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A REVIEW OF MONTE CARLO SIMULATION OF ORGANS AT RISK IN PROSTATE CANCER TREATMENT USING SPACER GEL IN NIGERIA

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ABSTRACT

In Nigeria, prostate cancer is a major burden in oncology due to its increasing incidence and mortality rates. The main curative treatment for localized disease is radiotherapy, but dose escalation required to achieve optimal tumour control is limited by the proximity of organs at risk (OARs) such as the rectum and bladder. The review examines the potential application of hydrogel spacers in prostate radiotherapy, the role that Monte Carlo (MC) simulation plays in accurate OARs dosimetry, the international evidence for the effectiveness of spacers, and the analysis of implementing feasibility within the Nigerian healthcare context. A narrative synthesis of peer-reviewed literature was conducted, focusing on hydrogel spacer applications, the MC dosimetry methodologies, the clinical outcomes from several trials executed in the settings of low- and middle-income countries, and infrastructure assessments of radiotherapy, in which specific emphasis was on Nigeria. Hydrogel spacers in international randomized controlled trials have shown to achieve a separation of 10-15 mm between the prostate and rectum, reducing rectal V70 Gy by 60-80% and decreasing late grade ≥2 rectal toxicity from 5-15% to 1-5%. The accuracy of MC simulation provides superior accuracy in modeling dose perturbations at the tissue-spacer interface to a greater extent, with errors reduced from >10% to <2%. However, there are significant barriers to its implementation in Nigeria, which include the 10-15 functional linear accelerators available for the over 220 million population, which is <0.05 per million versus the recommended >4 million, prohibitive spacer costs >$5,000 per procedure, scarcity of treatment planning systems that are MC-capable, and drastic shortages of qualified medical physics personnel. While hydrogel spacers combined with MC-based planning offer proven improvements in the therapeutic ratio of prostate radiotherapy, a variety of significant infrastructure, financing, and human resource challenges restrict the immediate implementation of these in Nigerian healthcare. Strategic investments in radiotherapy infrastructure, training of professionals, and conducting context-specific research are essential for everyone to access these advancements.

Keywords: Prostate cancer, radiotherapy, hydrogel spacer, Monte Carlo simulation, organs at risk, Nigeria, low-resource settings

Introduction

Prostate cancer is a significant healthcare challenge in Nigeria, with age-standardized incidence rates of 30 to 100,000 population well above the rest of Sub-Saharan Africa (1). This epidemiological burden is the consequence of various factors, including increasing life expectancy, food trends in Western countries, and insufficient measures for the early detection of the disease (2). The majority of Nigerian patients present with advanced stages of the disease due to low prostate-specific antigen screening, the lack of proper healthcare facilities, and poor socioeconomic barriers to timely diagnosis (2).

External beam radiotherapy (EBRT) is considered to be an essential component of the curative treatment of patients with localized prostate cancer. In this regard, the radiation oncological outcomes are comparable to those of radical prostatectomy across all risk groups (3). However, the therapeutic objective of dose escalation above 70-78 Gy to achieve better biochemical control is obstructed by the proximity of the organs at risk (OAR), particularly the rectum and bladder. The toxic effects of radiation on the body are the resulting cause of acute and late gastrointestinal and genitourinary complications, and this significantly affects the quality of life of the patient (3).

Hydrogel spacers, most notably polyethylene glycol-based products such as SpaceOAR, are used for this anatomical limitation by transperineal injection under transrectal ultrasound guidance, creating a temporary (3-6 months) separation of 10-15 mm between the prostate and the anterior rectal wall (4). The physical barrier that is produced by the hydrogel spacer allows for a reduction in the radiation dose to the rectum while at the same time improving the target coverage. The evidence from a randomized trial confirms that the toxicity benefits are sustained between 3-5 years post-treatment (5,6).

Monte Carlo (MC) simulation is so far one of the most optimal radiotherapy dose calculation strategies, as it uses concepts of stochastic modeling of photon and particle transport via heterogeneous media (7). While analytical algorithms work with simple heterogeneity corrections, the Monte Carlo (MC) approach accurately takes into consideration the pulse dose deficit at bounding media interfaces with divergent densities, a necessity in the case of hyaluronic acid gel spacers of low density (approximately 0.95 g/cm^3) for which the analytical engines can result in significant errors (7).

In settings with limited resources such as Nigeria, that is characterized by limited radiotherapy infrastructure and advanced treatment planning capabilities, the incorporation of hydrogel spacers together with MC-based dosimetry brings about both opportunities and difficulties. This review investigates: (1) the evidence base for hydrogel spacers in prostate radiotherapy, (2) the principles of MC simulation, the applications in dosage measuring, (3) the international evidence for MC modeling of spacer effects, and current Nigerian radiotherapy infrastructure, implementation barriers, and prospects for adopting these technologies.

Hydrogel Spacers in Prostate Radiotherapy

1. Mechanism of Action and Clinical Application

Hydrogel spacers function by creating physical separation between the prostate and anterior rectal wall, displacing the radiation-sensitive rectal mucosa from the site of the high-dose. SpaceOAR represents the most extensively studied product, which comprises polyethylene glycol, which polymerizes in situ after transperineal injection, and forms a biodegradable barrier that resorbs over 3-6 months (4). The procedure is performed under local or general anesthesia, with transrectal ultrasound guidance, typically immediately before the imaging for the radiotherapy planning is performed.

The pivotal stage III experimental controlled study carried out by Mariados et al. (5) proved that 98% of patients had a successful spacer placement, which resulted in a prostate-rectum separation of 12.6 mm (range 7-18 mm). This anatomical separation had a direct

dosimetric impact; a 73% reduction in volume of the rectum receiving 70 Gy (V70Gy) and the respective side effect levels decreased. Further observations after 3 years by Hamstra et al. (6) reported that rectal toxicity was reduced in the long term and the quality of life related to the bowel was preserved compared to control groups.

2. Dosimetric and Clinical Outcomes

A comprehensive systematic review and meta-analysis by Miller et al. (8), encompassing 17 studies with 1,987 patients, quantified the clinical impact of hydrogel spacers. Key findings included:

- **Dosimetric parameters:** Pooled analysis demonstrated a mean rectal V70 Gy reduction from 12.4% to 3.2% (74% relative reduction)
- **Acute toxicity:** Grade ≥2 rectal toxicity decreased from 9.8% to 2.1% (79% relative risk reduction)
- **Late toxicity:** Grade ≥2 late rectal toxicity reduced from 5.7% to 1.3% (77% relative risk reduction)
- **Quality of life:** Clinically meaningful improvements in bowel domain scores on expanded prostate cancer index composite (EPIC) questionnaires at 3 years

Subsequent meta-analyses have proven these findings across diverse treatment regimens, which have been typically fractionated (74-78 Gy in 37-39 fractions), moderately hypofractionated (60-70 Gy in 20-28 fractions), and stereotactic body radiotherapy (SBRT) schedules (9). The advantages of spacers in dosimetry become noticeable with hypofractionation, in which the rise in doses per fraction can lead to dangerous levels of OAR toxicity (10).

3. Safety Profile and Technical Considerations

The safety profile of hydrogel spacer insertion is favorable, with just <2% of the patients facing event-related issues during the procedure (8). Complications that were documented include short-term perineal distress, negligible urinary retention, and those that are extremely rare (<1%), infectious complications. The disadvantages of these procedures relate to the previous pelvic radiotherapy, active rectal inflammatory disease, and contraindications to transperineal needle placement. The SpaceOAR Vue, which is a radiopaque formulation, is a noteworthy addition that greatly assists in enhancing visualisation through CT as well as in verifying the position of the spacer during treatment (11). Alternative spacer materials, including biodegradable balloons and hyaluronic acid preparations, have been investigated but demonstrate inferior conformality and clinical evidence base compared to polyethylene glycol hydrogels (11).

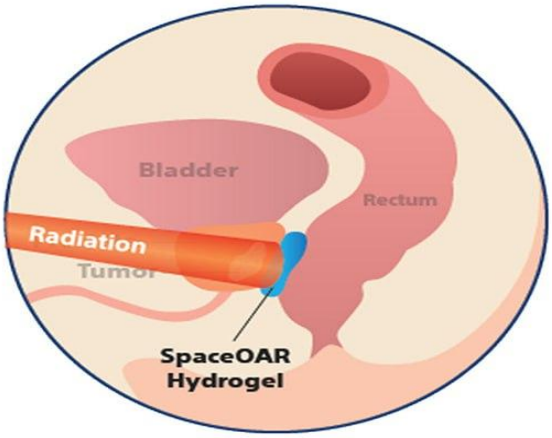


Figure 1. Sagittal view illustrating transperineal injection and placement of a polyethylene glycol-based hydrogel spacer (e.g., SpaceOAR) between the prostate and anterior rectal wall, creating a temporary ~12–15 mm separation to reduce rectal radiation exposure during prostate radiotherapy.

Monte Carlo Simulation in Radiotherapy Dosimetry

1 Fundamental Principles

Monte Carlo methods simulate radiation transport by tracking large numbers of individual particles (photons, electrons, positrons) through patient anatomy, with each particle's trajectory determined by random sampling from probability distributions based on physical interaction cross-sections (12). This stochastic approach accounts for all relevant physical processes, including photoelectric absorption, Compton scattering, pair production, and secondary electron transport.

The principal advantage of MC over deterministic analytical algorithms (pencil beam, collapsed cone convolution) lies in accurate modeling of charged particle disequilibrium at tissue interfaces, in low-density regions, and near high-Z materials (13). Analytical algorithms employ simplifying assumptions such as homogeneous water-equivalent media with one-dimensional density corrections, which introduce clinically significant errors in heterogeneous anatomies.

2 Clinical Implementation and Accuracy

Modern commercial treatment planning systems (Monaco® Elekta, RayStation® RaySearch, Eclipse™ Varian) incorporate MC algorithms for clinical use, with calculation times reduced from hours to minutes through variance reduction techniques and graphics processing unit (GPU) acceleration (14). Validation studies demonstrate MC accuracy within 2% of measured dose in heterogeneous phantoms, compared to errors exceeding 5-10% for pencil beam algorithms in similar conditions (15).

For prostate radiotherapy specifically, MC provides critical advantages in several scenarios (16):

- Prostate-rectum interface: Accurate modeling of backscatter and lateral electron transport
- Femoral head heterogeneity: Proper accounting for bone attenuation
- Rectal gas pockets: Correct handling of air-tissue interfaces
- Implanted fiducials: Modeling of dose perturbations from gold markers
- Hydrogel spacers: Accurate dosimetry at low-density interfaces

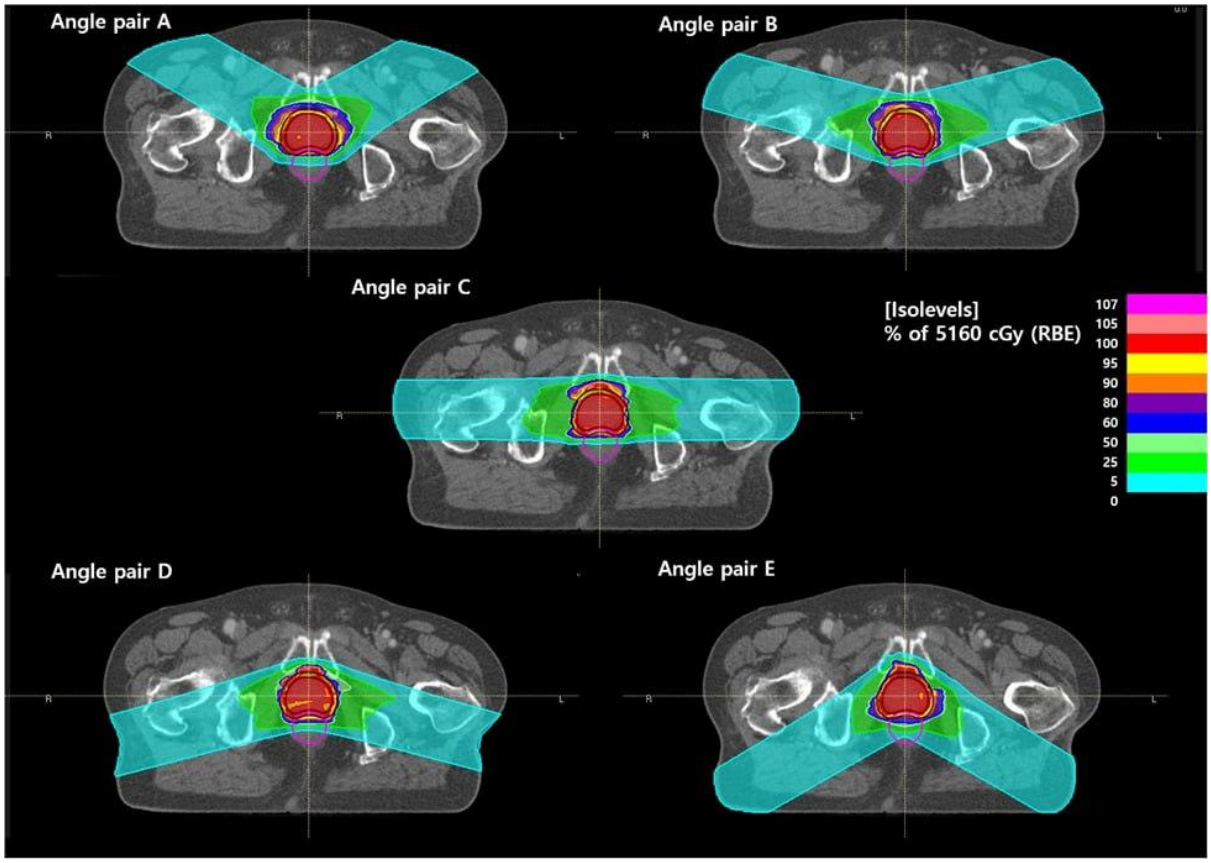


Figure 2: illustrates representative axial isodose distributions in advanced prostate radiotherapy planning, demonstrating high conformity to the planning target volume (PTV) with steep dose gradients and rectal sparing, features that are accurately modeled using Monte Carlo-based algorithms.

3 Proton Therapy Applications

In proton therapy, MC simulation is essential due to heightened sensitivity of Bragg peak position to tissue density variations (17). Analytical pencil beam algorithms may misestimate range by several millimetres in the presence of low-density spacers, potentially compromising target coverage or increasing OAR dose. MC accurately models reduced stopping power ratios in spacer regions and accounts for increased lateral scattering, providing range uncertainty estimates essential for robust treatment planning (17).

Monte Carlo Modeling of Spacer Gel Effects: International Evidence

1 Photon Beam Radiotherapy

Multiple international investigations have employed MC simulation to quantify and validate hydrogel spacer dosimetry. Schneider et al. (18) performed preclinical MC studies demonstrating that low-density hydrogels reduce rectal wall dose through combined effects of increased source-to-rectum distance, altered photon attenuation, and modified electron scatter patterns. These effects were most accurately modeled by MC compared to analytical algorithms, which overestimated rectal sparing by 10-15%.

Fischer-Valuck et al. (19) analyzed post-implantation CT scans from 45 patients receiving prostate SBRT with hydrogel spacers, using MC recalculation to evaluate dosimetric impact. Optimal rectal sparing correlated with symmetric spacer distribution (≥50% rectal circumference coverage), achieving median rectal V36 Gy reduction from 4.8 cm^3 to 1.2 cm^3 (75% reduction). Asymmetric spacer placement resulted in inferior but still clinically meaningful sparing (45% reduction).

Comparative algorithm studies by Eckerman et al. (20) demonstrated that analytical models systematically overestimate spacer benefits due to inadequate heterogeneity correction. In a phantom study comparing measured dose, MC (error <2%), and pencil beam algorithms (error 8-12%), analytical methods incorrectly predicted greater rectal sparing than physically achievable, potentially leading to underappreciation of residual toxicity risks.

2 Proton Beam Radiotherapy

Hedrick et al. (21) investigated the impact of hydrogel spacer on proton therapy uncertainty using a Monte Carlo (MC) simulation of 20 patient anatomies. Spacers reduced end-of-range uncertainty by 3-5 mm through elimination of rectal filling variability and provided consistent stopping power ratios. MC simulations revealed that pencil beam algorithms overestimated distal fall-off sharpness and underestimated range uncertainty, with clinically relevant differences in predicted rectal dose-volume metrics.

Wolf et al. (22) extended these findings using MC to evaluate spacer effects across proton therapy delivery techniques (passive scattering, uniform scanning, pencil beam scanning). Spacer presence reduced rectal biologically effective dose by 40-60% across all techniques, with MC confirming robustness against setup and range uncertainties. Iodinated spacer formulations demonstrated no clinically significant disruption to proton range while improving visualization for verification imaging (23).

3 Clinical Trial Integration

Contemporary clinical trials increasingly mandate MC-based dosimetry for spacer-containing treatment plans. The multi-institutional PROSPER trial (NCT03093428) incorporated MC recalculation for all patients receiving hydrogel spacer with dose-escalated radiotherapy (70 Gy in 28 fractions), demonstrating consistent OAR dose reduction across participating centres and enabling pooled toxicity analysis (24). Such standardization facilitates evidence generation and supports guideline recommendations for spacer use in dose-escalated and hypofractionated regimens (8, 25).

Application and Challenges in Nigeria

Nigeria is afflicted with a challenging prostate cancer situation, accounting for more than 13,000 new cases every year, along with high fatality rates inflicted by late presentation and a lack of curative options (1). Access to radiotherapy treatment is radically curtailed. At the beginning of 2026, there were only 10-15 linear accelerators that were in operation throughout the country and were available to serve a population that far exceeds 220 million, which is far below the recommended number of 100+ machines (28, 29). Regular breakdowns, power instability, and long waiting times (often >6 months) not only hinder but also compromise the outcome of the treatments (30, 31). There is no documented significant use of hydrogel spacer among Nigerian of, if not in the African region, due to prohibitive costs (>$5,000 per procedure), lack of transrectal ultrasound proficiency, and focus on basic radiotherapy delivery (32). MC simulations necessitate the use of advanced planning systems, powerful computers, commissioning design that has been validated, and medical physicists; unfortunately, these prerequisites are in extremely scarce supply amidst the mass emigration of skilled manpower and training gaps in the field (33). The majority of the centres rely on the cobalt machines or basic linacs with 3D conformal techniques, lacking MC and image-guided capabilities (29).

On the other hand, emerging investments, such as a forecast of the procurement of 35 machines by 2028 and the building of new Oncology Centers (e.g., NSIA partnerships), are seen as positive developments (34). The local research in MC-based radiotherapy that will

utilize a few Nigerian patient examples in simulating the effects of a spacer is going to be advantageous in the demonstration of feasibility and cost-effectiveness, whereas, through co-operations, the centres will be empowered (35).

Metric	Without Spacer	With Spacer	Relative Reduction	Key References
Rectal V70 Gy (%)	10–20%	2–5%	70–80%	Mariados et al. (2015), Miller et al. (2020)
Mean rectal dose (Gy)	~40–45 Gy	~30–35 Gy	25–50%	Hamstra et al. (2017), Tehrani et al. (2023)
High-dose rectal volume (V75 Gy)	Higher	Significantly reduced	>50%	Meta-analyses (2020–2025)
Late grade ≥2 rectal toxicity	5–15%	1–5%	50–75%	Phase III trials & real-world data

Table 1: *Summary of Rectal Dosimetric Reductions with Hydrogel Spacers (International Evidence from Key Trials and Meta-Analyses)*

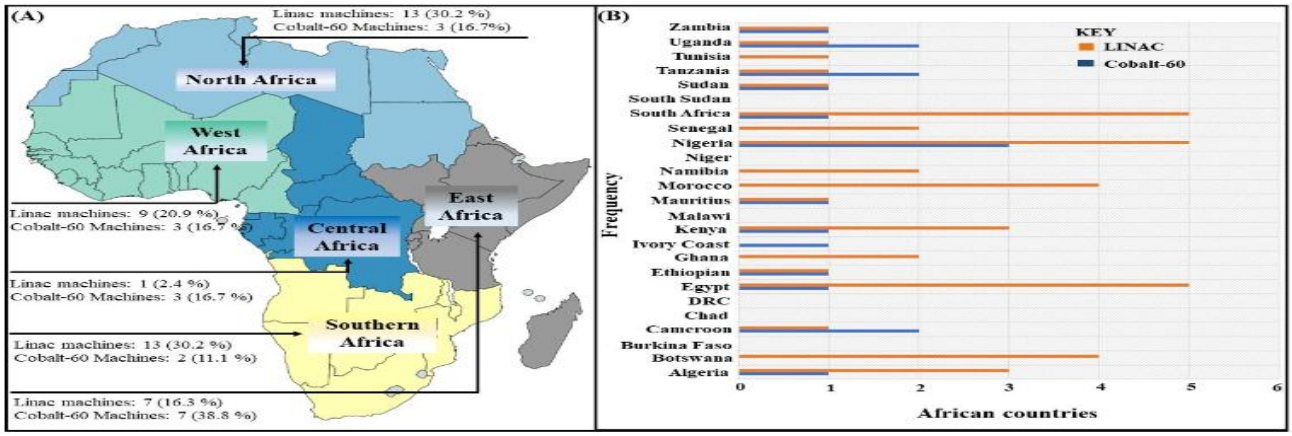


Figure 3. *Distribution of radiotherapy machines (linear accelerators and Cobalt-60 units) across Africa as of recent surveys, demonstrating the severe scarcity in Nigeria and sub-Saharan Africa relative to population needs and international recommendations*.

Parameter	Value/Statistic	Comparison/Notes
Population (approx.)	>220 million	One of the largest in Africa
Functional Radiotherapy Machines	~15 (mostly LINACs, some Cobalt-60)	Includes recent additions; frequent breakdowns reported
Recommended/Needed Machines	~120	Based on the incidence and IAEA guidelines
Machines per Million Population	<0.1	Far below global averages (e.g., >4 in high-income countries)
Access Challenges	Long waiting times (>6 months), power instability, and limited advanced systems	Concentrated in urban centers (e.g., Lagos, Abuja)

Table 2. *Current radiotherapy infrastructure in Nigeria (2025–2026 data) compared to the recommended needs.*

Discussion

This review synthesizes evidence demonstrating that hydrogel spacers, in conjunction with MC-based treatment planning, significantly increase the therapeutic ratio in prostate radiation therapy. The use of international randomized trials and meta-analyses has led to a conclusive determination of the effectiveness of spacers in reducing rectal toxicity across various radiation fractionation schedules, and the sizes of the effects are large enough to justify the usefulness of the spacers in the case of dose-escalated and hypofractionated regimens (5,6,8). MC simulation is the only way to achieve the dosimetric accuracy necessary for the treatment of patients with spacers. It is used to correct tissue heterogeneity effects, which are not handled properly by analytical algorithms (20,21).

The Nigerian context is quite perplexing. The population has a cancer burden that is considerably high; it is this same disease that would best serve treatment advances, but there is an existence of infrastructure, economic, and manpower issues that are themselves limiting the adoption of the very changes required. Lack of only 10-15 functional linear accelerators for about 220 million people means that access to basic radiotherapies is also still very much a problem in nearly all of the parts of the country of Nigeria (26, 27). Costs of a spacer, which go beyond the usual annual costs of healthcare, make them unaffordable without a subsidy or alternative funding source.

However, the trajectory of Nigerian radiotherapy development offers opportunities for strategic integration of advances. New facility development and equipment procurement present opportunities to incorporate MC-capable planning systems and train personnel in advanced techniques. Context-specific implementation research, potentially supported by international partnerships, could establish evidence for spacer use in Nigerian populations and develop cost-effective delivery models (34).

Conclusion

This review confirms that hydrogel spacers, validated through Monte Carlo simulation, achieve significant and clinically measurable reductions in rectal toxicity during prostate radiotherapy. MC studies demonstrate that spacers reduce rectal V70 Gy by 60-80% with dosimetric accuracy within 2%, compared to 10-15% errors in analytical algorithms, translating to reduction of grade ≥2 late rectal toxicity from 5-15% to 1-5% (8,18-20). For hypofractionated regimens particularly relevant in resource-constrained settings MC-verified spacer effects enable safe delivery of shortened treatment courses, potentially increasing patient throughput by 40-60%. In the Nigerian context, these findings support strategic prioritization of MC-capable planning systems during equipment procurement and context-specific MC modeling using local patient data to quantify expected benefits. While infrastructure and cost barriers currently limit spacer availability, the quantitative evidence provides clear rationale for investment as facilities expand, ensuring future adoption delivers proven toxicity reductions.

References

1. Adeloye D, David RA, and Aderemi AV. An estimate of the incidence of prostate cancer in Africa: a systematic review and meta-analysis. PLoS One. 2016;11(4): e0153496.
2. Odedina FT, Akinremi TO, and Chinegwundoh F. Prostate cancer disparities in Black men of African descent: a comparative literature review. Lancet Oncol. 2016;17(10): e430-e438.
3. Hamstra DA, Mariados N, and Sylvester J. Continued benefit to rectal separation for prostate radiation therapy: final results of a phase III trial. Int J Radiat Oncol Biol Phys. 2017;97(5):976-985.
4. Pinkawa M. Spacer application for prostate cancer radiation therapy. Future Oncol. 2014;10(5):775-786.
5. Mariados N, Sylvester J, Shah D, et al. Hydrogel spacer prospective multicenter randomized controlled pivotal trial: 12-month follow-up. Int J Radiat Oncol Biol Phys. 2015;93(3): S1-S2.
6. Hamstra DA, Mariados N, Sylvester J, et al. Continued benefit to rectal separation for prostate radiation therapy: final results of a phase III trial. Int J Radiat Oncol Biol Phys. 2017;97(5):976-985.
7. Chetty IJ, Curran B, Cygler JE, et al. Report of the AAPM Task Group 105: issues associated with clinical implementation of Monte Carlo-based photon and electron external beam treatment planning. Med Phys. 2007;34(12):4818-4853.
8. Miller LE, Efstathiou JA, Bhattacharyya SK, et al. Association of the placement of a perirectal hydrogel spacer with the clinical outcomes of men receiving radiotherapy for prostate cancer: a systematic review and meta-analysis. JAMA Netw Open. 2020;3(6):e208221.
9. Tehrani FJ, Krempien R, Krempien M, et al. Comprehensive review of hydrogel spacers prior to radiation therapy for prostate cancer. BJU Int. 2023;131(1):13-21.
10. Hedrick SG, Fagundes M, Robison B, et al. Hydrogel rectum-prostate spacers mitigate the uncertainties in proton therapy of the prostate with full bladder. Acta Oncol. 2017;56(5):663-669.
11. Chao M, Ho H, Chan Y, et al. Application of a radiopaque viscous hydrogel spacer for prostate cancer radiation therapy. Pract Radiat Oncol. 2024;14(1):45-52.
12. Andreo P. Monte Carlo techniques in medical radiation physics. Phys Med Biol. 1991;36(7):861-920.
13. Ma CM, Li J. Dose calculation and verification for photon beam radiotherapy with Monte Carlo methods. Med Phys. 2011;38(Suppl 1):S164.
14. Wilcox EE, Daskalov GM, Pavlović R, et al. Accuracy of dose calculations in prostate radiotherapy using Monte Carlo. J Appl Clin Med Phys. 2010;11(3):200-210.
15. Fragoso M, Pillai S, Solberg TD, et al. Experimental verification of a commercial Monte Carlo-based dose calculation algorithm for prostate cancer treatment planning. Phys Med Biol. 2010;55(24):7361-7374.
16. Schneider U, Hälg RA, Besserer J. Monte Carlo simulation of a prostate gold seed marker with a spacer. J Appl Clin Med Phys. 2022;23(5):e13578.
17. Wolf J, Schneider U, Hälg RA. Hydrogel rectum-prostate spacers mitigate the uncertainties in proton therapy of the prostate with full bladder. Acta Oncol. 2017;56(5):663-669.
18. Hissoiny S, Ozell B, Després P. Fast Monte Carlo dose calculation using GPU technology for radiotherapy. Med Phys. 2011;38(12):6549-6557.
19. Götstedt J, Karlsson H, Kero T, et al. Monte Carlo simulations for dosimetry in prostate radiotherapy with different intravesical volumes. PLoS One. 2016;11(7):e0159497.
20. Schneider U, Vees H, Besserer J, et al. Preclinical investigations towards the first spacer gel application in prostate cancer treatment. Phys Med. 2013;29(3):258-262.
21. Fischer-Valuck BW, Chundury A, Gay H, et al. Hydrogel spacer distribution and dosimetric impact on rectal sparing in prostate SBRT. J Appl Clin Med Phys. 2024;25(1):e14294.
22. Eckerman KF, et al. Systematic study of the iodinated rectal hydrogel spacer material effect on the proton dose. Med Phys. 2022;49(10):6525-6535.
23. Hedrick SG, Fagundes M, Robison B, et al. Hydrogel rectum-prostate spacers mitigate the uncertainties in proton therapy. Acta Oncol. 2017;56(5):663-669.
24. Wolf J, et al. Hydrogel rectum-prostate spacers in proton therapy. Acta Oncol. 2017.
25. Eckerman KF, et al. Systematic study of the iodinated rectal hydrogel spacer. Med Phys. 2022.

26. Alongi F, et al. Hydrogel spacers in prostate radiotherapy: a promising approach to decrease rectal toxicity. Future Oncol. 2021;17(24):3237-3246.
27. Alongi F, et al. Rationale for utilization of hydrogel rectal spacers in dose escalated SBRT for prostate cancer. Front Oncol. 2022;12:860848.
28. Duncan OC, Irabor OC, et al. Infrastructural challenges lead to delay of curative radiotherapy in sub-Saharan Africa: the case of Nigeria. JCO Glob Oncol. 2020;6:271-276.
29. BusinessDay. Nigeria needs 120 cancer treatment machines but has only 15 - report. 2025. Available from: https://businessday.ng/health/article/nigeria-needs-120-cancer-treatment-machines-but-has-only-15-report
30. Oboh AE, et al. Radiotherapy waiting time in Northern Nigeria. Afr J Med Med Sci. 2020.
31. Irabor OC, et al. Radiotherapy in Nigeria: a silent emergency in cancer care. Lancet Oncol. 2023.
32. Vanderpuye V, et al. Expanding radiotherapy access in Sub-Saharan Africa. Lancet Oncol. 2023.
33. Abdel-Wahab M, et al. Global radiotherapy challenge: the gap between need and access. Lancet Oncol. 2023.
34. News Agency of Nigeria. FG activates 8 oncology clinics, unveils new cancer plans. 2026. Available from: https://nannews.ng/2026/02/04/fg-activates-8-oncology-clinics-unveils-new-cancer-plans
35. Zubizarreta E, et al. Need for radiotherapy in Africa. Lancet Oncol. 2023.