

# Isodose Volume Analysis in Postoperative High-Dose-Rate Brachytherapy: A Study on Total-Reference-Air-Kerma Correlations and Organ-at-Risk Doses

Azam Eskandari<sup>1</sup>, Erfan Saatchian<sup>2</sup>, Mohammad Yasin Mohammadi<sup>1</sup>, Mehdi Momennezhad<sup>3</sup>, Sare Hosseini<sup>4</sup>, Shahrokh Nasseri<sup>5</sup>, Fatemeh Homaei Shandiz<sup>4</sup>, Hamid Gholamhosseinian<sup>4,5\*</sup>

1. Department of Medical Physics, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran
2. Department of Radiology Technology, School of Paramedical Sciences, Mashhad University of Medical Sciences, Mashhad, Iran
3. Nuclear Medicine Research Center, Mashhad University of Medical Sciences, Mashhad, Iran
4. Cancer Research Center, Mashhad University of Medical Sciences, Mashhad, Iran.
5. Medical Physics Research Center, Basic Sciences Research Institute, Mashhad University of Medical Sciences, Mashhad, Iran

ARTICLE INFO	ABSTRACT
<p><b>Article type:</b> Original Paper</p> <hr/> <p><b>Article history:</b> Received: Jul 30, 2025 Accepted: Dec 28, 2025</p> <hr/> <p><b>Keywords:</b> Endometrial Neoplasms Brachytherapy Radiotherapy Isodose Surface Volume Total Reference Air Kerma</p>	<p><b>Introduction:</b> High-Dose-Rate (HDR) Vaginal Brachytherapy (VBT) is a standard adjuvant treatment for early-stage endometrial cancer following surgery. While the Total-Reference-Air-Kerma (TRAK) reflects the overall radiation output, its relationship with the actual irradiated tissue volumes and Organ-At-Risk (OAR) exposure remains underexplored in treatments using cylindrical applicators. The aim of this study is to evaluate the correlation between TRAK, irradiated volumes, and doses to OARs.</p> <p><b>Material and Methods:</b> This retrospective study included 28 Iranian women with histologically confirmed endometrial carcinoma postoperatively treated with HDR brachytherapy using single-channel vaginal cylinder applicators. CT-based treatment planning was performed using Elekta Oncentra software. Prescribed doses were delivered over three weekly fractions. The volumes enclosed by the prescribed isodose surface (<math>V_{ISV}</math>) were quantified using 3D Slicer software. TRAK, dosimetric parameters (<math>D_{90\%}</math>, <math>D_{2cc}</math>, <math>D_{0.1cc}</math>), and <math>V_{ISV}</math> were analyzed. The geometric volume of the applicator was subtracted to determine the actual irradiated tissue volume. Statistical analysis involved Pearson and Spearman correlation coefficients.</p> <p><b>Results:</b> The mean TRAK was calculated as <math>0.45 \pm 0.06</math> cGy·m<sup>2</sup>. A significant positive correlation (<math>R^2=0.981</math>) was found between TRAK/dprescribed and the irradiated volume (<math>V_{ISV}</math>). No significant correlation was observed between TRAK and <math>D_{2cc}</math> doses for the bladder and rectum (<math>R^2=0.075</math> and <math>0.46</math>).</p> <p><b>Conclusion:</b> This study demonstrates a strong association between TRAK and isodose volumes in HDR brachytherapy, suggesting TRAK could be a surrogate for overall dose delivery. However, its lack of correlation with OAR dose metrics emphasizes the need for comprehensive (Dose-Volume-Histogram) DVH assessments. Future research may explore incorporating TRAK into models for predicting toxicity and outcomes, enhancing brachytherapy planning and monitoring.</p>

► Please cite this article as:

Eskandari A, Saatchian E, Mohammadi MY, Momennezhad M, Hosseini S, Nasseri Sh, Homaei Shandiz F, Gholamhosseinian H. Isodose Volume Analysis in Postoperative High-Dose-Rate Brachytherapy: A Study on Total-Reference-Air-Kerma Correlations and Organ-at-Risk Doses. Iran J Med Phys 2025; 22 (6): 389-394. 10.22038/ijmp.2025.90069.2592.

## Introduction

Endometrial cancer ranks as the sixth most frequently diagnosed cancer in women worldwide, with its incidence rising significantly over the past 20 years [1]. The primary treatment approach typically involves a total abdominal hysterectomy combined with bilateral salpingo-oophorectomy. To further reduce the risk of cancer recurrence, adjuvant radiotherapy is often recommended based on histopathological findings, with vaginal brachytherapy (VBT) being a common choice following surgery. In women diagnosed at an early stage who receive surgery followed by VBT, the likelihood of cancer returning in the vaginal area is relatively low, typically reported between 0% and 3.1% [2-4]. Since its early

use by Margaret Cleaves in 1903, intracavitary brachytherapy has remained a cornerstone in the management of gynecologic malignancies. In particular, vaginal cuff brachytherapy has emerged as a critical component in the adjuvant treatment of patients with endometrial cancer and, in some cases, cervical cancer, who face a heightened risk of recurrence following hysterectomy. Given that the vaginal cuff is the most common site for post-surgical relapse, VBT is frequently incorporated into postoperative care, either as a standalone therapy or in combination with external beam radiotherapy (EBRT), to effectively reduce the likelihood of local recurrence in appropriately selected patients [2, 5].

This technique involves the remote manipulation of a small radioactive source attached to a cable, which is guided through single or multiple channels and temporarily positioned at predetermined dwell points to deliver the prescribed radiation dose with high precision. Vaginal HDR brachytherapy can be administered using various applicator types, with the segmented vaginal cylinder being a commonly employed option [6, 7].

Delivering the prescribed radiation dose accurately to the intended target remains one of the central challenges in radiotherapy [8]. Advancements in imaging modalities, particularly computed tomography (CT) and magnetic resonance imaging (MRI), have significantly improved the accuracy of brachytherapy planning. These technologies enable clearer delineation of tumor margins and surrounding healthy tissues, allowing for more individualized and precise dose distributions. Additionally, in clinical practice, dose-volume histograms (DVHs) are widely used to assess how radiation is distributed within the treatment volume and adjacent organs at risk (OARs). Nonetheless, both DVHs and single-point dose measurements are often insufficient for capturing the full spatial complexity of dose distributions. Integrating isodose surface volumes (ISVs) into clinical assessments alongside conventional DVH data provides a more comprehensive view of how radiation is distributed. This added spatial perspective can enhance our understanding of dose-response relationships and may contribute to improved treatment planning, clinical outcomes, and patient safety [9, 10].

The International Commission on Radiation Units and Measurements (ICRU) Report 89 highlights the importance of total reference air kerma (TRAK) as a key physical parameter in brachytherapy dosimetry. TRAK represents the cumulative air kerma produced by all radiation sources at a standard distance of one meter over the entire course of treatment, offering a global measure of the radiation output delivered. Although TRAK represents a purely physical quantity and, as such, lacks a direct correlation with biological outcomes. This limitation arises because TRAK does not incorporate critical dosimetric factors such as the distribution of absorbed dose, dose fraction, or the rate at which the dose is delivered [11].

Several studies have demonstrated a correlation between total reference air kerma and isodose surface volumes, indicating TRAK's potential value in characterizing spatial dose delivery in cervical cancer brachytherapy [10, 12-15]. However, these investigations have primarily focused on intracavitary treatments using tandem and ovoid or ring applicators, with limited attention given to cylindrical applicators used in other clinical contexts. Despite its clinical significance and broad application, the dosimetric relationship between TRAK, irradiated volumes, and OAR exposure has not been comprehensively explored

in this patient group, underscoring the need for further investigation [16, 17].

In this context, the current study investigates the relationship between total reference air kerma and the volumes of tissue encompassed by the prescribed isodose surfaces in Iranian patients receiving high-dose-rate intracavitary brachytherapy (HDR-ICBT) for endometrial cancer. Additionally, the study explores potential associations between TRAK and the  $D_{2cc}$  doses to the bladder and rectum, with the aim of evaluating its usefulness in anticipating and potentially reducing treatment-related toxicities.

## Materials and Methods

A retrospective analysis was performed at Imam Reza Hospital, Mashhad, Iran, encompassing patient data from August 2024 to June 2025. The study population comprised 28 female patients aged over 60 years, diagnosed with stage IA or IB endometrial carcinoma based on histopathological confirmation. All participants underwent high-dose-rate intracavitary brachytherapy with curative intent subsequent to surgical management. To maintain a homogeneous treatment protocol, individuals who received external beam radiotherapy in conjunction with brachytherapy were excluded from the analysis. In this study, following surgical treatment, HDR brachytherapy was performed using an Elekta HDR system (Elekta AB, Stockholm, Sweden) incorporating a cobalt-60 source. Treatment was delivered via a single-channel vaginal cylinder applicator, available in diameters ranging from 20 to 35 mm and selected to fit each patient's anatomy. The treatment regimen consisted of three weekly fractions, each delivering a prescribed dose of 7 Gy [4].

### Imaging and Treatment Planning

Simulation imaging was conducted using a Siemens CT scanner (Siemens Healthineers, Erlangen, Germany) with a slice thickness of 3 mm. The acquired images were imported into the Elekta Oncentra Brachy treatment planning system (version 4.6.0) for planning. Contouring of the clinical target volume (CTV), bladder, rectum, and sigmoid colon was performed in accordance with the GEC-ESTRO guidelines [4]. The source pass was reconstructed, and the dose was prescribed at a depth of 0.5 cm laterally and superiorly from the surface of the vaginal cylinder, in alignment with the American Brachytherapy Society (ABS) recommendations [4, 18]. Treatment plans were subsequently optimized to ensure that at least 90% of the CTV received the prescribed dose while minimizing radiation exposure to adjacent organs at risk. From the cumulative dose-volume histograms, dosimetric parameters were extracted, including  $D_{90\%}$  for the CTV, and  $D_{2cc}$  and  $D_{0.1cc}$  values for the bladder, rectum, and sigmoid. All dose calculations were based on the TG-43 formalism, which is standard for treatments involving non-shielded applicators [19, 20].

### Isodose Surface Volume Analysis

To quantify the isodose surface volumes, patient-specific DICOM datasets including RT dose, RT structure, and CT images were exported from the treatment planning system (TPS) and analyzed using 3D Slicer software (version 5.2.2). The analysis was performed using the software's Isodose and Model modules. The irradiated volume enclosed by the prescribed isodose surface ( $V_{ISV}$ ), which covered at least 90% of the target volume ( $D_{90\%}$ ), was first identified and reconstructed in three dimensions. To estimate the actual irradiated tissue volume ( $V_{irradiated}$ ), the geometric volume of the cylindrical applicator contained within the  $D_{90\%}$  isodose surface was subtracted from the total isodose volume.

### Statistical Analysis

All statistical analyses were conducted using SPSS software (version 27.0, IBM Corp., Armonk, NY, USA). The distribution of quantitative variables was assessed using the Kolmogorov–Smirnov test to evaluate normality. Depending on data distribution, Pearson or Spearman's correlation coefficients were used to examine the relationships between total reference air kerma, dosimetric parameters, and the volumes of irradiated tissue.

## Results

A retrospective analysis was conducted on 28 patients with histologically confirmed endometrial carcinoma who underwent HDR brachytherapy using a single-channel vaginal cylinder applicator. The applicator diameter varied, with 3 patients treated using a 3.0 cm applicator and 25

patients using a 3.5 cm applicator. The mean total reference air kerma was determined to be  $0.45 \pm 0.06$  cGy·m<sup>2</sup>. Dosimetric assessments included critical parameters such as the mean  $D_{90\%}$  for the clinical target volume (CTV) and the  $D_{2cc}$  and  $D_{0.1cc}$  values for organs at risk, representing the doses received by the most exposed 2 cm<sup>3</sup> and 0.1 cm<sup>3</sup> of tissue, respectively. Our findings showed that the bladder received a  $D_{2cc}$  dose of  $6.23 \pm 0.88$  Gy, while the rectum received  $6.61 \pm 1.10$  Gy. For the  $D_{0.1cc}$ , the bladder had a dose of  $7.82 \pm 1.02$  Gy, and the rectum had  $8.69 \pm 1.21$  Gy. The CTV's  $D_{90\%}$  was  $7.21 \pm 0.15$  Gy, demonstrating sufficient coverage of the target volume. Volumes encompassed by the prescribed isodose surfaces ( $V_{ISV}$ ) were quantified using 3D Slicer software. The computed  $V_{ISV}$  distributions are illustrated in Figure 1. Furthermore, the volume enclosed by the prescribed isodose surface was  $77.81 \pm 15.68$  cc, with  $29.63 \pm 5.72$  cc corresponding to the actual irradiated tissue volume, after accounting for the applicator volume.

To explore dosimetric relationships, the ratio of TRAK to the prescribed dose ( $TRAK/d_{prescribed}$ ) was correlated with the  $V_{ISV}$ , revealing a strong positive linear relationship (Figure 2), with a Pearson correlation coefficient ( $R^2$ ) of 0.981. Additionally, a moderate correlation was identified between  $TRAK/d_{ref}$  and the total irradiated volume ( $V_{irradiated}$ ), with  $R^2 = 0.791$ . In contrast, no statistically significant correlation was found between TRAK and the  $D_{2cc}$  values for the bladder or rectum (Figure 3). The corresponding Spearman correlation coefficients were 0.075 and 0.46, respectively, indicating negligible association.

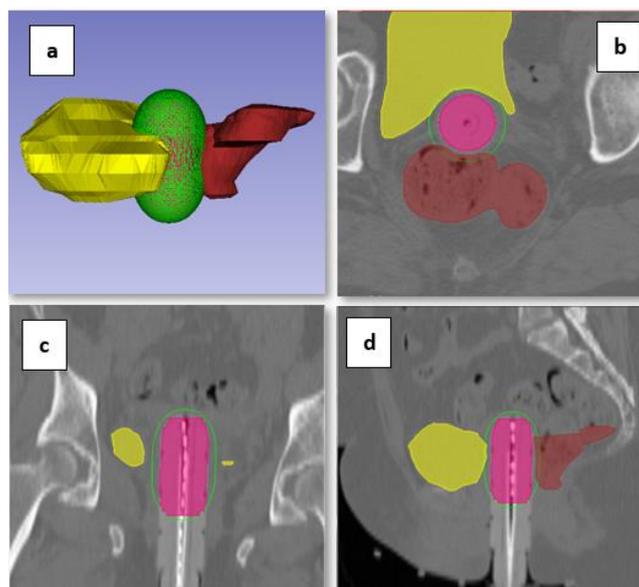


Figure 1. Visualization of irradiated volumes and contoured structures in cylindrical high-dose-rate brachytherapy for vaginal cylinder (pink), isodose surface volume (green), bladder (yellow), and rectum (brown): (a) 3D model of the vaginal cylinder, (b) axial view, (c) coronal view and, (d) sagittal view.

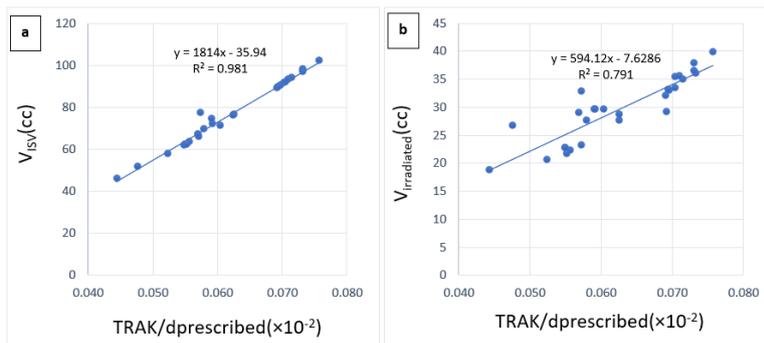


Figure 2. Scatter plots illustrating the relationship between TRAK/dprescribed and (a) isodose surface volume, (b) irradiated volume for all 28 patients.

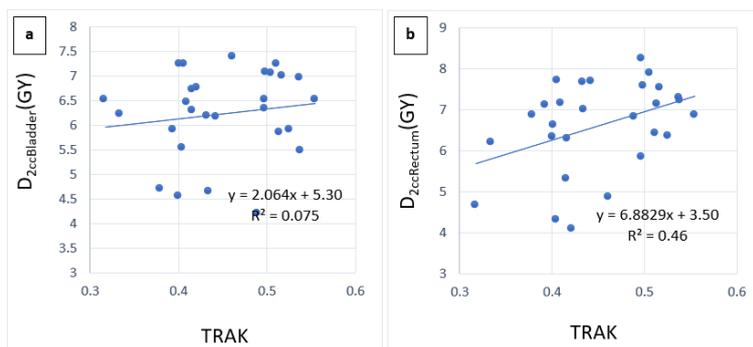


Figure 3. Scatter plots showing the association between TRAK and  $D_{2cc}$  values for (a) the bladder and (b) the rectum in all 28 patients.

## Discussion

Intracavitary brachytherapy remains a key component in the curative treatment of gynecologic malignancies, where accurate dose delivery is essential to achieving effective tumor control while reducing exposure to nearby organs at risk. Among the various dosimetric parameters used in clinical practice, total reference air kerma represents a straightforward yet often underreported metric, despite long-standing guidance from GEC-ESTRO recommending its routine inclusion in treatment documentation [21].

This study evaluated the relationship between total reference air kerma and prescribed isodose volumes in postoperative high-dose-rate vaginal brachytherapy for patients with early-stage endometrial cancer. Using CT-based treatment planning and 3D modeling, we quantified the irradiated volumes enclosed by the prescribed isodose surfaces and examined how well TRAK, a globally reported physical quantity, correlates with volumetric dose distribution and organ-at-risk exposure. A key finding of this analysis was the strong linear correlation between TRAK (normalized to the prescribed dose) and the volume enclosed by the prescribed isodose surface ( $V_{ISV}$ ), with a Pearson correlation coefficient ( $R^2$ ) of 0.981. This result is consistent with earlier reports in gynecologic brachytherapy, particularly in cervical cancer, where TRAK has been shown to reflect the overall extent of irradiated tissue [12-17]. On the other hand, in vaginal cylinder brachytherapy, the volume enclosed by the prescribed isodose surface also encompasses the physical volume of the applicator itself, meaning that it

does not exclusively represent the true volume of irradiated patient tissue. This limitation reduces the practical value of reporting the isodose surface volume in the context of vaginal cylinder brachytherapy, as it may not accurately reflect the actual irradiated tissue. However, the moderate correlation observed between TRAK/ $d_{prescribed}$  and the actual irradiated volume ( $V_{irradiated}$ ) after subtracting applicator volume ( $R^2 = 0.791$ ) suggests that TRAK retains predictive value even when accounting for the non-tissue components within the treatment area. Given that the length of the vagina treated is directly associated with the volume of irradiated tissue, it can be inferred that TRAK, as a physical indicator of treatment intensity, may serve as a valuable parameter in future investigations examining treatment-related toxicity in vaginal cylinder brachytherapy. Therefore, these results support the potential use of TRAK as a surrogate marker for estimating irradiated tissue volumes in routine clinical workflows.

Importantly, our analysis demonstrated no significant correlation between TRAK and the  $D_{2cc}$  values for either the bladder or rectum, with Spearman correlation coefficients of only 0.075 and 0.46, respectively. These weak associations suggest that TRAK is not a reliable surrogate for estimating localized dose exposure to organs at risk. Although TRAK provides a general measure of the overall radiation output [11], it lacks the spatial specificity required to assess dose concentration within critical anatomical structures. This limitation reinforces the importance of conventional volumetric dosimetric

parameters such as  $D_{2cc}$  and  $D_{0.1cc}$  for accurately evaluating OAR dose burden and guiding toxicity risk assessments. Previous studies have further emphasized that the toxicity profile of vaginal brachytherapy is influenced by several treatment parameters, including total dose, dose rate, fractionation, and the length of the vaginal cylinder used, all of which must be considered in conjunction with site-specific dosimetry for comprehensive risk evaluations [22, 23].

The methodological rigor of this study is underscored by several strengths. Notably, the uniform treatment protocol, restricted to patients undergoing postoperative HDR brachytherapy without adjunct external beam radiotherapy, helped reduce potential confounding factors, thereby enhancing internal validity. In addition, the quantitative approach employed to exclude applicator volume from the isodose surface volume yielded a more precise assessment of actual tissue exposure, improving the accuracy of dosimetric evaluation. Nonetheless, some limitations should be acknowledged. The retrospective nature of the study and the relatively small sample size may limit the generalizability of the findings. In addition, our analysis focused exclusively on single-channel cylindrical applicators, and extrapolation to multichannel techniques should be approached with caution. Further research involving larger cohorts and alternative applicator designs would help validate and refine these observations.

In summary, the results of this study underscore the utility of TRAK as a practical dosimetric indicator for approximating isodose volumes in high-dose-rate intracavitary brachytherapy for endometrial cancer. These findings support the routine inclusion of TRAK in clinical documentation to facilitate more comprehensive evaluation of treatment parameters.

## Conclusion

In conclusion, this study provides valuable insight into the dosimetric implications of total reference air kerma in high-dose-rate intracavitary brachytherapy using single-channel vaginal cylinders for early-stage endometrial cancer. The observed strong linear correlation between TRAK and the volume encompassed by the prescribed isodose surface confirms TRAK's potential utility as a surrogate parameter for estimating irradiated tissue volumes. Importantly, by adjusting for applicator volume, a moderate but meaningful association with actual tissue irradiation was also demonstrated, supporting TRAK's relevance in spatial dose characterization. However, its lack of correlation with OAR-specific dose metrics underlines the need for comprehensive DVH-based evaluations in clinical practice. Future investigations may explore incorporating TRAK into predictive models for toxicity risk or treatment outcome, potentially enhancing the efficiency of brachytherapy planning and monitoring.

## Acknowledgment

This research is a part of the PhD thesis and has been funded by the vice chancellor for research of Mashhad

University of Medical Science (Project Number 4020619).

## References

1. Mazidmoradi A, Momenimovahed Z, Khalajinia Z, Allahqoli L, Salehiniya H, Alkatout I. The global incidence, mortality, and burden of uterine cancer in 2019 and correlation with SDI, tobacco, dietary risks, and metabolic risk factors: An ecological study. *Health Science Reports*. 2024;7(1):e1835.
2. Jensen GL, Barry PN, Eldredge-Hindy H, Silva SR, Todd SL, Hammonds KP, et al. Vaginal cuff brachytherapy: do we need to treat to more than a two-centimeter active length? *Journal of Contemporary Brachytherapy*. 2021;13(3):294-301.
3. Harkenrider MM, Block AM, Alektiar KM, Gaffney DK, Jones E, Klopp A, et al. American Brachytherapy Task Group Report: Adjuvant vaginal brachytherapy for early-stage endometrial cancer: A comprehensive review. *Brachytherapy*. 2017;16(1):95-108.
4. Van Limbergen E, Pötter R, Hoskin P, Baltas D. The GEC ESTRO handbook of brachytherapy. Part II Clinical Practice Version. 2019:1-30.
5. Kim H, Lee Y, Yoon H, Son T, Kim M. Comparative Dosimetric Study Using Various Applicators for Vaginal Cuff Brachy-therapy; Three Ovoid Technique Proposal. *J Oncology*. 2023;3(1):1084.
6. Banerjee R, Kamrava M. Brachytherapy in the treatment of cervical cancer: a review. *International journal of women's health*. 2014:555-64.
7. KHAN AA, VIJAY A, WANI SQ, Mohib-ul HAQ M. Vaginal Applicators in High-Dose Rate Brachytherapy for Endometrial Carcinoma: A Dosimetric Study. *Turkish Journal of Oncology/Türk Onkoloji Dergisi*. 2023;38(2).
8. Mohammadi MY, Momennezhad M, Nasserli S, Saatchian E, Eskandari A, Hosseini S, et al. The Importance of Organ-Specific Setup Uncertainties Assessment for Determination of the Planning Target Volume Margin in Prostate and Cervical Cancer Using Electronic Portal Imaging Device (EPID). *Iranian Journal of Medical Physics*. 2025;22(3):185-93.
9. Sturdza AE, Knott J. Image-guided brachytherapy in cervical cancer including fractionation. *International Journal of Gynecological Cancer*. 2022;32(3):273-80.
10. Nkiwane KS, Andersen E, Champoudry J, de Leeuw A, Swamidas J, Lindegaard J, et al. Total reference air kerma can accurately predict isodose surface volumes in cervix cancer brachytherapy. A multicenter study. *Brachytherapy*. 2017;16(6):1184-91.
11. Pötter R, Kirisits C, Erickson B, Haie-Meder C, Van Limbergen E, Lindegaard J. Prescribing, recording, and reporting brachytherapy for cancer of the cervix, ICRU report 89. Oxford: Oxford University Press; 2016.
12. Deshpande DD, Shrivastava SK, Nehru RM, Viswanathan PS, Dinshaw KA. Treatment volume from total reference air kerma (TRAK) in intracavitary applications and its comparison with ICRU reference volume. *International Journal of*

- Radiation Oncology\* Biology\* Physics. 1994;28(2):499-504.
13. Datta NR, Das KJM, Basu R, Singh U. Total reference air kerma: To what extent can it predict intracavitary volume enclosed by isodose surfaces during multiple high-dose rate brachytherapy? *Brachytherapy*. 2003;2(2):91-7.
  14. Robert N, Chauhan R, Oinam A, Rai B. Formulation of normal tissue irradiation volumes in Co-60 and Ir-192 HDR ICBT of Ca cervix using Total Reference Air Kerma (TRAK). *Reports of Practical Oncology and Radiotherapy*. 2019;24(6):568-75.
  15. Mourya A, Choudhary S, Sharma N, Shahi UP, Singh G, Pradhan S, et al. A mathematical model to predict the different isodose volumes using TRAK value in HDR intracavitary brachytherapy for revised Manchester and ICRU-89 based Point A plans using computer tomography images. *Journal of Cancer Research and Therapeutics*. 2022;18(4):1105-13.
  16. Yaparpalvi R, Mehta KJ. Correlation of total reference air-kerma (TRAK) to prescription isodose surface volume in vaginal cylinder high-dose-rate brachytherapy. *Journal of Contemporary Brachytherapy*. 2021;13(4):447-50.
  17. Yaparpalvi R, Kuo H-C, Hsu S-H, Goddard L, Mynampati DK, Mehta K. TRAK relates to prescription isodose surface volume and treatment time in vaginal cylinder HDR brachytherapy. *Brachytherapy*. 2019;18(3):S113.
  18. Nag S, Erickson B, Parikh S, Gupta N, Varia M, Glasgow G, et al. The American Brachytherapy Society recommendations for high-dose-rate brachytherapy for carcinoma of the endometrium. *International Journal of Radiation Oncology\* Biology\* Physics*. 2000;48(3):779-90.
  19. Rivard MJ, Coursey BM, DeWerd LA, Hanson WF, Saiful Huq M, Ibbott GS, et al. Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. *Medical physics*. 2004;31(3):633-74.
  20. Hofbauer J, Kirisits C, Resch A, Xu Y, Sturdza A, Pötter R, et al. Impact of heterogeneity-corrected dose calculation using a grid-based Boltzmann solver on breast and cervix cancer brachytherapy. *Journal of Contemporary Brachytherapy*. 2016;8(2):143-9.
  21. Thimmaiah N, Malavade V, AS UK, CR TP, Vishwanath L. Dosimetric Comparison of Isodose Surface Volume and Total Reference Air Kerma (TRAK) based Volume in Cervical Cancer Brachytherapy. *Asian Pacific Journal of Cancer Prevention: APJCP*. 2024;25(2):587.
  22. Harkenrider MM, Block AM, Siddiqui ZA, Small Jr W. The role of vaginal cuff brachytherapy in endometrial cancer. *Gynecologic oncology*. 2015;136(2):365-72.
  23. Sampath G, Anbazhagan S, Lokhande CD. Analysis of central vaginal cuff HDR brachytherapy using various cylinder sizes-literature review. *Onkologia i Radioterapia*. 2021;15(6).