RESEARCH ARTICLE

Intensity-modulated radiotherapy (IMRT) versus three-dimensional conformal radiotherapy (3DCRT) as treatment plans for head and neck tumours

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Abstract

Objective: To compare intensity-modulated radiation therapy with three-dimensional conformal radiation therapy 3DCRTwith respect to dose coverage for target volume.

Method: The cross-sectional study was conducted at Al-Amal National Hospital, Baghdad, Iraq, from November 2020 to March 2021 and comprised patients with head and neck cancerous tumours. The patients underwent computed tomography scans, and were subsequently subjected to three-dimensional conformal radiotherapy and intensity-modulated radiotherapy treatment planning techniques on the basis of Monaco 5.1. The oncologist selected the better plan depending on evaluation parameters for each patient who was then irradiated with X-ray treatment. Data was analysed using SPSS 24.

Results: There were 30 patients, 17 (57%) females and 13 (43%) males with the age range of 19-45 years. Of the total, 28 received chemotherapy and 6 patients underwent brain surgery. The intensity-modulated radiation therapy resulted in significant coverage of the tumour than the three-dimensional conformal radiation therapy in phase 1 ($p<0.00001$) and phase II ($p=0.0023$). The intensity-modulated radiation therapy technique achieved a lower homogeneity value ($p=0.0004$) and higher conformity value ($p<0.00001$) than three-dimensional conformal radiation therapy. In phase II, no significant homogeneity index was found between the two therapies ($p=0.072$). The intensity-modulated radiation therapy showed significantly better conformity compared to three-dimensional conformal radiation therapy ($p<0.00001$).

Conclusion: The intensity-modulated radiation therapy significantly improved coverage, plan conformity, and humongous dose distribution for head and neck tumours compared to the three-dimensional conformal radiation therapy 3DCRT.

Key Words: Radiotherapy, Monaco, X-Rays, Radiotherapy, Conformal, Head and Neck, Tomography, Brain

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Introduction

The incidence of head and neck (H&N) tumours is estimated to be about 6% in the United Kingdom[1] of all cancer cases excluding skin cancer. Also, treatment planning for H&N tumours is complex due to a large number of organs at risk (OARs) that are located close to the planning target volume (PTV)[2]. The anatomy of the patient and the target tumour can be shown as three-dimensional (3d) models in computed tomography (CT) scans, and a treatment planning system (TPS) is often used in external beam radiotherapy to create uniform beam and dose distributions to maximise tumour control and minimise normal tissue complications[3,4].

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Three-dimensional conformal radiation therapy (3DCRT) is a widely used technique in oncology cases worldwide based on 3D anatomic information, typically a thin-section CT scan. The 3DCRT does not conform well to a random 3D structure unless large numbers of beams are used, and the target has a relatively simple shape. Using beam eye viewing (BEV) of volumes identified on a CT scan for treatment planning, beam directions and beam forms may be chosen to correspond to the shape of the predicted target, and to reduce the dose to OARs. The definition of conformal dose distribution has also been expanded to include clinical goals, such as optimising tumour control probability (TCP) and minimising the risk of normal tissue complication probability (NTCP). To achieve optimal clinical outcome, the 3DCRT technique incorporates both physical and biological rationales[5,6].

The intensity-modulated radiation therapy (IMRT) is a technique that uses a non-uniform intensity to deliver radiation to the tumour, allowing better dose conformity with PTV and sparing OARs. The growing complexity of

IMRT treatments demands an efficient and systematic quality assurance (QA) programme, both in terms of precision delivery of treatment machines, and TPS[7-9]. The PTV is generally generated by adding geometric margins to the clinical target volume (CTV). The CTV to PTV margins is determined to eliminate the uncertainties that occur during the delivery phase of the treatment beam due to organ deformation, internal organ motion, external patient motion, and patient setup variations[10].

A conformity index (CI) measures how well a radiation dose distribution's volume matches the shape and size of

$$\mathrm{CI} = \frac{V_{95\%}}{\text{volume of PTV}} \ldots\ldots(1)$$

a target volume[11,12]. The CI is defined by the following equation[1,13]:

V95% is the PTV volume covering 95% of the prescription dose.

The International Commission on Radiation Units and

$$\mathrm{HI} = \frac{D_2 - D_{98}}{D_{50}} \ldots\ldots(2)$$

Measurements (ICRU) has recommends a homogeneity index (HI)(14):

D2, D50 and D98 are the maximum, mean, and minimum doses, respectively. In another explanation, D98 represents the lowest dose received in 98% of the volume. If the dose-volume histogram (DVH) is steep, the HI will be close to zero, showing the dose to be homogenous[14].

Gupta et al.[15] studied comparison of 3DCRT and IMRT in H&N squamous cell carcinoma (HNSCC) curative-intent irradiation, and conclude that the IMRT dramatically decreased the frequency and severity of xerostomia. El Zayat et al.[16] discovered that the IMRT improved dose distribution within the CTV, while the dose to OARs was reduced.

The current study was planned to compare IMRT and 3DCRT to evaluate which technique provided better dose coverage PTV.

Materials and Methods

The cross-sectional study was conducted at Al-Amal National Hospital, Baghdad, Iraq, from November 2020 to March 2021. After approval from the ethics review committees of Al-Nahrain University and Mustansiriyah University, Baghdad, the sample was raised using consecutive sampling technique. Those included were adult patients with malignant H&N tumours needing two phases of radiation treatment depending on their stage and pathological change. Patients with benign tumours, patients suffering from infections, and patients with psychological disorders were excluded. Written informed consent was taken from all the participants.

The patients underwent computed tomography (CT) simulation from imaging and were then treated with an X-ray beam using 3DCRT and step-and-shoot IMRT techniques separately using Monaco [5].[1].

Data was analysed using SPSS 24. Student paired t-test was used for comparisons. P<0.05 was taken as significant.

Results

A total of 30 patients were included in this study. There were 17 (57%) females and 13 (43%) males. The ages ranged from 19-45 years. Twenty-eight out of thirty patients had previous chemotherapy whereas six patients had undergone craniotomy surgery. IMRT resulted in

Table-1: PTV comparison between 3DCRT and IMRT treatment planning techniques for PTV1 and PTV2.

Coverage	3DCRT	IMRT	p-value
PTV1	97.48 ± 1.98	99.07 ± 0.89	< 0.00001*
PTV2	94.53 ± 1.78	98.13 ± 1.45	0.0023*

PTV: Planning target volume, 3DCRT: Three-dimensional conformal radiotherapy, IMRT: Intensity-modulated radiotherapy treatment.

Table-2: Homogeneity and conformity indices for 3DCRT and the IMRT treatment planning techniques for PTV1.

Indexes	3DCRT	IMRT	p-value
PHI	0.16 ± 0.096	0.14 ± 0.093	0.0004*
CI	0.94 ± 0.0054	0.99 ± 0.008	< 0.00001*

3DCRT: Three-dimensional conformal radiotherapy, IMRT: Intensity-modulated radiotherapy treatment, PTV: Planning target volume, HI: Homogeneity index, CI: Conformity index.

Table-3: Homogeneity and conformity indices for 3DCRT and IMRT treatment planning techniques for PTV2.

Indexes	3DCRT	IMRT	p-value
HI	0.14 ± 0.028	0.11 ± 0.026	0.07275
CI	0.95 ± 0.014	0.98 ± 0.015	0.0006*

3DCRT: Three-dimensional conformal radiotherapy, IMRT: Intensity-modulated radiotherapy treatment, PTV: Planning target volume, HI: Homogeneity index, CI: Conformity index.

significant coverage of the tumour than 3DCRT in phase 1 ($p<0.00001$) and phase II ($p=0.0023$) (Table 1). IMRT achieved a lower homogeneity value ($p=0.0004$) and higher CI ($p<0.00001$) than 3DRT in PTV1 (Table 2). In PTVII, no significant HI value was found between the two therapies ($p=0.072$), but IMRT showed significantly better CI value compared to 3DRT ($p<0.00001$) (Table 3).

Discussion

In the current study, IMRT demonstrated much superior tumour coverage in all stages than 3DCRT (phase I: 97.48% vs. 99.07%, phase II: 94.53% vs. 98.13 %).

El Zayat et al.[16] reported similar findings. Ferreira et al.[17] stated that while using IMRT, the recommended dosage increased in all the defined PTV areas, leading to an increase in the chance of successful treatment. Deasy et al.[18] explored the effect of IMRT on salivary gland functions, and found that the IMRT had superiority over conventional radiotherapy. Ding et al.[19] stated that the tumours of small volumes showed significantly better coverage with 3DCRT than IMRT. At the same time, IMRT showed superior results for large tumour volumes. Chandra A et al.[20]found IMRT to be more effective than 3DCRT in target coverage of distal oesophageal cancer.

The 3DCRT plans are still competitive for small brain tumours, and IMRT is not recommended for treating small brain tumours of size PTV <2cm^3 because the number of beamlets is limited for such tumours. Thus, the number of possible plans designed to meet the given limitations successfully is restricted.[19,21].

In the current study, IMRT obtained lower homogeneity values in phase I than 3DCRT, but there was no significant difference in phase II. IMRT produced considerably greater CI value than 3DCRT for both phases.

Due to the non-uniform flounce of radiation treatment and continuous multi-leaf collimator movement during IMRT, homogenous dose distribution to the tumour can be acquired. The inverse plan of IMRT gives an additional benefit for the plan quality, including the plan's conformity. The current study achieved highly significant conformity and homogeneity values with IMRT compared to 3DCRT.

All tissues may be affected if the irradiated amount exceeds the target volume. When CI is <1, goal irradiation is insufficient. Values of measurement should range 1-5, where 1 is ideal, and 5 is non-compliant[22].

The current results were in line with El Zayat et al.[16]. Cardinale et al.[23] Compared 3DCRT designs for 3 intracranial target shapes with arc treatment, IMRT and conventional radiotherapy. Dose conformity and homogeneity were enhanced using IMRT.

A. Caraman et al.[24] compared various methods, but they may not be up to the mark in the modern environment.

Chandra A et al.[20] proved that 3DCRT resulted in low-dose homogeneity and conformity than IMRT.

L. Cozzi et al.[25] indicated that 3D conformal and proton therapy were also effective in treating advanced H&N tumours.

Ding et al.[19] compared 3DCRT, dynamic conformal arc, and IMRT for brain tumour treatment, and found that IMRT had better HI and CI values.

In general, IMRT is found better than 3DCRT in terms of tumour coverage, conformance to tumour shape, and uniformity of dose distribution. This is likely owing to the sophisticated and precise nature of IMRT. However, it is essential to note that unique patient features and treatment planning details might significantly impact such findings.

Limitation: The current study has limitations as the sample size was not calculated which could have affected the power of the study and the and generalisability of the findings.

Conclusion

Inversely optimised IMRT should be selected over directly optimised 3DCRT because of its significant therapeutic benefits for H&N tumours.

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