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ORIGINAL ARTICLE

# Dosimetric Comparison of Plans Obtained by Applying 3DCRT-VMAT and Tomotherapy Radiotherapy Methods in Patients with Thyroid' Ophthalmopathy Diagnosis

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**OBJECTIVE**

The aim of our study is to compare the effectiveness of Lateral Three Dimensional Conformal Radiotherapy (3DCRT), Volumetric Modulated Arc Therapy (VMAT) and Helical Tomotherapy (HT) treatment planning systems (TPS) in patients receiving radiotherapy (RT) for thyroid ophthalmopathy (TO).

**METHODS**

In our study, each of 10 patients who received TO treatment between 2012 and 2019 were retrospectively planned with three different TPS and dosimetrically obtained data of the doses received by the planned target volume (PTV) and normal tissues for three TPS were compared.

**RESULTS**

When the Conformity Index (CI) and Homogenity Index (HI) were evaluated in terms of homogeneous coverage of the PTV target volume, it was shown that HT and VMAT techniques covered the target volume better than 3DCRT. Although the Monitor Unit (MU) value of HT was higher than the other two techniques, it was clearly seen that HT gave better results in the lenses and optic chiasm, which are critical organs. The VMAT technique, on the other hand, gave lower results than HT in the lacrimal glands. It was also observed that HT and VMAT techniques gave better results than 3DCRT in other organs at risk such as eyes, optic nerves and retinas.

**CONCLUSION**

The results of the study showed that all treatment techniques can be recommended as safe and effective in the treatment of TO.

**Keywords:** Cancer; helical tomotherapy; radiotherapy; thyroid ophthalmopathy.


## INTRODUCTION

TO is a disease of the posterior orbital region, also known as Graves' disease, endocrine orbitopathy, and Graves'-related ophthalmopathy.[1] The annual incidence rate is 16 females and 3 males per 100,000 population.

TO belongs to the group of diseases defined as benign or non-malignant and has two basic forms of treatment: Surgical or medical intervention. Surgical treatments are applied in the initial stage of the disease to preserve functionality, improve appearance, and address cases that cannot be controlled with medical treatments. In complicated cases that do not respond to medical treatment, RT may be recommended to control the disease.[2]

The high radiosensitivity of lymphocytes infiltrating the orbital tissue is due to the fact that these cells

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are particularly sensitive to radiotherapy. Therefore, orbital radiotherapy may be effective in the treatment of inflammatory diseases by helping to reduce the molecules produced by lymphocytes during inflammation. The main positive effect of orbital radiotherapy is that it helps to reduce the limitation of eye movement.[3] Although RT is well tolerated and safe, its use in the treatment of benign diseases is very limited due to fear of toxicity and the risk of radiation-induced tumors.

In orbital radiotherapy, the dose prescription is designed for 10 days, and the daily fraction dose per session ranges from 150 to 200 cGy. It has been reported that the variation between daily fraction dose values does not lead to a significant change in treatment, but care should be taken to ensure that the daily fraction dose for TO does not exceed 240 cGy.[4]

Reciprocal lateral three-dimensional conformal radiotherapy (3DCRT) is an RT modality used to reduce exposure to organs at risk while narrowing the target volume.

In volumetric modulated arc therapy (VMAT), the multileaf collimator (MLC) leaves and gantry move continuously along the arc with varying dose rates. To achieve homogeneous dose distribution, MLC models assume new positions as the gantry values change along the defined arc.[5]

Helical tomotherapy (HT) treatment techniques are similarly used to narrow the target volumes and expose less dose to organs at risk. The tomotherapy device has a gantry structure that allows it to make 360-degree rotations quickly, making it faster than other planning techniques. Due to the collimator structure and MLC speed of the device, treatments can be completed in a shorter time as the opening and closing functions can be fulfilled within milliseconds. This is an advantage of using the tomotherapy device.[5]

The aim of our study was to compare the updated planning techniques with the evolving technology, including HT based on classical radiotherapy applications, in terms of target volume and critical organs.

## MATERIALS AND METHODS

In our study, 10 patients who received TO treatment in Ege University Faculty of Medicine, Department of Radiation Oncology between 2012 and 2019 were retrospectively planned with a prescription dose of 20 Gy in 10 fractions. In order to minimize lens doses in the 3DCRT, plans were made by determining the reciprocal lateral angles of 80°–90° and 270°–280°. In the VMAT treatment method, two partial arcs of 300° starting at 210° and ending at 150° were used by choosing a clockwise gantry angle. For HT, the treatment was planned with a field width of 2.5 cm, a pitch factor of 0.100, and a modulation factor of 3,000. Figure 1 shows the isodose lines and DVH views of the 20 Gy prescription dose obtained for 3DCRT, VMAT, and HT planning techniques.

The following parameters were measured to assess the effects of radiation therapy on the tumor and normal tissues: the dose received by x% of the volume for the planned target volume (PTV), minimum, maximum, and mean dose values ($D_{\%2}$, $D_{\%50}$, $D_{\%95}$, $D_{\%98}$, $D_{min}$, $D_{max}$, $D_{mean}$); and the $D_{\%1}$, $D_{\%5}$, $D_{min}$, $D_{max}$, and $D_{mean}$ values of the critical organs in the area being treated (right and left eye, right and left lens, right and left lacrimal, right and left optic nerve, right and left retina, and optic chiasm), as per Quantec dose limits. Using these values, the homogeneity index (HI) and conformity index (CI) were calculated. Finally, the monitor unit (MU) values were analyzed in all three treatment plans. Radiation therapy effects were assessed by measuring parameters such as dose values for the planned target volume (PTV), critical organs, homogeneity index (HI), conformity index (CI), and monitor unit (MU) values in three treatment plans. Radiation therapy effects were assessed by measuring parameters such as dose values for the planned target volume (PTV), critical organs, homogeneity index (HI) and conformity index (CI), and monitor unit (MU) values in three treatment plans.The dose-volume histogram (DVH) results of the three plans for each patient were summarized and statistically evaluated. Figure 2 shows that 100% of the prescribed dose covered 95% of the PTV volume as a result of the three plans for each patient.

"The Statistical Package for the Social Sciences" (SPSS) PASW Statistics 21 software was used to statistically evaluate the dose data of three different plans for each patient. The results of the analysis were interpreted according to the p-value obtained. $p \leq 0.005$ was considered significant.

## RESULTS

Our study evaluated three planning techniques for the PTV, and the results are presented in Table 1 for dose evaluations and Table 2 for HI, CI, and MU values. Our observations indicate that VMAT and HT radiotherapy techniques provided statistically better results compared to 3DCRT in terms of both HI and CI for the target PTV. Specifically, the statistical significance values for HI were p=0.005 to p=0.011, and for CI, they were p=0.007 to p=0.004. Considering the

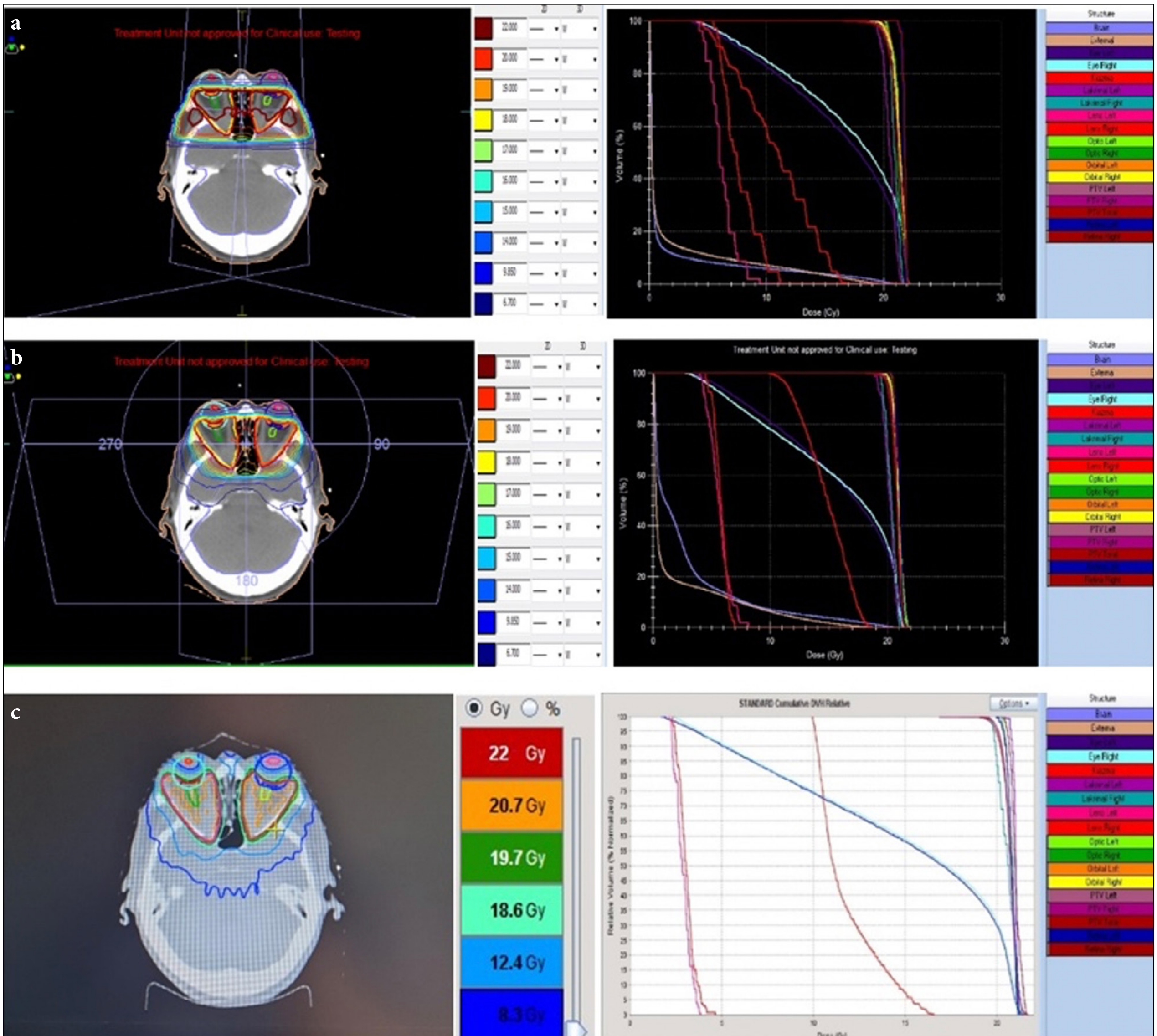


**Fig. 1.** (a) 20 Gy isodose lines and DVH view for the 3DCRT plan, (b) 20 Gy isodose lines and DVH view for the VMAT plan, (c) 20 Gy isodose lines and DVH view for the HT plan.
DVH: Dose-volume histogram; VMAT: Volumetric Modulated Arc Therapy; HT: Helical Tomotherapy.

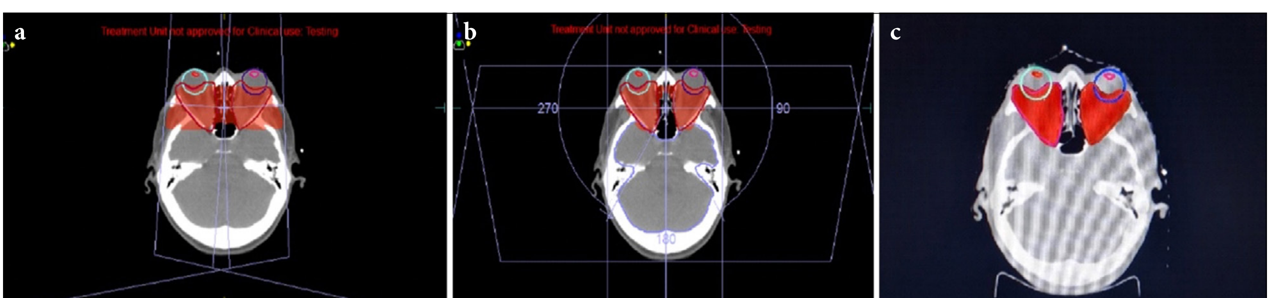


**Fig. 2.** (a) 20 Gy isodose view for the 3DCRT plan, (b) 20 Gy isodose view for the VMAT plan, (c) 20 Gy isodose view for the HT plan.
3DCRT: Three Dimensional Conformal Radiotherapy; VMAT: Volumetric Modulated Arc Therapy; HT: Helical Tomotherapy.

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**Table 1** Dx doses (Gy) of PTV and comparison of statistical data of Dx (Gy) doses for three TPS (p<0.05)

| PTV | 3DCRT | VMAT | HT | p | |
|---|---|---|---|---|---|
| $D_{2\%}$ | 22.021±0.282 | 21.594±0.265 | 21.641±0.149 | 0.007 | 3DCRT-VMAT |
| | | | | 0.005 | 3DCRT-HT |
| | | | | 1 | VMAT-HT |
| $D_{50}$ | 21.377 (21.031–21.801) | 20.809 (20.719–21.371) | 21.063 (20.746–21.288) | 0.001 | 3DCRT-VMAT |
| | | | | 0.042 | 3DCRT-HT |
| | | | | 0.791 | VMAT-HT |
| $D_{98\%}$ | 18.863 (17.712–19.614) | 19.694 (19.045–19.794) | 19.621(19.110–19.827) | 0.002 | 3DCRT-VMAT |
| | | | | 0.002 | 3DCRT-HT |
| | | | | 1 | VMAT-HT |
| $D_{min}$ | 11.832±2.299 | 15.765±1.177 | 14.797±2.946 | 0 | 3DCRT-VMAT |
| | | | | 0.01 | 3DCRT-HT |
| | | | | 0.64 | VMAT-HT |
| $D_{max}$ | 22.173±0.464 | 22.102±0.304 | 22.106±0.197 | p>0.005 | 3DCRT-VMAT |
| | | | | p>0.005 | 3DCRT-HT |
| | | | | p>0.005 | VMAT-HT |
| $D_{mean}$ | 22.210 (20.906–21.551) | 20.745 (20.669–21.215) | 20.950 (20.690–21.100) | 0 | 3DCRT-VMAT |
| | | | | 0.076 | 3DCRT-HT |
| | | | | 0.353 | VMAT-HT |

PTV: Planned target volume; TPS: Treatment planning systems; 3DCRT: Three Dimensional Conformal Radiotherapy; VMAT: Volumetric Modulated Arc Therapy; HT: Helical Tomotherapy

**Table 2** Comparison of CI, HI and MU for PTV and comparison of these values for three TPS (p<0.05)

| | 3DCRT | VMAT | HT | p | |
|---|---|---|---|---|---|
| CI | 0.366±0.048 | 0.697±0.050 | 0.795±0.038 | 0.007 | 3DCRT-VMAT |
| | | | | 0.004 | 3DCRT-HT |
| | | | | 1 | VMAT-HT |
| HI | 0.149 (0.090–0.215) | 0.087 (0.074–0.145) | 0.098 (0.075–0.133) | 0.005 | 3DCRT-VMAT |
| | | | | 0.011 | 3DCRT-HT |
| | | | | 1 | VMAT-HT |
| MU | 258.7±7.119 | 497.2±18.890 | 4569.1±146.909 | 0 | 3DCRT-VMAT |
| | | | | 0 | 3DCRT-HT |
| | | | | 0 | VMAT-HT |

CI: Conformity Index; HI: Homogenity Index; MU: Monitor Unit; PTV: Planned target volume; TPS: Treatment planning systems; 3DCRT: Three Dimensional Conformal Radiotherapy; VMAT: Volumetric Modulated Arc Therapy; HT: Helical Tomotherapy

total MU values, the lowest values were obtained with 3DCRT, while high MU values were reported with HT (p=0.000-p=0.000-p=0.000-p=0.000).

Tables 3 and 4 show the values of the dose received by the organs at risk. The results indicate that the VMAT technique is more effective in protecting the right and left lacrimal glands compared to the HT technique (right: p=0.042; left: p=0.023). However, there was no significant difference between the other techniques when compared pairwise. According to the planning results, there was no statistically significant difference between the three techniques in the right eye. In the left eye, the VMAT technique provided statistically better protection than the 3DCRT technique (p=0.003). There was no significant difference in the pairwise comparisons of the other techniques. In the evaluation of the target volume affecting the right and left eyes, it was observed that the total target volume of the left eye was larger than that of the right eye. The study evaluated the maximum doses for the right and left lenses and optic chiasm and compared three-dimensional conformal radiation therapy (3DCRT), helical tomotherapy (HT), and volumetric modulated arc therapy (VMAT). The study findings indicate that HT is significantly better than 3DCRT and VMAT in terms of the right lens (p=0.025-p=0.000), left lens (p=0.005-p=0.000), and optic chiasm (p=0.007-p=0.001). HT provided better

**Table 3** $D_{max}$ and $D_{mean}$ doses (Gy) of critical organs and comparison of statistical data of $D_{max}$ and $D_{mean}$ (Gy) doses for three TPS (p<0.05)

| | 3DCRT | VMAT | HT | p | |
|---|---|---|---|---|---|
| **Optic chiasm** | | | | | |
| $D_{max}$ | 17.468 (13.228–20.521) | 18.431 (15.786–19.789) | 15.270 (12.810–18.550) | 0.502 | 3 DCRT-VMAT |
| | | | | 0.007 | 3 DCRT-HT |
| | | | | 0.001 | VMAT-HT |
| $D_{mean}$ | 9.081±2.568 | 14.535±1.625 | 11.886±0.912 | 0 | 3 DCRT-VMAT |
| | | | | 0.028 | 3 DCRT-HT |
| | | | | 0.002 | VMAT-HT |
| **Right lacrimal gland** | | | | | |
| $D_{max}$ | 21.528 (19.294–21.958) | 20.976 (16.677–21.651) | 21.570 (19.500–21.900) | 0.353 | 3DCRT-VMAT |
| | | | | 1 | 3DCRT-HT |
| | | | | 0.042 | VMAT-HT |
| $D_{mean}$ | 21.025 (17.083–21.762) | 20.345 (13.819–20.755) | 21.180 (15.920–21.390) | 0.011 | 3DCRT-VMAT |
| | | | | 1 | 3DCRT-HT |
| | | | | 0.005 | VMAT-HT |
| **Left lacrimal gland** | | | | | |
| $D_{max}$ | 21.433±0.481 | 21.077±0.412 | 21.570±0.164 | 0.08 | 3DCRT-VMAT |
| | | | | 1 | 3DCRT-HT |
| | | | | 0.023 | VMAT-HT |
| $D_{mean}$ | 20.737±0.695 | 20.255±0.773 | 21.129±0.147 | 0.142 | 3DCRT-VMAT |
| | | | | 0.383 | 3DCRT-HT |
| | | | | 0.019 | VMAT-HT |
| **Right eye** | | | | | |
| $D_{max}$ | 21.998±0.319 | 21.693±0.323 | 21.837±0.230 | >0.005 | 3DCRT-VMAT |
| | | | | >0.005 | 3DCRT-HT |
| | | | | >0.005 | VMAT-HT |
| $D_{mean}$ | 15.951±1.425 | 16.047±0.766 | 14.871±0.649 | 1 | 3DCRT-VMAT |
| | | | | 0.03 | 3DCRT-HT |
| | | | | 0.004 | VMAT-HT |
| **Left eye** | | | | | |
| $D_{max}$ | 21.939±0.315 | 21.562±0.316 | 21.777±0.235 | 0.003 | 3DCRT-VMAT |
| | | | | 0.625 | 3DCRT-HT |
| | | | | 0.266 | VMAT-HT |
| $D_{mean}$ | 15.555±1.255 | 16.233±0.556 | 14.728±0.556 | 0.228 | 3DCRT-VMAT |
| | | | | 0.187 | 3DCRT-HT |
| | | | | 0.001 | VMAT-HT |

3DCRT: Three Dimensional Conformal Radiotherapy; VMAT: Volumetric Modulated Arc Therapy; HT: Helical Tomotherapy

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**Table 4** $D_{max}$ and $D_{mean}$ doses (Gy) of critical organs and comparison of statistical data of $D_{max}$ and $D_{mean}$ (Gy) doses for three TPS (p<0.05)

| | 3DCRT | VMAT | HT | p | |
|---|---|---|---|---|---|
| **Right lens** | | | | | |
| $D_{max}$ | 7.488±1.634 | 8.541±1.193 | 4.637±0.862 | 0.12<br>0.004<br>0 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| $D_{mean}$ | 4.696 (3.013–8.523) | 6.623 (5.439–7.775) | 3.240 (2.470–4.210) | 0.044<br>0.044<br>0 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| **Left lens** | | | | | |
| $D_{max}$ | 7.455±1.177 | 8.853±0.804 | 4.698±0.694 | 0.072<br>0.005<br>0 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| $D_{mean}$ | 5.061±1.422 | 6.680±0.593 | 3.191±0.373 | 0.017<br>0.008<br>0 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| **Right optic nerve** | | | | | |
| $D_{max}$ | 21.914 (19.936–22.268) | 21.633 (21.077–22.342) | 21.510 (21.140–21.740) | 0.18<br>0.007<br>0.18 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| $D_{mean}$ | 21.472±0.279 | 20.961±0.363 | 21.064±0.220 | 0.009<br>0.004<br>1 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| **Left optic nerve** | | | | | |
| $D_{max}$ | 21.886±0.255 | 21.549±0.291 | 21.550±0.101 | 0.135<br>0.008<br>1 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| $D_{mean}$ | 21.443±0.316 | 20.951±0.281 | 21.043±0.169 | 0.023<br>0.009<br>0.912 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| **Right retina** | | | | | |
| $D_{max}$ | 21.798±0.313 | 21.246±0.350 | 21.387±0.236 | 0.003<br>0.036<br>0.682 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| $D_{mean}$ | 21.587±0.309 | 20.685±0.337 | 20.917±0.206 | 0<br>0.001<br>0.153 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| **Left retina** | | | | | |
| $D_{max}$ | 21.776±0.299 | 21.179±0.227 | 21.386±0.154 | 0.003<br>0.014<br>0.108 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |
| $D_{mean}$ | 21.579±0.301 | 20.668±0.279 | 20.807±0.234 | 0<br>0.001<br>0.605 | 3DCRT-VMAT<br>3DCRT-HT<br>VMAT-HT |

protection in these three organs compared to other techniques. When the right and left optic nerves and right and left retinas were evaluated in terms of maximum doses, VMAT and HT techniques protected with lower doses compared to 3DCRT, but there was no statistically significant difference between these two techniques (right retina: p=0.036-p=0.003; left retina: p=0.014-p=0.003).

## DISCUSSION

The management of TO is usually based on the use of corticosteroids or, in unresponsive cases, orbital radiotherapy. Orbital radiotherapy can be applied to patients with moderate to severe TO. Studies with orbital RT [6] report a partial or complete response rate of 67%. In a study of 197 patients who underwent orbital irradiation, it was reported that radiation therapy with or without corticosteroids can lead to exophthalmos and improvement in ocular muscle function in 50–60% of patients, and up to 70% improvement in soft tissue reactions.[7] The ophthalmic index improved in 96% of irradiated patients. Another study reported that 84.2% of 211 patients with TO had improved symptoms before radiotherapy.[8]

While TO is defined as an effective treatment, many different approaches have been proposed in the literature for RT technique. In the study by Li et al.,[9] the Lateral Counter-Field (LOF) technique is traditionally recommended with the advantage of easy and fast application; however, the most prominent disadvantage of the technique is interpreted as blocking the anterior part of the globes to minimize the dose to the lenses. As a result, it caused an insufficient dose in the anterior part of the retro-orbital adipose tissue defined as the target volume. In addition, it is difficult to achieve homogeneous dose distribution within the target with the LOF technique.

IMRT, an evolutionary form of 3DCRT, has the ability to provide a dose distribution around a more irregular and complex target volume. Furthermore, steeper dose gradients are achieved between the target and normal structures, so that planning can reduce the dose delivered to surrounding tissues without compromising target coverage. In conclusion, IMRT may be advantageous in retro-orbital delivery due to the highly irregular target volume of retro-orbital structures.

Li et al.[9] reported the dosimetric superiority of IMRT in retro-orbital radiation in a dosimetric study involving 10 TO patients treated with IMRT. They concluded that IMRT has a significantly superior conformity index and homogeneity index than 3DCRT and LOF and can provide better dose savings to the eyes, lenses, and optic nerves. However, clinical efficacy and side effect results have not been reported since this was a dosimetrically retrospective study.

In our study, similar results to Li et al.[9] were obtained in target volume coverage. VMAT and HT techniques representing IMRT applications are superior in target volume coverage in CI and HI terminology compared to the 3DCRT technique. When evaluated in terms of eyes, lenses, and optic nerves, VMAT and HT techniques were observed to be lower than 3DCRT in terms of maximum doses, supporting the results obtained by Li et al.[9]

In a retrospective evaluation of 14 consecutive patients diagnosed with bilateral TO and treated with retro-orbital irradiation between August 2012 and August 2014, San-Miguel et al.[10] determined that a dose of 10 Gy in 10 fractions was prescribed for LOF, 3DCRT, and VMAT techniques. It confirmed that VMAT provided a significantly better CI compared to 3DCRT (p=0.001) and LOF (p<0.001). Furthermore, 3DCRT was superior to LOF (p=0.007). The median HI produced by VMAT, 3DCRT, and LOF was 1.05 (1.03–1.08), 1.08 (1.05–1.14), and 1.60 (1.06–4.60), respectively, with no statistically significant difference between the three groups.

When we compared the results obtained in the study by San-Miguel et al.[10] with our current results, VMAT and HT gave more conformal results than 3DCRT when analyzed in terms of the CI of PTV (p=0.007-p=0.004). In addition to this study, although there was no significant difference between VMAT and HT in our study, it was clearly seen that HT wrapped the target volume more conformally (p=1.000).

In a study by San-Miguel et al.,[10] the dose PTV values of VMAT were compared with LOF or 3DCRT. The study showed that lower minimum values (p=0.004; p=0.040) and higher maximum values (p<0.001, p=0.004) were obtained with VMAT. However, there was no difference reported in mean dose, median, D05, or D01. Additionally, no significant difference was observed between 3DCRT and LOF. In our study, unlike this situation, when evaluated in terms of minimums for PTV, 3DCRT was the lowest, and the VMAT technique was the highest. Comparison of 3DCRT with both VMAT and HT was statistically significant (p=0.000; p=0.010) and it was found to have a lower dose value. When evaluated in terms of PTV maxima, no statistical difference was found for the three techniques.

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MU assessment is important for treatment in terms of low-dose exposure. The mean MU values obtained by San-Miguel et al.[10] were higher for VMAT (268 MU) compared to 3DCRT (174 MU) and LOF (120 MU) (p=0.00; p=0.00). In our study, 3DCRT (258.7 MU), VMAT (497.2 MU), and HT (4569.1 MU) were found. Considering that San-Miguel et al.[10] applied a dose of 10 Gy in 10 fractions, consistent MU values are observed in the current study. In addition, in our study, it was reported that the MU value of the 3DCRT technique was lower than the other two techniques.

In the study by San-Miguel et al.,[11] comparing the protection of organs at risk for three different techniques, VMAT was shown to provide better protection in the eyes than 3DCRT or LOF for all dosimetric parameters (p<0.001), if the minimum dose distribution width was ignored. Significant differences between 3DCRT and LOF were reported only in mean and minimum doses. Better protection is reported to be achieved in all dosimetric parameters, with no statistical difference between VMAT and the other two techniques. When comparing 3DCRT with LOF, it should be noted that the lacrimal gland shows lower minimum and mean doses with the LOF technique; in contrast, all dosimetric parameters in the lens appear to fail significantly with 3DCRT. These results can be explained by the fact that in LOF, the anterior part of the eye where the lacrimal glands or the lens are located is blocked from radiation. While there is no significant difference in dosimetric parameters for the optic nerves between the three techniques, a different situation emerges in terms of the protection of the optic chiasm. Compared to LOF, VMAT and 3DCRT techniques resulted in a clear increase in the radiation dose for all dosimetric parameters, resulting in a pulse with a spread of the dose distribution. This results in an increase of the low-dose fields of the beams directed from the posterior area in the VMAT and 3DCRT techniques, as expected in the optic chiasm.

In our study, it was observed that VMAT provided better protection in the eyes, similar to the results obtained by San-Miguel et al.[11] (p=0.003). When we evaluated the retina, there was a significant statistical difference in the VMAT treatment technique compared to 3DCRT, with better protection in favor of VMAT (p=0.003). In the lacrimal area, although there was no significant statistical difference in VMAT compared to 3DCRT (p=0.353), results in favor of VMAT were obtained. In this case, as stated by San-Miguel et al.,[11] better protection can be provided in VMAT for lacrimals. However, when evaluated in terms of lenses, although there was no statistically significant difference between 3DCRT and VMAT in terms of maximum doses (p=0.072), it is observed that 3DCRT has a lower value. When analyzed in terms of optic nerves, there was no finding supporting San-Miguel et al.[11] in terms of maximum doses. When the results of 3DCRT and VMAT were evaluated in terms of the optic chiasm, similar results were observed. However, it was found that both techniques were more inadequate than the HT technique.

In the study published by Wang et al.[12] in 2020, the target dose for patients was prescribed as 20 Gy delivered in 10 fractions to cover 95% of the PTV, and the beam angle for double partial arc VMAT plans was 240° to 120° clockwise and 120° to 240° counterclockwise. The gantry angle for the 7-fixed-beam IMRT plans was 0°, 30°, 70°, 120°, 240°, 290°, and 330°. There was no significant statistical difference in CI between VMAT and IMRT (p=0.0673, p>0.05). When the VMAT values of the CI in this study were compared with the values in our study, the mean value of 0.606 was reported similar to the mean CI of 0.697 in our study. When compared with VMAT in terms of HI, a superior HI was observed in IMRT (p=0.0014). When the VMAT values of HI were compared with our study, Wang et al.[12] reported a mean HI of 0.1175, while the mean HI in our study was 0.0941.

The results obtained by Wang et al.[12] showed that VMAT produced a lower $D_{min}$ (p=0.0009), higher $D_{max}$ (p=0.0105), and $D_{mean}$ (p=0.0276) than IMRT. Although the dose received by the maximum 5% of the PTV was higher in VMAT, there was no significant statistical difference in the dose received by the maximum 95%. Considering this result and ICRU criteria, PTV %2 and PTV %98 values were also evaluated in our study to make a statistical inference in terms of PTV. The lowest value for PTV%2 was obtained in VMAT compared to other techniques. For D98%, it was observed that the maximum dose of the VMAT technique was higher than the other techniques.

Wang et al.,[12] similar to PTV, reported that VMAT produced a higher dose distribution in the left lens ($D_{max}$: p=0.0246, $D_{mean}$: p=0.0114) and a higher $D_{max}$ in the right lens (p=0.0463). VMAT had the highest dose value, achieving a similar result for the lenses. The rings of both lenses received a higher $D_{max}$ (left: p=0.0161 and right: 0.0034). Wang et al.[12] achieved similar results in the optic nerve (left: p=0.0050 and right: p=0.0225) and eyes (left: p=0.0045 and right: p=0.0031).

Nguyen et al.[13] compared HT dosimetry and conventional half-beam technique (HBT) or non-split-beam technique (NSBT) in terms of target coverage and radiation dose to the lacrimal glands and lens. In the evaluation of 7 patients with CTR who received radiotherapy for disease progression at high steroid doses, 3 patients were treated with HT and 4 patients with HBT. Patients were selected from those with TO unresponsive to high steroid doses (30 mg prednisone orally every day) and severe exophthalmos and/or extraocular muscle paralysis resulting in blurred vision and/or diplopia. No patient had optic nerve compression, keratitis, or retinopathy. The anterior borders of the fields were determined as the lateral bone canthus, and the posterior borders were determined by the peripheral target volume (PTV), which included the retro-orbital soft tissues and extraocular muscles to avoid marginal misses. A total dose of 2,000 cGy in 200 cGy/fraction was delivered to the PTV. After 2008, when the HT unit (6MV photons) was installed, 3 patients were treated with an intensity-modulated radiotherapy technique.

Compared to HBT, the most common technique for TO, HT provides better coverage of the target volume and more optimal sparing of the lacrimal glands. However, since the cataract threshold for fractionated radiotherapy is estimated at 500 cGy, the maximum lens dose is higher with HT, possibly leading to an increased risk of cataracts. The undivided beam technique has been observed to provide adequate coverage of the target volume at the expense of excessive irradiation to the lens and lacrimal glands. In a retrospective study of seven patients by Nguyen et al.,[13] HT, conventional HBT, and NSCT were compared dosimetrically. Target dose delivery was better with HT, and values supporting this result are reported in our study. However, lens doses were higher in this study, and unlike this study, the lowest lens dose was obtained with HT in our study.

Kargıoğlu et al.[14] compared 3DCRT, VMAT, HT, and HYPERARC on single patient data. Extraocular eye muscles and retrobulbar adipose tissue were contoured as clinical target volumes. The lens, lacrimal gland, macula, brain, pituitary gland, and hippocampus were identified as organs at risk. In their treatment plans, they aimed for 95% of the target volume to receive 95% of the prescribed dose. When the maximum dose results obtained were analyzed, close values were measured between the planning techniques in the right and left lacrimal glands and the right and left retina, which are critical organs. In the right and left lenses, the best values are seen in the HT technique. The MU value was by far the highest in the HT technique (4715.5 MU).

When the HT results of our study were compared with this study, similar results were observed for the retina, lacrimal glands, and lens doses, which are critical organs. When the same study is evaluated in terms of MU values, we see that the 3DCRT, VMAT, and HT in our study support the average MU values obtained as a result of the planning. In addition, in the study by Pete et al.,[15] devices with helical tomotherapy units, such as TomoTherapy Hi-Art, offer many more monitor units than conventional linear accelerators. To combat the higher head leakage resulting from this increased machine output, the jaws are made thicker, and the accelerator head is heavily shielded. This protection is effective, even reported to reduce the total peripheral dose to a lower value than conventional accelerators under certain conditions.

## CONCLUSION

Although 3DCRT is traditionally defined as the technique used to treat TO, the values in favor of VMAT and HT should also be taken into account in the studies carried out. There have not been many studies and comparisons regarding HT in the treatment of TO. In this study, the advantages and disadvantages of the three techniques were evaluated in detail. New radiotherapy techniques need to be backed up by a greater number of clinical trials.

The results of this study show that all treatment techniques can be recommended as safe and effective in the treatment of TO.

**Ethics Committee Approval:** The study was approved by the Ege University Medical Research Ethics Committee (no: 24-4.1T/65, date: 25/04/2024).

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