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Evaluation of Intensity-Modulated Radiation Therapy (IMRT) Treatment Plans Using Various Numbers of Beams in Pelvic Cases

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Abstract: **Objective:** To evaluate the better plan for pelvic tumors in which achieving high target coverage dose and low normal tissues tolerance dose by using variable number of radiation beams in Intensity-Modulated Radiation Therapy (IMRT) technique . **Materials and method:** thirty pelvic cancer patients were included and four treatment plans contain different number of beams (5, 7, 9 and 11 beams) in each case were planned. The cross-sectional clinical study conducted in Al-Amal National Hospital for Radiotherapy and Nuclear Medicine, Baghdad, Iraq. The patients are delineated by oncologists according to Radiation Therapy Oncology Group RTOG 1005 protocol and prepare for radiation planning by MONACO 5.1 treatment planning system (TPS) with an X-ray photon beam of 6 MV energy using ELEKTA's Agility linear accelerator**. Results:** Significant differences between the treatment plans, after the comparison, it was found that the 7-beams treatment plan and 9-beam treatment plan achieved the optimal results among the treatment plans, it achieved adequate coverage of the tumor, sparing of organ at risk, homogeneity index and conformity index. As for the treatment plans of the 11 and 5 beams, they did not achieve good results in terms of coverage, sparing of organ at risk, homogeneity index, and conformity index. **Conclusion:** This analysis showed that increased beam count was associated with better dose formation of PTV. However, there was no noticeable improvement with the use of more than nine beams.

Key points: Pelvic Cancer, Intensity Modulated Radiation Therapy, coverage, organs at risk, homogeneity index, Conformity index, treatment plan evaluation.

INTRODUCTION

Radiation therapy is used to treat tumors because of its ability to control cell growth. Ionizing radiation works by damaging the exposed tissue's DNA, therapy killing it. To spare normal tissues (such as skin or organs that radiation must pass through to treat a tumor), doctors target weaker beams from several angles. The beams intersect at the tumor, providing a much greater absorbent dose than the surrounding healthy tissue[1][2][3].

Combination radiation treatment (IMRT) has been established as a method that can treat tumors or recurrent and nodal metastasis areas, while sparing surrounding normal tissues at high doses from radiation. IMRT is a state-of-the-art method of radiation therapy that enables different levels of radiation during the treatment package. Unlike conventional treatment planning techniques that use a wide range of beams, wedges and beam weights until a desired therapy plan has been obtained, IMRT reverses dose constraints and/or constraints, and automates treatment plans. IMRT provided therapy that was more consistent with the desired target volume irradiation and reduced dose into normal pelvic tissue, including small intestines, bladders, rectums and femoral head, by determining constraints on priority coverage of tumor volumes and sparing normal tissue. IMRT is commonly utilized to provide additional therapy that coincides with irregular treatment volumes including prostate, gastric and head and neck malignancies [4]

Radiation efficiency and treatment-plan quality are closely tied to beam angle arrangements and the number of beams used. Research into computer optimization of beam-angle selection has not proved to be clinically useful because of the large angular search space and the dependence on a specific clinical situation[5].

Treatment Planning System (TPS) it is a very important component in the process of establishing patient treatment planning in radiotherapy, in particular, with the arrival of three dimension-conformal radiotherapy (3D-CRT) and image-based IMRT in recent years. Currently, treatment planning system (TPS) relies on complex algorithms such as Monte Carlo (MC) or Convolution/Superposition [6][7]. Monte-Carlo simulation, or algorithm, is one of the statistical methods that solve physics and mathematics problems in the form of deviation or integration and so on. In radiotherapy, the MC is the best way to solve the complex problem of deposition of energy and the transport of particles within an inhomogeneous medium such as the human body[8].

MATERIALS AND METHOD

Thirty patients with pelvic cancer were selected for this study. The prescription doses, photon energy, IMRT constraint and rest parameters are all constant except the number of beams. The critical structures included the following: bladder, rectum, small intestine. For all cases, four plans were created in each patient by using SS-IMRT technique were prepared using X-ray energy of 6 MV in MONACO 5.1TPS. Planning process includes acquiring CT images using CT simulator. After determination of coordinates of organs to be treated by virtual simulation, laser system was used to tattoo the patients. Five, seven, nine and eleven-field (beam) multi-leaf collimator technique was used for IMRT photon beam delivery. Gantry angles differ according to the number of beams used in the treatment plan. Collimator and couch angle were 0^0 for all cases Static treatment planning was conducted with Eclipse treat. The treatment plans were compared in terms of their dose–volume histograms (DVH), target volume covered by 95% of the prescription dose ($D_{95\%}$), maximum and mean structure doses (D_{max} and D_{mean}), homogeneity index and conformity index. Steps to create a treatment plan with IMRT technique, where the prescribed dose and the number of its fractions are entered, the number of beams and the angles of the gantry, and then we enter the IMRT constraint for both the PTV and the exposed organs, and then optimize1 to calculate the dose and optimize 2 for the segment and through DVH statistic the oncologist can know the prescribed dose arrived for the tumor and organ at risk.

The study is a comparison of different treatment plans in the same dataset. However, there was no change in the patient's treatment plan for the proposed study. So the Ethics Committee permission was not required. The study was approved and permitted by the hospital director.

Planning Evaluation

Evaluation of planning done by the Oncologist firstly on dose distribution for target and OARs by reading the curves in DVH histogram that contains a volume for the target and OAR such as: min., max., mean dose and specific dose to OAR and statistic DVH. Recorded the data used in this study such as CI, HI two parameters to evaluate the plan for each patient and technique and check if it needs to be edited. Finally, if the plan accepted the oncologist approved the patient treatment plan and then the patients prepared for irradiation

STATISTICAL ANALYSIS

Analysis of data was carried out by using the available statistical package of Statistical Packages for Social Sciences- version 24 (SPSS-24). Data were presented in simple measures of percentage, mean, standard deviation, and range (minimum-maximum values). The significance of the difference of different means (quantitative data) was tested using T-test. Statistical significance was considered whenever the *p*-value was equal or less than *0.05*

RESULT

1-Dose coverage (the tumor receives 95% from prescribed dose):

Through the statistical results reached by the study. The results showed a significant difference between the treatment plans showed in table (1) and figure (1). The 7-beam treatment plan showed the best coverage for the tumor, as the mean coverage was 99.2087, followed by the 9-beam treatment plan with mean coverage of 94.1667, then the 5-beam treatment plan with mean coverage of 81.714 and finally the 11-beam plan with mean coverage of 80,1593 .

	5-beam	7-beam	9-beam	11-beam	*p* - value
Dose coverage 95% from PTV	81.714 ±11.7997	99.2087±7.6243	94.1667±4.8404	80.1593±13.9527	0.0305 *

TABLE (1) demonstrates dose coverage for different beams.

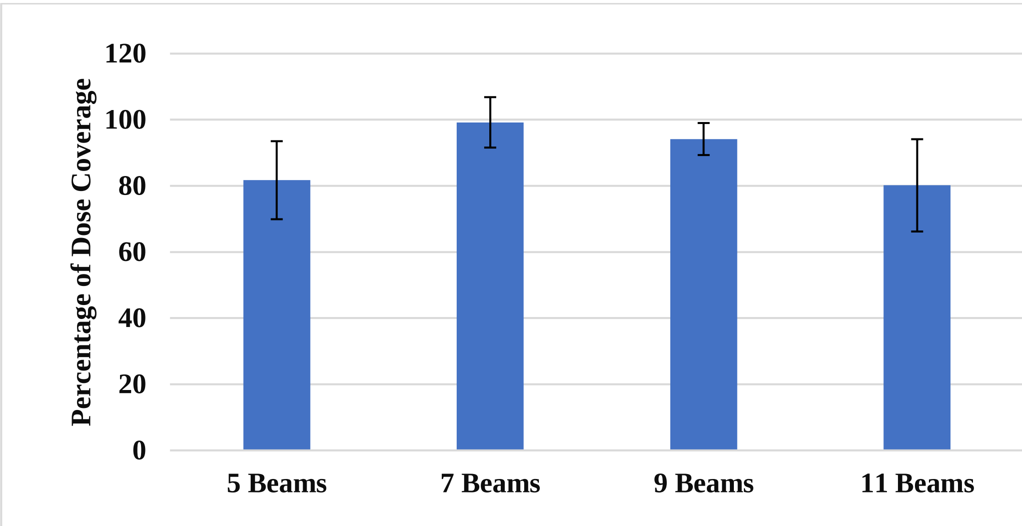

Figure (1). show percentage dose coverage in different beams

Organ at risk (OAR)

The organ at risk sparing values presented in this part as $D_{n\%}$ which is the absolute Dose (radiation dose to n% of structure ,such as D95%) and V_m is organ volume (percentage of structure received < certain mGy).The tolerance dose used in this study for each organ was, rectum(5000cGy<50%), small intestine(maximum dose 45Gy), and bladder(5000cGy<50%). The terms studied involved in this study are the mean dose to the rectum, the mean dose to the bladder and mean dose to the Small Intestine.

The statistical results are summarized in table (2). Statistics showed that the four treatment plans achieved protection for the organs at risk, as the dose received for the organ was among the tolerance. As for the rectum, the 7-beam plan achieved the best result, followed by the 9-beam plan, the 11-beam plan, and finally the 5-beam. As for the bladder, the 11-beam treatment plan gave the best protection, followed by the 9-beam plan, followed by the 5-beam plan, and finally the 7-plan

plan. For the small intestine, the best result was with the treatment plan of 9 beams, followed by the 7 beams, then the 11 beams, and finally the 5 beam.

TABLE (2) it shows the mean dose for each organ in different beams.

No. of beam	Rectum	Bladder	Small intestine
5-beam	4154.07 ± 932.41	4401.95 ± 654.89	2189.56 ± 811.99
7-beam	2026.93 ± 1070.74	4446.95 ± 633.68	1727.73 ±807.35
9-beam	2062.41 ± 1079.25	3401.49 ± 670.68	1627.89 ± 806.77
11-beam	4111.78 ±1067.23	2223.47 ± 817.21	2187.55 ± 810.37
p -value	0.0426*	0.0289*	0 .0398*

3-Homogeneity and Conformity Indexes

The ideal dose coverage for the PTV volume planned using treatment planning system should have a homogeneity index equal to zero, while the conformity index is equal to one. The homogeneity index was for the treatment plan with 5 beams 0.1293±0.0413 and for the 7 beam plan 0.0267±0.0037 as for the 9 beam plan 0.1158±0.0359 and finally the 11 beam plan 0.1323± 0.0707. Statistics show that the best homogeneity in the dose occurred in the 7-beam treatment plan, as show in table (3) and figure (2).

TABLE (3): it shows the mean dose homogeneity of the tumor in different beams

	5-beam	7-beam	9-beam	11-beam	*p* -value
Homogeneity index mean±SD	0.1293±0.0413	0.0267±0.0037	0.1158±0.0359	0.1323± 0.0707	0.0236*

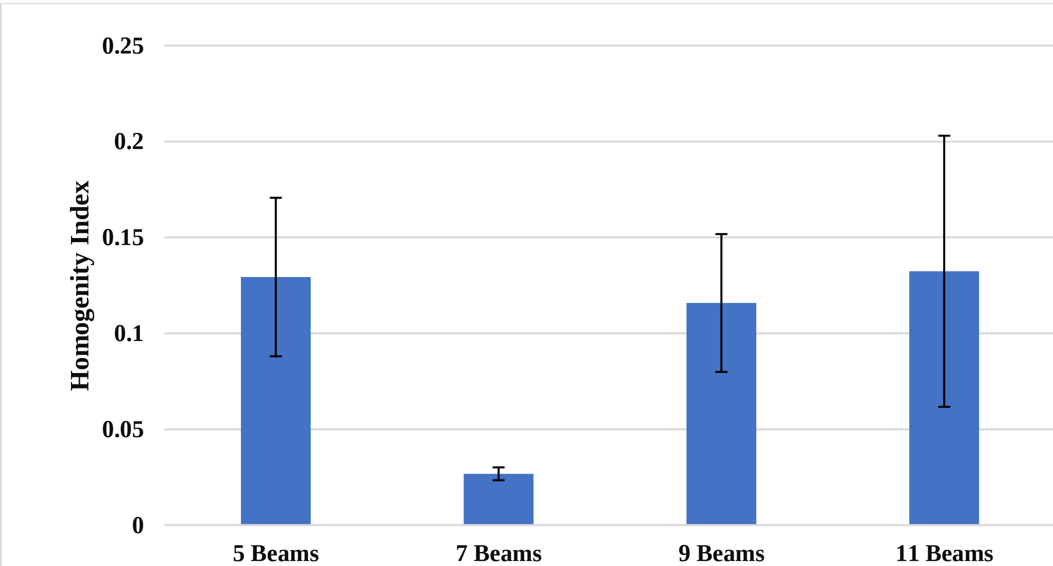

Figure (2). show homogeneity index in different beams

As for the conformity index, the statistical results in table(4) and figure(3) showed that the treatment plans with 7 and 9 beams almost achieved the same results 0.9373±0.0763 and 0.9373±0.0492 with best conformity indexes, followed by the 5-beams plan 0.6133±0.1185 and finally the 11-beams plan 0.5953±0.1396 .

TABLE (4): it shows the mean dose homogeneity of the tumor in different beams

	5-beam	7-beam	9-beam	11-beam	*p* -value
Conformity index mean±SD	0.6133±0.1185	0.9373±0.0763	0.9373±0.0492	0.5953±0.1396	0.0412*

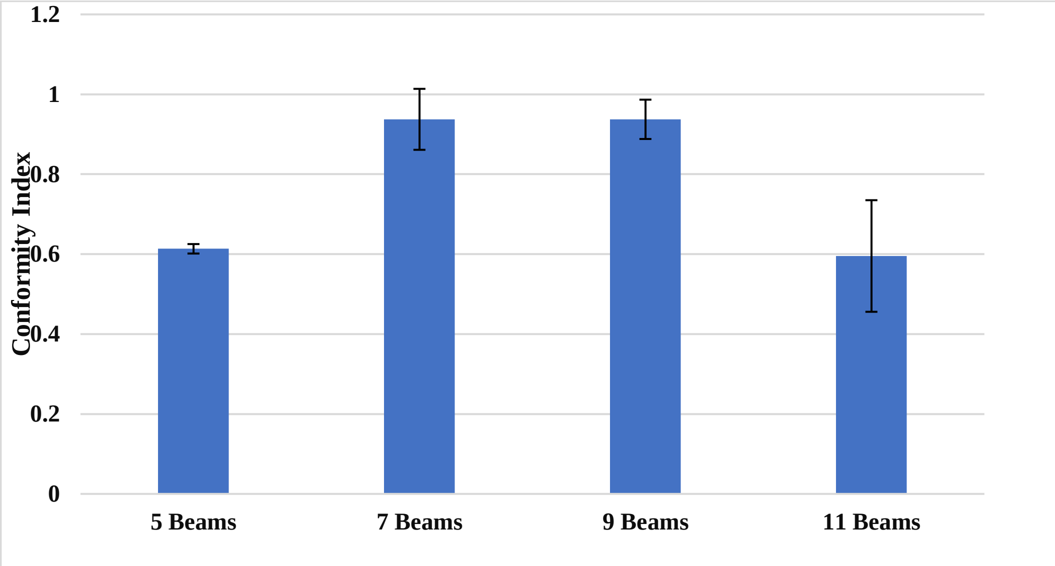

Figure (3): show conformity index in different beams

DISCUSSION

An optimal treatment plan was used in this study so that it was able to give good results that were achieved. An increase in the number of beams leads to an adequate dose of the tumor and a more homogeneity of the dose within the tumor, but this is not a standard in our study proving that the tumor shape, size and location have an effect on dose delivery. There are 5 beams that may be sufficient to deliver the largest possible amount of dose to the tumor, and there are 11 beams that do not lead to covering the tumor with the dose, and all this depends on the reasons that mentioned the shape, location and size of the tumor. There is no fixed number of beams and there is no study that has proven this. In our study we have proven that the best coverage is the tumor was achieved in the 7-beam plan, followed by the 9-beam plan, and this indicates that the number of beams and angles had a major role in achieving these results.

Better conformity may help in delivering minimum dose to organs at risk (OARs) and maximum dose to planning target volume (PTV). As per the requirements of modern radiotherapy, 95% isodose should cover the PTV, so conformity indices (CIs) are used for evaluating quality of conformation of treatment plans. We will discuss in our study the results that we have reached and explain what is the best treatment plan that was able to achieve perfect results.

The 5-beam treatment plan did not achieve adequate coverage of the tumor, but it was able to protect the healthy organs. As for the homogeneity index, it did not give a good result, and this indicates that the amount of dose that reached the tumor is small, as for the conformity index it also did not give an acceptable result, and this is also due to the low dose of the tumor.

Through the statistics, the 7-beam treatment plan showed ideal results in terms of dose coverage of the tumor, complete protection of healthy organs, homogeneity and conformity indexes. This is due to the appropriate direction and number of beams in delivering the largest dose to the tumor and the lowest dose to the healthy organs, and for this reason the homogeneity and conformity indicators were high within the tumor due to the arrival of a high tumor dose.

As for the 9-beam treatment plan, the statistical results were acceptable for tumor coverage with dose, as well as this plan achieved complete protection for healthy organs, as well as ideal results in terms of the conformity index and acceptable results in terms of the homogeneity index. The 9-beam treatment plan is good and can be applied plan

The 11-beam treatment plan did not fulfill the conditions that must be met in conducting the treatment plan. Only it was able to protect healthy organs, and this is only unacceptable.

Finally, through knowing the results of the study and discussing them, we can say that both the 7 and 9 beams treatment plans are ideal plans for as they were able to achieve high tumor coverage and protect healthy organs, as well as HI and CI.

The 7-beam treatment plan gave 99% tumor coverage and this is considered an extra-ideal result. As for the 9-beam treatment plan, the tumor coverage 94% and this plan can be used in some cases that cannot tolerate a high-dose tumor in the 7-beam plan because it may lead to the death of the patient; therefore we resort to using the 9-beam plan to avoid such damages.

Several studies have explored the number of beams required to produce an optimum treatment plan for coplanar IMRT. Ehab M at el 2017 [9] was shown that the prescription dosage to the tolerance dose of important structures determines the lowest number of equilateral beams and that as this ratio grows, a significant number of beams are essential. They point out that when the beam angles are increased for just a few beams, which have no alignment, the dosimetric advantage is much higher than when beams are positioned equiangularly.

Mahdavi et al 2017[10] and the Zope MK at el 2019[11]. Their study did not agree with our study, as they concluded that the 7beam and 9beam treatment plan did not achieve good results in terms of covering the tumor with the dose and protecting the organs, and the difference between the two plans was very small.

CONCLUSION

In our study, we have searched for the best treatment plan that provides the best coverage of the tumor and the protection of the OAR for cases of pelvic cancer, by changing the number of fields in each treatment plan. Among the four treatment plans for pelvic cancer cases, the 7 and 9 beam treatment plan gave better dose coverage as well as homogeneity and conformity indexes, and organ at risk protection. This research gives an indication of the use of IMRT technique with an optimal treatment plan for pelvic cancer to obtain a good and life-satisfactory outcome for these patients.

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