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Fabrication and Dosimetric Evaluation of a 3D-Printed Multichannel Cylindrical Applicator Prototype for HDR Gynecological Brachytherapy

Guimarães[a*], P. V.; Fortes[a], S. S.; Batista[b], D. V. S.; Reisner[a], R. G.

[a]Instituto Nacional do Câncer, Rio de Janeiro, Rio de Janeiro, Brasil
[b] Instituto de Radioproteção e Dosimetria, Rio de Janeiro, Brasil

*Correspondence: patriciavieirag@gmail.com

Abstract: High dose-rate (HDR) brachytherapy is widely used in the treatment of gynecological cancers, but the availability of multichannel applicators remains limited in many radiotherapy centers. 3D printing has emerged as a viable alternative for manufacturing customized devices, allowing for optimized dose distribution and reduced exposure to organs at risk. This study aimed to develop and evaluate a 3D-printed multichannel cylindrical applicator for gynecological brachytherapy. The printing material was selected based on its physical properties, followed by an analysis of Hounsfield Units (HU) for different infill percentages and printing patterns. The applicator was printed using polylactic acid (PLA), and different physical and imaging tests were performed. The dose distributions obtained with the 3D-printed multichannel applicator and a single-channel were compared, with focus on target coverage and organ-at-risk exposure. Dosimetric evaluation was performed using Gafchromic® EBT4 film. The results show that the multichannel applicator enabled better dose conformity, reducing rectal exposure compared to the single-channel applicator while maintaining target coverage. Gamma analysis confirmed the accuracy of the calculated dose distribution. 3D printing seems to be a viable alternative to produce customized applicators, potentially expanding therapeutic options in gynecological brachytherapy, however, future studies should investigate the biocompatibility of the material and the clinical feasibility of the applicator.

Keywords: Brachytherapy, 3D printing, dosimetry, multichannel cylindrical applicator.

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Fabricação e avaliação dosimétrica de um protótipo de aplicador cilíndrico multicanal impresso em 3D para braquiterapia ginecológica HDR

Resumo: A braquiterapia de alta taxa de dose (HDR) é amplamente utilizada no tratamento de cânceres ginecológicos, porém a disponibilidade de aplicadores multicanais ainda é limitada em muitos centros de radioterapia. A impressão 3D surgiu como uma alternativa viável para a fabricação de dispositivos personalizados, permitindo uma distribuição de dose otimizada e menor exposição aos órgãos de risco. Este estudo teve como objetivo desenvolver e avaliar um aplicador cilíndrico multicanal impresso em 3D para braquiterapia ginecológica. O material de impressão foi selecionado com base em suas propriedades físicas, seguido por uma análise dos valores de Unidades Hounsfield (HU) para diferentes porcentagens de preenchimento e padrões de impressão. O aplicador foi impresso utilizando ácido polilático (PLA) e submetido a diferentes testes físicos e de imagem. As distribuições de dose obtidas com o aplicador multicanal impresso em 3D e com um aplicador de canal único foram comparadas, com foco na cobertura do volume alvo e na exposição aos órgãos de risco. A avaliação dosimétrica foi realizada utilizando filme Gafchromic® EBT4. Os resultados demonstraram que o aplicador multicanal proporcionou melhor conformidade da dose, reduzindo a exposição retal em comparação ao aplicador de canal único, mantendo a cobertura do alvo. A análise gama confirmou a precisão da distribuição de dose calculada. A impressão 3D mostra-se uma alternativa viável para a produção de aplicadores personalizados, com potencial para expandir as opções terapêuticas na braquiterapia ginecológica. No entanto, estudos futuros devem investigar a biocompatibilidade do material e a viabilidade clínica do aplicador.

Palavras-chaves: Braquiterapia, impressão 3D, dosimetria, aplicador cilíndrico multicanal.

1. INTRODUCTION

The estimated cancer incidence in Brazil for the 2023–2025 period ranks endometrial cancer as the sixth most common cancer among women, with 7,840 new cases reported nationwide [1]. Pelvic recurrence of endometrial cancer (EC) is frequent, with approximately half of these cases occurring in the vagina. Salvage treatment combining external beam radiotherapy (EBRT) and brachytherapy is a common approach for vaginal recurrence and has demonstrated favorable long-term local control [2].

The single-channel vaginal cylinder (SVC) is widely employed in intracavitary brachytherapy. However, lesion characteristics such as size, location, thickness, and morphology may vary significantly among patients, which can limit the effectiveness of single-channel applicators due to their axially symmetric dose distribution. In such cases, personalized alternatives are essential to ensure optimal treatment outcomes [3].

In recent years, the application of 3D printing in radiotherapy has been studied for different treatment sites and techniques, and gynecological brachytherapy is widely investigated. In high dose-rate (HDR) brachytherapy, 3D printing enables the creation of standard or patient-specific applicators, as well as tools for interstitial needle applications. By addressing anatomical variations among patients, 3D printing offers a solution to the limitations of standard applicators [4].

At the radiotherapy department of Hospital do Câncer I – Instituto Nacional de Câncer (INCA), gynecological intracavitary brachytherapy is performed using three-dimensional (3D) imaging techniques based on computed tomography (CT). These allow visualization and precise delineation of the treatment volume and organs at risk. However, the absence of multichannel applicators in the department limits the delivery of prescribed doses for certain lesion anatomies, potentially compromising treatment feasibility.

This study aims to develop a prototype multichannel cylindrical applicator for gynecological brachytherapy using 3D printing and to evaluate its dosimetric performance. Additionally, the feasibility of integrating this applicator into clinical practice will be assessed.

2. MATERIALS AND METHODS

The methodology involved the analysis of the Hounsfield Unit (HU) values obtained using different 3D printing parameters to identify the configuration that produce HU values closer to the ones of water. Based on the results, a cylindrical applicator was designed and fabricated for use in gynecological brachytherapy. A physical analysis of the applicator was performed to ensure its dimensional accuracy. Subsequently, the applicator was scanned using computed tomography (CT) while immersed in a cubic water phantom, simulating the conditions of a brachytherapy treatment. The dosimetric analysis was conducted by measuring the radiation dose distribution using radiochromic film. The measured dose distributions were then compared with the calculated dose distributions obtained from the treatment planning system to evaluate the accuracy and effectiveness of the design.

2.1. Hu analysis

The TG-43 formalism, published by the American Association of Physicists in Medicine, serves as the clinical standard for dosimetry calculations in brachytherapy. This formalism simplifies calculations by modeling the patient as a uniform water phantom, disregarding tissue and material heterogeneities [5].

To address these limitations, 3D printing technology enables control over parameters such as infill percentage and pattern, allowing for adjustments in the density of printed objects and achieving optimal Hounsfield Unit (HU) values [6].

The printing technique employed was Fused Deposition Modeling (FDM), a method that involves melting a thin plastic filament and depositing it layer by layer with precise linear positioning [7]. Polylactic acid (PLA), a biodegradable thermoplastic polymer derived from lactic acid polymerization, was selected as the printing material [8].

The choice of white PLA from Creality as the printing material was influenced not only by its availability but also by its extensively investigated radiation interaction properties and its widespread application in radiotherapy [9-12]. A previous study demonstrated that PLA blocks with 85% infill exhibit photon beam attenuation comparable to that of RW3 plates at shallow depths, based on the analysis of the Tissue-Maximum Ratio (TMR) curve [13].

For the HU analysis, a set of nine PLA disks was fabricated. Each disk had a diameter of 20 mm, thickness of 10 mm, and varying infill percentages of 85%, 90%, and 95%, using grid, gyroid, and rectangular infill patterns. The material used was white PLA with a diameter of 1.75 mm, manufactured by Creality®. Printing was performed at the Instituto de Radioproteção e Dosimetria (IRD) in Rio de Janeiro using a Raise3D® Pro 2 Plus printer. The constant printing parameters are detailed in Table 1.

The printed disks were scanned using a Brilliance CT scanner (Philips®), located in the radiology department of Hospital do Câncer I at the Instituto Nacional de Câncer (INCA) in Rio de Janeiro. The resulting CT images were imported into the Eclipse® treatment planning system (version 13.6, Varian Medical Systems) for further analysis.

Table 1: Configuration of the Printing Parameters Used for the PLA Disks and the Cylindrical Applicator

PARAMETER	CONFIGURATION
Print bed temperature	60 °C
Extruder nozzle temperature	205 °C
Layer thickness	0,2 mm
Initial layer thickness	1,6 mm
Infill speed	80 mm/s
Extruder nozzle diameter	0,8 mm
Filament diameter	1,75 mm

Source: Prepared by the authors

To measure HU values, the histogram measurement tool within the treatment planning system was used. This tool calculates the average HU value within a defined Region of Interest (ROI). For each disk, three ROIs measuring approximately 10 mm × 5 mm were created on the CT images to ensure accurate and reproducible measurements.

2.2. Development and printing of the cylindrical applicator

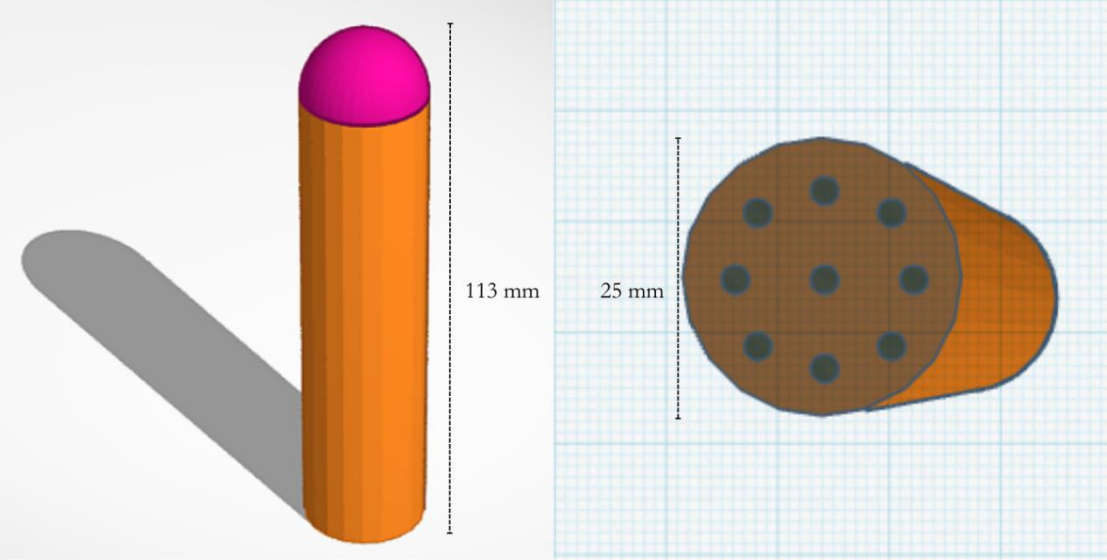
The use of 3D printing technology simplifies the fabrication of complex three-dimensional objects by Computer-Aided Design (CAD) data. This process requires only fundamental dimensional specifications and an understanding of the equipment and materials employed in the construction of the object [14].

The cylindrical applicator was designed using Tinkercad®, an online CAD platform developed by Autodesk. The applicator design included a length of 113 mm, a diameter of 25 mm, rounded-edge geometry, a central hole, and eight additional holes symmetrically distributed around it, as depicted in Figure 1. Upon completion of the design, the model was exported in .stl format, a standard file type for data transmission in 3D printing.

The applicator configuration was prepared using ideaMaker®, a slicing software from Raise3D. The infill percentage and pattern settings were selected based on the results of the Hounsfield Unit (HU) analysis conducted for different configurations. The remaining printing parameters were kept consistent with those listed in Table 1. The printing process was performed at IRD using the same PLA material described in Section 2.1.

After the completion of 3D printing, a physical analysis of the applicator was performed using a calibrated physical ruler with millimetric resolution to measure the key dimensions of the object and confirm their agreement with the original CAD model.

Figure 1: Cylindrical Applicator Design Developed in Tinkercad Software. The model has a length of 113 mm and a diameter of 25 mm, with rounded-edge geometry. It features a central hole and eight additional holes symmetrically distributed around it



Source: Screenshot from Tinkercad Software

2.3. Treatment simulation

Three-dimensional (3D) brachytherapy relies on computed tomography (CT) or magnetic resonance imaging (MRI) scans for the calculation and evaluation of dose distributions across different anatomical volumes, such as the clinical target volume (CTV) and organs at risk (OARs) [15]. The radiotherapy department at Hospital do Câncer I, part of the Instituto Nacional de Câncer (INCA), developed a guide for the clinical implementation of 3D brachytherapy. This guide is based on the recommendations of the GEC-ESTRO working group and the ICRU 89 report, which define criteria for target volume delineation, dose coverage objectives, and dose constraints for OARs [16].

The cylindrical applicator was scanned while immersed in water within a cubic acrylic phantom using a Brilliance Big Bore CT scanner (Philips), located in the radiotherapy department of Hospital do Câncer I. The resulting CT images were imported into the Eclipse treatment planning system (Varian Medical Systems, version 13.6), where the cylinder and virtual anatomical structures representing the rectum, bladder, and vaginal mucosa were

delineated to optimize the treatment plan. Additionally, a structure simulating an uneven lesion on the anterior vaginal wall, designated as CTV_HR (high-risk CTV), was delineated.

For treatment planning simulations in the Eclipse system, the cylindrical applicator was configured with nine channels, each containing source stop positions at 5 mm intervals and activations up to 35 mm. To determine the exposure time at each source position, the volume optimization tool and the clinical objective model specific to the radiotherapy department at Hospital do Câncer I were used, as outlined in Table 2. The prescribed dose was set at 800 cGy to the CTV_HR.

For comparative purposes, an additional treatment plan was generated using only the central channel, simulating a single-channel applicator. This single-channel plan was optimized to ensure equivalent CTV_HR coverage compared to the multi-channel configuration. The volumetric doses delivered to the bladder and rectum were calculated, and the dose homogeneity index (DHI) [17]. In Equation 1, the Dose Homogeneity Index (DHI) is calculated as:

$$DHI = 1 - \frac{V_{CTV,150}}{V_{CTV,100}} \qquad 1$$

where:

$V_{CTV,150}$ represents the volume of the clinical target volume (CTV) receiving at least 150% of the prescribed dose, indicating regions of high dose (hot spots) within the target.

$V_{CTV,100}$ is the volume of the CTV receiving at least 100% of the prescribed dose, corresponding to the full coverage of the target by the planned dose.

Table 3: Restrictions Table for the Application of 3D Brachytherapy at Hospital do Câncer I at INCA

STRUCTURE	PARAMETER	IDEAL	ACCEPTABLE
TARGET ORGANS OF TREATMENT			
GTV	D98%	> 10,0 Gy	> 9,4 Gy
CTV_HR	D90%	8,6 Gy - 9,4 Gy	7,9 Gy – 8,6 Gy ou 9,4 Gy – 10,0 Gy
	D98%	> 7,1 7,9 Gy	-
CTV_IR	D98%	> 4,3 Gy	-
ORGANS AT RISK			
RETO	D2cc	< 4,5 Gy	< 5,7 Gy
BEXIGA	D2cc	< 6,2 Gy	< 7,3 Gy
SIGMOIDE	D2cc	< 5,1 Gy	< 5,7 Gy

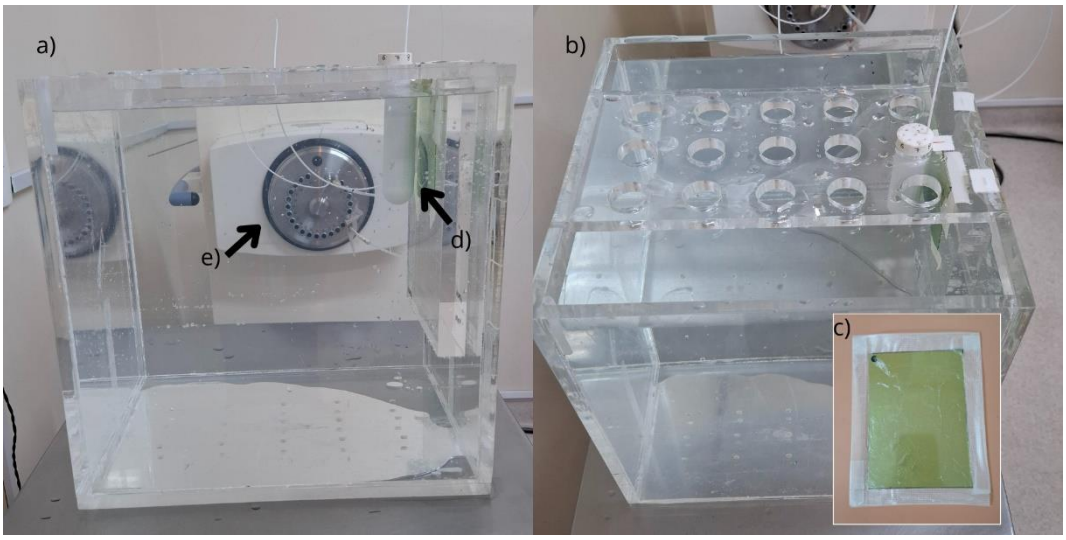
Source: Guide for the Implementation of 3D Brachytherapy at the Instituto Nacional de Câncer

2.4. Dosimetric analysis

The dosimetric analysis was performed by comparing the measured dose distribution with the dose distribution calculated by the treatment planning system using gamma analysis. For this purpose, the cylindrical applicator was immersed in water inside an acrylic phantom, replicating the conditions of the CT scan used for treatment planning, as illustrated in Figure 2. A Gafchromic® EBT4 film, properly sealed to prevent water exposure, was affixed to the phantom wall at a distance of 12 mm from the cylinder's edge.

The treatment plan was simulated with exposure times adjusted to deliver a clinically relevant dose to the phantom wall where the film was positioned. The treatment was delivered using a GammamedPlus™ afterloader (Varian Medical Systems) in the radiotherapy department of Hospital do Câncer I.

Figure 2: a) Frontal view and b) superior view of irradiation setup for the dosimetric analysis. c) Gafchromic EBT4 film protected with PVC plastic to prevent changes due to contact with water. d) Printed cylindrical applicator with inserted catheter for placement of the radiation source. e) GammamedPlus afterloader



To establish a calibration curve, a set of Gafchromic EBT4 films was irradiated using a Varian Medical Systems Clinac 600C® linear accelerator at a depth of 50 mm in solid water. Known doses ranging from 100 cGy to 1000 cGy, in increments of 100 cGy, were delivered to the films. The irradiated films were scanned at least 24 hours post-irradiation using an Epson Perfection® V800 flatbed scanner. The films were consistently aligned at the center of the scanner, maintaining the same orientation used during calibration. The red color channel was extracted for analysis using the ImageJ® software.

The dose distribution calculated by the treatment planning system, corresponding to the same plan as the irradiated film, was exported for analysis. Gamma analysis was conducted using Verisoft® software, developed by PTW-Freiburg GmbH, with the calibration curve applied. Verisoft is a specialized software used for quality assurance and analysis in radiotherapy dosimetry. During the analysis, the origins of the measured and calculated dose distributions were manually aligned at the center of the respective distributions. Dose normalization was performed with respect to the calculated dose at the origin.

The gamma index is a composite metric used to quantitatively compare two dose distributions, combining the dose difference (DD) and the distance-to-agreement (DTA) criteria. The DD criterion, expressed as a percentage, evaluates the point-by-point dose deviation between measured and calculated values. However, in high dose-gradient regions, this metric alone may not be sufficient. To address this, the DTA criterion measures the spatial tolerance by identifying, for a given reference point, the closest point in the evaluated distribution with an equivalent dose. The gamma method, proposed by Low and Dempsey (2003), combines both criteria into a single index to ensure a more robust evaluation.

In this study, several combinations of DD (1% to 5%) and DTA (1 mm to 5 mm) were assessed. A 20% dose threshold (TH) was applied, meaning that the analysis was restricted to points receiving at least 20% of the prescribed dose, in order to exclude low-dose regions that are less clinically relevant or more sensitive to noise.

3. RESULTS AND DISCUSSION

3.1. Hu analysis

The results of the HU measurements for the printed disks, as detailed in Section 2.1, are summarized in Table 3. In all cases, the HU values were negative. A consistent trend was identified: as the infill percentage increased, the HU values also increased, independent of the infill pattern used.

The HU analysis is one of the key techniques employed to validate 3D printing materials as tissue-equivalent [19-21]. For optimal tissue equivalence, HU values close to zero are preferred, as they reflect the interaction properties of radiation with body tissues, particularly regarding the Compton and photoelectric effects. While water has an HU value of 0, most human tissues also exhibit HU values near zero, with the exception of dense bone

[22]. According to the results shown in Table 3, the grid pattern with 95% infill produced the HU value closest to zero (-18).

Table 3: Hounsfield Units (HU) measured for PLA white disks printed with Creality material

PATTERN/% INFILL	ROI1	ROI2	ROI3	MÉDIA
RECTILINEAR/85%	-72,5	-94,0	-82,9	-83,1 ± 8,8
RECTILINEAR/90%	-46,6	-63,4	-68,6	-59,5 ± 9,4
RECTILINEAR/95%	-18,2	-31,59	-30,8	-26,9 ± 6,1
GRID/85%	-97,8	-119,0	-99,4	-105,4 ± 9,6
GRID/90%	-56,7	-89,5	-89,6	-78,6 ± 16,5
GRID/95%	-12,2	-25,2	-16,6	-18,0 ± 5,4
GYROID/85%	-118,3	-123,5	-135,5	-125,8 ± 7,2
GYROID/90%	-81,9	-102,2	-90,8	-91,6 ± 8,3
GYROID/95%	-34,4	-54,8	-31,6	-40,3 ± 10,3

The findings of this study align with previous investigations. Pereira et al. (2021) validated PLA as a soft-tissue-equivalent material in radiotherapy, reporting that infill percentages between 85% and 90% correspond to the radiological reference value for water. Similarly, Waluk and Pietrzak (2023) indicated that for a linear infill pattern, the fill percentage required to achieve soft-tissue radiological density ranges from 70% to 100%. Although slight variations were observed in the HU values obtained in this study, the results are consistent with the findings of these earlier studies.

3.2. Impression of the cylindrical applicator

Based on the results of the HU analysis, the cylindrical applicator was configured for printing using the grid pattern with 95% infill. This combination of parameters resulted in the HU value closest to that of water, demonstrating the suitability of this configuration for the intended application. The printing process was completed in approximately five hours, without any complications. A total of 53.6 g of PLA material was required for the print. The printed cylindrical applicator is depicted in Figure 3.

Figura 3: Cylindrical multi-channel applicator printed in PLA using a Raise3D Pro 2 Plus printer.

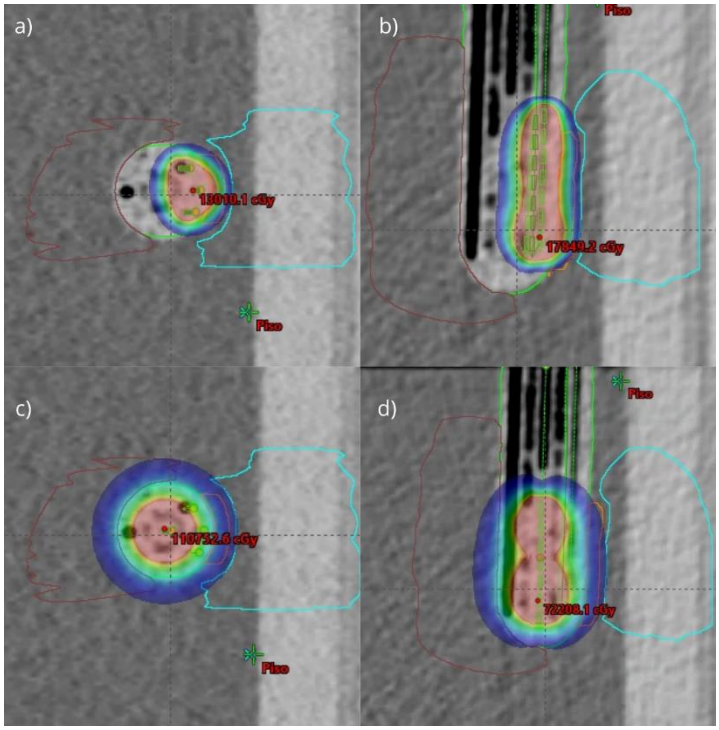
Physical analysis of the applicator confirmed the success of the printing process, with no defects observed during fabrication. The designed channels, which serve as openings, were found to be free from obstructions and possess the correct diameter to accommodate the dosimetry catheter. This ensures the passage of the source during treatment without the presence of air gaps. The final printed applicator measured 113 mm in length and 26 mm in diameter, in alignment with the intended design specifications.

3.3. Treatment simulation

The treatment planning optimization for the multi-channel cylinder activated three peripheral channels on the side of the lesion, whereas, in the single-channel applicator, only the central channel was activated. The dose distributions are shown in panels a) and b). Notably, the 800 cGy dose distribution calculated for the multi-channel cylinder demonstrates a more flattened shape and does not reach the rectum, while the dose distribution calculated for the single-channel cylinder, shown in panels c) and d), has a circular shape and extends to a significant portion of the rectum with the 800 cGy dose. This difference arises from the fact that the single-channel applicator distributes the dose

symmetrically around its structure, while the multi-channel applicator offers greater flexibility, allowing for personalized adjustments for each patient.

Figure 4: Dose distribution of 800 cGy for applicators: (a) and (b) multi-channel cylinders, and (c) and (d) single-channel cylinders

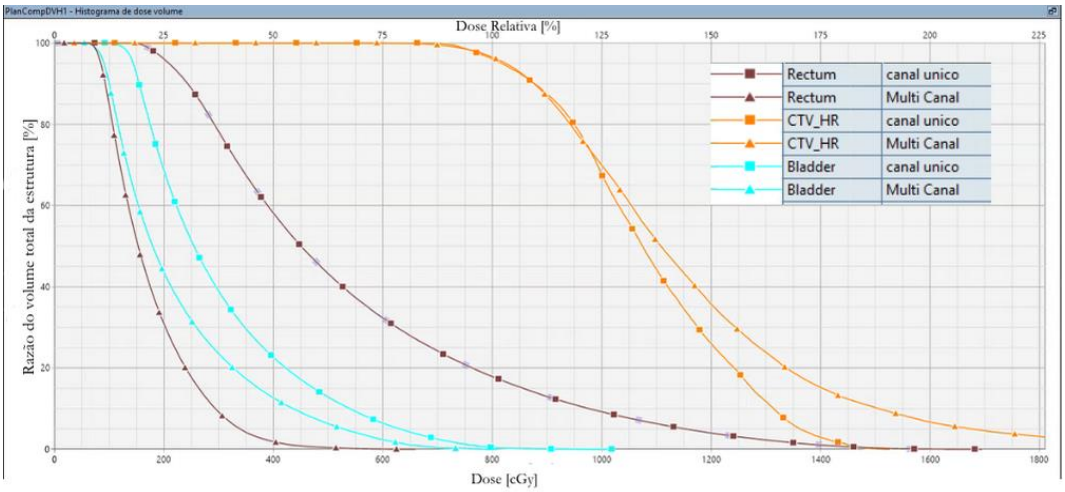


The values for the coverage of the CTV_HR and the organs at risk are presented in Table 4 and Figure 5. It can be observed that, for similar coverage of the CTV_HR, the 2 cc volumetric dose to the rectum was considerably higher in the single-channel cylinder. Organs such as the rectum are often limiting factors in the delivery of the prescribed dose in brachytherapy treatments. In contrast, the Dose Homogeneity Index (DHI) was lower for the multi-channel cylinder, which can be attributed to the higher dose gradient observed in this planning, as illustrated in Figure 5.

Table 4: Dosimetric parameters and homogeneity index for multi-channel and single-channel cylinder plans

PARAMETER	MULTI-CHANNEL	SINGLE-CHANNEL
D90% CTV_HR	876,3 cGy	876,7 cGy
D98% CTV_HR	768,9 cGy	765,2 cGy
D2cc BLADDER	551,6 cGy	653,9 cGy
D2cc RECTUM	356,0 cGy	1211,5 cGy
DHI	0,63	0,73

Figura 5: Comparative DVH between the plans simulated with the multi-channel cylinder and the single-channel cylinder.



The advantage of using a commercially available multi-channel cylindrical applicator was compared to a single-channel applicator in a retrospective study conducted by Kim et al. (2014). The authors demonstrated that doses to the rectum were significantly lower when using the multi-channel applicator, with the degree of dose reduction depending on the location of the lesion. When the lesion was confined to the vaginal dome, both applicators yielded similar results. Additionally, Iftimia et al. (2013) reported their experience with the Miami multi-channel cylindrical applicator (Mick Radio-Nuclear Instruments), highlighting that it is possible to achieve an asymmetric dose distribution with this device, potentially reducing doses to critical organs at the cost of a slightly higher average dose to the vaginal wall. These findings are consistent with the results obtained in the simulations presented in

this study, demonstrating that the 3D-printed multi-channel cylindrical applicator can achieve similar outcomes to those of commercially available applicators.

It is important to note that the evaluations conducted in this study did not involve real patient images. Instead, a phantom was used, and the critical organs and treatment volume were optimized to fit the applicator, which contributed to the satisfactory results. However, for the multi-channel cylindrical applicator developed in this study to be incorporated into clinical practice, further investigation using real patient images is necessary. This study should include a representative sample capable of generating statistically significant results.

3.4. Dosimetric analysis

Table 5 presents the approval rates obtained with different gamma criteria. It is observed that combinations with broader gamma criteria resulted in higher approval rates, which is expected, as less restrictive criteria allow for greater tolerance in the analysis. Conversely, when the Distance to Agreement (DTA) criterion was reduced, fewer points were approved, possibly due to positioning uncertainties. Although efforts were made to replicate the applicator positioning as recorded in the CT scan, small discrepancies persisted, which may explain the observed approval rates. Nevertheless, the results obtained are considered satisfactory.

Table 5: Results of gamma analysis using different Distance to Agreement (DTA), Dose Difference (DD) criteria. The used threshold was 20%

	DTA (mm)				
DD (%)	1	2	3	4	5
1	50,9	82,5	93,2	95,8	96,8
2	52,1	83,0	93,4	96,0	97,0
3	55,7	84,2	93,9	96,2	97,1
4	61,3	86,1	94,5	96,5	97,3
5	67,1	88,1	95,1	96,7	97,5

Despite the favorable outcomes from the gamma analysis, this study did not account for the energy dependence of the Gafchromic EBT4 film. Chan et al. (2023) investigated the

energy dependence of the Gafchromic EBT4 film with different X-ray beams and found that the film's response is energy-independent for high-energy photon beams but exhibits energy dependence in low-energy beams. They reported a statistically significant dose-response difference of up to 12% between 70 kV and 6 MV beams. This phenomenon occurs because, in high-energy beams, the Compton interaction dominates, whereas in low-energy beams, the photoelectric effect prevails [22]. A Monte Carlo simulation study [25] further confirmed this conclusion, showing the energy dependence of the Gafchromic EBT4 film at low energies. Therefore, specific calibration for the energy used may be necessary, especially in applications such as brachytherapy, which employs low-energy beams.

Several limitations identified throughout this study warrant further investigation to enable the use of the applicator in clinical practice. First, a biocompatibility study is recommended to ensure the material's safety for use in clinical settings.

Furthermore, a more in-depth material analysis is needed. Future work should employ techniques such as Fourier-transform infrared spectroscopy (FTIR) to investigate the PLA's long-term structural integrity and potential molecular changes under irradiation. A comparative study evaluating alternative materials, including Acrylonitrile Butadiene Styrene (ABS), High-Density Polyethylene (HDPE), and Polytetrafluoroethylene (PTFE), would also be valuable to identify the optimal polymer for this application.

Additionally, the Fused Deposition Modeling (FDM) printing technique results in parts that are difficult to sterilize, requiring the applicator to be disposed of after each use and necessitating the use of a disposable protective cover on the cylinder. This implies the need for a new applicator for each treatment fraction. Another crucial point is the need for clinical study to statistically compare dose coverage in the target and dose to critical organs. Finally, performing a gamma analysis with a calibration curve specific to the brachytherapy source used is essential due to the energy dependence of the film.

4. CONCLUSION

This study demonstrated the feasibility of manufacturing a multichannel cylindrical applicator for high-dose-rate (HDR) gynecological brachytherapy using 3D printing with polylactic acid (PLA) as the base material. The prototype successfully met the clinical objectives of target volume coverage and significantly reduced the rectal dose when compared to a single-channel applicator, confirming its potential to improve treatment conformity.

The results of the dosimetric, physical, and planning tests were consistent with those obtained in studies involving commercial multichannel applicators, suggesting that the proposed model represents a technically viable and low-cost alternative—especially useful in resource-limited institutions. The gamma analysis confirmed the accuracy of the simulated dose distribution, reinforcing the reliability of the planning process.

However, further investigations are required before the applicator can be incorporated into clinical practice. These include evaluating the biocompatibility of the material used, developing safe sterilization methods, performing source-specific calibration for brachytherapy, and conducting clinical studies with real patients to enable statistical validation in diverse treatment scenarios.

In summary, 3D printing proves to be a promising tool for the customization of medical devices in brachytherapy, with the potential to expand therapeutic possibilities and promote more individualized, safe, and accessible treatments.

CONFLICT OF INTEREST

The authors declare no knowledge of any financial conflicts of interest or personal relationships that could have influenced the work reported in this article.

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