to patients must be measured in a dose calibrator. This activity should be known for the need for radiation protection and successful treatments or good quality imaging [1,2].

Dose calibrators are important in the area of nuclear medicine. Because they are widely used to measure the activity of radioisotopes to be administered to patients. Dose calibrator is a pressurized gas-filled (usually argon gas) cylindrical ionization chamber and it works on the principle of ion chambers. When the radiopharmaceutical to be applied is placed, in the ion chamber, the radiation emitted interacts with the gas in the ion chamber. This interaction results in ion pairs, and when a potential difference is applied between the two electrodes in the ion chamber, the ions travel towards the cathode and the negatively charged ions (electrons) travel towards the anode, hence forming a measurable signal. Then, these signals are converted to current by devices connected to the ion chamber. The total current generated in the ion chamber is directly proportional to the amount of radioactive material. The ion chamber processes the current as a result of the ionization generated by the incoming radiation, allowing the source activity to be read in Curie (Ci) or Becquerel (Bq) units. Dose calibrator operates over a very wide range of activities, from hundreds of kilobecquerels to tens of Giga Becquerels [3].

The most important part of the dose calibrator is the ionization chamber. The quantity of current produced in the chamber be linked upon the quantity of radioactivity present. Due to distinctness in the types of radiations emitted and photon abundance and energy, equal activities of different radionuclides will generate Technetium-99m (Tc-99m) different current flow [4].

The high-quality isotope calibrators assist responsible staff in nuclear medicine laboratories to perform precise activity measurements and to fulfill the International Commission on Radiological Protection (ICRP) 60 requirement to keep the radiation load as low as achievable for patients. To ensure the measurement accuracy of the dose calibrator, quality control tests must be performed at regular periods. Because routine performance tests are indispensable for evaluating and maintaining equipment efficiency. These tests of the dose calibrator ensure the overall characteristics of the instrument to be within acceptable limits to the user. Accordingly, some standard tests (accuracy, constancy, linearity, geometry, and stability tests) within the aim of these quality control tests are a must. Some of these tests are performed with long half-life standard sources and some with very short half-life isotopes. The accuracy test is carried out using long half-life standard radioisotopes (eg Cesium-137; Cs-137), while the linearity test is performed using short half-life (eg Tc-99m) radioisotopes. Suggested testing procedures and methods of analysis are found in the Nuclear Regulatory Commission Regulatory (NRC) Guide 10. The quality management program enforced by the NRC requires the administration of certain radiopharmaceuticals to be within 5%-10% of the prescribed dose [5,6].

In Turkey, dose calibrators for calibrations are sent to the Turkish Atomic Energy Authority (TAEK) at least once a year. However, during this period, factors such as electricity, humidity, etc. may affect the calibration of the dose calibrator. The one-year calibration period is quite long. Mechanical and electrical damage during this period may affect the dosing calibrator's measuring capacity. This changes the amount of radiation dose to be delivered directly to the patient. In this study, it is aimed to perform the quality control tests of for a dose calibrator by using another newly calibrated calibrator by TAEK. The other objective of this study is to highlight the importance of the quality assurance program in nuclear medicine.

2. Material and Method

ATOM LAB 400 and 500 dose calibrators which are actively used in our clinic were used in this study (Fig.1). We aim to verify the accuracy of the dose calibrator (Atom lab 400) which needs to be updated by using a recently calibrated dose calibrator (Atom lab 500). Accuracy, precision, geometry, and linearity measurement have been performed for two dose calibrators at the Nuclear medicine department, Okmeydanı Training, and Research Hospital, as part of the quality control test. The quality control tests performed on these devices are described below.

Figure 1. Dose calibrators used in this study

2.1. Quality controls of dose calibrators

2.1.1. Physical Inspection

By the time starting the quality control test, the researcher should be checked the instrument housing for evidence of damage. Especially, the researcher should be inspected all controls, check that none are missing, and examine cables, plugs, and sockets for evidence of damage. It should be checked for any accompanying sealed radiation sources for external radioactive contamination.

2.1.2. Geometry Test

Dose calibrator should be provided the same reading for the same amount of activity regardless of the volume or orientation of the sample. This test is designed to show that correct readings can be obtained regardless of the sample size or geometry [7].

First, a reading of a certain amount of Tc-99m activity in a small volume (0,2 cc in our study) is obtained. The volume is then increased by adding the nonradioactive water or saline and additional readings are performed. Each time the liquid increase, the vial is shaken slightly to ensure a homogeneous distribution.

According to NRC limit, the following readings should not vary from the original reading (first reading) by more than 10%. The test is repeated at least once a year [5,6].

2.1.3. Linearity Test (Decaying Source Method)

The linearity test is designed to determine the response of the calibrator over a range of measured activities. A common approach is to use a sample of Tc-99m and sequentially measure it during radioactive decay at its own scale at different times. In the linearity test, the measurement meanwhile calibrator is reported at 6 hours intervals in accordance with the half-life of Tc-99m for a given activity [4].

Background activity is subtracted from the measured value to obtain net activity. In addition, considering the decay law of the radioactive source used, theoretically time-dependent reduction activities are calculated. A comparison is made between the experimental value and the theoretically calculated values.

Due to the fact that the change in activity with time is a definable physical parameter, any deviation in the observed assay value indicates equipment malfunction and nonlinearity. According to NRC, this test is repeated every 15 days. [5,6]

2.1.4. Accuracy and Precision Test

2.1.4.1. Accuracy Test

Accuracy test is a quality control measurement performed upon acceptance, repair, and then annually, to ensure that the activity values determined by the dose calibrator are traceable to standards of radioactivity within the acceptable uncertainties.

The accuracy of the dose calibrator is measured as a part of routine QC of nuclear pharmacy using Cs-137 as a reference source. The background is measure after the source is removed from the dose calibrator. To obtain net activity, we subtract the ground activity from the measured activity. The accuracy test measured 10 times for each device and the results of these measurements are averaged.[8]

The test should be performed at least once a year. Calculations are performed by using the following formula

$$\% \text{ Accuracy} = [(A_{mean}-A_c)/A_c]x100$$

In this formula, it means that A_{mean}: mean value of 10 activity measurements,

Ac: The amount of activity on the calibration certificate of the source.

2.1.4.2. Precision Test

The precision test is to confirm that the random uncertainty of a single measurement is primarily determined by the random nature of radioactive decay. It is a measure of the spread of values obtained from a sequence of measurements.

For the precision test, the Cs-137 radioisotope source has 10 measurements on its scale. The background is measured after the sources are removed from the dose calibrator. To obtain net activity, we subtract the ground activity from the measured activity.[8]

Calculations are performed by using the following formula

$$\% \text{ Precision} = [(A_i-A_{mean})/A_{mean}] \text{ x}100$$

A_{mean}: mean value of 10 activity measurements

A_i: Each measured activity value

According to NRC, precision test results should be within ± 10% error limit. The test should be performed at least once a year[5,6].

2.1.5. Stability and Extended Stability Test

In this test, long half-life Cs-137 radioactive sources are measured using Tc-99m and the other radioisotope scales. To obtain net activity, background activity correction is performed by subtracting the background activity value from the measured activity and these measurements are performed for five days.

According to NRC, The expected result is a maximum deviation of 5% of the measurement results on the other day compared to the first-day measurement. This test should be performed every day. [5,6]

3. Results

3.1. Physical Inspection

No physical damage was detected before the start of quality control tests.

3.2. Geometry Test Result

Geometric deviations may occur as the vial volume expands. This may result in a reduction in the activity measurement of the source. A decrease in the measured activity is an expected situation. However, it should not exceed a ± 5% error. The geometry results are given in Table 1.

Table 1. Geometry test results for both Dose Calibrators

	Dose Calibrator	
Syringe Volume	**Atom lab 500 (mCi)**	**Atom lab 400 (mCi)**
0,2 cc *Reference volume*	5,73	5,5
0,3 cc *(Error %)*	5,70 *(-0,52%)*	5,49 *(-0,18%)*
0,5 cc *(Error %)*	5,69 *(-0,69%)*	5,46 *(-0,9%)*
1 cc *(Error %)*	5,64 *(-1,57%)*	5,45 *(-0,9%)*
5 cc *(Error %)*	5,6 *(-2,2%)*	5,37 *(-2,36%)*
10 cc *(Error %)*	5,55 *(-3,14%)*	5,37 *(-2,36%)*
15 cc *(Error %)*	5,55 *(-3,14%)*	5,36 *(-2,54%)*
20 cc *(Error %)*	5,55 *(-3,14%)*	5,6 *(-2,54%)*
25 cc *(Error %)*	5,54 *(-3,13%)*	5,34 *(-2,9%)*
30 cc *(Error %)*	5,53 *(-3,4%)*	5,49 *(-0,18%)*
35 cc *(Error %)*	5,52 *(-3,66%)*	5,33 *(-3,09%)*
40 cc *(Error %)*	5,50 *(-4,0%)*	5,40 *(-1,81%)*
45 cc *(Error %)*	5,49 *(-4,18%)*	5,44 *(-1,09%)*
50 cc *(Error %)*	5,49 *(-4,18%)*	5,42 *(-1,45%)*
55 cc *(Error %)*	5,47 *(-4,5%)*	5,40 *(-1,81%)*
60 cc *(Error %)*	5,45 *(-4,8%)*	5,39 *(-2%)*

mCi: miliCurie

3.3. Linearity (Decaying Source Method) Test Result

Figure 2 shows the theoretically calculated time-dependent reduction of the Tc-99m radioactive source and the activity measurements performed at different hours. When the graph was examined, it was observed that the time-dependent activity decay of the Tc-99m radioactive source was highly consistent with the theoretical calculations.

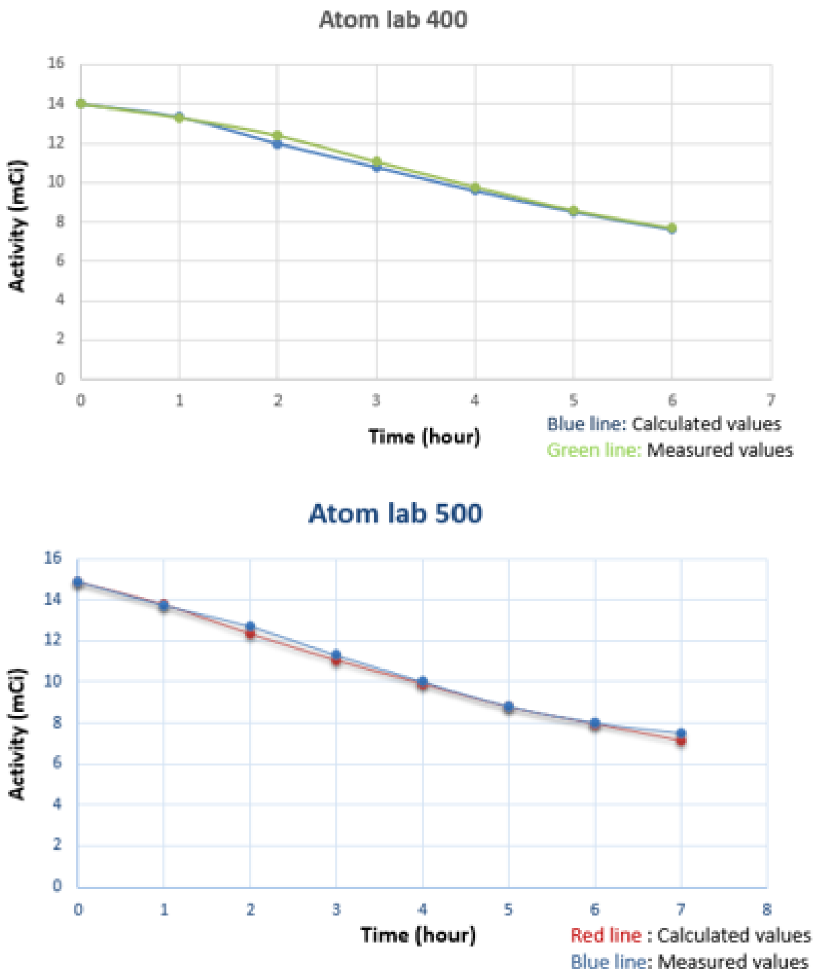

Figure 2. The graphs are drawn using the theoretically calculated values with the radioactive decay formula with measurements performed at every hour for 7 hours.

The reduction of the radioactive material used in the test, calculated according to the radioactive decay theory, is expected to be the same as the reduction of the experimentally measured measurements (Table 2). No value has exceeded the limit.

Table 2. Percentage error limits between measured and calculated activities

Time (hour)	**Dose Calibrators**	
	Atom lab 500 (% error between measured and calculated activities)	Atom lab 400 (% error between measured and calculated activities)
1st hour	0,3	0,3
2nd hour	3	3
3rd hour	2	2
4th hour	1	2
5th hour	0,07	0,06
6th hour	1	0,09
7th hour	5	5

3.4. Accuracy and Precision Test Results

Accuracy and precision values were calculated with the help of the formulas given in the material and method section. Accuracy results are given in Table 3. And also Precision results are given in Table 4.

Table 3. Accuracy Test Results

	Atom lab 500	**Atom lab 400**
% Accuracy (Cs-137)	5,5	2,9

Table 4. Precision test results for both Dose Calibrators

PRECISION VALUES – ATOM LAB 500				
Measurement No	Cs-137 Measured Activity (µCi)	57- Co Measured Activity (µCi)	Cs-137 Calculated % Precision Values	57-Co Calculated % Precision Values
1	201	239	0	0,42
2	201	238	0	0
3	201	240	0	0,84
4	200	236	-0,49	-0,84
5	201	237	0	-0,42
6	201	238	0	0
7	201	239	0	0,42
8	202	239	0,49	0,42
9	202	236	0,49	-0,84
10	200	238	-0,49	0
Average	201	238		
PRECISION VALUES – ATOM LAB 400				
Measurement No	Cs-137 Measured Activity (µCi)	57- Co Measured Activity (µCi)	Cs-137 Calculated % Precision Values	57-Co Calculated % Precision Values

1	195	231	-0,5	0
2	198	231	1,02	0
3	197	232	0,5	0,43
4	197	233	0,5	0,86
5	197	233	0,5	0,86
6	196	226	0	-2,16
7	195	229	-0,5	-0,86
8	197	229	0,5	-0,86
9	195	236	-0,5	-2,16
10	196	231	0	0
Average	196	231		

3.5. Stability and Extended Stability Test Results

Based on the activity value measured in the first day in Table 5, measured in other days activity values are within ± 5% margin of error. Stability and Extended stability results are given in Table 5 for Atom lab 500 Dose Calibrator

Table 5. Five-day activity and ±% error results obtained with Stability and Extended stability test for Atom lab 500 Dose Calibrator.

DAYS **ISOTOPES**	1. DAY ***Reference Activity***	2. DAY	3. DAY	4. DAY	5. DAY
Tc-99m ***(Error %)***	429 µCi	419 µCi *(-2,39%)*	418 µCi *(-2,5%)*	420 µCi *(-2,09%)*	419 µCi *(-2,33%)*
TI-201 ***(Error %)***	234 µCi	229 µCi *(-2,13%)*	229 µCi *(-2,13%)*	229 µCi *(-2,13%)*	229 µCi *(-2,13%)*
I-123 ***(Error %)***	152 µCi	149 µCi *(-1,97%)*	149 µCi *(-1,97%)*	150 µCi *(-1,31%)*	149 µCi *(-1,97%)*
I-131 ***(Error %)***	262 µCi	258 µCi *(-1,52%)*	257 µCi *(-1,9%)*	258 µCi *(-1,52%)*	257 µCi *(-1,9%)*
Lu-177 ***(Error %)***	1290 µCi	1274 µCi *(-0,44%)*	1267 µCi *(-1,78%)*	1270 µCi *(-1,55%)*	1264 µCi *(-2,01%)*
Ge/Ga68 ***(Error %)***	113 µCi	111 µCi *(-1,76%)*	111 µCi *(-1,76%)*	110 µCi *(-2,65%)*	110 µCi *(-2,65%)*

Co-57 ***(Error %)***	391 µCi	385 µCi *(-1,53%)*	384 µCi *(-1,79%)*	380 µCi *(-2,81%)*	380 µCi *(-2,81%)*
Ga-67 ***(Error %)***	363 µCi	358 µCi *(-1,37%)*	356 µCi *(-1,92%)*	357 µCi *(-1,92%)*	355 µCi *(-2,20%)*
In-111 ***(Error %)***	146 µCi	144 µCi *(-1,36%)*	144 µCi *(-1,36%)*	143 µCi *(-2,05%)*	143 µCi *(-2,05%)*
F-18 ***(Error %)***	107 µCi	106 µCi *(-0,93%)*	105 µCi *(-1,86%)*	105 µCi *(-1,86%)*	105 µCi *(-1,86%)*
Y-90s ***(Error %)***	3,91 µCi	3,86 µCi *(-1,27%)*	3,82 µCi *(-2,30%)*	3,80 µCi *(-2,82%)*	3,8 µCi *(-2,82%)*
Cs-137 ***(Error %)***	201 µCi	199 µCi *(-0,99%)*	197 µCi *(-1,97%)*	197 µCi *(-1,97%)*	197 µCi *(-1,97%)*
Ba-133 ***(Error %)***	82 µCi	81 µCi *(-1,21%)*	81 µCi *(-1,21%)*	80 µCi *(-2,43%)*	80 µCi *(-2,43%)*
Mo-99 ***(Error %)***	1954 µCi	1927 µCi *(-1,38%)*	1914 µCi *(-2,04%)*	1927 µCi *(-1,38%)*	1917 µCi *(-2,04%)*
Sr-89 ***(Error %)***	7,66 µCi	7,54 µCi *(-1,59%)*	7,5 µCi *(-2,08%)*	7,5 µCi *(-2,08%)*	7,5 µCi *(-2,08%)*

Stability and Extended stability results are given in Table 6 for Atom lab 400 Dose Calibrator.

Table 6. Five-day activity and ±% error results obtained with Stability and Extended stability test for Atom lab 400 Dose Calibrator.

DAYS **ISOTOPES**	1.DAY ***Reference Activities***	2. DAY	3. DAY	4. DAY	5. DAY
Tc-99m ***(Error %)***	405 µCi	418 µCi *(2,20%)*	420 µCi *(3,7%)*	418 µCi *(1,7%)*	418 µCi *(1,7%)*
Tl-201 ***(Error %)***	235 µCi	237 µCi *(0,85%)*	236 µCi *(0,43%)*	235 µCi *(0%)*	235 µCi *(0%)*
I-123 ***(Error %)***	144 µCi	145 µCi *(0,69%)*	144 µCi *(0%)*	144 µCi *(0%)*	144 µCi *(0%)*
I-131 ***(Error %)***	242 µCi	252 µCi *(4,13%)*	251 µCi *(3,72%)*	251 µCi *(3,72%)*	251 µCi *(3,72%)*

Lu-177 ***(Error %)***	1278 µCi	1287 µCi *(0,7%)*	1286 µCi *(0,62%)*	1285 µCi *(0,54%)*	1279 µCi *(0,07%)*
Ge/Ga68 ***(Error %)***	113 µCi	114 µCi *(0,88%)*	114 µCi *(0,88%)*	114 µCi *(0,88%)*	113 µCi *(0%)*
Co-57 ***(Error %)***	364 µCi	382 µCi *(4,9%)*	380 µCi *(4,39%)*	380 µCi *(4,39%)*	379 µCi *(4,12%)*
Ga-67 ***(Error %)***	364 µCi	367 µCi *(0,82%)*	367 µCi *(0,82%)*	366 µCi *(0,54%)*	354 µCi *(-2,74%)*
In-111 ***(Error %)***	140 µCi	146 µCi *(4,28%)*	146 µCi *(4,28%)*	146 µCi *(4,28%)*	146 µCi *(4,28%)*
F-18 ***(Error %)***	107 µCi	108 µCi *(0,93%)*	108 µCi *(0,93%)*	108 µCi *(0,93%)*	108 µCi *(0,93%)*
Y-90s ***(Error %)***	3,92 µCi	3,9 µCi *(-0,51%)*	3,94 µCi *(0,50%)*	3,94 µCi *(0,50%)*	3,93 µCi *(0,25%)*
Cs-137 ***(Error %)***	191 µCi	194 µCi *(1,57%)*	193 µCi *(1,04%)*	193 µCi *(1,04%)*	192 µCi *(0,52%)*
Ba-133 ***(Error %)***	83 µCi	84 µCi *(1,20%)*	83 µCi *(1,21%)*	83 µCi *(0%)*	83 µCi *(0%)*
Mo-99 ***(Error %)***	1964 µCi	1978 µCi *(0,72%)*	1969 µCi *(0,25%)*	1969 µCi *(0,25%)*	1964 µCi *(0%)*
Sr-89 ***(Error %)***	7,69 µCi	7,75 µCi *(0,78%)*	7,71 µCi *(0,26%)*	7,71 µCi *(0,26%)*	7,7 µCi *(0,13%)*

4. Discussion

The main objective in nuclear medicine applications is to get the best image with minimum and accurately measured radiation. The availability of dose calibrators and regular quality control tests in nuclear medicine centers is one of the requirements of IAEA for the determination of these dosage amounts given to the patient in the most efficient way. Optimization refers to the principle that the radiation dose to the patients should be "as low as reasonably achievable (ALARA)". The main efforts for optimization of radiation protection in nuclear medicine have been made in terms of the reduction of administered radiopharmaceutical activity [9]. The ALARA principle is important for patients as well as workers.

Our clinic is conducted with two different radioisotope calibrators branded Biodex ATOM LAB-500 and Biodex ATOM LAB 400. The quality controls of the devices are extremely important in terms of giving the patient minimum radiation. Even though very small doses are administered to the patient in nuclear medicine applications, these small doses should also be completely accurate, especially for a child patient. For this; the fact that the factory settings of an electronic system can change continuously, the right tests at the right times are essential for patient health and success in the examination. This study was carried out in a nuclear medicine center with high patient capacity. Test results of the currently certified dose calibrator and ATOM LAB 400 dose calibrator which hasn't got certificate updated were found to be compatible with each other. The tests performed on both dose calibrators remained with the error limits. The calibration certificate of the ATOM LAB 400 calibrator has been updated in accordance with NRC protocol in our department.

In our study, for the Geometry test, the doses of the calibrators decreases as the radioactive material in the syringe moves away from the center (Table 1). When the error value of the measured values is examined according to the measurement results from 0,2 cc, it is seen that the deviation occurred within ± 5% error.

For the linearity test, it is observed that the time-dependent activity reduction of the Tc-99m radioactive source is quite consistent with the theoretical calculations for two-dose calibrators (Figure 2).

In our study, Tc-99m, which has a half-life of 6 hours, was used in the test of linearity. As shown in Table 2, the calculated error increases after the sixth hour. The error results from both calibrators were similar.

In the study of Koç, the measurement for linearity tests were performed with two different radioisotope calibrators, Capintec 15R and Biodex ATOM LAB 500 in a Nuclear Medicine Center. These measurements, linearity tests of devices have been performed by using the method of decaying source, increasing source, and sample -volume effect [10].

In the study of Koç, the results show that both calibrators have a very high performance, but the first calibrator (Capintec 15 R) has about 1% better performance. The results of the method used for the linearity test in our study and the decaying source method used by Koç in their study are consistent with each other.

In our study, accuracy values were calculated for Cs-137according to the accuracy formula. 5.5 % accuracy value was calculated for Atom lab 500 and 2.9 % accuracy value was calculated for Atom lab 400 (Table 3).

The precision of a measurement is determined by how close it is to the true value (reference condition) [11]. When % precision values are examined for both dose calibrators, it is seen that calculated % accuracy values are within the 5% limit (Table 4).

In Table 5 and Table 6, the activity values measured on the other days are within ± 5% error according to the activity value observed on the first day. For the Stability and Extended Stability test in Table 6 and Table 7, it is seen that the margins of error are very small and dose calibrators perform very stable repetitions.

In Mohamed's study, four different quality control tests were performed using two standard radionuclides, Cs-137, and Co-57, which are accuracy, stability, linearity, and geometry for two-dose calibrators in different medical departments. [11]. All results obtained from the study have been compared with the international standard (±5%) and the results showed that two-dose calibrators have good performance and there is no need for any correction tables or factors or maintenance. In Muhammed’s study, the results of accuracy showed that two-dose calibrators have accurate reading and the percentage of error was 0.39% which was accepted. The percentage of accuracy of dose calibrator was easily detected by using the accuracy equation. Quality control test results of Mohammed's study are consistent with our study.

In the Alameen study, four quality-control tests accuracy, constancy, linearity, and geometry tests were performed for two-dose calibrators, Capintec PTW CURIEMENTOR4, and Capintec CRC-25R. The results of quality control tests revealed that the parameters monitored for dose calibrators were within the limits of international standards. (±5%) [12].

As a result of the measurements made for our quality control tests, it was found that the performances of both calibrators (Atom lab 400 and Atom lab 500) in the clinic were within the determined limits and were quite good. It is thought that the reason for the high performance of the devices is the continuous quality control studies.

5. Conclusions

According to the current standards and regulations for Nuclear Medicine worldwide practices, the radioactivity of any radiopharmaceutical that contains a photon emitting radionuclide must be measured by a dose calibrator prior to administration to patients or for human research purposes [9].
The calibration period of one year is quite long for these devices. Mechanical and electrical damage during this time may affect the dosing calibrator's measuring capacity. Any damage such as electrical fault may change the amount of radiation dose to deliver directly to the patient. We have repeated the tests of a calibrator exposed to electrical damage in accordance with such a situation by using a current calibrated dose certificate for another dose calibrator.

The compliance to the Research and Publication Ethics: This study was carried out in accordance with the rules of research and publication ethics.

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