Chula Med J. September - October 2025;69(5): 299 - 306 **DOI : 10.56808/2673-060X.**5569

Original article

Organs at risk receiving therapeutic doses during prostate cancer treatment using intensity modulated and three-dimensional conformal radiotherapies: a comparative study

Talib Abdulwahid[a], Hussien Mraity[a], Mustafa Al-Aseebee[a, b], Zeyad Al-Dulaimi[c], Ali Abid Abojassim[a, *]

[a]*Department of Physics, Faculty of Science, University of Kufa, Al-Najaf, Iraq*
[b]*Middle Euphrates Cancer Center, Al-Najaf, Iraq*
[c]*The Islamic University, College of Medical Technology, Radiology Techniques Department, Al-Najaf, Iraq*

Abstract

Background: The radiotherapy domain imposes undesired risks of radiation exposure to normal tissues surrounding the tumor. To address this issue, treatment planning systems are being developed to obtain a perfect therapeutic method, as the organs surrounding prostate tumors are sensitive to high doses of radiation.
Objective: This study compared the efficiencies of three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiation therapy (IMRT) techniques and calculated the radiation dose that actually reaches specific organs in prostate cancer patients.
Methods: This cross-sectional study, from Najaf, Iraq, involved 25 prostate tumor patients who were enrolled for treatment. They underwent computerized tomography (CT) scans, 3D-CRT using X-ray beams, and IMRTs. 3DCRT enhanced protection ability. All doses applied to the organs at risk were within the tolerance limits. An ethical pre-approval was obtained from the Institutional Review Board, No. MEC-87.
Results: IMRT better protected most radiation-sensitive normal tissues, while other organs also require shielding, depending on the patient's status.
Conclusion: IMRT better protects most normal tissues, i.e., right and left femoral heads, and bladder, while 3DCRT better safeguards other organs, such as the rectum, depending on the patient's status.

Keywords: CT scans, intensity-modulated radiation therapy, organs at risk (OAR) dose, radiotherapy, three-dimensional conformal radiotherapy.

In radiotherapy using an external photon beam, a majority of treatments involve beams with uniform intensities across the field. Wedges are often used to adjust the beam intensity, trade off tissue contour irregularities, and further achieve uniform dose distributions, a process known as intensity modulation.[1]

*correspondence to: Ali Abid Abojassim, Department of physics, Faculty of Science, University of Kufa, Al-Najaf, Iraq
E-mail: ali.alhameedawi@uokufa.edu.iq
Recerved: December 24, 2024
Revised: August 13, 2025
Accepted: September 15, 2025

Intensity modulated radiation therapy (IMRT) is a technique that uses radiation at a non-uniform intensity. Such an ability allows doses with better conformity to the planning target volume (PTV) and avoids affecting the organs at risk (OAR). The growing complexity of IMRT demands an efficient and systematic quality assurance (QA) program regarding precision treatment delivery machines and treatment planning systems (TPSs).[2, 3] IMRT has been applied for the treatment of prostate cancer for less than a decade and is an evolving technology within radiation oncology. Thus, it is being carefully evaluated for conformity.[4, 5]

IMRT provides lower toxicity and higher survival rates during the treatment of a variety of diseases, including prostate tumors. It also allows for the distribution of doses with varying intensities to multiple targets, allowing versatility in instantenously integrated boosted treatments. IMRT is an inverse planning technique, and finding an accurate dose delivery solution is complex, resulting in non-uniform dose distributions across targets. In contrast, the 3D-CRT (forward-planning approach) employs a uniform beam profile to generate homogeneous dose distributions when prepared properly.[6]

The critical normal structures are tissue types that could experience severe morbidity if irradiated, thereby affecting treatment preparation and dose prescriptions. Not all radiologically targeted tissues may, in theory, be considered as an OAR. However, the designation of normal tissues as OAR in clinical practice typically depends on their radiosensitivity and the dosage to which their total or fractional volume is exposed in terms of the recommended dose.[7] The head and neck region includes various intricately arranged organs vital for fundamental physiological functions and is essential for appearance, speech, and social interactions. While accounting for ~4% of all cancers, these organs are divided into two types: parallel and serial.[8, 9] In parallel organs, all subunits are functionally homologous, and the total organ output is the sum of the functional outputs of each subunit. In serial organs, functional damage to one subunit results in harm to the entire organ.[10, 11]

During radiotherapy sessions, ionizing radiation from a linear accelerator (LINAC) is directed at the tumor or the area from which it has been excised. Even though radiation is focused on a target area, the adjacent organs are inevitably irradiated. Since several techniques are used to direct these ionizing rays onto the target (i.e., 3D-CRT and IMRT), it has become necessary to study the one that concentrates the maximum levels of radiation doses at the region of interest while minimizing exposure to the adjacent healthy tissues or organs, saving them from being irradiated.[12]

This research aimed to determine which of the two techniques, i.e., 3D-CRT or IMRT, achieved the least radiation exposure to the OARs, such as the femoral head, bladder, rectum, and pelvic area, in prostate cancer patients. Such investigations in this regard are unavailable within the current body of knowledge, at least in Iraq, and specifically, prostate cancer.

Materials and methods

In this prospective study, 25 patients, 60–100 kg, 40–90 years old, and diagnosed with prostate tumors from 2020 to 2022 were selected from the National Center of Cancer, Najaf, Iraq. The treated sites were scanned with 3D computed tomography (CT). The radiation oncologist prescribed the dose emitted by the DHX linear accelerator (Varian Medical Systems, CA, USA) and delineated the target volumes. The TPS, "Eclipse 13" was adopted for contouring and dose comparison concerning the OARs. The OARs considered in this study were the right and left head femur, the rectum, and the bladder. Physical planning employed two techniques: 3DCRT and IMRT of a step-and-shoot type. Statistical analysis employed the Statistical Package for the Social Sciences software package 20. Data were expressed as means ± standard deviation(SD). Inter group comparisons employed a t-test. $P < 0.05$ was considered statistically significant.

IMRT was used for dose calculation via TPS, achieved through several stages. The first step is a CT scan, followed by determining the field size to identify the tumor. A dose calculation algorithm then determined the radiation dose by applying Equation 1; calibration and correction factors were ascertained using the Monte Carlo program. To ensure quality, the beam output and specified dose were tested before radiation therapy. The TPS calculates the MU for each segment by employing the following equations[13, 14]:

$$\text{Dose (cGy)} = \sum_{i=1}^{n} MU_i \times (\text{cGy/MU})_i \quad \text{.....................1}$$

Calculating the optimal dose for a specific tumor is more straightforward with 3D conformal radiotherapy than with IMRT, as this technology incorporates advanced planning and imaging. After precise CT scanning, the tumor size (target volume) was determined, and the organs at risk were identified. After ascertaining the collimator direction, dose calculation using the TPS employed a dose distribution calculated based on the beam data for the LINAC and patient anatomy (assessed using CT). Dose calculation algorithms for a specific point were calculated using Equation 2.[15]

$$D = MU \times (\text{cGy/MU})_{ref} \times CF \quad \text{.....................2}$$

Where:
MU, Monitor Units per beam; $(cGy/MU)_{ref}$, Calibration dose rate; and CFs, Correction factors for: Beam energy; Tissue depth (via PDD, TMR, or TAR); Field size (output factors); SSD/SAD distance (inverse square correction); and Beam modifiers (wedge factors, etc.)

Results and discussion

The results of the statistical analyses of the actual dose intensity reaching the organs at risk in patients treated with 3DCRT and IMRT are shown in **Table 1.** The organs at risk examined were the right and left head femur, the rectum, and the bladder. No significant differences were detected in the organs at risk between the two techniques, except for the right head femur, PTV tumor region at average dose values, and the rectum. However, the bladder demonstrated highly marked variations at an average dose value.

On observing and comparing the average radiation doses **(Table 1),** 3DCRT results indicated its ability to protect the organs at risk more efficiently than IMRT for the rectum, CT scan body, and PTV **(Figure 1)** except for the right/left femoral heads and the bladder, where IMRT demonstrated a lower necessary dose than 3DCRT **(Figure 2). Figure 3** shows the distribution of radiation doses between 3DCRT and IMRT used for prostate cancer radiotherapy. The prescribed dose was typically restricted by the tolerance levels of the organs at risk and the ability of the irradiation technique to preserve such normal tissues. Hence, depending on the technique used, the benefits of any new treatment method may derive from an increase in the likelihood of tumor cure, a decrease in that of patient damage, or both. It is critical to protect the organs at risk. Because cancer patients must not be exposed to early- or late-stage radiation-associated toxicity, it is extremely essential to preserve the healthy tissues from damage. A very sensitive organ may be found near the prostate. This research covered a majority of the surrounding organs of the prostate, confirming that the planning strategy adopted was safe.

Data analysis demonstrated that 3DCRT delivered a lower radiation dose than IMRT to the rectum, considering CT scans and PTV. In contrast, the IMRT supplied superior doses to the other organs studied (i.e., right and left femoral heads as well as the bladder).

Pardo-Montero, *et al.* and Banaei A, *et al.*[16, 17] evaluated the radiobiological influence of IMRT on prostate tumors. IMRT, as inversely optimized, was significantly radiobiologically and dosimetrically superior to 3DCRT or the so-called conventional planning technique. Concerning prostate damage, the number of injuries decreased by 20.0% when the dosage did not exceed the 45 Gy allowed. Radiation-based treatment of prostate tumors also impacts the most essential organs, such as the rectum and the bladder. Generally, no highly irradiated tissues were observed, and thus were not defined.[14-17]

The protective effects of 3DCRT on normal tissues and organs were reported.[18-20] with special focus on prostate cancer. They found out that the effects of the doses received by all prostate cancer patients were consistent with those expected of the planning technique. These findings agreed with our results, where the compatibility was superior to that of the IMRT. Luxton G, *et al.*[21] reported a better protection for prostate cancers with IMRT.

Table 1. A comparison of the dose reached to the organs at risks using the 3DCRTand the IMRT treatment planning techniques.

No.	OAR	3DCRT (Gy)			IMRT (Gy)			*P* – value
		minimum	maximum	Average	minimum	maximum	Average	
1	Rt. head femur	2.1 ± 1.3	43.3 ± 7.6	26.5 ± 6.7	2.5 ± 1.8	41.4 ± 6.7	21.0 ± 4.6	0.002*
2	Lt head femur	2.3 ± 2.3	43.0 ± 7.6	25.0 ± 7.2	2.4 ± 2.0	42.5 ± 8.9	21.1 ± 4.4	0.025
3	Rectum	4.9 ± 6.9	60.9 ± 2.3	30.5 ± 8.8	3.4 ± 2.8	62.8 ± 1.3	33.6 ± 11.3	0.288
4	Bladder	5.5 ± 12.2	62.6 ± 1.1	27.5 ± 10.5	2.9 ± 5.4	63.5 ± 1.0	26.1 ± 11.1	0.651
5	CT-scan Body	0.0 ± 0.0	63.3 ± 1.0	3.8 ± 1.6	0.0 ± 0.0	63.7 ± 0.8	5.9 ± 10.4	0.320
6	PTV	48.3 ± 8.6	63.3 ± 1.0	61.3 ± 1.5	57.6 ± 3.4	63.7 ± 0.8	62.4 ± 1.0	0.005*

*Significant difference at a level less than 0.05.

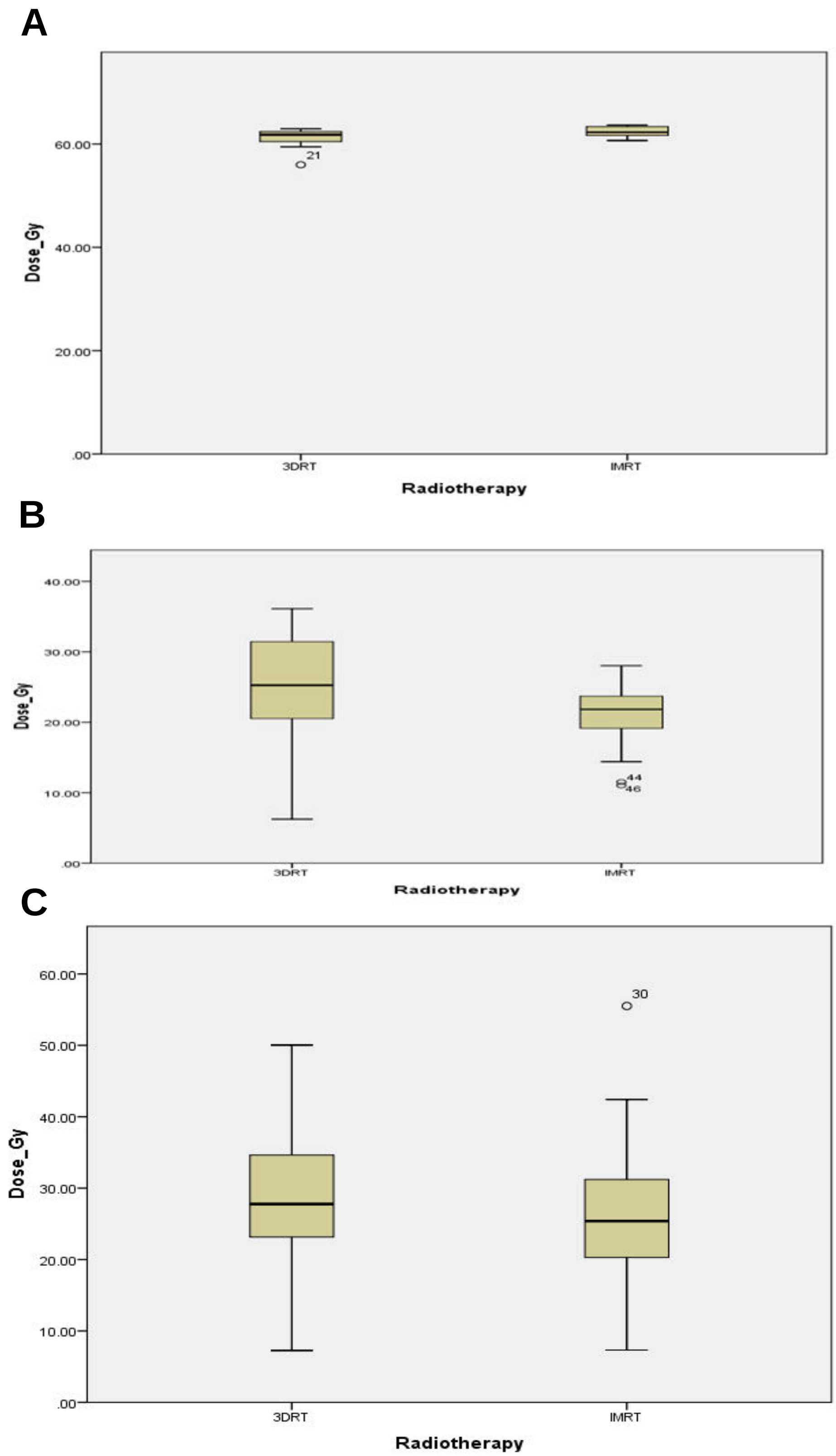

Figure 1. (A) The dose spared to PV (average) using the 3DCRT and the IMRT treatment planning techniques; **(B)** The dose spared to the right head femur (average) using the 3DCRT and the IMRT treatment planning techniques; and **(C)** The dose spared to bladder (average) using the 3DCRT and the IMRT treatment planning techniques. IMRT, intensity-modulated radiation therapy; 3DCRT, three-dimensional conformal radiotherapy.

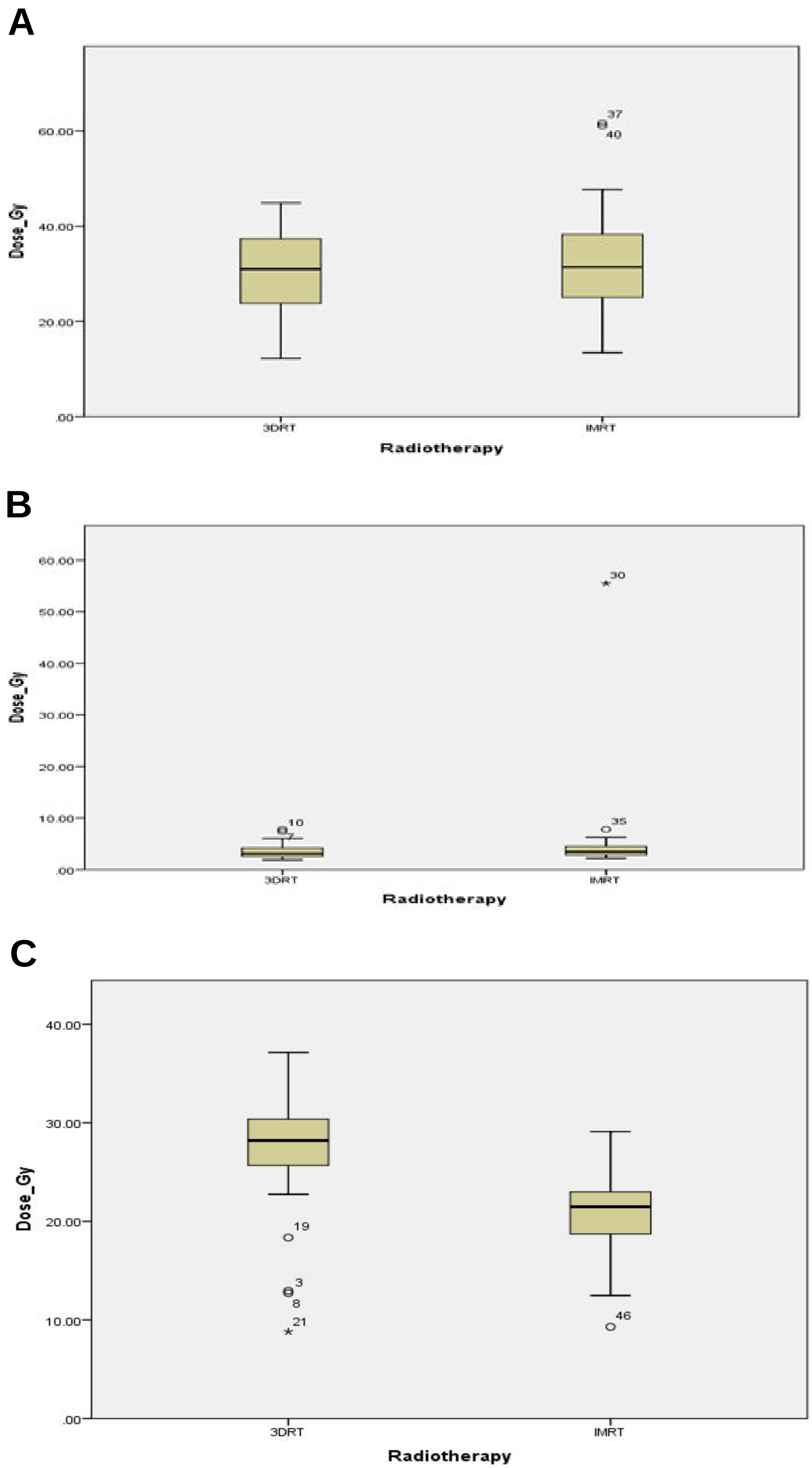

Figure 2. (A) The dose spared to the rectum (average) using the 3DCRT and the IMRT treatment planning techniques; **(B)** The dose spared to CT- scan body (average) using the 3DCRT and the IMRT treatment planning techniques; and **(C)** The dose spared to the right head femur (average) using the 3DCRT and the IMRT treatment planning techniques. IMRT, intensity-modulated radiation therapy; 3DCRT, three-dimensional conformal radiotherapy.

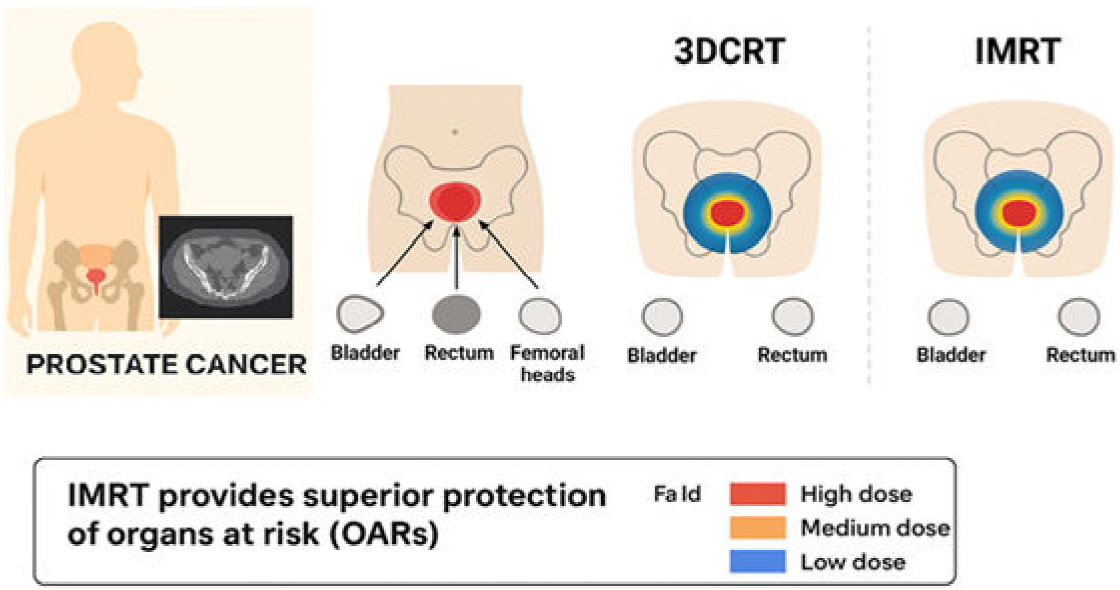

Figure 3. Comparison of 3DCRT and IMRT in prostate cancer radiotherapy: dose distribution and protection of organs at risk. IMRT, intensity-modulated radiation therapy; 3DCRT, three-dimensional conformal radiotherapy.

Fiandra C, *et al.*[22] supported our findings of lower radiation dose exposure to the surrounding healthy tissues/organs. Nevertheless, such an outcome was much better with IMRT distal than 3DCRT regarding rectal cancer. Arbea L, *et al.*[23] compared the effects of the 3DCRT and IMRT plans on non-spherical intracranial targets, and found that IMRT delivered a decreased radiation dose to healthy prostate glands. Recent studies[24-26] indicated no significant differences in the maximum doses delivered to the small bowels, rectum, and bladder in cervical cancer patients between 3DCRT and IMERT.[27-29]

IMRT, as an inverse planning strategy, can easily generate an optimal plan for a large target, as used in a previous investigation.[29] It reported that IMRT was more effective than 3DCRT in curing cancers, particularly those with irregular forms and proximal to vital organs. Additional improvements in treatment outcomes may be expected when intensity modulation is added to a fixed-field configuration, as shown previously.[30-34]

Conclusion

This study is unique in that the amounts of radiation dosages received by the organs directly in the path of the radiation beam were calculated using two techniques: 3DCRT and IMRT during the physical planning stage. Based on these observations, it can be suggested that these two techniques allowed the least amount of radiation doses to reach the surrounding OARs.

The step-and-shoot IMRT better protected most radiation-sensitive, normal tissue structures, including right and left femoral heads, and the bladder. However, while other organs, such as the rectum, need to be protected from the adverse effects of the 3DCRT technique, depending on the patient's status, as indicated by CT scans and PTVs.

Acknowledgements
We thank the staff of the Al Najaf Teaching and Middle Euphrates hospitals for facilitating tumor treatment studies as well as for their help and cooperation, which enabled us to complete this study.

Conflicts of interest
There is no conflict-of-interest statement.

Data sharing statement
The datasets generated and analyzed during this current study are available with the corresponding author and can be provided upon reasonable request.

References

1. Khan FM, Sperduto PW, Gibbons JP. Khan's Treatment Planning in Radiation Oncology: Lippincott Williams & Wilkins; 2021.
2. Lu W, Li Y, Huang W, Cui H, Zhang H, Yi X. Optimizing the region for evaluation of global gamma analysis for nasopharyngeal cancer (NPC) pretreatment IMRT QA by Compass: a retrospective study. Front Oncol 2022;12:859415.
3. Yi J, Han C, Zheng X, Zhou Y, Deng Z, Xie C, et al. Individual volume-based 3D gamma indices for pretreatment VMAT QA. J Appl Clin Med Phys 2017; 18:28–36.
4. Nguyen NP, Ceizyk M, Vock J, Vos P, Chi A, Vinh-Hung V, et al. Feasibility of image-guided radiotherapy for elderly patients with locally advanced rectal cancer. PLoS One 2013;8:e71250.
5. Zhao W, Shen L, Islam MT, Qin, W, Zhang Z, Liang X. Artificial intelligence in image-guided radiotherapy: a review of treatment target localization. Quant Imaging Med Surg 2021;11:4881.
6. Mallick S, Rath GK, Benson R. Practical Radiation Oncology: Springer; 2019.
7. Kilpatrick SK, Ecker JL, Obstetricians ACo, Gynecologists. Severe maternal morbidity: screening and review. Am J Obstetrics Gynecol 2016;215: B17–B22.
8. Tharmalingam H, Choudhury A, Van Herk M, McWilliam A, Hoskin PJ. New approaches for effective and safe pelvic radiotherapy in high-risk prostate cancer. Nat Rev Urol 2019;16:523–38.
9. Zuppone S, Bresolin A, Spinelli AE, Fallara G, Lucianò R, Scarfò F, Cozzarini C. Pre-clinical research on bladder toxicity after radiotherapy for pelvic cancers: state-of-the art and challenges. Front Oncol 2020;10:527121.
10. Tommasino F, Nahum A, Cella L. Increasing the power of tumour control and normal tissue complication probability modelling in radiotherapy: recent trends and current issues. Transl Cancer Res 2017;6:S807–21.
11. Mir R, Kelly SM, Xiao Y, Moore A, Clark CH, Clementel E, et al. Organ at risk delineation for radiation therapy clinical trials: Global Harmonization Group consensus guidelines. Radiotherapy Oncol 2020;150:30–9.
12. Biega³a M, Hydzik A. Analysis of dose distribution in organs at risk in patients with prostate cancer treated with the intensity-modulated radiation therapy and arc technique. J Med Physics/Assoc Med Physicists India 2016;41:198.
13. Abdulwahid TA, Bakir HA, Alsabari IK. Study the possibility of theoretically reducing the number of radiation sessions for patients with skin cancer using nanoparticles. In AIP Conference Proceedings: AIP Publishing; 2020;2290:1.
14. Khan FM, Gibbons JP. Khan's the physics of radiation therapy: Lippincott Williams & Wilkins; 2014.
15. Abdulwahid TA, AlQurashi NAJ, Alsabari IK, Abojassim AA, Jassim AS. Effect of manipulating the radiation treatment technique on the radiotherapy sessions. J Neonatal Surg 2025;14:80–6.
16. Pardo-Montero J, González-Crespo I, Gómez-Caamaño A, Gago-Arias A. Radiobiological meta-analysis of the response of prostate cancer to different fractionations: evaluation of the linear–quadratic response at large doses and the effect of risk and ADT. Cancers 2023;15:3659.
17. Banaei A, Hashemi B, Bakhshandeh M, Mofid B. Evaluation of various common prostate IMRT techniques based on estimated tumor control and normal tissue complication probabilities in correlation with patients anatomical parameters derived from the CT scans. Polish J Med Phys Eng 2019;25:35–41.
18. Bayley A, Rosewall T, Craig T, Bristow R, Chung P, Gospodarowicz M, et al. Clinical application of high-dose, image-guided intensity-modulated radiotherapy in high-risk prostate cancer. Int J Radiat Oncol Biol Phys 2010;77:477–83.
19. Nagar H, Spratt DE. Prostate SBRT dose escalation (9 Gy/ ×/ 5, 13.3 Gy/ ×/ 3, 24 Gy/ ×/ 1): are we making progress? Int J Radiat Oncol Biol Phys 2021;111:110-2.
20. Diven M, Hakansson A, Liu Y, Davicioni E, Dillard A, Khani F. Dynamic changes of molecular subtype classification and genomic classifier scores in high-risk prostate cancer patients undergoing pre-operative stereotactic body radiation therapy. Int J Radiat Oncol Biol Phys 2023;117:e377.
21. Luxton G, Hancock SL, Boyer AL. Dosimetry and radiobiologic model comparison of IMRT and 3D conformal radiotherapy in treatment of carcinoma of the prostate. Int J Radiat Oncol Biol Phys 2004;59:267–84.
22. Fiandra C, Filippi AR, Catuzzo P, Botticella A, Ciammella P, Franco P, et al. Different IMRT solutions vs. 3D-conformal radiotherapy in early stage Hodgkin's lymphoma: dosimetric comparison and clinical considerations. Radiat Oncol 2012;7:186.
23. Arbea L, Ramos LI, Martínez-Monge R, Moreno M, Aristu J. Intensity-modulated radiation therapy (IMRT) *vs*. 3D conformal radiotherapy (3DCRT) in locally advanced rectal cancer (LARC): dosimetric comparison and clinical implications. Radiat Oncol 2010;5:1–9.
24. Mesbahi A, Rasouli N, Mohammadzadeh M. Comparison of radiobiological models for radiation therapy plans of prostate cancer: three-dimensional conformal versus intensity modulated radiation therapy. J Biomed Phys Eng 2019;9:267.
25. Yu M, Lee JH, Jang HS, Jeon DM, Cheon JS, Lee HC, Lee JH. A comparison of dosimetric parameters between tomotherapy and three-dimensional conformal radiotherapy in rectal cancer. Radiat Oncol 2013;8:181.

26. Poncyljusz M, Kukołowicz P, Chorąży J, Czyżew B, Jankowska A, Paciorkiewicz A. Comparison of 3D-CRT and IMRT techniques in radiotherapy for post-prostatectomy patients with a higher risk of nodal involvement. Biuletyn Polskiego Towarzystwa Onkologicznego Nowotwory 2016;1:223–7.
27. Liu Y, Yu J, Qian L, Zhang H, Ma J. Extended field intensity-modulated radiotherapy plus concurrent nedaplatin treatment in cervical cancer. Oncol Lett 2016;11:3421–7.
28. Ye L, Wu Xr, Li Km, Bai H, Zheng J, Ai Yq. Effects of bladder status on cervical cancer treatment with intensity modulated radiation therapy plans. Precis Radiat Oncol 2017;1:94–101.
29. Gonzalez VJ, Hullett CR, Burt L, Rassiah-Szegedi P, Sarkar V, Tward JD, et al. Impact of prone versus supine positioning on small bowel dose with pelvic intensity modulated radiation therapy. Adv Radiat Oncol 2017; 2:235–43.
30. Wu Y, Zhu B, Han J, Xu H, Gong Z, Yang Y, Lu E. A comparative dosimetric study of cervical cancer patients with para-aortic lymph node metastasis treated with volumetric modulated arc therapy *vs*. 9-field intensity-modulated radiation therapy. Ann Transl Med 2019;7:675.
31. Faye MD, Alfieri J. Advances in radiation oncology for the treatment of cervical cancer. Curr Oncol 2022;29:928–44.
32. Betzel GT, Yi BY, Niu Y, Yu CX. Is RapidArc more susceptible to delivery uncertainties than dynamic IMRT? Med Phys 2012;39:5882–90.
33. Cakir A, Akgun Z, Fayda M, Agaoglu F. Comparison of three dimensional conformal radiation therapy, intensity modulated radiation therapy and volumetric modulated arc therapy for low radiation exposure of normal tissue in patients with prostate cancer. Asian Pacific J Cancer Prev 2015;16:3365–70.
34. Foroudi F, Wilson L, Bressel M, Haworth A, Hornby C, Pham D, et al. A dosimetric comparison of 3D conformal vs intensity modulated vs volumetric arc radiation therapy for muscle invasive bladder cancer. Radiat Oncol 2012;7:1–10.