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Assessing the Appropriateness of Three-Dimensional Conformal Radiotherapy Technique Planning Treatment for Rectal Versus Cervical Cancer: A Comparative Study

Ruaa Emad Al-Khalidi [1], Nashwan Karkhi Abdulkareem [2], Arthur Saniotis [3], Rojgar Najat Yousif [4]

[1,2] Department of pharmacology and medical physics and clinical biochemistry, college of medicine, Hawler Medical University, Erbil, Iraq.
[3] School of Biomedicine, Faculty of Health and Medical Sciences, The University of Adelaide, South Australia, Australia.
[4] Department of plan and dosimetry, Awat Radiation Oncology Center, Erbil, Iraq.

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Correspondence: Ruaa Emad Al-Khalidi
Email: ruaa.hussien@hmu.edu.krd

Website: https://djm.uodiyala.edu.iq/index.php/djm

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Abstract

Background: Radiotherapy is an important part of the treatment paradigm for many patients with rectal and cervical malignancies. With the development of more powerful 3D conformal treatment planning tools, the clinical application of three-dimensional conformal radiation therapy (3D-CRT) has gained recognition for its potential to enhance treatment results for these patients.

Objective: To assess which cancer type benefits more from the (3D-CRT) technique by comparing its effectiveness for rectal and cervical cancer, with a focus on dosimetric outcomes.

Patients and Methods: A retrospective analysis conducted from August 2023 to January 2024 assessed ten cases of rectal cancer and ten cases of cervical cancer, who treated with 3D-CRT technique at Awat Radiation Oncology Center (AROC), Erbil. Many dosimetric parameters, including mean dose (Dmean), minimum dose (Dmin), maximum dose (Dmax), target volume coverage (D95%), homogeneity index HI, conformity index CI, and the dose that is received by the organ at risk, have been evaluated in order to determine the efficacy of 3D-CRT technique for both cancers.

Results: Rectal cancer showed higher conformity and homogeneity index in the PTV int_sum phase (0.87 ± 0.05), (0.16 ± 0.02) compared to cervical cancer (0.66 ± 0.21), (0.19 ± 0.01), indicating better alignment of prescribed dose with target volume and more consistent dose distribution within the target volume. For organs small bowel (V45 < 195cc) and bladder (V45 < 50%), rectal cancer exhibits very high significantly superior sparing in comparison to cervical cancer, displaying lower average volumes and percentages of these organs receiving 45 Gy ($p < 0.001$ for both).

Conclusion: The investigation demonstrated that 3D-CRT offered better target coverage, dose homogeneity, and conformity for rectal cancer. Plans for rectal cancer also showed improved bladder and rectum sparing.

Keywords: Rectal cancer, Cervix cancer, Homogeneity index (HI), Conformity index (CI).

Introduction

Rectal cancer is a significant oncological health issue. It would be the third leading cause of

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mortality in the world due to oncological diseases. For radiotherapy treatment, it is crucial to rely on optimization techniques that can treat the target volume while also minimizing the amount of dosage that reaches the organs at risk (OARs) (1-2). Cervical cancer (CaCx) is a prevalent malignancy in women, affecting over 500,000 globally. Annually, 233,000 women die, primarily in poor nations. Treatment mainly involves external beam radiation and intravitreal brachytherapy for locally advanced cases (3). Radiotherapy has an established role in the curative treatment of rectal and cervical cancers (4). Choosing the right radiotherapy technique for rectal and cervical cancers is crucial. Different techniques, such as 3D-CRT, Intensity-modulated radiation therapy (IMRT), or Volumetric modulated arc therapy (VMAT), can improve tumor coverage and reduce the risk of recurrence. Careful selection of methods also helps spare critical organs-at-risk, reducing side effects. Personalized strategies enhance patient quality of life and treatment success rates (5). Three-dimensional conformal radiotherapy (3D-CRT) uses 3D anatomic information to provide an appropriate dosage to tumors and healthy tissue. Delivering high doses of ionizing radiation to the target volume and minimum doses the OARs. And uses for treat both rectal and cervical cancers (6). Despite the widespread use of 3D-CRT for both cancer types, there is limited research directly comparing its effectiveness between rectal and cervical cancers. Understanding the dosimetric differences is critical, as anatomical and physiological variations can significantly impact treatment outcomes. This study addresses this gap by examining dose coverage,

conformity, homogeneity, and organ-at-risk sparing, providing insights into the suitability of 3D-CRT for these two distinct malignancies. This study aims to assess and compare the dosimetric results of the 3D-CRT technique for rectal and cervical cancers, intending to identify the more appropriate cancer type for this treatment technique.

Patients and Methods

Patients' selection: In this study, 20 patients with two different types of cancer were included: 10 cases of rectal cancer, with a mean age of 52.6 years, six female patients (60%) and four male patients (40%); and 10 cases of cervical cancer, with a mean age of 59.2 years, all of them were female as shown in Table 1. They were treated with the 3D-CRT technique at the Awat Radiation Oncology Center, in Erbil from August 2023 to January 2024.

Table 1. Patient characteristics.

Characteristics	Rectal Cancer (n=10)	Cervical Cancer (n=10)
Mean age (years)	52.6 (35-85)	59.2 (67-55)
Sex: Male Female	 4 (40%) 6 (60%)	 - 10(100%)

CT simulation: Each patient will receive radiation therapy imaging using a CT scan with a 2–5 mm slice separation according to the size, type, and location of the tumor. They all scanned in the headfirst orientation in the supine position with an (A) headrest. The arms were either on the chest or raised up. All patients were breathing freely during the scan with an empty rectum and no contrast. We followed the bladder protocol, and patients were asked to drink 4-5 glasses of water to ensure a full bladder, which helps keep the bowel from moving into the pelvis. The isocenter location was in the middle of the pelvis, and the scan started from the upper abdomen to the mid-thigh for all patients. The image sets will be transferred to the Monaco treatment planning system version 5.51.02 for contouring and planning.

Target volumes and OARs contour: The

ORIGINAL RESEARCH
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radiation oncologist outlined the target volumes and OARs. Target volume includes gross target volume (GTV), clinical target volume (CTV), and planning target volume (PTV). The organs at risk were the small bowel, bladder, and right and left femoral heads for both rectal and cervical cancers as shown in figure 1 and 2, respectively. Contouring for rectal cancer, the GTV was defined as all gross disease; the CTV includes the GTV with a minimum of 1.5–2 cm superior and inferior margin as well as the entire rectum, mesorectum, and presacral space and internal iliac and obturator lymph node. The PTV includes the CTV + 5mm (7). In the cases of cervical cancers, the GTV is also defined as all gross tumors; the CTV consists of the common, external, and internal iliac and presacral lymph nodes with a 7 mm margin around the vessels and any additional visible lymph nodes, lymphoceles, or pertinent surgical clips, and the PTV initial (PTVinit.) included CTV + 7 mm, and the PTVboost included CTV, vaginal cuff + parametrium (8).

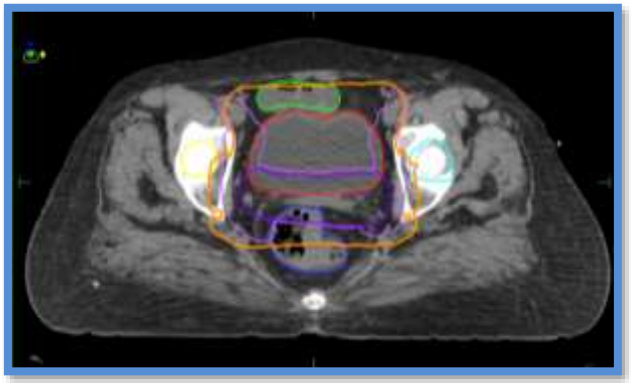

Figure 1. Axial image for patient with rectal cancer in AROC, bladder (red), small bowel (green), LFH (light blue), RFH (yellow), PTVinit.45Gy (pink), PTV boost 5.4Gy (purple), rectum (dark blue).

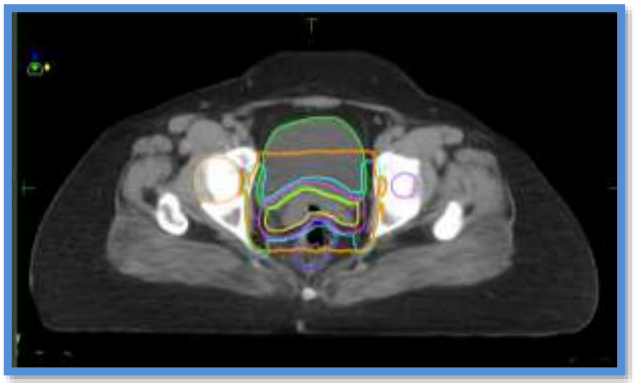

Figure 2. Axial image for patient with cervical cancer in AROC, bladder (green), LFH (dark purple), RFH (orang), PTV inti. 45Gy (turquoise), PTVboost 5.4Gy (pink), CTV (yellow), rectum (dark blue).

Treatment planning: For both rectal and cervical cancers, the prescribed dose was 1.8 Gy/fraction to 45Gy for the PTVinit. and 1.8 Gy/fraction to 5.4Gy for the PTV boost, which received a cumulative dose of 50.4 Gy. 3D-CRT plans were developed using Elekta's Monaco treatment planning system (TPS), which can accurately calculate 3D-CRT, IMRT, VMAT, SRS, and Brachytherapy plans using advanced algorithms such as Monte Carlo algorithm (the most accurate dose calculation available), pencil beam, and collapsed cone. Each of the 3D-CRT plans employs an isocentric technique and contained four photon beams: posteroanterior (PA), anteroposterior (AP), and two opposing lateral fields as shown in figure 3, with varying gantry angles (0˚, 90˚, 180˚, and 270˚), utilizing 10 MV of energy, provided by an Elekta infinity linear accelerator machine. To accomplish a consistent dose distribution and meet clinical objectives.

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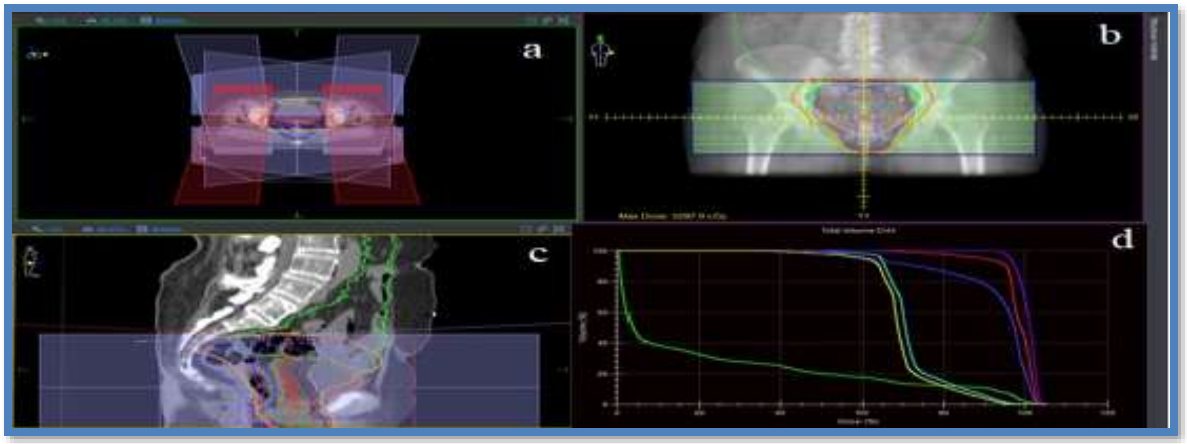

Figure 3. Screenshot for a treatment plan with 4 beams: PA, AP, and two opposing lateral fields, with three views: a: axial, b: coronal, c: sagittal, and d: the Dose- Volume Histograms (DVH) for patient with rectal cancer at AROC.

Plan evaluation: A distinction was made between the global plan, comprising the sum of both phases, and the results corresponding to each phase. PTV int._sum and PTV boost_sum is the same as PTV int. and PTV boost. The phrase "_sum" indicates that the related evaluated parameters (Dmean, Dmax, Dmin, HI, CI, D98%, and D2%) of each of them apply to the sum plan rather than the separate phase plans. The parameters of the individual phase plans have specifications for PTV int. and PTV boost. Plans were compared using the Dose-Volume Histograms (DVHs). For the PTV, the following data were analyzed: Dmean, Dmax, Dmin, D95%, The 95% of the prescribed dose of the PTV is helps to evaluate the dosimetry plans. The goal of the dosimetry plan is to cover at least 95% of the PTV (V95%) with 95% of the prescribed dose. A Homogeneity Index (HI) is a fast and easy-to-use scoring tool used to assess and quantify dose homogeneity in a target volume. The formula used in this study to calculate HI was suggested by ICRU-83 (9).

$$H1 = \frac{D_{2\%} - D_{98\%}}{D_P}$$

Where, D2% denotes the maximum dose that will be delivered to 2% of the PTV, Dp denotes the prescribed dose for the PTV, and D98% denotes the minimum dose calculated for the remaining 98% of the PTV. Conformity index (CI) is defined as the ratio of dosage volumes covered to PTV volume. In the present study, we use the following equation to calculate CI (9):

$$CI = \frac{volume\ covered\ by\ 95\%\ of\ prescribed\ dose}{volume\ of\ PTV}$$

The small bowel, bladder, and femoral heads were the OARs examined in this study. The OAR doses were evaluated on the global plan and compared with the constraints in QUANTIC and RTOG protocols (10). The constraint doses for small bowel, bladder, and right and left femoral heads were V45 < 195 cc, V45 < 50%, and V45 < 15%, respectively, for both types of cancer.

Statistical analysis

Data entry and analysis were conducted using the Statistical Package for Social Sciences (SPSS) version 26. Two approaches were used: in the first approach the descriptive statistics to calculate frequencies and percentages. While in the second approach: we used an independent t-test for normally distributed groups and a Mann-Whitney test for non-normally distributed data. A P-value ≤ 0.05 is regarded as statistically

ORIGINAL RESEARCH
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significant. Shapiro's test is used to assess the normality of the data.

Results

Dosimetric parameters for PTV: The study revealed significant variations in dosimetric parameters between rectal cancer and cervical cancer as shown in Table 2. Rectal cancer demonstrated a notably higher minimum dose Dmin to the PTV int_sum (4040 ± 213.43 cGy) compared to cervical cancer (3496.68 ± 213.81 cGy), with a p-value of <0.001, indicating superior coverage. However, the minimum dose for the PTV boost_sum did not differ significantly between rectal cancer (4577.49 ± 190.13 cGy) and cervical cancer (4410.20 ± 262.85 cGy, p = 0.09). The Dmax of the PTV int_sum was not significantly different between rectal cancer (5339.51 ± 49.24 cGy) and cervical cancer (5311.89 ± 39.94 cGy, p = 0.18), but rectal cancer had a very high significant maximum dose for the PTV boost_sum (5353.75 ± 30.11 cGy) compared to cervical cancer (5312.75 ± 9.76 cGy, p<0.001). Additionally, the mean dose Dmean to the PTV int_sum was slightly higher in rectal cancer (5025.26 ± 100.33 cGy) than cervical cancer (4907 ± 148.80 cGy, p = 0.05), and similar results were observed for the PTV boost. Rectal cancer also had a very high significant D95% dose for the PTV int_sum (4539.72 ± 165.76 cGy) compared to cervical cancer (4315.18 ± 103.28 cGy, p = 0.002), indicating better target coverage in rectal cancer. Conversely, the D95% dose for the PTV boost_sum did not show a significant difference. These results demonstrate that, rectal cancer generally received higher doses and achieved better target coverage.

Table 2. Dosimetric parameters for PTV.

	Rectal Cancer (Mean ± SD)	Cervical Cancer (Mean ± SD)	p-value
Dmin for PTV init._sum (cGy)	4040±213.43	3496.68±213.81	<0.001
Dmin for PTV boost_sum (cGy)	4577.49±190.13	4410.20±262.85	0.09
Dmax for PTV init._sum (cGy)	5339.51±49.24	5311.89±39.94	0.18
Dmax for PTV boost_sum (cGy)	5353.75±30.11	5312.75±9.76	<0.001
Dmean for PTV init._sum (cGy)	5025.26±100.33	4907±148.80	0.05
Dmean for PTVboost_sum (cGy)	5167.150±53.45	5114.55±54.04	0.04
D95% for PTVinit._sum (cGy)	4539.72±165.76	4315.18±103.28	0.002
D95% for PTVboost_ sum (cGy)	5068.87±195.04	5010.82±186.73	0.50

Physical Indices: There were marked variations in dose homogeneity and conformity between rectal cancer and cervical cancer as shown in Table 3. In the PTV inti. sum phase, rectal cancer exhibited significantly higher conformity (0.87 ± 0.05). compared to cervical cancer (0.66 ± 0.21) with a p-value of 0.01, indicating better alignment of the prescribed dose with the target volume for rectal cancer. When it

ORIGINAL RESEARCH
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comes to the PTV boost_sum phase, the conformity index was very high signeficantly between rectal cancer (0.98 ± 0.01) and cervical cancer (0.97 ± 0.05), with (p = 0.008). As for the homogeneity index, which measures the uniformity of dose distribution within the target volume, rectal cancer also displayed superior dose homogeneity in the PTV int_sum phase (0.16 ± 0.02) compared to cervical cancer (0.19 ± 0.01), with a p-value of 0.003, indicating a more consistent dose distribution for rectal cancer. In the PTV boost_sum phase, both rectal cancer and cervical cancer had similar homogeneity indices (0.086 ± 0.02 and 0.085 ± 0.01, respectively), with no significant difference (p = 0.89). These findings suggest that rectal cancer generally achieved better dose conformity and homogeneity, particularly in the initial phase, which could have implications for optimizing treatment precision and minimizing exposure to surrounding healthy tissues.

Table 3. Homogeneity index (HI) and conformity index (CI).

	Rectal Cancer (Mean ± SD)	Cervical Cancer (Mean ± SD)	p-value
$CI_{\text{for PTV int._sum}}$	0.87±0.05	0.66±0.21	0.01
$CI_{\text{for PTV boost_sum}}$	0.98±0.01	0.97±0.05	0.008
$HI_{\text{for PTV int._sum}}$	0.16±0.02	0.19±0.01	0.003
$HI_{\text{for PTV boost_sum}}$	0.086±0.02	0.085±0.01	0.89

Organ at risk: The comparison of organ sparing between rectal cancer and cervical cancer shows notable differences for certain organs as shown in Table (4) and Figure (4). For the organs small bowel (V45 < 195 cc) and bladder (V45 < 50%), rectal cancer exhibits very high significantly superior sparing (120.15±36.16 and 65.84 ± 13.31, respectively) in comparison to cervical cancer (197.87±7.70 and 36.55 ± 12.52, respectively), displaying lower average volumes and percentages of these organs receiving 45 Gy (p<0.001). However, for organs RFH and LFH (both V45 < 15%), there are no statistically significant differences in sparing between rectal cancer and cervical cancer (p = 0.40 and p = 0.96, respectively). These results imply potential variations in treatment planning or tumor characteristics that impact organ sparing for different cancer types.

Table 4. Organ at risk (OAR) sparing.

OAR	Rectal Cancer			Cervical Cancer			Mann- Whitny U	Z	p-value
	Mean ± SD	Median	Mean rank	Mean ± SD	Median	Mean rank			
SB, V45(cc)	120.15±36.16	-	-	197.87±7.70	-	-	-	-	<0.001
Bladder, V45(%)	36.55 ± 12.52	-	-	65.84±13.31	-	-	-	-	<0.001
RFH, V45(%)	0.28±0.50	0	11.40	0.32± 0.99	0	9.60	41	0.839	0.40*
LFH, V45(%)	1.33±1.99	0.39	10.45	2.22±2.49	1.10	10.55	49	0.039	0.96*

*Mann- Whitny U test

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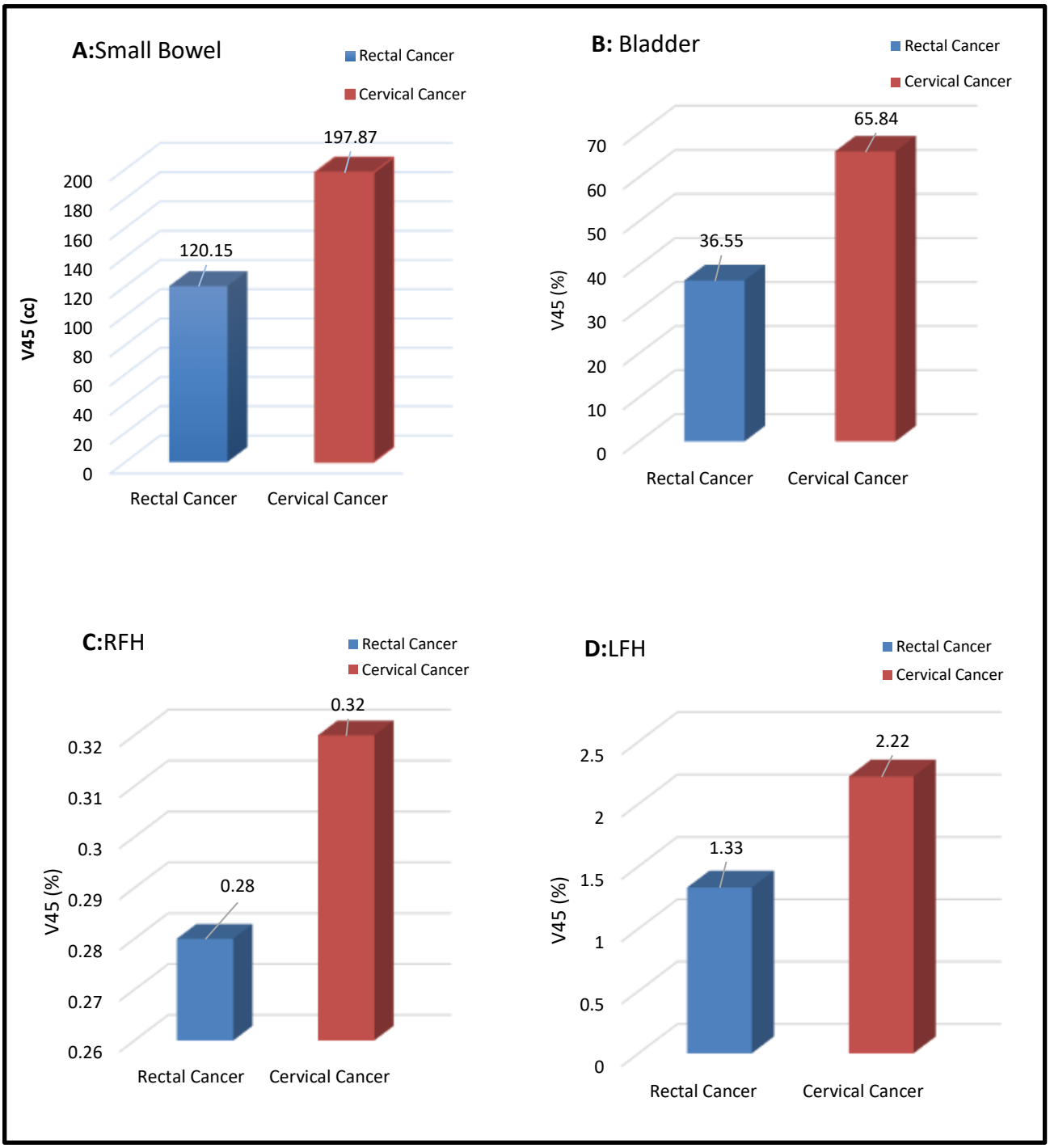

Figure 4. Bar graphs of (A) a comparison of the small bowel volume received 45Gy for rectum and cervical cancer, (B) a comparison of the bladder volume % received 45Gy for rectum and cervical cancer, (C) a comparison of the RFH volume % received 45Gy for rectum and cervical cancer, (D) a comparison of the LFH volume % received 45Gy for rectum and cervical cancer.

ORIGINAL RESEARCH
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Discussion

The results of the study show that 3D-CRT technique, is usually more effective for rectal cancer than cervical cancer in regards to dose coverage (D95%), homogeneity index (HI), conformity index (CI), and sparing of organs at risk (OARs). This study shows that, in comparison to cervical cancer, rectal cancer has a better dose coverage (D95%) with 3D-CRT treatment. This is primarily because of the rectum's anatomical stability. These results align with previous studies. For example, a study conducted in 2016 by Simson DK et al. (11) demonstrated that 3D-CRT offers sufficient dose coverage for rectal cancer and that most patients achieve favorable D95% results because of the relatively fixed position of the rectum within the pelvis. Conversely, studies on cervical cancer by Urban R et al. (2022) (12) supported our findings that D95% outcomes are less consistent for cervical cancer by demonstrating difficulties in achieving optimal D95% with 3D-CRT due to the cervix's variable position and movement caused by bladder and bowel filling. The results of this study, which show that the CI and HI are more advantageous for rectal cancer than for cervical cancer when utilizing 3D-CRT, are consistent with earlier research. For rectal cancer, Jun Zhao et al. (2016) (13) found that 3D-CRT could achieve satisfactory CI and HI due to the simpler geometry and fewer variations in target position. On the other hand, Zeng et al. (2024) (14) found that in the case of cervical cancer, the uneven form of the cervix and the mobility of surrounding organs typically result in inadequate CI and HI after 3D-CRT, necessitating the employment of more sophisticated techniques like IMRT to improve these indices. This confirms the finding that these anatomical difficulties may make 3D-CRT less effective for cervical cancer. Regarding OAR sparing, this study indicates that 3D-CRT is more appropriate for rectal cancer than for cervical cancer in terms of OAR sparing. In rectal cancer, the results of other studies, like those by Georgios Kouklidis et al. (2023) (15), which showed that 3D-CRT enables better organ sparing of nearby organs, like the small bowel and bladder, because the tumor is more localized and there is less overlap with critical structures, are consistent with this finding. While those in cervix cancer this technique couldn’t protected the small bowel, due to the specific shape of the pelvic floor and iliac lymph node. After a hysterectomy, a significant portion of the small bowel is situated in the pelvic space, leading to a larger volume of intestine receiving a high dose (16). The study results indicate that the average small bowel volume for patients with cervical cancer exceeded the tolerance dose. Therefore, it's crucial to minimize the dose to the small bowel to prevent gastrointestinal toxicity. According to Minsky et al. (1995) (16), there is a strong correlation between gastrointestinal toxicity and the volume of irradiated small bowel. However, because of the close proximity of the bladder and bowel to the cervix, several studies including one by Lv Y et al. (2014) (17) have demonstrated that OAR sparing is more difficult with 3D-CRT for cervical cancer. This results in higher rates of toxicity when these organs unintentionally receive radiation. The 3D-CRT technique is effective in protecting the bladder from high doses in patients with rectal cancer, while for patients with cervical cancer, it was ineffective. For the bladder in cervical cancer, our results cast a new light on the results for the patients who were treated with PD 50.4 Gy. All the percentage patients' bladder volumes were above the tolerance volume, the mean ± SD of the volume that receive 45Gy for cervical was 65.84 ± 13.31. And that is mean the 3D-CRT technique cannot protect the bladder from

ORIGINAL RESEARCH
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the high dose in cervical cancers. However, when comparing our results to those of older studies, the findings are directly in line with Lv Y et al.(2014) (17) the mean for V45(%) were 65.48, which was more than 50%.

Conclusions

This study demonstrates that 3D-CRT is generally more effective for treating rectal cancer compared to cervical cancer due to differences in anatomical structure, tumor positioning, and organ stability. Rectal cancer showed superior dose coverage (D95%), homogeneity index (HI), and conformity index (CI), as well as better sparing of organs at risk (OARs). Conversely, the mobility and variable position of the cervix and adjacent organs, such as the bladder and bowel, present significant challenges for achieving optimal outcomes in cervical cancer treatment with 3D-CRT.

Recommendations

Given the limitations observed in 3D-CRT for cervical cancer, it is recommended that further research explore alternative radiotherapy techniques to determine whether they offer superior outcomes, particularly in terms of organ sparing and dose homogeneity.

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Ethical clearance: The study was approved by the Ethical Committee of Hawler Medical University / college of medicine (KR, meeting code:1, paper code:1, date: 22/9/2024).

Conflict of interest: None.

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تقييم ملاءمة تخطيط تقنية العلاج الإشعاعي ثلاثي الأبعاد لعلاج سرطان المستقيم مقابل سرطان عنق الرحم: دراسة مقارنة

[١] رؤى عماد الخالدي، [٢] نشوان كرخي عبد الكريم ، [٣] آرثر سانيوتيس، [٤] روزكار نجاة يوسف

الملخص

الخلفية: يُعتبر العلاج الإشعاعي جزءًا مهمًا من بروتوكول العلاج للعديد من المرضى الذين يعانون من أورام المستقيم وعنق الرحم. ومع تطور أدوات تخطيط العلاج ثلاثية الأبعاد الأكثر قوة، اكتسب تطبيق العلاج الإشعاعي ثلاثي الأبعاد (3D-CRT) اعترافًا بإمكانياته في تحسين نتائج العلاج لهؤلاء المرضى.

الأهداف: لتقييم أي نوع من السرطان يستفيد أكثر من تقنية العلاج الإشعاعي ثلاثي الأبعاد (3D-CRT) من خلال مقارنة فعاليتها بين سرطان المستقيم وسرطان عنق الرحم، مع التركيز على النتائج الجرعية.

المرضى والطرق: تم إجراء تحليل باثر رجعي للفترة من أب ٢٠٢٣ إلى كانون الثاني ٢٠٢٤ لتقييم عشر حالات من سرطان المستقيم وعشر حالات من سرطان عنق الرحم تم علاجهم باستخدام تقنية العلاج الإشعاعي ثلاثي الأبعاد (3D-CRT) في مركز أوات للأورام الإشعاعية (AROC)في أربيل. تم تقييم العديد من معايير الجرعات، بما في ذلك الجرعة المتوسطة(Dmean) ، الجرعة الدنيا(Dmin) ، الجرعة القصوى(Dmax) ، تغطية حجم الهدف(D95%) ، مؤشر توزيع الجرعات(HI) ، مؤشر مطابقة الجرعة الإشعاعية لشكل الهدف (CI) ، والجرعة التي يتلقاها العضو المعرض للخطر، لتحديد فعالية التقنية في كلا النوعين من السرطان.

النتائج: أظهر سرطان المستقيم مؤشر لتوزيع الجرعات و مدى مطابقة الجرعة الإشعاعية لشكل الهدف (PTV) أعلى في مرحلة PTV int_sum (0.87 ± 0.05)، (0.16 ± 0.02)مقارنة بسرطان عنق الرحم (٠,٦٦ ± ٠,٢١)، (٠,١٩ ± ٠,٠١)، مما يشير إلى تحسين توزيع الجرعة ضمن حجم الهدف وتطابق أفضل بين الجرعة الموصوفة وحجم الهدف. بالنسبة للأعضاء المعرضة للخطر مثل الأمعاء الدقيقة ($V45 < 195cm^3$)والمثانة($V45 < 50\%$) ، أظهر سرطان المستقيم تفوقًا كبيرًا في الحماية مقارنة بسرطان عنق الرحم، مع تسجيل أحجام ومتوسطات أقل بشكل كبير من هذه الأعضاء التي تتلقى٤٥ Gy, ($p < 0.001$) لكلتا الحالتين.

الاستنتاج :أظهرت الدراسة أن تقنية العلاج الإشعاعي ثلاثي الأبعاد وفرت تغطية أفضل للهدف وتماثل لتوزيع الجرعات، ومطابقة الجرعة الإشعاعية لشكل الهدف لسرطان المستقيم. كما أظهرت خطط سرطان المستقيم تحسينًا في حماية المثانة والمستقيم.

الكلمات المفتاحية: سرطان المستقيم، سرطان عنق الرحم، مؤشر التجانس (HI)، مؤشر المطابقة (CI).

المؤلف المراسل: رؤى عماد الخالدي

الايميل: ruaa.hussien@hmu.edu.krd

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[١،٢]قسم الأدوية والفيزياء الطبية والكيمياء الحياتيه السريرية - كلية الطب - جامعة هولير الطبية - أربيل – العراق.

[٣] كلية الطب الحيوي، كلية الصحة والعلوم الطبية - جامعة أديلايد - جنوب استراليا – استراليا.

[٤]قسم التخطيط والجرعات - مركز أوات لعلاج الأورام بالإشعاع - أربيل - العراق.