



# Evaluation of Three-Dimensional Conformal Radiation Therapy in Rectal Cancer

Ruaa Emad Hussein Al-Khalidi<sup>1\*</sup>, Nashwan Karkhi Abdulkareem<sup>2</sup>, Samir M. Othman<sup>3</sup>

## Abstract

**Background:** Three-dimensional conformal radiotherapy (3DCRT) is a technique that is used to treat patients with rectal cancer. **Goal:** The aim of this study is to analyze the impact of the 3D-CRT technique on the planning outcomes for rectal cancer. **Methods:** A total of 10 cases of rectal cancer Patients will be treated with 3D-CRT at the Awat Radiation Oncology Center, Erbil. A lot of dose parameters, including maximum dose, minimum dose, mean dose, and final organ specific dose-volume values for both targets and OARs, have been measured. Every plan was calculated on a sequential two-phase treatment scheme with prescription doses of 45 Gy in the initial phase and 5.4 Gy in the boost phase. by using the ELECTA INFINITY linear accelerator machine with a 10MV photon beam. SPSS-version 26 was used to analyze and care for the data measurements. **Results:** The results show that the highest conformity and homogeneity indices have acceptable values in this technique. The mean conformity index for CI for PTV pelvis\_sum, PTV boost\_sum, PTV pelvis and PTV boost were (0.82±0.005, 0.98±0.001, 0.98±0.001 and 0.98±0.001), and the homogeneity index for them was (0.16 ± 0.03, 0.9 ± 0.03, 0.09 ± 0.01, 0.09 ± 0.02) respectively. In all plans, some of the average dose values for the organs at risk were less than the tolerance radiation doses, while others were more dependent on the location of the organ. **Conclusion:** Radiation therapy regimens using the 3D-CRT approach give high-quality dose distributions with significant benefits in the PTVs and OARs, and the application of 3D-CRT was successful in justification of radiation doses lower than the tolerance dose in the evaluated pelvic tissues.

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**Key Words:** Organs at Risk, Conformity Index (CI), Homogeneity Index (HI), Rectal Cancer.

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## Introduction

Rectal cancer is a significant oncological health issue. It would be the third leading cause of mortality in the country due to oncological disease (Xi and Xu, 2021). Rectal cancer can only be cured through surgery. Total mesorectal excision is considered the gold standard for this pathology. Preoperative chemoradiotherapy has been shown to have lower toxicity and local relapse rates than postoperative chemoradiotherapy, and is recommended as the standard therapeutic method for locally advanced non-metastatic rectal cancer in most clinical practice recommendations (Heald and Ryall, 1986). In terms of radiation treatment, it is critical to rely on optimization procedures that can treat the target volume while also reducing the dose reaching the organs at risk (OARs) as much as possible. This is especially essential in the case of

the small bowel, as gastrointestinal toxicity is one of the most serious side effects of pelvic radiation for rectal cancer (Parekh et al., 2013).

Three-dimensional conformal radiotherapy (3D-CRT), includes treatments based on 3D anatomic data and treatment fields that conform as closely as possible to the target volume in order to deliver an appropriate dosage to the tumor while sparing normal tissue (Wee et al., 2018).

The 3D-CRT technology delivers a high dosage of ionizing radiation to the tumor that is precisely targeted, contouring the spatial distribution of the dose to the precise 3D configuration of the tumor. The capacity to calculate the dose at each place in the full 3D space of the irradiated tissues using computer algorithms is a unique characteristic of 3D planning.

**Corresponding author:** Ruaa Emad Hussein Al-Khalidi

**Address:** <sup>1</sup>Department of Radiology, Erbil Technical Institute, Erbil, Kurdistan Region, Iraq; <sup>2</sup>Unit of Biophysics, Department Basic Science, College of Medicine, Hawler Medical University/ Gasha Technical Institute, Erbil, Kurdistan Region, Iraq.

<sup>3</sup>Department of Community Medicine College of Medicine, Hawler Medical University, Erbil, Kurdistan Regio-Iraq



Improved precision decreases the risk of anatomical misses and tumor under dosage. In 3D planning, the beam's eye-view display aids beam alignment and collimation for normal tissue protection. This permits dose-escalation to the tumor and a low dose of ionizing radiation to the normal tissue (Tseng et al., 2019).

In radiation oncology, the gross tumor volume (GTV) is used to make preliminary estimates of the size of a tumor that will be treated with external beam radiation or brachytherapy (Burnet et al., 2004). With suspected subclinical spread, such as to regional lymph nodes, additional quantities may exist. These are the quantities that have been designated as clinical target volumes (CTV). As a result, this volume must be effectively treated in order to fulfill the goal of therapy, cure, or palliation." (ICRU 50), (Lee et al., 2018).

The Planning Target Volume (PTV) is a geometric concept, introduced for treatment planning. The PTV adds a margin around the CTV to account for the various types of fluctuations and uncertainties in the beam compared to the CTV (Ashburner and Tudor, 2014). The Homogeneity Index (HI) is a metric used to assess the uniformity of dosage distribution in a given volume. The Conformity Index (CI) is a way to report on the difference between the PTV and the treated volume. It is usually expressed as a ratio of volumes (Kataria et al., 2012).

Organs at risk are healthy tissues or organs that are close to the clinical target volume (CTV) and whose irradiation may cause harm, requiring adjustments to the radiotherapy treatment plan (Wang et al., 2016). In this study, the right femoral head (Rt), left femoral head (Lt), bladder, and small bowel will be considered as organs at risk (OAR). In order to compare the outcomes of this technique, we considered DVHs, PTV coverage, Conformity Index, Homogeneity Index, and OARs received dose.

This study's objective was to analyze the dosimetric parameters and the dose-volume histograms (DVH) corresponding to the target volumes and the OARs of 10 rectal cancer patients treated with the 3D-CRT technique at the Awat Radiation Oncology Center, Erbil.

## Materials and Methods

### Patient Sample

Dose volume histograms DVHs and dosimetric parameters of 10 rectal cancer patients (5 male and 5 female) receiving three-dimensional conformal radiation therapy treatment between August 2021

and April 2022 were analysed. The median age was 51.3 years (range: 35–85 years). Every patient had been diagnosed with rectal cancer and had been submitted to simultaneous radiotherapy.

### Simulation of CT Scans and Structural Delineation

On an Open Somatom Sensation, each case received a simulated CT scan. Patients were instructed to have a comfortably full bladder before the CTs planning and every treatment section in order to reduce small bowel and bladder doses. In order to lower the irradiated intestinal volume and small intestine doses, patients were immobilized in a prone posture with extrinsic compression using a belly board (Allal et al., 2002). In terms of defining target volumes, the gross target volume (GTV) was defined as the macroscopic tumor observable by imaging modalities such as MRI and CT, as well as the perirectal nodal structures and probable malignant soft tissue lesions (Valentini et al., 2016). The mesorectum, inner iliac lymph nodes, and posterior pelvic wall were all included in the CTV pelvis. In the lower pelvis, tumors that were less than 6 cm from the anal verge or had an impacted sphincter were included. Only when the pelvic organs such as the urethra, prostate, vagina, bladder or uterus were involved were the external iliac chains contoured. The inguinal chains were only considered if the anal sphincter or inferior portion of the vaginal canal were involved. The GTV was included in CTVboost, along with the mesorectal region close to the tumor and a 2–3 cm margin. The planning target volumes (PTVs), PTVpelvis, and PTVboost were generated by adding an isotropic 1 cm margin to the CTVpelvis and the CTV boost. The bladder, small bowel, right femoral head, and left femoral head were all contoured and identified as organs at risk. The PTV boost was extended 1 cm over the small bowel.

### Prescriptions for Dosage and Constraint of Organs at Risk

The assessed plans were rectal cancer radiation programs provided in a two-phase sequential treatment strategy (PTV pelvis and PTV boost). 45 Gy in 25 fractions (1.8 Gy/fraction) was delivered to the PTV pelvis corresponding to the initial phase. 5.4 Gy in 3 fractions (1.8 Gy/fraction) was delivered only to the PTV boost, which received a total dose of 50.4 Gy. The dosimetrist required that at least 95 percent of the volume of each PTV receive 95 percent of the prescribed dose, with the



OARs receiving the lowest dose feasible. The fulfillment of this condition was assessed in each planning phase and in the global plan, which comprised the sum of both phases. The overall results of the complete treatment and the OAR doses were evaluated on the global plan, summarised in Table 1. The dose restrictions on the OARs are

**Table 1.** OAR constraints for plan acceptability

| Organ at risk      | Constrain |
|--------------------|-----------|
| Small bowel        | V45<195cc |
| Right femoral head | V45<5%    |
| left femoral head  | V45<5%    |
| Bladder            | V45<50%   |

**The 3D-CRT Technique**

Three-dimensional conformal radiation therapy is “a technique that can create three-dimensional images of a tumor and the surrounding structure using one of the imaging technologies (computed tomography CT, magnetic resonance imaging IMR, or positron emission tomography PET)” (Perez et al., 1995). The planning for each patient has been done at Awat Radiation Oncology Center, Erbil. Was performed by using a CT scan with a 5 mm slice separation according to the size, type, and location of the tumor. The plan uses a unique isocentric technique with several field beams: posteroanterior, anteroposterior field, and two opposite lateral fields. With different gantry angles (0, 90, 180, and 270). Photon beams are provided by an ELECTA INFINITY linear accelerator machine. The prescription dose (50.4 Gy) used for each patient, with total fractions of 28 per six weeks, in a daily 1.8 Gy with five fractions per week, satisfies the majority of international commission of radiation units (ICRU).

**Plan Calculation**

A 3D-CRT plans were calculated for each patient. Every plan was calculated with the Monaco program version 5.51.02. 3D-CRT was the former technique employed in our center for rectal cancer radiotherapy treatments. 3D-CRT dose distributions were calculated with a 10 MV beam. The planning was based on four fields: a posteroanterior field, anteroposterior field, and two opposite lateral fields, as the most straightforward way to reduce the dose to the bladder and small bowel as much as possible. The beams' weight was distributed so that no locations

beyond the PTV's immediate surroundings received dosages of 95 percent or greater.

The study was approved by the Awat Radiation Oncology Center’s research ethics committee. The dosimetric data set corresponding to each patient’s DVHs was exported from the program and fully anonymized before its inclusion in the study. The study was completed entirely using non-identifiable data, and no additional patient interaction was necessary. As a result, the ethics committee did not solicit informed consent.

**Evaluated Parameters**

Regarding the PTVs, the following characteristics were identified: conformity index (CI), homogeneity index (HI), near minimum dose (D98%), near maximum dose (D2%), minimum dose covering 95% of the PTV (D95%), median dose (D50%), and V95%. The HI was calculated with the formula suggested by ICRU (N, 2012):

$$HI = \frac{D98\% - D2\%}{D50\%}$$

The CI was calculated with the expression recommended by the RTOG (Shaw et al., 1993):

$$CI = \frac{V95\%}{VPTV}$$

This study includes the right and left femoral heads, bladder, and small bowel as OARs. The dosimetric characteristics included in the plan acceptance requirements, as well as the mean and maximum doses given to the OARs, were investigated.

**Statistical Analysis**

Spss version 26 was used for data entry and analysis. The two approaches were used in the first approach to calculate the descriptive statistics, which was used for frequencies and percentages. In the second approach, analytics statistics were utilized by using the first application t-test to determine the mean difference between numerical data of the study sample and each variable's p-value 0.005 regarded as statistically significant.

**Result**

Each 3D-CRT plan was reviewed by a radiation oncologist and was considered acceptable for treatment.

**Target Volumes**

A distinction was made between the global plan, comprising the sum of both phases, and the results



corresponding to each phase. Table 2 shows the results of the mean and standard deviation of the HI and CI of the PTVs according to the delivery technique. PTV pelvis\_sum and PTV boost\_sum are the same as PTV pelvis and PTV boost. The phrase "\_sum" indicates that the related evaluated parameters (HI, CI, D98%, D95%, D50%, and D20%) 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 pelvis and PTV boost. Table 3 shows the statistical analysis of the dosimetric parameters (D98%, D95%, D50%, D2%) related to the PTVs.

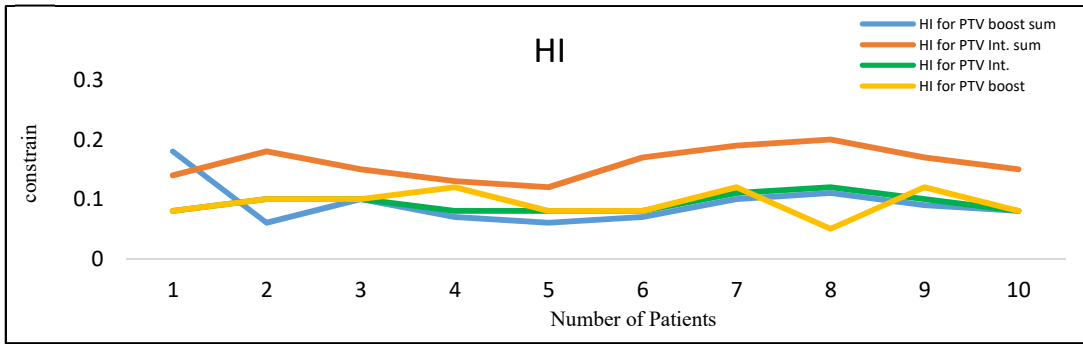
**Table 2.** Mean ± SD for HI and CI of PTVs among study participants (N=10)

|                | HI        | P-value | CI        | P-value |
|----------------|-----------|---------|-----------|---------|
| PTV pelvis_sum | 0.16±0.03 | 0.001   | 0.82±0.15 | 0.005   |
| PTV boost_sum  | 0.09±0.03 | 0.001   | 0.98±0.01 | 0.001   |
| PTV pelvis     | 0.09±0.01 | 0.001   | 0.98±0.01 | 0.001   |
| PTV boost      | 0.09±0.02 | 0.001   | 0.98±0.01 | 0.004   |

**Table 3.** Result of the statistical analyses of the dosimetric parameters corresponding to the PTVs

|                | D98%          | D95%            | D50%          | D2%           |
|----------------|---------------|-----------------|---------------|---------------|
| PTV pelvis_sum | 4465±128.6    | 4581±153.5      | 5094±100.7    | 5289±53.63    |
| PTV boost_sum  | 4803.6±216.47 | 4495.18±1455.7  | 5185.17±61.44 | 5295.84±54.88 |
| PTV pelvis     | 4304.5±65.73  | 4001.32±1251.99 | 4625.59±43.53 | 4751.34±23.04 |
| PTV boost      | 515.3±10.72   | 527.1±8.887     | 504.7±158.3   | 568.5±12.92   |

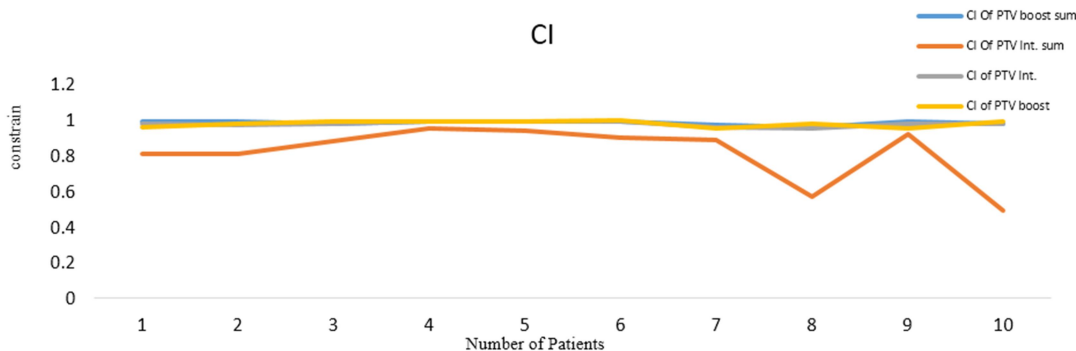
The homogeneity index (HI) is a quantitative tool used to evaluate the dose distribution uniformity in the PTV (Abdulkareem and Hassan, 2020). The optimal dosage distribution homogeneity is shown by an HI value of zero. The lower the HI value, the more uniform and better the dosage distribution in the PTV. The mean value of HI showed a significant improvement in the PTV boost sum, PTV pelvis, and PTV boost and the mean value of them was (0.09±0.03, 0.09±0.01, 0.09±0.02) respectively.



**Figure 1.** Homogeneity index

The optimal conformance index value is 1, which indicates the best conformation. A conformance index greater than one indicates that the irradiated volume within the patient's body is bigger than the dosage of the target volume, implying that normal tissues are also included and a hot spot may result. On the other hand, a conformance index of less than one shows partial irradiation of the target volume, implying that certain areas of the target volume are

not covered by radiation beams and a cold spot may result (Karkhi et al., 2020). According to table 2, all values of CI obtained by 3D-CRT planning techniques are less than 1 for all patients, and the mean value of CI for PTV pelvis\_sum, PTV boost\_sum, PTV pelvis and PTV boost are (0.82±0.005, 0.98±0.001, 0.98±0.001 and 0.98±0.001) respectively.



**Figure 2.** Conformity index

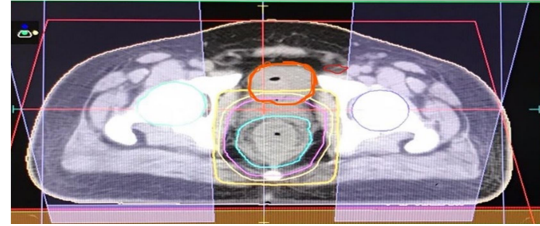
V95% of the 3D-CRT plans showed a significant improvement in the PTV boost\_sum, PTV pelvis\_sum, PTV boost and PTV pelvis.

**Table 4.** Results of the statistical analyses of the V95% parameters

|                | Plan parameter | 3D-CRT     |
|----------------|----------------|------------|
| PTV pelvis_sum | V95% (%)       | 99.58±0.60 |
| PTV boost_sum  | V95% (%)       | 99.95±0.16 |
| PTV pelvis     | V95% (%)       | 98.18±1.52 |
| PTV boost      | V95% (%)       | 98.35±1.42 |

**Organs at Risk**

The assessed dosimetric parameters of the OARs correspond to the outcomes of the complete treatment that includes the sum of both phases. (Fig 3) shows an image containing an axial plane of one of the patients included in the present study. The OARs are well protected by the 3D-CRT plan. Table 5 summarises the statistical results of the OARs' dosimetric parameters.



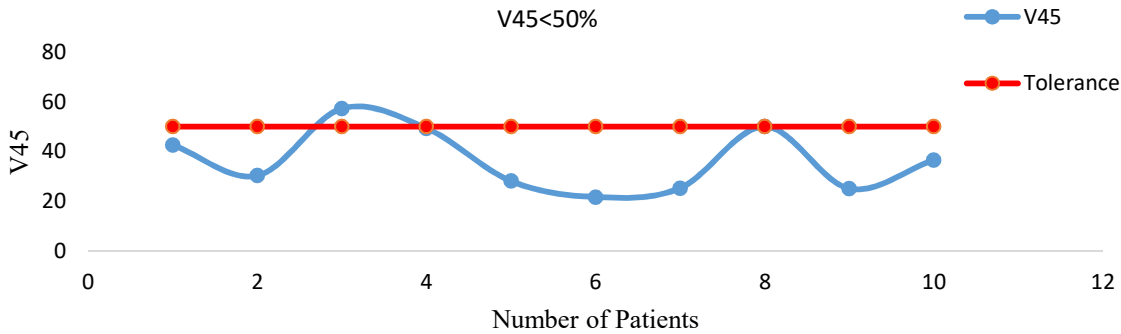
**Figure 3.** An axial plane one patient included in this study. The following structures are displayed: PTV pelvis in yellow, PTV boost in purple, bladder in orange, small bowel in red, right femoral head in green, left femoral head in blue

**Table 5.** Statistical results of the OARs' dosimetric parameters

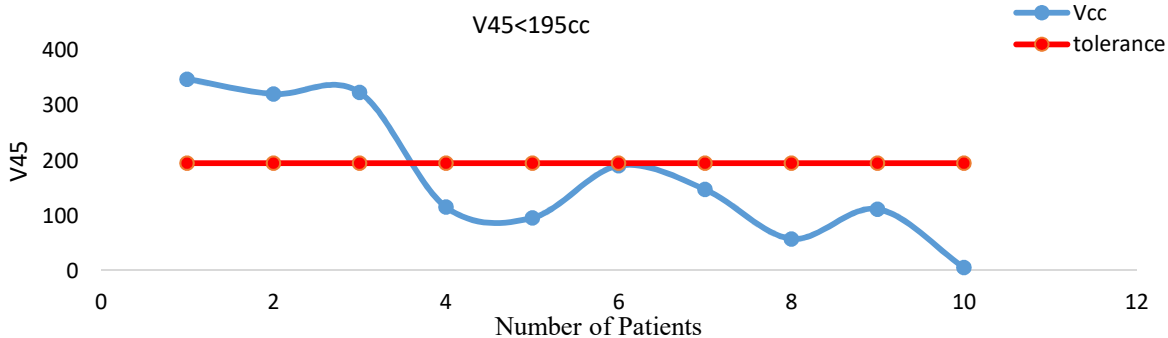
|                    | Plan parameter | Mean±SD        |
|--------------------|----------------|----------------|
| Bladder            | Dmin (cGy)     | 2370.7±737.01  |
|                    | Dmax (cGy)     | 5195.34±109.72 |
|                    | Dmean (cGy)    | 3995.54±515.94 |
|                    | V45            | 36.55±12.52    |
| Small bowel        | Dmin (cGy)     | 131.36±105.07  |
|                    | Dmax (cGy)     | 5222.82±135.02 |
|                    | Dmean (cGy)    | 1761.05±881.94 |
|                    | V45cc          | 171.45±120.26  |
| Right femoral head | Dmin (cGy)     | 7847.83±2526.8 |
|                    | Dmax (cGy)     | 4236.36±775.55 |
|                    | Dmean (cGy)    | 2300.58±915.09 |
|                    | V45            | 0.28±0.50      |
| Left femoral head  | Dmin (cGy)     | 734.52±557.37  |
|                    | Dmax (cGy)     | 4437.43±531.55 |
|                    | Dmean (cGy)    | 2371.46±452.27 |
|                    | V45            | 1.23±2.04      |

The listed data are the mean value ± standard deviation.

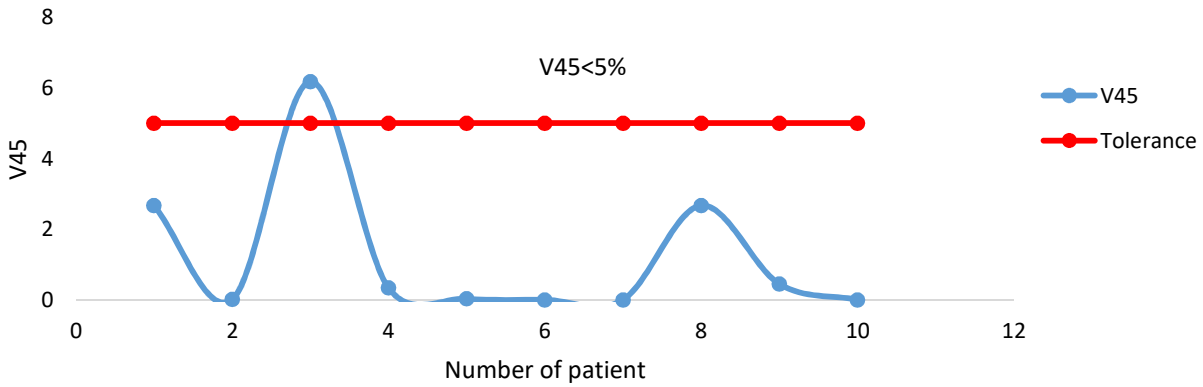
**FOR BLADDER**



**FOR SMALL BOWEL**



FOR LFH



For RFH

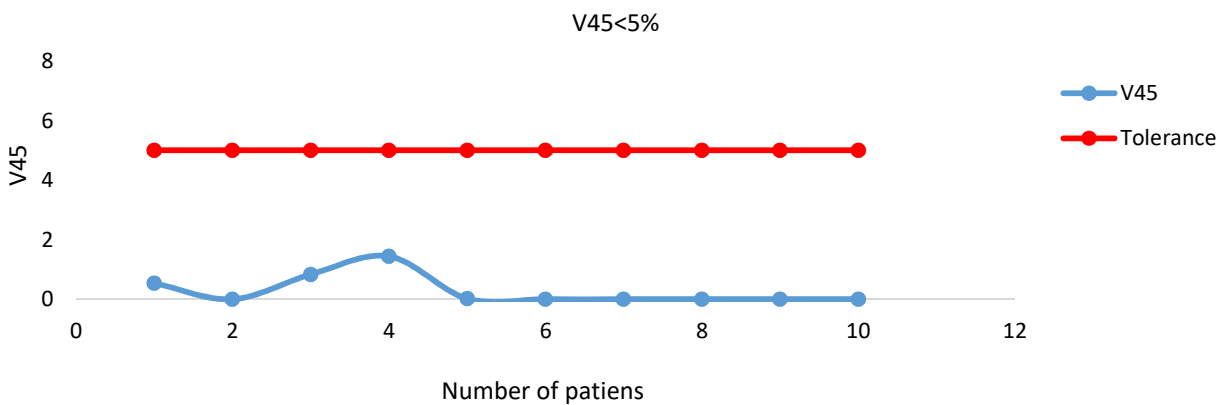


Figure 4. Constrain values of OARs

Discussion

A low HI value suggests a higher-quality plan with more consistent dose distribution in the PTV that can be attained as the target.

If the conformance value is equal to 1, the value is ideal or perfect, and the treatment planning quality is ideal and acceptable. If the CI is smaller than one, a portion of the target volume (PTV) is irradiated, and the treatment plan isn't great because the coverage of the target volume is less than the legal percentage (95%–107%) and there is a cold spot during the treatment planning process. This is a medically unacceptable situation. If the CI value is larger than 1, this indicates that the volume irradiated exceeds the target volume (PTV) and organs at risk near the target volume are also included. This is also not acceptable clinically, because it will require a higher dose than its tolerance dose, so the oncologist cannot accept this kind of plan (Petrova et al., 2017). It should be noted that CI values in the range of 1 to 2 are acceptable at most radiotherapy cancer centers as long as they are not more than 2, and CI values less

than 1 are acceptable as long as they are not less than 0.80.

In the results presented in Fig. (2) below, it can be seen that in most cases the value of CI is below 0.99, and in two cases it was under 0.80 (0.57 and 0.49). In these two cases, the value of the CI difference may be because of the location of the tumor or target volume may include some sensitive organs close to the tumor and the treatment plan may be difficult, so the conformity of the target volume is not perfect and the healthy tissue nearby the target volume either takes more radiation dose or less radiation energy than its tolerance dose. It is important to note that if the conformity index value is significantly lower than its ideal value, as it was in our cases (0.57 and 0.49), this indicates that the shape of the target volume is not more suitable for the shape of the target volume inside the patient's body, which is medically accepted in rare cases.

Regarding fig. 4, the effect of receiving doses by organs at risk like the bladder, small bowel, left femoral head, and right femoral head has consisted of the planning technique. The main goals of these



organs were to attain lower radiation exposures than their tolerance values.

For the estimated ten patients in the bladder, the plans indicate that OAR values were below established dose limits except in one patient. In the small bowel, all the plans were under the established dose except three cases, which were above the tolerance dose. In the left femoral head, all the plans referenced the value below the tolerance dose, except one case, which was a little above the tolerance dose. In the right femoral head, all the values were below the tolerance dose.

## Conclusions

For preoperative rectal cancer irradiation treatment in a sequential two-phase treatment scheme, three-dimensional conformal radiation therapy provides high-quality dose distributions with significant benefits in the PTVs and OARs. In the 3D-CRT technique, the greater isodose conformity allows for enhanced OAR sparing while preserving adequate PTV coverage. In the global plan that comprises the sum of both phases and, regarding the high dose PTV, these plans show superior results in the HI, CI, D98%, D50%, D2%, and D95% parameters. 3-DCRT designs improve femoral head, bladder, and small bowel protection, with statistically significant changes in the majority of the evaluated parameters.

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