Comparison of Tomotherapy, Volumetric Arc Therapy and Three-Dimensional Conformal Radiotherapy Planning Techniques with Dosimetric Parameters in Pediatric Craniospinal Radiotherapy

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ABSTRACT

In present study, the comparison results of craniospinal radiotherapy plans using three different planning techniques including helical tomotherapy (HT), volumetric arc therapy (VMAT) and three-dimensional conformal radiotherapy (3D-CRT) were evaluat-ed in pediatric patients diagnosed with medulloblastoma depending on dosimetric parame-ters. Ten pediatric patients with medulloblastoma were planned with 3 techniques. Standard-risk medulloblastoma treatment doses of 23.4 Gy in the craniospi-nal region and 54 Gy in the posterior fossa region were used. When comparing treatment plans, doses of PTV, V95%, maximum PTV dose, homogeneity index (HI) conformity index (CI) criteria were taken into account. When the dosimetric results of PTV are examined; It has been seen that all plans meet the desired criteria, but the target volume coverage of tomotherapy is superior in do-simetric results compared to VMAT and 3D-CRT due to its ability to irradiate at once without field intersection (p< 0.003). It was found that the HI results of the tomotherapy plans and the CI results of the VMAT plans were closer to the criteria expected from the ideal plan. Target max dose were reduced with for tomotherapy and vmat compared to 3DCRT. When all treatment modalities are compared, it can be said that modern radio-therapy techniques may be preferred in Medulloblastoma radiotherapy because they have sufficient target volume coverage, good dose homogeneity and low maximum doses.

Keywords: Dosimetric Comparison, Pediatric Craniospinal, Radiotherapy, Treatment planinng

INTRODUCTION

PNET (Primitive Neuroectodermal Tumor) is the most common malignant brain tumor in childhood. The most common observed infratentorial located PNET in this group is medulloblastoma. Medulloblastoma is a highly invasive and malignant embryonal tumor of the cerebellum.[1] Medulloblastoma accounts for 20-30% of childhood brain tumors and 40% of all posterior fossa (PF) tumors.[2] Cerebrospinal fluid (CSF) invasion and residual disease are the determining factors in the treatment of medulloblastomas.[3] Patients are treated by classifying them into two risk categories as standard risk and high risk. Postoperative radiotherapy doses and treatment agents are determined according to these risk groups.[4,5] The currently accepted treatment approach for medulloblastoma is maximum surgical resection, craniospinal radiotherapy (CRRT) and chemotherapy in children over 3 years of age. Radiotherapy is one of the main treatment modalities with a major role in medulloblastoma cancers, and craniospinal radiotherapy after surgery is the standard of care in children over 3 years of age.[6,7]

New RT techniques play an important role in very young children, in whom sensitivity to radiation is increased and the doses received by critical organs are very important.[8,9] The aim of technological advances in radiotherapy is to achieve high tumor control and low critical organ doses. The most widely used technique in craniospinal radiotherapy in the past years was based on two-dimensional treatment fields. This technique, which is performed with overlapping cranial and spinal fields, causes hot, cold and inhomogeneous dose regions, especially at the field overlap sites. With modern radiotherapy techniques, techniques such as Conformal RT, Intensity Modulated RT (IMRT) and proton beam therapy have enabled the delivery of the prescribed dose in the target volume as desired, especially thanks to advances in imaging and dosimetric software.[10] Especially in pediatric patients, the doses received by critical structures are significantly reduced with modern radiotherapy techniques and target volumes can be irradiated more homogeneously.[11] Intensity modulated arc therapy and tomotherapy techniques are advanced radiation therapy techniques.[12] There are studies showing that advanced technology radiotherapy techniques have a significant reducing effect on critical organ doses.[13] The most important step in selecting the appropriate treatment modality in radiotherapy is the evaluation of treatment plans. The main goal in the evaluation of treatment plans is to provide maximum control of the tumor while causing minimal damage to critical organs. Plans created with different treatment planning techniques can be analyzed with dose volume histograms and isodose curves. Homogeneity index and Conformity index are also parameters that help to analyze treatment plans.[12,13]

In present study, three different planning techniques, namely Helical Tomotherapy (HT), Volumetric Modulated Arc Therapy (VMAT) and Three-Dimensional Conformal Radiotherapy (3D-CRT), were used in the radiotherapy treatment of medulloblastomas, one of the most common central nervous system tumors among childhood cancers. Treatment planning results using three different techniques were compared in terms of target volume doses and dosimetric parameters in order to select the ideal plan.

PATIENTS and METHODS

Patient Selection and Contouring

In the comparison of treatment planning using three different treatment modalities in pediatric craniospinal patients, computed tomography (CT) data of 10 pediatric patients aged between 4 and 17 years who were previously diagnosed with medulloblastoma and underwent craniospinal irradiation were used. 10 pediatric patients in supine position and 5 mm thickness were used to draw critical organ and target volume drawings for the contouring process required for treatment planning. In the target volume definition, **PTV$_{brain}$, PTV$_{spinal}$** and **PTV$_{total}$ (PTV$_{brain}$+PTV$_{spinal}$)** and **PTV$_{boost}$** drawings were made for the posterior fossa (PF), which is the boost area.

Margins Used in Target Volume Drawings

For the **PTV$_{brain}$**, the **CTV$_{brain}$**, which includes the entire brain including the frontal lobe and Cribriform Plate, was defined. The PTVbrain was created by giving 3-5 mm margin to the CTVbrain.

For the **PTV$_{spinal}$**, the **CTV$_{spinal}$** was defined to include the intervertebral forramina laterally and the entire spinal canal inferiorly until the end of the tectal canal according to the spinal MRI. PTVspinal was created by giving 5-7 mm margin to CTVspinal.

For the **PTV$_{boost}$**, the tumor bed and residual tumor area were drawn and PTVboost was created with a margin of 3 mm in total. The craniospinal target volume guideline for brain tumors of the SIOPE working group was used as a reference for drawing PTVs.[14] Contouring was performed in the Eclips treatment planning system (TPS) and transferred to the tomotherapy planning system for HT plans.

Treatment Planning

In present study, Varian brand Eclips 13.4 version treatment planning system was used for 3D-CRT and VMAT treatment plans, while Tomotherapy HI ART series 5.1.4 version treatment planning system was used for Tomotherapy plans. In the dose prescription of the treatment plans, a total treatment dose of 54 Gy was applied with 23.4 Gy to the craniospinal area (PTVtotal) and an additional (boost) dose for the PF area, as determined for standard risk medulloblostomas.[15] As treatment

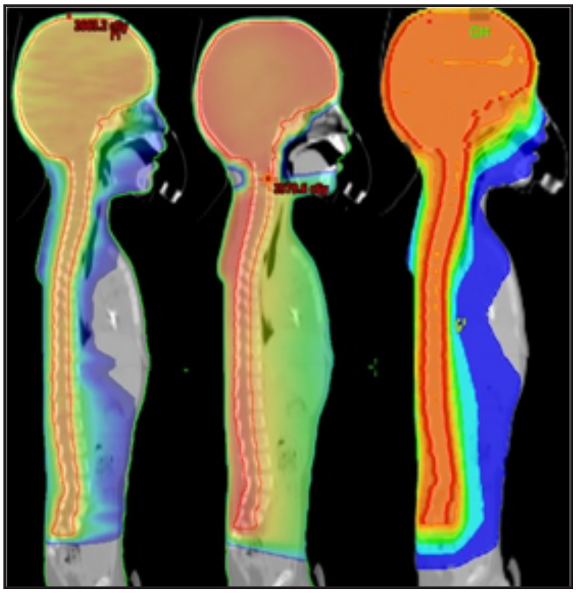

Figure 1. Sagittal section dose distributions of treatment plans; VMAT, 3D-CRT, Tomotherapy (from left to right).

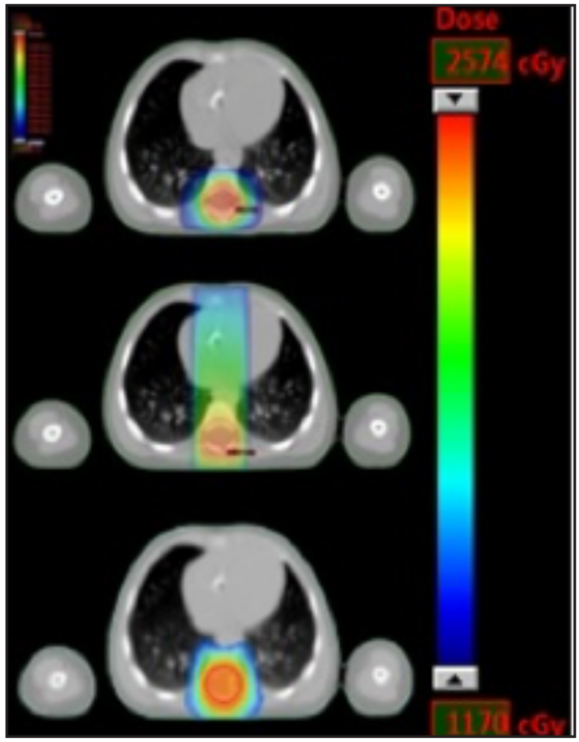

Figure 2. Transfer cross-sectional dose distributions of treatment plans from top to bottom: VMAT, 3D-CRT, Tomotherapy.

planning criteria, treatment plans were optimized and evaluated so that at least 95% of the (PTV_{total}) volume received 95% of the prescribed dose and the dose received by 0.03 cc of the (PTV_{total}) was less than 107% of the prescribed dose.

3D-CRT Treatment Planning

For three-dimensional conformal radiotherapy treatment fields, two lateral fields were used in the cranial field, respectively, with the lower border opened up to the C4-C7 (maximum allowed by the shoulders) limit to include the whole brain. Considering the overlap with the spinal field, a collimator angle of 5^0-10^0 was given to the lateral fields. For the spinal area, a single area was used with a gantry angle of 180^0 posteriorly and the lower border of the field was determined from the intersection with the cranial are to the S2 level. A photon energy of 6 MV was used in the cranial and spinal areas. In three pediatric patients with a total PTV above 50 cm, the pelvic area was opened as a third area. Considering the spinal area overlap in the pelvic area, two opposite areas were used with a 90^0 table angle and a 1^0-2^0 angle to the gantry in a non-coplanar plane. For boost planning, VMAT plans were performed at 6 MV photon energy using one isocenter and two full arc techniques.

VMAT Treatment Planning

In VMAT treatment planning, three different concentrations were defined as brain, thorax and pelvis considering the length of the treatment area. The first concentric center was placed below C1, the second concentric center was placed at the level of the heart and the third concentric center was placed between L3-L5. The overlap distance between the fields was kept at least 4.5-5 cm.[16] All planning was performed with 6 MV photons at a dose rate of 600 MU/minute and a total of 6 full arcs. For boost planning, VMAT plans were performed at 6 MV photon energy using one isocenter and two full arcs.

Tomotherapy Treatment Plans

In tomotherapy treatment planning, target structures PTV_{brain}, PTV_{spinal}, PTV_{total}) and critical organs (OAR) were identified at the planning station. These structures, which were divided into target and critical organs, were numbered in order to better perform dose modulation according to their interlacing and importance. Field width (FW) was

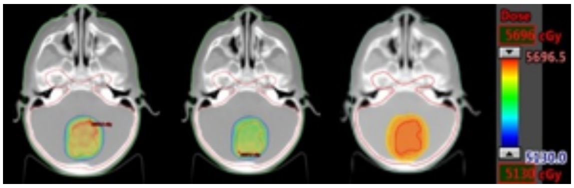

Figure 3. Cross-sectional dose distributions of transfers for Boost treatment plans. VMAT, 3D-CRT, Tomotherapy, (from left to right).

set as 5 cm, Pitch factor as 0.300 and modulation factor as 2.00. For boost planning, Tomotherapy treatment plans were made using a jaw width of 1 cm, Modulation factor 2.5, Pitch factor 0.300, and in-device parameters.

Figure 1 shows the dose distribution of the three treatment plans in the sagittal axis, Figure 2 shows the dose distribution of the treatment plans in the transverse plane and Figure 3 shows the dose distribution of the boost treatment plans.

Evaluation of Treatment Plans

While comparing the treatment plans made using tomotherapy, VMAT and 3D-CRT techniques, the minimum, maximum and mean doses received by the target volumes of both the craniospinal area (PTV_{total}) and the boost area, homogeneity and conformity index values (HI, CI) of PTV_{total}, V95% of PTV_{total} and maximum point dose results of 0.03 cc of PTVtotal were calculated and evaluated in all three planning techniques.

Evaluation of Target Volume Criteria

For target volume criteria, the minimum maximum and mean doses received by the target volume of the craniospinal area, PTV_{total}, which was prescribed 23.4 Gy, and PTV_{boost} target volume, which received 54 Gy additional dose, were evaluated in all three treatment planning techniques. The point dose values of V95% for the target volume coverage of PTV_{total} and 0.03cc for the maximum dose value were compared between the planning techniques.

Homogeneity Index (HI) Calculation

The target volume chosen to calculate HI in the present study was PTV_{total}. In this study, the formula of the ICRU-83 protocol was used to calculate HI.

$$HI= (D_{\%2}-D_{\%98}) / D_{\%50}$$

In this formula

$D_{\%2}$= Dose received by 2% of the PTV volume

$D_{\%98}$= Dose received by 98% of the PTV volume

$D_{\%50}$= defined as the dose received by 50% of the PTV volume.

When evaluating the HI, the HI approaching 0 is an indication that the dose distribution in the PTV is quite homogeneous, whereas the HI moving away from 0 decreases the dose homogeneity.[17]

Conformity Index (CI) Calculations

It expresses the relationship between the target and the treated volume. According to the Radiation Therapy Oncology Group (RTOG) criteria, it is possible to talk about ideal dose distribution when the conformity index is equal to 1. If the conformity index is greater than 1, it means that the irradiated volume is greater than the target volume. If the CI is less than 1, the target volume is partially irradiated. A value of 1 for the conformity index is rarely obtained. If the index value is between 1-2, the treatment is in accordance with the plan. If it is between 2-2.5 or 0.9-1, there is a small deviation.[18]

In the present study, the formula derived by Van't Riet, et al. was used for CI calculations. CI formula derived by Van't Riet[19] is given as follows:

$$CI= (TV_{RI}/TV) (TV_{RI}/V_{RI})$$

In this expression;

TV_{RI}= Target volume receiving reference isodose,

TV= Target volume,

V_{RI}= The irradiated reference volume.

Statistical Analysis

In present study, the results of the physical parameters were statistically analyzed by Shapiro-Wilk test for conformity of the data to normal distribution. Measurements conforming to normal distribution were shown as mean±standard deviation and repeated measures analysis of variance and

Table 1. Statistical analysis results of maximum, minimum, mean doses of PTVtotal of Tomotherapy, VMAT and 3D-CRT treatment plans for 10 pediatric patients

PTV (total) 2340cGy	Tomotherapy	VMAT	3B-KRT	p
Maksimum	2520.5±51.75[a,b]	2549.79±28,01[a]	2582.81±8.73[b]	0.007
Minimum	1846.5 (1575.25-1900.75)	1662.4 (1512.8-1849.18)	1927.2 (1522.7-1987.45)	0.122
Mean	2361.5 (2358-2369)	2396.8 (2344.48-2427.08)	2395.6 (2371.18-2419.33)	0.067

[a, b] The difference between measurements with different superscripts is statistically significant

Bonferroni posthoc method were used for comparisons. Median (1st quarter-3rd quarter) values were used to summarize the measurements that did not fit the normal distribution. Friedman test and Bonferroni pairwise comparison method were used for comparisons. The significance level was accepted as 0.05 in all tests and the analyses were performed using IBM SPSS Statistics for Windows version 22.0.

Ethical approvel was obtained from Malatya Clinical Research Ethics Committee (Date: January, 09, 2016; No: 2019 / 06).

RESULTS

The results of the evaluation of the doses received by the target volumes (PTV_{total}, PTV_{boost}), V95%, HI, CI and maximum doses received by 0.03 cc of the PTVtotal target volume in the treatment plans made using three different treatment techniques are as follows, respectively.

Maximum, Minimum and Mean (Gy) dose results of the target volume in craniospinal radiotherapy planning using tomotherapy, VMAT and 3D-CRT techniques:

The results of the statistical analysis of the maximum, minimum and mean doses received by the target volume (PTVtotal) of 10 pediatric patients who underwent craniospinal radiotherapy planning using tomotherapy, VMAT and 3D-CRT with a prescribed treatment dose of 23.4 Gy are given in Table 1.

According to the statistical results given in Table 1, no statistically significant difference was found between the minimum and mean dose values of PTVtotal in all three planning techniques (p> 0.067). When the results of the maximum dose received by PTV_{total} between the planning techniques were examined, it was seen that the lowest maximum dose belonged to the tomotherapy treatment plan and the maximum dose results showed a statistically significant difference between the techniques (p< 0.007).

The results of the statistical analysis of the maximum, minimum and mean doses received by PTVboost in tomotherapy, VMAT and 3D-CRT treatment plans by giving 54 Gy to PTVboost are given in Table 2.

When the techniques were compared, as shown in Table 2, the maximum and minimum dose results of tomotherapy treatment plans showed a statistically significant difference compared to the other two techniques (maksimum dose p= 0.001; mimimum dose p= 0.002).

Dosimetric Parameter Results of HI, CI and Target Volume Criteria

Table 3 shows the results of statistical analysis of dosimetric parameter data of 10 patients with Tomotherapy, VMAT and 3D-CRT.

According to the results given in Table 3, it was seen that all three planning techniques met the planning criterion when the target volume value (V95%) that received 95% of the prescribed dose was evaluated. However, when the techniques were compared among themselves, it was seen that Tomotherapy planning was better than VMAT and 3D-CRT planning techniques in target volume coverage, and VMAT and 3D-CRT treatment techniques gave similar results in target volume coverage.

Table 2. Statistical analysis results of maximum, minimum, mean doses of PTVboost of Tomotherapy, VMAT and 3D-CRT treatment plans for 10 pediatric patients

PTV (boost) 5400 cGy	Tomotherapy	VMAT	3B-KRT	p
Maksimum	5517.4±40.74[a]	5639.55±78.08[b]	5608.26±77.19[b]	<0.001
Minimum	5349 (5300.5-5388.5)[a]	5181.5 (5147-5236.98)[b]	5165.9 (5150.98-5319.58)[b]	0.002
Mean	5442.2±13.04	5503.1±66,18	5481,31±57.24	0.059

[a,b] The difference between measurements with different superscripts is statistically significant.

Tomotherapy planning technique revealed a statistically significant difference in target volume coverage (V95%) compared to VMAT and 3D-CRT techniques (p< 0.003). While Tomotherapy and VMAT planning also gave results close to the plan criterion, the maximum point dose values of the 3D-CRT technique showed higher maximum dose results. No statistically significant difference was found between the three techniques (p> 0.135). When the homogeneity index was evaluated, the closest HI result to zero was obtained in the Tomotherapy plan (0.04). For the conformity index results, the VMAT technique gave the closest result to the value of 1 required for the ideal plan compared to the other two techniques (0.8). Tomotherapy planning results showed a significant difference in the homogeneity index compared to the other two techniques (p< 0.001). Statistically comparing the conformity index results, VMAT technique showed a statistically significant difference compared to Tomotherapy and 3D-CRT technique (p< 0.001).

DISCUSSION

In the treatment of medulloblastoma, whole craniospinal irradiation with higher doses to the tumor bed is part of the standard adjuvant treatment in children older than 3 years. In younger children, radiotherapy is not given in the low-risk group, while dose adjustment is made according to the risk level in other groups.[20] The current treatment protocol in standard-risk patients is 23.4 Gy craniospinal irradiation followed by a 30.6 Gy boost radiotherapy to the posterior fossa, followed by adjuvant chemotherapy.

In the evaluation of the target volume doses of craniospinal treatment planning using tomotherapy, VMAT and 3D-CRT techniques, when 23.4 Gy was given to the target volume PTVtotal determined for the craniospinal area, the minimum maximum and mean dose results for all three planning techniques showed that modern radiotherapy techniques were superior to the 3D-CRT technique by giving lower maximum dose results. It is thought that the reason for the high maximum dose results in the 3D-CRT technique is due to the

Table 3. Dosimetric parameters of Tomotherapy, VMAT and 3D-CRT plans for PTVtotal

PTV (total)	Tomotherapy Median (Gy)	VMAT Median (Gy)	3B-KRT Median (Gy)	p
V%95	99.8 (99.7-99.83)[a]	98.9 (96.25-99.75)[b]	98.8 (97.78-99.23)[b]	0.003
PTVmaximum (0.03 cc point dose)	107.5 (106-109)	107.5 (106-110)	109.45 (108.58-109.85)	0.135
HI	0.04 (0.03-0.53)[a]	0.08 (0.06-0.14)[b]	0.12 (0.11-0.14)[b]	<0.001
CI	0.70 (0.68-0.70)[a]	0.80 (0.80-0.90)[b]	0.70 (0.70-0.80)[a]	<0.001

[a, b] The difference between measurements with different superscripts is statistically significant

PTV_{total}= PTV_{spinal}+PTV_{brain}; V%95= Target volume receiving 95% of the prescribed dose; PTVmax= Maximum point dose; HI= Homogeneity Index

CI= Conformity Index

divergence of the beam geometry in the upper and lower fields. The intersection of the two fields is adjusted to give the desired dose to the target, but the volume of the intersection area increases with depth. Accordingly, the maximum dose value also increases. At the same time, the dose normalization value adjusted in 3D-CRT to deliver a more homogeneous dose to the target volume also causes an increase in the maximum dose in the target volume. The most important reason for the low maximum dose in tomotherapy technique is that the target volume can be radiated at one time without field intersection. According to the study by Studenski et al.[10] patients who received 3D conformal radiotherapy were planned with YART and YAAT and the difference between them was investigated. According to the study, while 36 Gy was prescribed to all patients, the maximum dose was 47.34 Gy with 3D-CRT, 41.61 Gy with YART and 41.25 Gy with YAAT. Similar to the results in our study, it was found that the maximum dose results were lower in modern radiotherapy techniques.[21] In another study by Sharma et al. on craniospinal radiotherapy, Tomotherapy, 3D-CRT and YART techniques were compared. As one of the comparison parameters, the maximum doses received by the target volume were examined and the target volume was analyzed separately for both brain (PTV_{brain}) and spinal (PTV_{spinal}) areas. In PTVbrain, the change in maximum doses (V107%) was considered insignificant as it was very small. In PTV_{spinal}, the lowest maximum dose was found for the Tomotherapy technique. The reason for this is that the Tomotherapy technique has a more homogeneous dose distribution due to the absence of field overlap.[22]

In the 54 Gy target volume (PTVboost) maximum and minimum dose results, it was observed that the maximum dose results of the tomotherapy planning technique were lower, while in the minimum dose results, it was superior to the other techniques because it gave the closest results to the prescribed dose. This is thought to be due to the unique radiation technique of tomotherapy.

When the dosimetric parameter results of HI, CI and target volume criteria in tomotherapy, VMAT and 3D-CRT planning were evaluated, it was seen that all planning techniques met the criteria expected from the ideal plan. However, when the three techniques were compared among themselves, it was observed that the best PTV dose roll-up was observed in the Tomotherapy technique. All three techniques were statistically significant among themselves as shown in Table 3 ($p< 0.005$). It was also reported in studies with different plans that the tomotherapy planning technique covers the target volume better. In the study by Myers et al. on craniospinal radiotherapy, they compared Tomotherapy, Smartarc and 3D-CRT techniques and similar to the results of our study, they found that the prescribed dose covers the target better in Tomotherapy compared to other techniques and it is also advantageous in protecting critical structures close to the target.[23] In present study, this advantage of Tomotherapy is thought to be due to its ability to irradiate the target volume more homogeneously and in a way to cover the target at once with a unique irradiation pattern without field intersection.

In the comparison of the point dose received by 0.03 cc of PTVtotal, it was observed that Tomotherapy and VMAT techniques gave similar dose results, while the maximum point dose results were higher in the 3D-CRT technique due to the divergence effect of the intersecting fields.

In the evaluation of homogeneity and conformity indices of tomotherapy, VMAT and 3D-CRT planning, according to the HI (homogeneity index) results, it can be said that tomotherapy is a more ideal treatment plan approach than VMAT and 3D-CRT planning techniques. This superiority in tomotherapy results is thought to be due to its ability to irradiate the target volume more homogeneously and in a way to cover the target in a single pass without field intersection. In CI results, all three planning techniques failed to provide the expected value from the ideal plan. In this study, the closest result to the ideal plan was obtained with the VMAT technique. This superiority of the VMAT technique is thought to be due to the functions of the planning algorithm, which allows for the blocking of beam entry at certain angles of treatment planning in the balance between preserving critical structures and meeting PTV criteria. In the CI evaluation of craniospinal radiotherapy in the present study, it was aimed to make an optimal treatment plan in a way not to exceed the tolerance dose of critical structures while trying to meet the planning criteria determined for PTV due to both the large target volume irradiated and the high number of critical structures (OAR) adjacent to the target volume. Especially in all three planning techniques, the deviation in the conformity index results is thought to be due to the evaluation on the PTVtotal.

Conclusion

Radiotherapy is important in the treatment of medulloblastoma. Radiotherapy may have early and late complications. While early complications lead to disruptions in treatment, late complications decrease the quality of life. Treatment planning plays an important role in reducing complications.

Craniospinal irradiation in medulloblastoma is technically complex due to the large target volume. Radiotherapy outcomes are associated with irradiation techniques that deliver sufficient dose to the target volume while preserving critical organs within tolerance limits. Therefore, it is of great importance to evaluate the target volume doses, HI and CI magnitudes of craniospinal treatment planning using Tomotherapy, VMAT and 3D-CRT techniques.

In recent years, optimizations in dose levels have been achieved with the development of irradiation options using Tomotherapy, VMAT and 3D-CRT techniques with advanced technology devices. In the present study, these three techniques were compared in terms of dosimetric parameters and their advantages were evaluated.

When the dosimetric results of PTV were analyzed, it was observed that all plans met the desired criteria, but tomotherapy was superior to the other two techniques (VMAT, 3D-CRT) in target volume coverage in dosimetric results due to its ability to radiate without field intersection at one time. When HI and CI results were compared, it was found that HI results of tomotherapy plans and CI results of VMAT plans were closer to the criteria expected from the ideal plan.

In conclusion, it was suggested in the present study that modern radiotherapy techniques may be preferred for medulloblastoma irradiation because they provide better results than the ideal plan.

REFERENCES

1. Smoll NR, Drummond KJ. The incidence of medulloblastomas and primitive neurectodermal tumors in adults and children. J Clin Neurosci 19: 1541-1544, 2012.
2. Heideman RL, Packer RJ, Albright LA, et al. Tumors of the central nervous system. In: Pizzo PA and Poplack DG, editors. Principles and Practice of Pediatric Oncology, 3rd edition. Philadelphia, USA: Philip, Lippincott-Raven, 1997: 633-697.
3. Gilbertson RJ. Medulloblastoma: signalling a change in treatment. Lancet Oncol 5: 209-218, 2004.
4. Yao MS, Mehta MP, Boyett JM, et al. The effect of M-stage on patterns of failure in posterior fossa primitive neuroectodermal tumors treated on CCG-921: a phase III study in a high-risk patient population. Int J Radiat Oncol Biol Phys 38: 469-476, 1997.
5. Chintagumpala M, Berg S, Blaney SM. Treatment controversies in medulloblastoma. Curr Opin Oncol 13: 154-159, 2001.
6. Packer RJ, Goldwein J, Nicholson HS, et al. Treatment of medullabolastomas with reduced-dose craniospinal radiation therapy and adjuvant chemotherapy: A Childiren's Cancer Group Study. J Clin Oncol 17: 2127-2136, 1999.
7. Külh J, Müller HM, Berthold F, et al. Chemotherapie vor der Bestrahlung von Kindern und jungen Erwachsenen mit einem malignen Hirntumor: Ergebnisse der Pilotstudie HIT'88/'89. Klin Paeditr 210: 227-233, 1998.
8. Breneman J, Meza J, Donaldson SS, et al. Local control with reduced-dose radiotherapy for low-risk rhabdomyosarcoma: A report from the Children's Oncology Group D9602 study. Int J Radiation Oncol Biol Phys 83:720-726, 2012.
9. Seeringer A, Bartelheim K, Kerl K, et al. Feasibility of intensive multimodal therapy in infants affected by rhabdoid tumors–experience of the EU-RHAB registry. Klin Padiatr 226: 143-148, 2014.
10. Verellen D, Ridder MD, Linthout N, et al. Innovations in image-guided radiation therapy. Nat Rev Cancer 7: 949-960, 2007.
11. Clair WHSt, Adams JA, Bues M, et al. Advantage of protons compared to conventional X-Ray or IMRT in the treatment of a pediatric patient with medulloblastoma. Int J Radiat Oncol Biol Phys 38: 727-734, 2004.
12. Onay O, Karabey AU, Morgul Y, et al. Comparison of step and shoot IMRT and helical tomotherapy plan in treatment of craniospinal tumors. TJO 29:, 46-55, 2014.
13. Knöös T, Kristensen I, Nilsson P. Volumetric and dosimetric evaluation of radiation treatment plans: radiation conformity index. Int J Radiat Oncol Biol Phys 42: 1169-1176, 1998.
14. Hoeben BA, Carrie C, Timmermann B, et al. Management of vertebral radiotherapy dose in paediatric patients with cancer: Consensus recommendations from the SIOPE radiotherapy working group. Lancet Oncol 20: e155-e166, 2019.

15. Thomas PRM, Deutsch M, Kepner JL, et al. Low-stage medulloblastoma: Final analysis of trial comparing standard-dose with reduced-dose neuraxis irradiation, J Clin Oncol 18: 3004-3011, 2000.

16. Fogliate A, Bergström S, Cafaro I, et al. Cranio-Spinal irradiation with volumetric modulated arc therapy: A multi-institutional treatment experience. Radiother Oncol 99: 79-85, 2011.

17. Cantürk E, Topgül G, Gürler O, et al. Qantitative evaluation of dose homogeneity index and comparison of homogeneity index value in intensity modulated radiotherapy technique of endometrium, cervix and larynx cancers. J Baun Inst Sci Technol 19: 135-140, 2017.

18. Celik Z. Calculation of conformity index (CI), homogeneity index (HI) and quality of coverage (QC) parameters in three-dimensional conformal radiotherapy and comparison of calculated values. Master's Thesis.. Yildirim Beyazit University Institute of Healty Sciences, Ankara, 2015.

19. Van't Riet A, Mac AC, Moerland MA. et al. A conformation number to quantify the degree of conformation brachytherapy and externel beam irradiation: Application in prostate Int J Radiat Oncol Biol Phys 37: 731-736, 1997.

20. Chevignard M, Câmara-Costa H, Doz F, et al. Core deficits and quality of survival after childhood medulloblastoma: A review. Neuro-Oncology Pract 4: 82-97, 2017.

21. Studenski MT, Shen X, Yu Y, et al. Intensity-modulated radiation therapy and volumetric-modulated arc therapy for adult craniospinal irradiation– A comparison with traditional techniques. Med Dosim 38: 48-54, 2013.

22. Sharma DS, Gupta T, Jalali R, et al. High-precision radiotherapy for craniospinal irradiation: Evaluation of three-dimensional conformal radiotherapy, intensity modulated radiation therapy and helical TomoTherapy. Br J Radiol 82: 1000-1009, 2009.

23. Myers P, Stathakis S, Gutiérrez A, et al. Dosimetric comparison of craniospinal axis irradiation (CSI) treatments using helical tomotherapy, smartarc TM, and 3D conventional radiation therapy. IJMPCERO 2: 30-38, 2013.

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