Accuracy Testing of Dose Calibrators

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Current methods for testing a dose calibrator's accuracy use measurements of ^{60}Co, ^{137}Cs, ^{57}Co, and ^{133}Ba sources but do not directly measure the accuracy of clinical radionuclides such as ^{99m}Tc, ^{123}I, ^{111}In, ^{67}Ga, or ^{201}Tl. It is possible that some dose calibrators inaccurately determine the activity of these clinical radiopharmaceuticals. To correct this possible deficiency, we have devised a method to test the accuracy of each radionuclide setting on a dose calibrator using a single long-lived calibration source. Differences in emission characteristics of assayed radionuclides are incorporated in the ionization current-to-activity conversion factors (CAF) that are determined experimentally by the manufacturer. The correct functioning of a dose calibrator requires that each CAF be accurately reproduced electronically by the calibrator circuitry and that the measured ionization current be consistent and precise. Our results have shown that our procedure tests the total function of the dose calibrator for detecting all radionuclides specified by the manufacturer including the accuracy of the electronic representations of the CAF. The procedure is easily implemented for all dose calibrator systems using one of several possible sources available in most laboratories (e.g., ^{57}Co, ^{137}Cs, or ^{133}Ba).

The quantitation of a radiopharmaceutical is measured in activity rather than drug mass. For prepackaged ready-to-use radiopharmaceuticals, the initial activity measurement is performed by the vendor, and the dose must be confirmed by the user at the time of administration. The levels of radiopharmaceutical activity present in in-house formulated agents rely solely on the activity measurement made by the clinical laboratory. In either case, the device used to measure the activity is a dose calibrator. Current practice (*1*) for testing the accuracy of a dose calibrator is to assay several low-level, long half-lived radionuclides in the geometry of a 10–20-ml vial. Whereas the emission energies from several of the calibration sources are similar to the radionuclides they are used to measure, most of the "mock" sources have significantly different energy emissions. For example, ^{133}Ba is used as a mock ^{131}I source, and when used to check the accuracy of the dose calibrator the unit is set for ^{133}Ba not ^{131}I. This setting results in the unit not being tested for that portion of the circuitry unique for measuring ^{131}I activity. This omission of direct radionuclide measurement is generally true for all of the clinically used radionuclides. It is therefore possible that significant errors may arise in these activity measurements using dose calibrator settings which are not directly tested for accuracy.

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DOSE CALIBRATOR FUNCTION

The design and function of a dose calibrator are well known (*2,3*). The radiation detector is a large deep cavity ionization chamber that effectively surrounds the assayable source. The ionization current flowing in the chamber's bias circuitry depends on the photon density, the energies of the photons emitted by the source, and the absorption characteristics of the chamber assembly. The character of photon absorption in the chamber is constant and is experimentally measured by the manufacturer. Two unknown factors contribute to the chamber response; the photon density which is proportional to the source activity and the array of photon energies. For radionuclides commonly used in clinical nuclear medicine, the relative abundance of the distribution of photon energies has been accurately established through experimental measurements (*4,5*).

The physical effect of the source activity actually measured by a dose calibrator is current flow in the bias circuitry of the ionization chamber produced by the absorption of the ionizing radiation emitted from the source within the chamber. Energy discrimination of the chamber response is not possible since current flow is continuous. In knowing the radionuclide (X), the activity A(X) of a sample of the radionuclide can be determined by using this equation:

$$R(X) = I(X) \times F(X) \qquad \text{(Eq. 1)}$$

where R(X) is the calibrator activity readout; I(X) is the current flow through the chamber (and bias circuit); and F(X) is an ionization current-to-activity conversion factor (CAF) for the radionuclide (X).

For a given chamber design, the CAF values are different for each radionuclide and are measured by the manufacturer. The dose calibrator is made a functional and convenient laboratory tool by electronically producing values of F(X) that are proportional to experimentally determined values for the various radionuclides. The user "selects" the appropriate electronic equivalent F(X) value by setting a potentiometer, pressing a selector button, or installing a selector module. In each case, the effect is to choose a F(X) value to use in determining R(X) as shown in Eq. 1.

A potential source of error in dose calibrator accuracy testing arises from the fact that emission characteristics are source dependent, and the F(X) values for clinical radionuclides differ from the F(X) values generated for the mock sources used in accuracy testing. The various F(X) values are incorporated

TABLE 1. ^{137}Cs Calibration Source (199 μCi)*

Radionuclide Selection	Unit No. 1	Unit No. 2	Unit No. 3
^{99m}Tc	192.6	189.3	196.9
^{131}I	197.5	194.3	199.9
^{123}I	196.9	196.9	200.4
^{133}Xe	197.9	193.4	199.7
^{67}Ga	194.5	191.4	198.7
^{201}Tl	196.8	194.9	198.7
^{111}In	198.3	198.3	198.3
^{137}Cs (Direct Readout)	197.0	194.0	201.0

*Calculated dose calibrator readout (Eq. 2) in microcuries.

in the dose calibrator as electronic circuit components, potentiometer settings, or as values stored in ROM-type digital memories. Accuracy testing procedures that use low activity and long half-life sources do not test the dose calibrator circuit functions used to assay the clinical radionuclides since only the F(X) values for the mock sources are used in the test procedures. Unless additional steps are added, the accuracy of measuring clinical radionuclide activity may be invalid (*1*). This factor is of critical importance when determining therapeutic radionuclide doses.

ACCURACY TESTING WITH A SINGLE SOURCE: THEORY

Unlike the gamma ray photopeak count rates obtained with pulse height analysis of the signals produced in scintillation detector systems, the ionization current in a dose calibrator cannot be analyzed for the specific gamma ray energies present in the source. The accuracy of current measurements by the electrometer can therefore be checked with a single source. If a single precalibrated source is measured for activity, and the instrument reading R(S) agrees with the true source activity A(S) within acceptable limits (better than 3.0% is typical), then the corresponding current measurement I(S) function of the system is working properly. Furthermore, for the specific radionuclide used, the electronic F(S) is also correct. To complete a true accuracy test of the system, it is imperative not only to directly test the electronic F(X) for all radionuclides to be used, but also test the system's linearity over the range of activities for these radionuclides.

Accuracy testing of all other F(X) values can be performed with the same single calibration source. In the process of designing and building the instrument, the manufacturer determines the numerical value of F(X) for all radionuclides specified to be measured with each dose calibrator. The numerical values for these F(X) constants are either available from the manufacturer or can be determined from the radionuclide selector values provided with the instrument. Following the direct measurement of the single calibration source, instrument readings for all the other clinical radionuclides are made with the same calibration source. The activity readout for each radionuclide setting R(Sx) is then multiplied by the ratio of F(Sc)/F(Sx) in which F(Sc) is the numerical value of F(X) for the calibration source Sc and F(Sx) is the F(X) numerical value for clinical radionuclide Sx. The product of R(Sx) × F(Sc)/F(Sx) is the true activity of the calibration source if the instrument's electronic representation of F(Sx) is accurate. With this procedure, accuracy of all dose calibrator electronic functions for any radionuclide can be tested.

MATERIALS AND METHODS

We used the single source calibration method to test the accuracy of three dose calibrators.* To evaluate radionuclide dependence in this method, measurements were made with three different calibrated sources (^{137}Cs, ^{133}Ba, and ^{57}Co) on each dose calibrator. After testing for background, zero, and bias voltage level, an initial measurement was made with each source by the radionuclide selection indicator set to that of the calibration source radionuclide. The system readout R(Sc) was compared to the true activity of the source A(Sc). With the single calibration source still in the dose calibrator, system readouts were obtained by changing the radionuclide selection process sequentially set to the commonly used radionuclides ^{99m}Tc, ^{131}I, ^{123}I, ^{133}Xe, ^{67}Ga, ^{201}Tl, and ^{111}In. The accuracy of the electronic representation for each radionuclide was evaluated by using the system readout R(Sx) and the numerical values of the conversion factors F(Sx) and F(Sc) to obtain a calculated activity reading R(A) using the following equation:

$$R(A) = R(Sx) \times F(Sc)/F(Sx) \qquad \text{(Eq. 2)}$$

where R(Sx) is the system readout of the single calibration source and the radionuclide selection dial set for radionuclide Sx; F(Sc) is the numerical value of the conversion factor for the calibration source; and F(Sx) is the numerical value of the conversion factor for radionuclide Sx.

If the electronic representation of the conversion factor for radionuclide Sx is accurate, then the calculated reading R(A) in Eq. 2 should be close to the directly measured activity of the single calibration source.

TABLE 2. ^{133}Ba Calibration Source (169 μCi)*

Radionuclide Selection	Unit No. 1	Unit No. 2	Unit No. 3
^{99m}Tc	163.3	162.1	167.2
^{131}I	167.3	165.9	170.8
^{123}I	168.9	168.4	170.8
^{133}Xe	168.8	166.7	170.3
^{67}Ga	165.9	165.1	168.7
^{201}Tl	168.5	167.6	168.9
^{111}In	168.9	168.9	168.4
^{133}Ba (Direct Readout)	169.0	169.0	171.0

*Calculated dose calibrator readout (Eq. 2) in microcuries.

TABLE 3. ^{57}Co Calibration Source (3.20 mCi)*

Radionuclide Selection	Unit No. 1	Unit No. 2	Unit No. 3
^{99m}Tc	3.14	3.14	3.18
^{131}I	3.19	3.22	3.22
^{123}I	3.24	3.24	3.24
^{133}Xe	3.22	3.22	3.24
^{67}Ga	3.18	3.22	3.22
^{201}Tl	3.23	3.23	3.23
^{111}In	3.24	3.26	3.22
^{57}Co (Direct Readout)	3.18	3.20	3.20

*Calculated dose calibrator readout (Eq. 2) in millicuries.

RESULTS

The results of the measurements on three different dose calibrators, using ^{137}Cs, ^{57}Co, and ^{133}Ba as calibration sources are shown in Tables 1-3. In all direct measurements of these calibration sources, the value of [A(Sc) − R(Sc)] / A(Sc) was $< 3\%$. This agreement between R(Sc) and A(Sc) confirms the system's accuracy in measuring the ionization current I(Sc) and the accuracy of the electronic representation of the conversion factor F(Sc) for the calibration source radionuclide Sc. The table entries for radionuclides (i.e., ^{99m}Tc and ^{131}I) were obtained using Eq. 2 and the measurements described above. Accuracy of the dose calibrators tested is reflected by only small variations occurring in the column of results for each unit.

DISCUSSION

The sensitivity and accuracy of present day dose calibrators precludes the use of mock sources to test the accuracy of these devices for related clinical radionuclide settings. This is evident when measurements are made with ^{57}Co and ^{133}Ba. When ^{57}Co is used, the measured activity differs on an average of 17% between the ^{57}Co setting and the ^{99m}Tc setting. This difference is even more pronounced when the ^{133}Ba source is measured on the ^{131}I setting giving an average difference of 183% from the true ^{133}Ba activity. Clearly mock sources cannot be used to test for calibrator accuracy unless the design and function of the dose calibrator is taken into account. The alternative is to obtain different calibrated sources of the clinical radionuclides to be checked. However, this alternative would be cost-prohibitive and would require a significant effort to achieve such measurements even on an annual calibration basis. The results in Tables 1-3 of a single source accuracy test of three different dose calibrators indicates that all were mutually consistent and accurate to 5% or better for the radionuclide settings tested.

CONCLUSION

An easily applied method for accuracy testing that directly tests dose calibrator function for all radionuclides specified by the manufacturer has been developed. This procedure uses any of several commercially available calibrated sources and requires little additional time to perform. Insignificant differences in accuracy were observed when measurements were made with ^{57}Co, ^{137}Cs, and ^{133}Ba on three different dose calibrators (Tables 1-3). The major advantage of this technique is that it directly tests the accuracy of the dose calibrator for measuring clinical radionuclides without requiring individual and expensive calibrated sources for the measurements. Although we did not observe radionuclide dependence of a calibration source, we prefer to use ^{133}Ba since it emits low and high energy photons, has a long half-life, and detects all changes in dose calibrator chamber absorption characteristics over long periods of time.

The procedure takes minimal time and no source investment is required since any source currently used for dose calibrator accuracy testing can be employed.

FOOTNOTE

*Capintec Model CRC5 (2 units) and Capintec Model CRC 17, Capintec Inc., Ramsey, NJ.

REFERENCES

1. Methods for calibration of dose calibrator. In *NRC Regulatory Guide 10.8 (Rev. 1): Guide for the Preparation of Applications for Medical Programs*, Appendix D. Washington, DC, NRC 10.8, 1980, pp 27-30.

2. Orvis AL. Assay of radiopharmaceuticals. In *Instrumentation in Nuclear Medicine*, Vol 2, Hine GJ, Sorenson JA, eds, New York, Academic Press, 1974, pp 460-85.

3. Kowalsky RJ, Johnston RE, Chan FH. Dose calibrator performance and quality control. *J Nucl Med Technol* 1977;5:35-40.

4. Table of Nuclear-Decay Data, Appendix A3. In *A Handbook of Radioactivity Measurements Procedures, NCRP Report No. 58.* Washington, DC, NCRP, November 1, 1978, pp 322-441.

5. Dillman LT, Von der Lage FC. *Radionuclide Decay Schemes and Nuclear Parameters for Use in Radiation-Dose Estimates, MIRD Pamphlet No. 10.* New York, Society of Nuclear Medicine, September, 1975.