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Methodology for determining radiation dose distribution of strontium-90 applicators for veterinary intraoperatory betatherapy

Metodologia para determinação da distribuição de dose de radiação de aplicadores de estrôncio-90 para betaterapia intraoperatória veterinária

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Abstract

Betatherapy is a modality within brachytherapy that uses beta radiation applicators, which are used in the treatment of superficial injuries. With the advancement of therapeutic techniques, new clinical protocols in veterinary medicine will be established. In this sense, betatherapy appears as an important option for performing radiotherapy procedures and, consequently, further studies are necessary to define the clinical oncological protocols. Therefore, the aim of this study was to present a methodology for determining the dose distribution of beta radiation from strontium-90 (^{90}Sr) applicators for use in intraoperative radiotherapy in veterinary medicine. Planar radiation dose distributions from three ^{90}Sr applicators were analyzed using radiographic films, which were exposed to beams from sources at different exposure times. The optical density (O.D.) of the radiation field was verified with a digital densitometer. After scanning the films, using the ImageJ software, the brightness intensities (BI) for the radiation exposure fields were measured. The analysis of the radiation dose distribution of the betatherapy applicators, produced results similar to those already described in the literature. The use of the ImageJ software, as well as the O.D. obtained, helped in the analysis of dosimetric studies. The behavior of the dose-effect curves provided a better understanding of the homogeneity of the radiation field in the treatment plan and, therefore, the radiation dose distributions in the treatment fields indicate the use of these types of applicators in veterinary radiotherapy procedures.

Keywords: Veterinary Radiotherapy, Intraoperative Brachytherapy, Beta Radiation.

Resumo

A betaterapia é uma modalidade dentro da braquiterapia que utiliza aplicadores de radiação beta, os quais são usados no tratamento de lesões superficiais. Com o avanço das técnicas terapêuticas, novos protocolos clínicos da medicina veterinária serão estabelecidos. Neste sentido, a betaterapia surge como uma opção importante para a realização de procedimentos radioterápicos e, consequentemente, estudos são necessários para definições de protocolos clínicos oncológicos. Desta forma, o objetivo do presente estudo foi apresentar uma metodologia para determinação da distribuição de dose de radiação beta proveniente de aplicadores de estrôncio-90 (Sr^{90}), para uso em radioterapia intraoperatória em medicina veterinária. Foram analisadas as distribuições de dose de radiação planar de três aplicadores de Sr^{90}, por meio de filmes radiográficos, aos quais foram expostos aos feixes oriundos das fontes em diferentes tempos de exposição. Foi verificado a densidade óptica (D.O.) do campo de radiação por um densitômetro digital. Após o escaneamento dos filmes, com o uso do software ImageJ, foram medidas as intensidades de brilho (IB) referente aos campos de exposição da radiação. A análise da distribuição de dose de radiação dos aplicadores de betaterapia, produziu resultados semelhantes aos já descritos. O uso do software ImageJ, assim como a D.O. obtida auxiliaram na análise dos estudos dosimétricos. Os comportamentos das curvas de dose-efeito proporcionaram maior compreensão da homogeneidade do campo de radiação no plano de tratamento e, deste modo, as distribuições da dose de radiação nos campos de tratamento indicam o uso destes tipos de aplicadores nos procedimentos de radioterapia veterinária.

Palavras chaves: *Radioterapia Veterinária, braquiterapia Intraoperatória, radiação beta.*

1. Introduction

Radiotherapy is the medical modality that uses sources of ionizing radiation for the treatment of diseases, especially cancer (1). Regarding the radiation sources location, radiotherapy is divided into two different techniques: teletherapy and brachytherapy (2,3). In teletherapy, radiation source is positioned at a certain distance from the lesion, usually 100 cm in the case of linear accelerator type equipment (L.A.), and 80.0 cm in the telecobalt therapy units (1,2). In the brachytherapy technique, the radiation source is in direct contact with the lesion or even inserted into it (3).

Betatherapy is a modality of brachytherapy where the source emitting beta rays is placed directly in the treatment area or even inserted in it (2,4-6). Beta rays are corpuscular radiation, and have a low penetrating power in the tissue (7-9).

This modality uses beta radiation applicators, which are widely used in the treatment of superficial lesions, since beta particles have great ionization power and small reach in the tissue (10). The most widely used nuclide is strontium-90 (^{90}Sr), with a physical half-life ($T_{1/2}$) of 28.7 years, which emits beta energy particles from 0.54 to 2.27 megaelectronvolts (MeV) (11).

In radiotherapy in humans, the use of betatherapy has been more indicated for the preventive treatment of skin lesions, such as keloids and hypertrophic scars. In ophthalmology, betatherapy has shown excellent results in the prevention of recurrent post-surgical pterygium (12-16).

As for veterinary medicine, the use of this practice is already implemented in several countries (17-21), in Brazil it is still a procedure that is being implemented. The applications of radiotherapy in the veterinary have shown excellent results (20-23). The feasibility of the technique depends, mainly, on the consolidation of the procedures, and the success of the therapeutic proposal (23, 24).

According to literary reports, veterinary radiotherapy started in 1927, since then, this oncological modality has been growing worldwide (25). This practice in veterinary medicine has found a strong trend in terms of the therapeutic results offered (26). Research involving this therapeutic modality in animals is growing slowly in Brazil. The studies point to the need for further deepening of the techniques performed and better knowledge of the applied radiation sources (20,21,27-28).

Due to the advancement of therapeutic techniques, new clinical protocols in veterinary medicine must be established. In this sense, betatherapy appears as an important option for performing radiotherapy procedures and, consequently, there will be studies to define clinical oncological protocols. The application of radiotherapy in superficial injuries requires the use of bundles of corpuscular radiation. Modern clinical L.A. products produce both electromagnetic radiation beams (X-ray photon beams) and corpuscular radiation beams (megavolt electrons). However, this equipment is expensive (above 1.0 million dollars). On the other hand, betatherapy applicators, which have sources emitting beta rays (corpuscular radiation), are more compact and less expensive (around 50 thousand dollars), representing an important option for the treatment of superficial injuries.

Betatherapy applicators are generally made up of metal plates on which the ^{90}Sr is deposited on one of the surfaces. These plates may be flat (with dimensions of approximately 10 to 22.57 mm in diameter, or 2 cm x 1 cm or 2 cm x 2 cm) that are used in dermatological applications. Concave plates (with a diameter of 10 to 15 mm in radius of curvature) are used for ophthalmic applications (29).

The SIA.6 applicator is the most common type of concave font used, as it has a radius of curvature of 10 mm, and that is precisely why it is indicated because its shape to the eye. The active diameter is equal to 12 mm (15 mm in total). The applicator is 1 mm thick and has a 0.1 mm stainless steel filter, and has a radius of curvature of 10 mm (30).

The quality control of the beam is essential to ensure the minimum operating requirements for radiotherapy services, since the evaluation of parameters such as symmetry, flatness, dim light, filter and tray factors, in addition to other parameters, are necessary to ensure consistency to radiotherapy treatments minimizing errors in dose delivery. Ionization cameras, radiographic films or semiconductor detectors usually perform the evaluation of these parameters in radiotherapy (31).

Radiographic films are sensitive to light. In general, they consist of a polyester base and double gelatinous layer (emulsion) where the halogen silver crystals (Silver Bromide (AgBr) and Silver Iodide (Agl)) are dissolved. When the radiation interacts with the silver bromide crystals, they are susceptible to chemical changes and form what is known as latent image, where after processing the film, under the action of chemicals on the emulsion, it will become visible image (32).

When the radiographic film is exposed to radiation it undergoes changes in gray scale and is presented in the image due to their respective differences in the anatomical densities of tissues under examination (32). Films may be used for quality control, as long as they have low sensitivity, otherwise, a small dose will already darken the film too much, making any type of analysis impossible. Therefore, slow films, suitable for radiotherapy, are used (33-35).

Dosimetry and quality control of betatherapy sources have become a necessity in oncological practice, and dosimetry with radiographic films is advantageous in comparison with thermoluminescent dosimeters and extrapolation chambers due to the high spatial resolution (13, 14).

Dose distribution analysis for ^{90}Sr applicators in radiographic films, such as the evaluation of the behavior of optical density (O.D.) and brightness (BI) are yet to be properly described in the veterinary medicine literature.

Therefore, the aim of this study was to present a methodology for determining the dose distribution of beta radiation from ^{90}Sr applicators for use in intraoperative radiotherapy in veterinary medicine.

2. Materials and methods

This research was approved by the School of Veterinary Medicine and Animal Science (FMVZ/UNESP) Ethics Committee on the Use of Animals (CEUA) (Protocol No. 0050/2017).

The planar and axial radiation dose distribution of three Amersham ^{90}Sr applicators available at the Araçatuba Veterinary Medicine School (FMVA/UNESP) were analyzed.

The betatherapy applicators used in the study were calibrated at the calibration laboratory of the Brazilian Institute for Energy and Nuclear Research (IPEN/CNEN-SP) on 01/13/2009 (No. 1), 03/06/2009 (No. 2) and 03/03/2009 (No. 3).

Tables 1 and 2 describe the characteristics of each source, as well as the values of dose rates obtained during calibration at the IPEN/CNEN-SP calibration laboratory.

Kodak films (EDR model) for exclusive use in radiotherapy, which were exposed to the beams coming from the sources of betatherapy at different exposure times, were used for the analysis of dose distribution.

Table 1. Characteristics of betatherapy applicators.

Applicator	Manufacturer	Model	Application	Format		Active Diameter (cm)
1	Amersham	SIA 20-1102 ML	Ophthalmology/ Dermatology	Flat	Circular	0.90
2	Amersham	SIA 6/1418	Ophthalmology	Concave	Circular	0.90
3	Amersham	Sr 5072 2096	Dermatology	Flat	Circular	2.00

Table 2. Activities and dose rates of betatherapy applicators.

Applicator	Reference date	Initial activity (mCi) /MBq	Dose rate cGy/s	Calibration date	Calibration cGy/s	Current activity (mCi)/MBq	Experiment date	Dose rate cGy/s
1	07/31/1996	55.00 / 2035	43.80	13/01/2009	32.88 ± 0.60	32.53 / 1203.71	02/28/2018	25.91
2	05/14/2003	23.865 / 883	4.01	03/06/2009	3.53 ± 0.14	16.65 / 616.04	02/28/2018	2.798
3	05/14/2003	4.768 / 176.42	2.96	03/03/2009	2.08 ± 0.03	3.333 / 123.08	03/20/2018	2.06

mCi = milicurie; MBq = megabecquerel; cGy/s = centigray per second; Reference date = date that corresponds to the activity that was used to base the decay when it was calibrated in IPEN; Initial activity = activity on the reference date; Calibration = dose rate measured at calibration at IPEN; Current activity = activity on the day of the experiment.

The films exposed to the sources of ^{90}Sr were measured on a digital densitometer CQ-01 produced by MRA (series 01-268). In this step, each field was checked three times to avoid alterations in the measurements.

The mean and standard deviation (σ) for O.D. was then obtained for each exposure. The O.D. value was also measured from the base of each film in order to subtract the values of the exposures if or when necessary.

For the analysis of beta beam distribution, the films were scanned on a HP Scanjet G4050 device, which is used exclusively to digitize images from radiographic films. The scanning settings used were 24-bit grayscale images and a resolution of 200 dpi.

The gray scale histogram (GSH) tool available in the software (ImageJ - National Institutes of Health) was used to measure the brightness intensity (BI) for the pixels of each exposure using the parameters obtained (*Count, Mean* and *StdDev*).

In ImageJ, the *Count* parameter indicates the number of pixels selected for reading the area corresponding to a small region representative of the central point of the radiation field. The *Mean* parameter indicates the BI corresponding to the exposure in the entire measurement region (throughout the *Count*). *StdDev* corresponds to the standard deviation (σ) and indicates the variation of the measured values of the *Mean* parameter, that is, the variation of the BI.

Through the use of ImageJ, the complete field (Figure 1), the center of each respective exposure (Figure 2) and the base of the film (Figure 3) were measured. The center of the field was defined by two perpendicular axes (X and Y). To acquire the GSH in the center of the field, a sample size (*Count*) of 225 pixels was standardized.

3. Results

The values represented by "..." in tables 3, 4 and 5 refer to O.D and BI measurements that were not obtained in the respective exposure time and, therefore, are not recorded.

Table 3 shows the mean and standard deviation (σ) for O.D. recorded on the film for the three betatherapy applicators at different exposure times.

The number of measurements at the mean experimental points represented in Figures 4 to 7 was equivalent to three times for each exposure time. Figure 4 illustrates the behavior of the O.D. according to the exposure time. Note that the exposure time is gradually different between applicators.

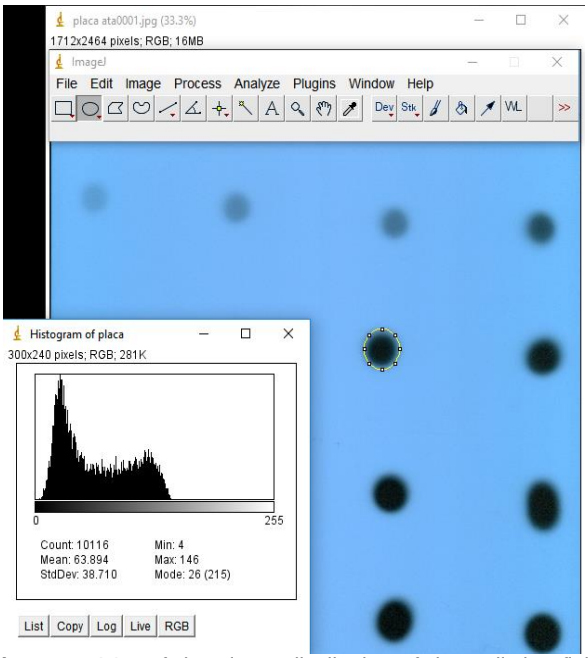

Figure 1. GSH of the planar distribution of the radiation field (^{90}Sr applicator).

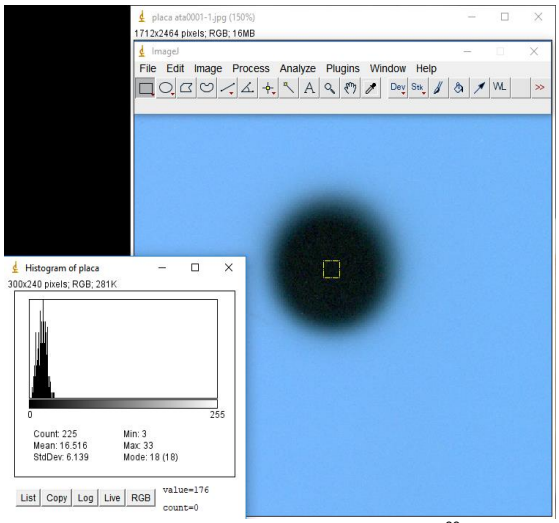

Figure 2. GSH of the center of the radiation field (^{90}Sr applicator) (amplified).

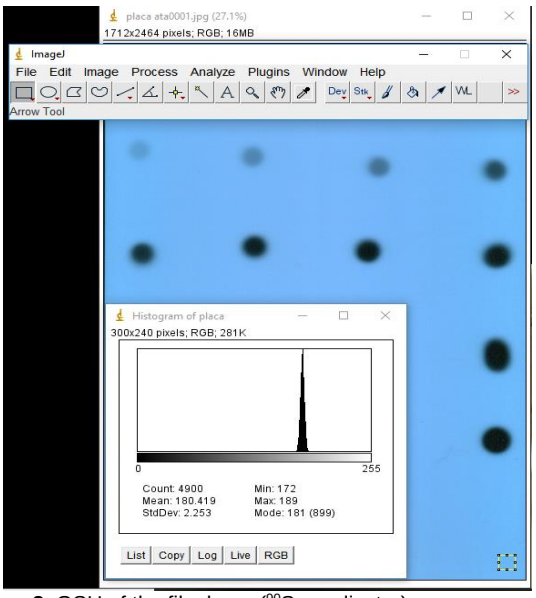

Figure 3. GSH of the film base (^{90}Sr applicator).

Table 3. Mean and standard deviation of O.D. exposure times for applicators.

Exposure time	Applicator 1		Applicator 2		Applicator 3	
(s)	O.D.	σ	O.D.	σ	O.D.	σ
1	0.293	0.005	...	...	...	...
2	0.337	0.025	...	...	...	...
3	0.463	0.017	...	...	...	...
5	0.723	0.005	...	...	...	...
8	0.823	0.017	...	...	...	...
10	1.153	0.017	0.250	0.007	0.362	0.001
15	1.467	0.025	...	...	...	...
20	1.817	0.054	0.307	0.009	0.550	0.002
30	2.177	0.053	0.383	0.031	0.728	0.002
50	...	...	...	...	1.148	0.002
60	2.603	0.031	0.647	0.018	1.257	0.001
90	...	...	0.883	0.004	...	...
100	2.890	0.022	...	...	2.030	0.002
120	2.920	0.016	1.070	0.027	2.408	0.002
150	2.947	0.009	1.320	0.013	2.776	0.002
180	2.990	0.022	1.413	0.042	3.081	0.003
210	...	...	1.547	0.029	3.385	0.003
240	3.017	0.009	1.830	0.007	3.481	0.001
300	...	...	1.957	0.038	3.585	0.004
330	...	...	1.977	0.031	...	...
360	...	...	2.267	0.022	...	...
390	...	...	2.340	0.027	...	...
420	...	...	2.487	0.004	...	...
450	...	...	2.557	0.018	...	...
480	...	...	2.630	0.013	...	...
600	...	...	2.883	0.011	...	...

O.D. = optical density; σ = standard deviation ... = are measures that were not obtained in the respective exposure time

The O.D. corresponding to the base of the film was 0.200 for plates 1, 2 and 3. This is due to the fact that the films used are of the same batch and model.

Using Origin software, we tried to determine a mathematical expression that best fits the profile of the O.D. X irradiation time:

For applicator 1, the polynomial expression with the best fit was:

O.D. = 0.2381 + 0.0929(t) – 0.00115(t)^2 + 0.00000587(t)^3 – 0.0000000104(t)^4.

For applicator 2, the polynomial expression with the best fit was:

O.D. = 0.1997+ 0.0076(t) – 0.00000535(t)^2.

For applicator 3, the polynomial expression with the best fit was:

O.D. = 0.0567+ 0.02421(t) – 0.00004123(t)^2.

Table 4 shows the values obtained from ImageJ. The values refer to the reading at the central point of the images of the radiation fields (center of the betatherapy applicators). They are illustrated in Figure 5, except for the *Count* parameter, which was standardized at 225 pixels and, therefore, did not present variations.

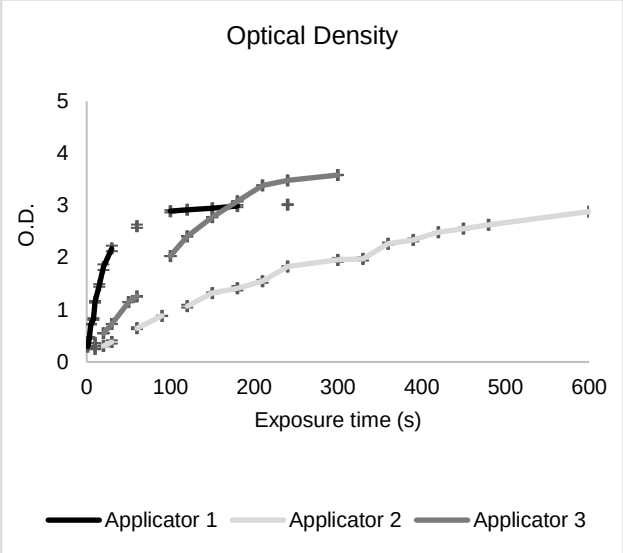

Figure 4. Behavior of the O.D. according to exposure times.

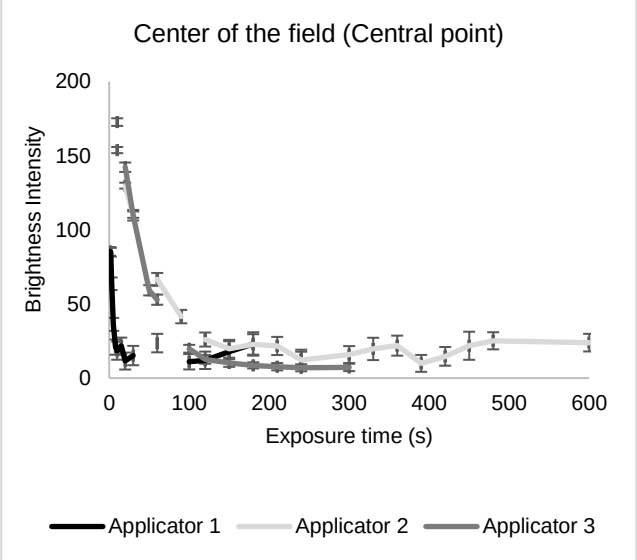

Figure 5. BI measurements from the center of the applicators field.

As seen in Table 4, the readings of BI (*Mean*) with ImageJ for applicator No. 1 show fluctuations for exposure times exceeding than 10 seconds. This can occur due to the high dose rate of this applicator, which saturates the radiographic film and leads to uncertainties in the measurements.

Table 5 shows the values obtained with ImageJ referring to the readings in the total exposure field of the betatherapy applicators.

Figure 6 shows the behavior of the BI (*Mean* and *StdDev)*, while Figure 7 illustrates the sample size

(*Count*) in the full radiation field of the betatherapy applicators according to the exposure time (No. 1, 2 and 3).

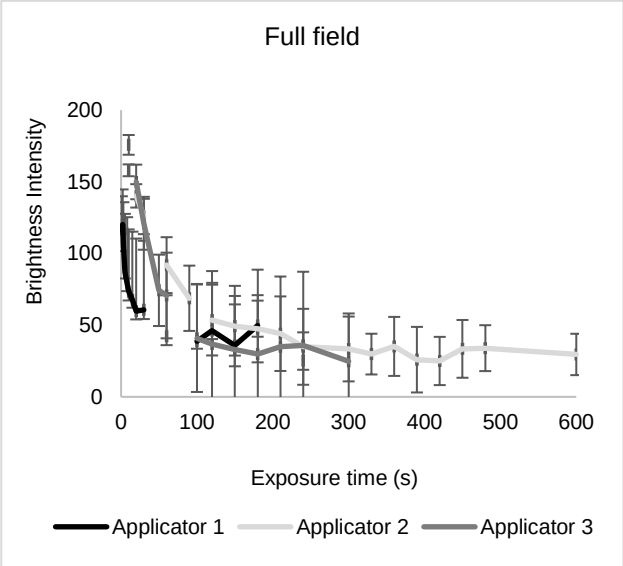

Figure 6. *BI* measurements of the full field of applicators.

Table 6 presents a comparison between the readings of the BI in the center of the field and the same measurement considering the entire extension of the radiation field. In this table it can be seen that, for the three applicators analyzed, the longer the exposure time, the greater the absorbed dose along the length of the treatment field plan, that is, the lower the BI.

The values obtained for BI (*Mean* and *StdDev)* referring to the base of the film were 180.346 ± 1.884 (plate 1), 183.050 ± 2.261 (plate 2) and 182.456 ± 0.668 (plate 3).

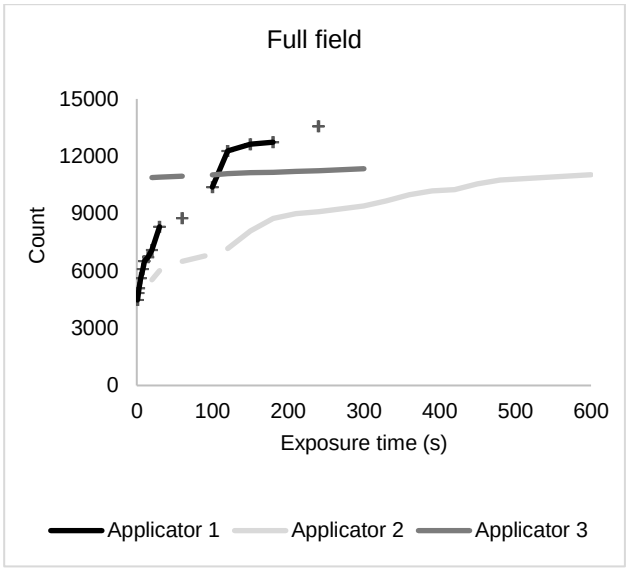

Figure 7. *Count* measurements of the full field of applicators.

Table 4. GSH of the applicators at the central point.

Exposure time	Applicator 1			Applicator 2			Applicator 3		
(s)	*Count*	BI	σ	*Count*	BI	σ	*Count*	BI	σ
1	225.00	85.47	2.91	...	...	...	...	...	...
2	225.00	84.92	2.95	...	...	...	...	...	...
3	225.00	63.64	4.25	...	...	...	...	...	...
5	225.00	36.24	4.38	...	...	...	...	...	...
8	225.00	20.88	5.13	...	...	...	...	...	...
10	225.00	18.51	6.12	225.00	153.82	2.08	225.00	172.71	2.56
15	225.00	21.69	5.62	...	...	...	...	...	...
20	225.00	11.49	5.71	225.00	129.83	1.99	225.00	142.26	3.16
30	225.00	15.19	6.52	225.00	110.280	2.16	225.00	109.86	3.56
50	...	...	...	...	...	...	225.00	59.24	3.46
60	225.00	23.62	6.23	225.00	66.5	4.34	225.00	52.90	3.42
90	...	...	...	225.00	41.49	4.53	...	...	...
100	225.00	11.02	5.20	...	...	...	225.00	19.80	2.63
120	225.00	12.00	5.88	225.00	26.02	4.74	225.00	12.62	2.93
150	225.00	17.78	7.07	225.00	19.80	6.00	225.00	10.20	2.60
180	225.00	23.03	7.89	225.00	22.69	6.90	225.00	8.58	2.06
210	...	...	...	225.00	21.68	6.12	225.00	7.69	2.46
240	225.00	12.70	6.46	225.00	12.14	5.69	225.00	6.96	2.37
300	...	...	...	225.00	15.86	5.72	225.00	7.20	2.49
330	...	...	...	225.00	19.68	7.53	...	...	...
360	...	...	...	225.00	21.88	6.76	...	...	...
390	...	...	...	225.00	9.92	5.70	...	...	...
420	...	...	...	225.00	14.67	6.31	...	...	...
450	...	...	...	225.00	21.82	9.48	...	...	...
480	...	...	...	225.00	25.16	5.78	...	...	...
600	...	...	...	225.00	23.91	5.95	...	...	...

Count = Number of selected pixels (sample size); BI = brightness intensity (value provided by *Mean*); σ = standard deviation of BI (value provided by *StdDev*); ... = are measures that were not obtained in the respective exposure time.

Table 5. GSH of applicators in the full field.

Exposure time (s)	Applicator 1			Applicator 2			Applicator 3		
	Count	BI	σ	*Count*	BI	σ	*Count*	BI	σ
1	4.48	116.80	23.10	...	...	...	...	...	...
2	4.84	120.30	24.46	...	...	...	...	...	...
3	5.09	105.90	29.86	...	...	...	...	...	...
5	5.62	86.98	40.67	...	...	...	...	...	...
8	6.09	78.88	46.48	...	...	...	...	...	...
10	6.51	73.36	43.45	4.60	158.1	4.14	10.86	175.81	6.89
15	6.71	67.81	47.43	...	...	...	...	...	...
20	7.09	59.73	50.70	5.53	140.2	8.15	10.88	149.95	12.08
30	8.30	60.79	48.11	6.02	125.9	12.35	10.91	121.10	18.46
50	...	...	...	...	...	...	10.94	74.31	24.89
60	8.76	42.30	28.55	6.50	91.9	19.50	10.96	70.71	29.88
90	...	...	...	6.78	68.8	22.77	...	...	...
100	10.38	38.78	39.99	...	...	...	11.02	40.90	37.51
120	12.27	46.19	41.57	7.17	53.57	24.70	11.08	36.86	42.69
150	12.62	35.87	28.67	8.10	49.38	28.06	11.14	32.95	37.44
180	12.73	49.84	38.91	8.75	47.50	23.44	11.16	29.84	37.30
210	...	...	...	8.99	44.07	26.01	11.20	34.99	48.96
240	13.57	25.34	19.66	9.09	34.92	26.50	11.23	35.98	51.32
300	...	...	...	9.40	33.40	22.61	11.35	24.79	33.40
330	...	...	...	9.67	29.84	14.23	...	...	...
360	...	...	...	9.98	35.19	20.58	...	...	...
390	...	...	...	10.18	25.94	22.88	...	...	...
420	...	...	...	10.26	25.02	16.82	...	...	...
450	...	...	...	10.55	33.48	20.16	...	...	...
480	...	...	...	10.75	33.98	16.01	...	...	...
600	...	...	...	11.03	29.58	14.43	...	...	...

Count = Number of selected pixels (sample size); BI = brightness intensity (value provided by *Mean*); σ = standard deviation of BI (value provided by *StdDev*); ... = are measures that were not obtained in the respective exposure time.

Table 6. Comparison in the center and the extension of the radiation field.

Exposure time (s)	Applicator 1 (0.9 cm) BI		Applicator 2 (0.9 cm) BI		Applicator 3 (2.0 cm) BI	
	Center of the field	Full field	Center of the field	Full field	Center of the field	Full field
10	18.517	73.356	153.822	158.060	172.707	175.806
20	11.493	59.735	129.827	140.231	142.258	149.950
30	15.191	60.788	110.280	125.856	109.862	121.105
60	23.618	42.303	66.587	91.893	52.902	70.714
120	12.004	46.189	26.018	53.574	12.622	36.857
150	17.782	35.873	19.796	49.375	10.196	32.952
180	23.027	49.838	22.693	47.502	8.582	29.840
240	12.702	25.343	12.138	34.924	6.964	35.977

BI = brightness intensity (value provided by *Mean*)

4. Discussion

The use of radiographic films helps to interpret the quality of the radiation dose distribution provided by teletherapy equipment and radioactive sources. The dose distribution analysis is performed with an optical densitometer, through the evaluation of the degree of blackness (O.D.) resulting from the interaction of radiation in the radiographic film (36, 37).

As recommended in the specific literature (11,31), this study observed (Figure 4) that longer exposure times to the betatherapy applicators led to greater the blackening in the films. That is to say, the more radiation reaches the radiographic film, the blacker it gets since the blackness of the film depends on the radiation dose received. Therefore, it is possible to plot a curve correlating the O.D. with the radiation dose.

After a certain radiation dose, the characteristic curve of the film (O.D. as a function of exposure time) shows little variation in the degree of blackness. This fact may be related to the saturation of the radiographic film (11, 14, 32, 38).

The use of ImageJ allows the assessment of the BI of radiographic films (39). This tool can be related to the O.D. of the film, where the pixels with the highest BI are closest to white and, therefore, have the least exposure, while pixels with lower BI (closer to black) have greater exposure. This behavior was observed in the results of this study, and the curve relating BI to the exposure time shown is a downward slope (Figures 5 and 6).

The measurement of O.D. with the optical densitometer have some limitations, such as dependence on the calibration conditions and variations in the readings due to the oscillations in their electro-electronic circuit. Storing the film for a long time can cause deterioration, which makes it impossible to reread the O.D values.

The ImageJ software shows more details of the analyzed parameters than just the O.D. measurements, since it provides several variables (*Count, Mean, StdDev*, among others) that can be measured on less time (reading the central point of the radiation field), or to a greater extent (coverage area of the entire exposure field).

Through the *Count* variable, we noticed that, with the increase in exposure time, the area of the entire

field increases and, therefore, more pixels are selected (Figure 7).

The results also showed that, for the three betatherapy applicators studied, the longer the exposure time, the more heterogeneous the BI corresponding to the radiation field. This fact may be related to the increase in the scattering effects of radiation, which may produce more intense shadows in the film due to the exposure time in the region of the active volume of the applicator.

In studies conducted by Coelho (14), the O.D. mean and gray tones obtained from radiochromic films of betatherapy applicators were directly proportional to the dose administered. The increase in the amount of gray tones suggests variations in BI, and consequently, its heterogeneity. This was in line with the findings of this study regarding the shadows of the active volume.

In this study we verified that the use of the ImageJ software can aid in the quality control routine of the radiotherapy beams, since it provides a more precise reading resolution than the one obtained with the optical densitometer. However, the digitalization process of the images must have standardized parameters and must be performed only in devices intended exclusively for digitalization of radiographic films, so that the interpretation of variables remains reliable.

5. Conclusions

The methodology proposed in this study for the analysis of the radiation dose distribution from ^{90}Sr betatherapy applicators presented results similar to those found in the literature related to ionizing radiation dosimetry.

The behavior of dose-effect curves, such as: O.D. against exposure time obtained with the optical densitometer, as well as the BI against radiation time plotted with the ImageJ software, provide a greater understanding of the homogeneity of the radiation field in the treatment plan with betatherapy beams. Therefore, the radiation dose distributions in the treatment fields indicate the use of these types of applicators in veterinary radiotherapy procedures.

The use of the ImageJ software assists in the analysis of dosimetric studies regarding the quality of betatherapy radiation beams. In general, both methods for analyzing the radiation dose distribution in the treatment field plan presented similar results and interpretations regarding homogeneity and dose variation as a function of exposure time. This suggests that the two methods can be performed individually and independently according to the availability of equipment (optical densitometer) for each radiotherapy service, or as complementary methods, for double analysis (double check) of the functionality conditions (active area integrity) of beta-therapy applicators.

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