

Volume corrections factors in the measurement of ^{99m}Tc and ^{123}I activities in radionuclide calibrators*

Fatores de correção volumétrica na medição de atividade de ^{99m}Tc e ^{123}I em calibradores de radionuclídeos

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Abstract Objective: To determine correction factors for the variation in volume of radiopharmaceuticals in containers of different geometries, comparing the influence of such factors on the determination of ^{99m}Tc and ^{123}I activity with two types of calibrators – one with ionization chamber and another with Geiger-Müller (G-M) detector –; and to evaluate calibrators performance in the measurement of ^{99m}Tc and ^{123}I activities. **Materials and Methods:** Eight calibrators, 10R glass vials, 3 and 5 mL plastic syringes and ^{99m}Tc and ^{123}I solutions were utilized. The correction factors were determined with basis on practical measurements of the variation in the calibrators' response according to the volume of radionuclide solution in the glass vials. The performance was evaluated according to the acceptance criterion of $\pm 10\%$ accuracy required by the Brazilian standard. **Results:** The variation of the calibrators' response according to the variation in radionuclide volume was reasonably greater in the calibrator with G-M detector. It was also greater for ^{123}I than for ^{99m}Tc . **Conclusion:** The results confirm that the calibrators' response depends on the radionuclide volume contained in the vials. Such dependence is more critical for the calibrators equipped with G-M detector and for ^{123}I as compared with ^{99m}Tc . **Keywords:** Radionuclides calibrator; Nuclear medicine; Activity; Tc-99m; I-123.

Resumo Objetivo: Determinar os fatores de correção para a variação volumétrica dos radiofármacos contidos em recipientes de diferentes geometrias. Comparar a influência desses fatores na determinação da atividade de ^{99m}Tc e ^{123}I utilizando dois tipos de calibradores: um com câmara de ionização e outro com detector Geiger-Müller (G-M). Avaliar o desempenho de calibradores de alguns serviços de medicina nuclear em medição de atividade de ^{99m}Tc e ^{123}I . **Materiais e Métodos:** Foram utilizados oito calibradores, frascos de vidro 10R, seringas de plástico de 3 e 5 mL e soluções de ^{99m}Tc e ^{123}I . Os fatores de correção foram determinados a partir das medições práticas da variação da leitura do calibrador com a variação do volume da solução no recipiente. O desempenho foi avaliado em relação ao critério de aceitação de $\pm 10\%$ de exatidão exigida pela norma brasileira. **Resultados:** A variação da resposta do calibrador com a variação do volume do frasco foi bem maior no calibrador que utiliza G-M. Ela também foi maior para ^{123}I do que para ^{99m}Tc . **Conclusão:** Os resultados confirmam que a resposta dos calibradores depende do volume contido nos recipientes. Essa dependência é mais crítica para os calibradores equipados com detector G-M e para ^{123}I quando comparado com ^{99m}Tc .

Unitermos: Calibrador de radionuclídeos; Medicina nuclear; Atividade; Tc-99m; I-123.

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INTRODUCTION

In nuclear medicine, the activity of a radiopharmaceutical must be measured with high accuracy in order to achieve the diagnostic or treatment objectives and, at the same time, minimize the dose to the patient, according to the basic principle of optimization in radioprotection. The regulating agencies have established the accuracy limits for activity measurements in nuclear medicine procedures. In Brazil, the

Comissão Nacional de Energia Nuclear (CNEN)⁽¹⁾ (Brazilian Nuclear Energy Commission) has established the limit of $\pm 10\%$ for accuracy in radiopharmaceuticals activity measurements in radionuclide calibrators (also known as curiometer or dose calibrator), while the International Atomic Energy Agency (IAEA) has established $\pm 2\%$ for Secondary Standards Radioactivity Laboratories and $\pm 5\%$ for other laboratories⁽²⁾.

In order to determine the activity value in the calibrator, nuclear medicine services utilize different types of vials. The most utilized ones are the glass vials or plastic

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syringes with different radiopharmaceutical volumes. The differences in volume, geometry and composition require correction of the original calibration factors of the calibrators. This matter has been the object of studies and discussion by several authors in the literature⁽³⁻⁵⁾. Normally, a radiopharmaceutical contained in a glass vial has its activity measured in a calibrator before being administered to a patient. Later, an aliquot of such radiopharmaceutical is transferred to a plastic syringe and its activity is measured by utilizing the same calibration factor. This later value is considered as being the activity administered to the patient. Thus the radioactive fluid is manipulated in different vials, with different geometries, volumes and compositions. If such differences are not taken into consideration and their correction factors are not previously determined for correction of the activity read on the calibrator, the patient will probably be administered an incorrect activity.

The objective of the present study is to determine the correction factors that should be utilized for a correct activity measurement on calibrator of radionuclides originated from the volumetric variation of ^{99m}Tc and ^{123}I radiopharmaceuticals contained in 3 and 5 mL plastic syringes.

MATERIALS AND METHODS

In the present study, the volume correction factors were determined with basis on practical measurements of the response (activity) variation of the radionuclide calibrator with the solution volume in the vial. Two 3 and 5 mL BD Plastipak type plastic syringes (Becton, Dickinson and Company; São Paulo, SP, Brazil) were selected for the study. Such models were selected because they are widely utilized in nuclear medicine services in Rio de Janeiro. The 10R Schott type 1+ glass vials were also selected for being widely utilized by radiopharmaceutical suppliers and radionuclide calibrator manufacturers^(6,7). The ^{99m}Tc sources were supplied by the Instituto de Pesquisas Energéticas e Nucleares (IPEN), São Paulo, SP, Brazil, and the ^{123}I sources, by the Instituto de Energia Nuclear (IEN), Rio de Janeiro, RJ, Brazil. Measurements were performed in three radionu-

clide calibrators: two with ionization chamber (IC) as detectors and the third, equipped with a Geiger-Müller detector (G-M). The 5 mL syringe and the 10R vial were initially filled with 1 mL of ^{99m}Tc solution and the activity was measured with the three calibrators. Subsequently, successive additions 1 mL of distilled water and new measurements were made until 5 mL were completed. The same procedure was repeated with the 3 mL syringe, but with an initial volume of 0.5 mL and successive additions of 0.5 mL of distilled water until 3 mL were completed. The procedure was the same for ^{123}I . In order to test the radionuclide calibrators' performances, the ^{99m}Tc and ^{123}I solutions contained in 3 and 5 mL syringes were utilized for comparing the activities measured with the calibrators in nuclear medicine services with the activities measured according to the standard reference systems of Laboratório Nacional de Metrologia das Radiações Ionizantes (LNMRI) (Brazilian Laboratory of Ionizing Radiation Metrology). The comparison criteria adopted for the performance analysis is the accuracy limit of $\pm 10\%$ established

by CNEN, i.e., the R ratio of A activity measured by a nuclear medicine service, for the A_0 activity measured by LNMRI, adopted as a reference, which must be within the $0.90 \leq R \leq 1.10$ interval in order for the performance to be considered acceptable.

RESULTS

Figures 1 and 2 demonstrate the volumetric variation results with the activity obtained for ^{99m}Tc measured with 3 and 5 mL syringes, respectively, with three different radionuclide calibrators: Capintec CRC-15R, Veccsa Vexcal and Victoreen Cal-Rad 34-061. The first two calibrators utilize ICs while the third utilizes a G-M detector. Figures 3 and 4 demonstrate the results for ^{123}I . The A_0 activity at a normalization volume V_0 was utilized for denominating the graphical representation of the activity A versus the individual volume V . For the 5 mL syringe, the V_0 was 1 mL, while for the 3 mL syringe the V_0 was 0.5 mL. Such data were utilized to obtain the ratio between A/A_0 versus V and a second-

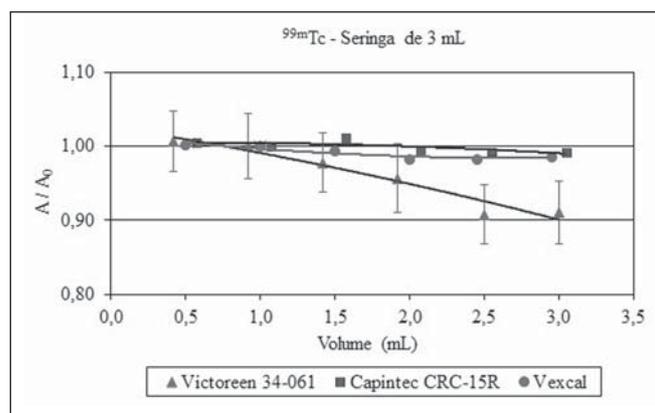


Figure 1. Variation of the activity readings of a ^{99m}Tc solution with radionuclide calibrators as a function of volume variation in a 3 mL plastic syringe.

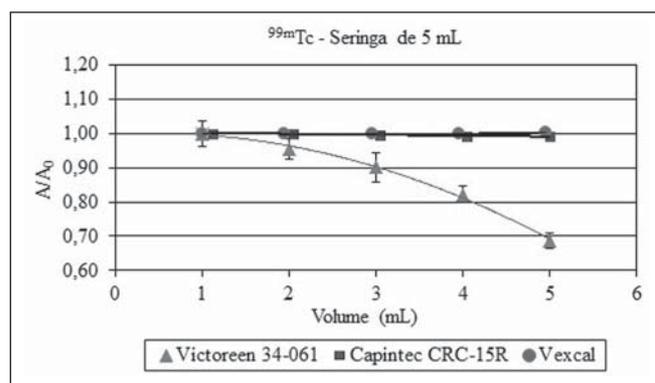


Figure 2. Variation of the activity readings of a ^{99m}Tc solution with radionuclide calibrators as a function of volume variation in a 5 mL plastic syringe.

Figure 3. Variation of the activity readings of a ¹²³I solution with radionuclide calibrators as a function of volume variation in a 3 mL plastic syringe.

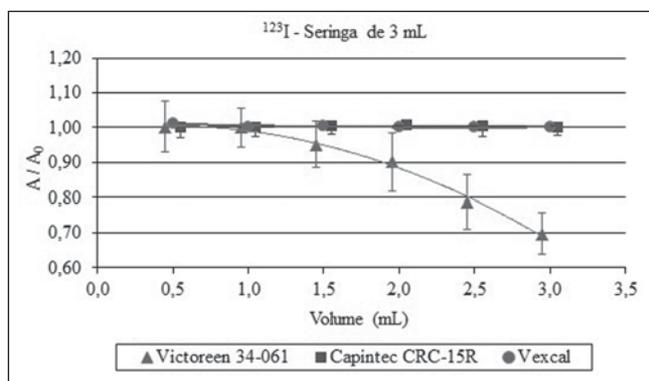


Figure 4. Variation of the activity readings of a ¹²³I solution with radionuclide calibrators as a function of volume variation in a 5 mL plastic syringe.

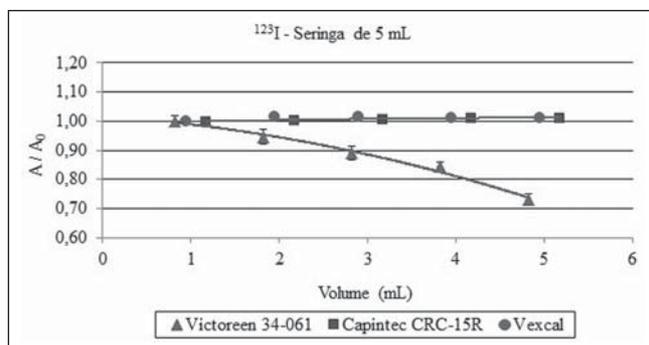


Figure 5. Performance of the calibrators in the measurement of ^{99m}Tc in terms of R ratio, according to Standard CNEN NN-3.05. The performance is considered satisfactory (or compliant) when 0.90 ≤ R ≤ 1.10.

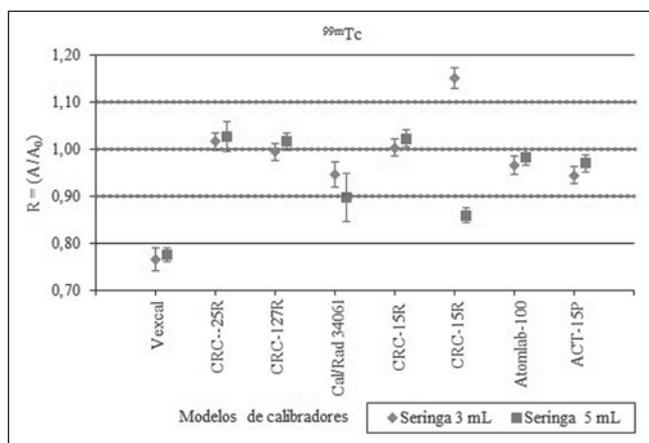
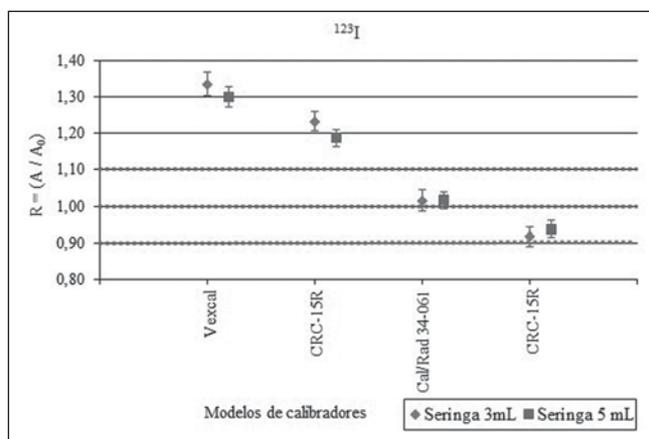


Figure 6. Performance of the calibrators in the measurement of ¹²³I in terms of R ratio according to Standard CNEN NN-3.05. The performance is considered satisfactory (or compliant) when 0.90 ≤ R ≤ 1.10.



degree polynomial equation was utilized as the best approach for determining the correction factors, as follows:

$$A/A_0 = aV^2 + bV + c$$

where: A_0 is the activity corresponding to the normalization volume V_0 and A is the activity measured in an individual volume V .

Tables 1 and 2 show the coefficients of the volume correction factors for ^{99m}Tc and ¹²³I, respectively in the 3 and 5 mL syringes and the 10R vial. Such coefficients represent the volumetric correction factors for obtaining the correct activity as the volume of the radioactive solution contained in the syringe is varied.

Plastic 3 and 5 mL syringes containing 1 mL of ^{99m}Tc and ¹²³I with known activities were utilized to evaluate the performance of different types of radionuclide calibrators. Eight calibrators from several nuclear medicine services in the city of Rio de Janeiro participated in this performance testing, and the results analysis was based on accuracy criterion established by the CNEN Standard NN-3.05. Figures 5 and 6 show the results of this performance test for 3 and 5 mL syringes with ^{99m}Tc and ¹²³I, respectively. Each experimental point is the result of five repetitive measurements with the radionuclide calibrators, and the uncertainty bars correspond to the standard deviation of such measurements.

DISCUSSION

For the 3 mL syringe with ^{99m}Tc, the volume variation from 1 to 3 mL did not cause significant change in the activity measured with the Capintec and Vexcal calibrators. However the measurements with the Victoreen model presented with greater variation, reaching a value 10% lower when the volume increases from 1 to 3 mL. The same behavior was observed for the 5 mL syringe with the two calibrators with ICs, but the Victoreen model presented greater volumetric dependence, with a result 30% lower for the 5 mL volume as compared with the 1 mL initial volume. In the 10R vial, also there was no significant variation in the measurements with the Capintec calibrator, and the variations with the Victoreen model were higher as compared with those observed in the measure-

Table 1 Volumetric correction factors coefficients of a second-degree polynomial for ^{99m}Tc .

Radionuclide calibrator	3 mL syringe		
	a	b	c
Victoreen 34-061	-0.003289	-0.031911	1.026022
Capintec CRC-15R	-0.002371	0.002504	1.004153
Veccsa Vexcal	0.004067	-0.022478	1.014803
5 mL syringe			
Victoreen 34-061	-0.014667	0.012099	0.997898
Capintec CRC-15R	-0.000033	0.002357	1.003261
Veccsa Vexcal	0.000691	-0.003397	1.002647
10R vial			
Victoreen 34-061	0.011286	-0.091141	0.913848
Capintec CRC-15R	-0.000276	0.003159	0.995127

Table 2 Volumetric correction factors coefficients of a second-degree polynomial for ^{123}I .

Radionuclide calibrator	3 mL syringe		
	a	b	c
Victoreen 34-061	-0.050397	0.044860	0.996044
Capintec CRC-15R	-0.002598	-0.010525	0.995670
Veccsa Vexcal	0.002621	-0.012576	1.016197
5 mL syringe			
Victoreen 34-061	-0.007684	-0.020918	1.017485
Capintec CRC-15R	-0.000689	0.016061	0.998927
Veccsa Vexcal	-0.002474	0.007541	0.991423
10R vial			
Victoreen 34-061	0.006248	-0.042279	1.035615
Capintec CRC-15R	-0.000391	0.005891	0.995829

ments in the syringes, according to coefficients presented on Table 1. However, in this case, there was a reversal in the tendency towards activity decrease with the increase in volume, with an approximately 10% higher result when the volume is increased from 1 to 5 mL. On Table 1, one can observe that the *a* and *b* coefficients are lower for the calibrators equipped with ICs utilized in the present study as compared with the one equipped with G-M detector, and the *c* coefficient is closer to 1 for those equipped with ICs, confirming the lower volumetric dependence of the first ones in relation to the latter one. Such a tendency is also confirmed for ^{123}I , as shown on Table 2.

The behavior for ^{123}I is similar to that for ^{99m}Tc in the three calibrator models. Again, a higher variation was observed with the Victoreen model, in which the measured activities in the 3 and 5 mL syringes were

70% lower for both syringes, as compared with the activity of the initial volume of 1 mL. Such a greater variation in comparison with ^{99m}Tc can be explained by the high absorption in the sample itself of numerous X-rays typical of low energy (27 to 32 keV, with approximately 87% probability of emission)⁽⁸⁾ emitted by ^{123}I , which contribute for producing the activity shown on the calibrator reading. The absorption is lower for ^{99m}Tc , which preferably emits 140 keV gamma rays. Such effects may also be observed on the uncertainty bars, representing the repeatability of experimental data measurements that are many times greater with the Victoreen model than in the Capintec one. In the case of the 10R vial, the tendency towards activity decrease was maintained with the increase in volume. However, the lowest activity was measured on an intermediate volume of 3 mL, and then increasing, demonstrating a contradic-

tory behavior. New measurements must be performed both for ^{123}I and ^{99m}Tc to confirm such unexpected results. The volumetric correction factor coefficients presented on Tables 1 and 2 are valid only for the calibrators, types of vials and radionuclides utilized in the present study, as well as for the studied volumetric ranges. The calibrator owners should determine their own correction factors for each type of vial and radionuclide, with the different volumes routinely utilized in their activities.

In the evaluation of the eight calibrator's performance in the measurement of ^{99m}Tc activity, the authors have observed a similar behavior for 3 and 5 mL syringes. Amongst the eight tested calibrators, with 16 results, only two with four results were out of the accuracy limits required by the Brazilian standard, presenting a good overall performance. The exception was one of the CRC-15R models, which presented a contradictory behavior as compared with the others (deviation of +15% for the 3 mL syringe and -15% for the 5 mL syringe), requiring new measurements for confirmation of such results. In the case of ^{123}I , only four calibrators were evaluated, as some of them were out of service or were not calibrated for ^{123}I measurements at the time the present study development. One half of the results were out of the accuracy limits of $\pm 10\%$, with maximum deviation of approximately +30%, while for ^{99m}Tc the maximum deviation was -20%. More robust conclusions regarding the performance cannot be generalized, since for that purpose the comparison should comprise all nuclear medicine services which utilize ^{99m}Tc and ^{123}I in their routine activities.

CONCLUSIONS

The results of the present study confirm that the radionuclide calibrator responses depend on the volume, type of vial, and the radionuclide utilized in the measurement, with more critical results with the calibrators utilizing G-M detectors analyzed in the present study, reaching deviations of up to 70% lower as compared with the standard volume. In the performance testing, the maximum deviations were similar for both radionuclides. In order to obtain more robust conclusion on activity measurements

in the syringes, the number of elements in the comparison should be higher, particularly for ^{123}I . As nuclear medicine services utilize different types of vials with variable volumes of radiopharmaceuticals, the correction factors required for correct activities administration, must be determined for each calibrator and radionuclide, with the objective of minimizing the administration of unnecessary doses to patients. There is no universal correction factor for each calibrator model and make. Considering that the correct measurement of activity administered to the patient is a relevant part of a nuclear medicine procedure, it is recommended that the regulating agency CNEN intensifies its inspections of nuclear medicine services to verify their compliance with the Standard NN-3.05 requirements. Another recommendation would be for a gradual replacement of calibrators equipped with G-M detectors because of their poor performance, requiring more corrections, as demonstrated by the present study as well as by other studies previously published by the authors⁽⁹⁻¹²⁾. The present study neither endorse nor divulge any ra-

dionuclide calibrator model, but is limited to a description of the results obtained with the studied calibrators.

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