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Dosimetric Comparison between 3D Conformal and IMRT Techniques in Medulloblastoma Cases in Radiotherapy

Sarah Ashraf[1], Ahmed M Abdelaal[1,*], and T. M. Hegazy[2]

[1]Nasser Institute, Radiotherapy Department, Cairo, Egypt
[2] Physics Department, Women Faculty for Arts, Science and education, Ain Shams University

Abstract

Craniospinal irradiation (CSI) has become an important treatment method for primary tumors. three dimensional conformal radiotherapy (3DCRT) and intensity modulated radiation therapy (IMRT), are used in CSI treatment. A number of patients were selected for this study were diagnosed with medulloblastoma disease. In the 3D technique, two lateral parallel opposed fields were used for the head irradiation and a matched posterior field for spine irradiation. IMRT technique was planned using a seven field inverse treatment planning technique. The beams were distributed around the target with equidistant gantry angles with gantry angles of 0°, 50°, 100°, 150°, 210°, 260°, and 310° were used and the Homogeneity Index (HI) and Conformity Index (CI) is calculated for all targets. There is a good coverage, low maximum doses in the brain with IMRT in comparison to 3D techniques, while the conformity and homogeneity index of the brain dose and spinal dose is nearly the same in IMRT and 3D techniques. IMRT achieves the lowest dose to all organs at risk while the 3D techniques show little difference. It is recommended to use the IMRT technique in the treatment of medullablastoma cases to achieve good coverage for the target (brain and spinal cord) and more sparing to organs at risk.

Keywords: Medulloblastoma: Radiotherapy; IMRT; 3D-Conformal: CI; HL

***Corresponding author**: Ahmed M Abdelaal, Nasser Institute, Radiotherapy Department, Cairo, Egypt
Email: mosa_science2010@yahoo.com
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1. Introduction

Medulloblastoma is a central nervous system (CNS) tumor of cerebellar origin that comprises approximately 1% of all brain tumors. However, medulloblastoma is the most common malignant brain cancer in children, accounting for 25–30% of childhood brain tumors. Thus, medulloblastoma is primarily a childhood cancer [1]. Medulloblastomas are embryonal tumors of the posterior fossa [2] .

Therapy for children diagnosed at minimum 4 years or older consists of maximal safe surgical resection, craniospinal irradiation (CSI), and cytotoxic chemotherapy. Therapy for young children diagnosed with medulloblastoma is designed to avoid or delay craniospinal irradiation and preserve neurocognitive function [3] .

Radiotherapy for medulloblastoma entails irradiation of the entire neuraxis, i.e. craniospinal irradiation (CSI) with a homogeneous dose. This still remains one of the most technically challenging processes in radiotherapy planning and delivery because of the need to irradiate Avery large and complex shaped target volume uniformly. With continuous improvements in long-term survival, particularly in children with average-risk medulloblastoma, there is a growing concern regarding treatment related long-term side effects. These include neurocognitive decline, hearing impairment, growth retardation, endocrine dysfunction, cataract formation, cardiomyopathy, impaired fertility and second malignancies. The majority of these late effects are dose- and volume-related and form the basis of reduced dose CSI (23.4 Gy) for average-risk disease in conjunction with chemotherapy and are the clinical motivation for investigating sophisticated emerging radiotherapy techniques to reduce doses to non-target tissues to ameliorate toxicity [4].

At present, adjuvant craniospinal axis irradiation (CSI) is a standard postoperative treatment. Radiation dose might be optimized through variable intensity beams [5]. Pioneered in 1993, IMRT obtains the shape of the radiation field in accordance with the projective shape of Planning Target Volume (PTV) in radiation beam direction. Thus, multiple fixed angle radiation beams are usually required for better qualities. In addition, the technology offers the ability to produce concavities in the treatment volume to improve conformality [6], which can greatly improve patients' quality of life [7, 8].

Nevertheless, exceedingly prolonged delivery time and monitor units (MUs) along with conventional conformal radiotherapy (CRT) can decrease efficiency and lead to more intrafraction setup errors during treatment [9,10].

Some concerns have persisted, namely that large MUs can increase the risks of secondary radiation-induced malignancies due to incremental scattered radiation and low-dose radiation to the rest of the body. [11].

The technique most commonly used for treating the craniospinal axis is a combination of two lateral opposed photon beams for the brain, matched to one or more posterior photon fields to treat the spine [12,13]. This approach results in dose inhomogeneity, especially at the beam junction(s), and a significant dose anterior to the spinal target volume. Over the last decade, other techniques for CSI have been investigated in order to decrease the dose to the organs outside the target volume, in particular the thyroid, heart, and intestines [14–16].

Intensity-Modulated Radiation Therapy(IMRT), Volumetric Modulated Arc Therapy (VMAT), and TomoTherapy are highly conformal techniques, which can reduce the dose to the structures anterior to the vertebrae at the expense of a larger volume of low-dose irradiation to the entire body. Due to the steep dose gradient, both electron and proton beam radiation provide substantial sparing of non-target tissues anterior to the spinal target volume compared to photons [17,18].

In clinical practice, the reason for using more conformal techniques is better sparing of healthy tissue. However, the vast majority of late effects reported after CSI in childhood arise from irradiation of the target volume [19–21]. Dose and age influence toxicity outcomes and are the justification for dose reduction, altered fractionation regimens, a combination with systemic agents, or target volume adaptations [22–24]. Further decrease of late toxicity, e.g., second malignancies outside the target volume, primary hypothyroidism, cardiovascular events, restrictive lung disease, and metabolic syndrome might be obtained with modern radiotherapy techniques that lower the dose to the structures anterior to the vertebrae without compromising the target coverage [25, 26].

Three-dimensional conformal radiation therapy (3DCRT) allows manual optimization of beam orientation, beam weighting, and beam eye view shaping. However, the problem of dose inhomogeneity and suboptimal conformity to the concave target volume is still unresolved. Intensity-modulated radiation therapy (IMRT), compared with 3DCRT, provides more freedom with allowing dose intensity modulation within each individual beam. As a result, the dose distribution can conform to the target to an extent that was not reached previously. In addition, the dose constraints assigned to critical structures in the optimization process allow better preservation of organs' function than achieved by the conventional two-dimensional radiotherapy (2DRT) or 3DCRT [27].

Craniospinal irradiation (CSI) has become an important treatment method for primary tumors. Commonly treated tumors include medulloblastoma, high-risk germ cell tumors, and some radio-sensitive secondary malignant tumors of the meninges. Emerging radiotherapy techniques, such as three-dimensional conformal radiotherapy (3DCRT) and intensity modulated radiation therapy (IMRT), have gradually replaced the traditional large field radiotherapy technology used in CSI treatment. CSI involves complex anatomical structures and requires complex treatment planning, which often entails setting multiple isocenters and matching a large number of fields to obtain satisfactory plans. IMRT technology can offer a better conformity Index (CI) and homogeneity index (HI) than traditional multi-field 3DCRT in complex target areas. Inverse treatment planning with IMRT reduces the difficulty of planning and implementation as well. These two advantages are particularly important in CSI. Helical tomotherapy and radiotherapy techniques based on protons have also been used in CSI. Another emerging radiotherapy technique, volumetric modulated arc therapy (VMAT), has also been applied in CSI treatment [28, 29].

In comparison to other IMRT techniques, the three-isocenter jagged-junction (TIJJ) IMRT recently proposed by Cao et al. achieves similar CI and HI and simplifies planning and implementation processes. Reducing the complexity of treatment plans and shortening treatment time will make the treatment more reliable and improve the overall treatment quality [30].

2. Materials and Methods

2.1. Materials

2.1.1. C.T Simulator

C.T SOMATOM allows you to routinely perform exams at 70-90 kV, even with adults. It has a gantry opening of 78 cm that allow full imaging for all patient without missing in body contour which is very important facility for radiotherapy. It obtains up to 64 slices per rotation . Reduce dose up to 68% while maintaining optimal image quality with Siemens' unique CARE solutions.

2.1.2. Monaco sim

Monaco sim is a three-dimensional, radiation therapy CT Simulation. Monaco uses DICOM services to import images, structures and to export images, structures parameters to other vendors. Monaco supports the network import of CT, MR, and PET images, RT Structure Sets, the network export of CT Images, RT Structure Sets and Rt digitally reconstructed radiographs (DRRs) as an RT Image or Secondary Capture.

2.1.3. Monaco TPS

Monaco treatment planning is designed to support all conventional Linear Accelerator (Linac). However, when used with Elekta linear accelerators. Monaco offers exclusive features that further enhance plan quality and faster delivery time. With Elekta's Sure Start (Accelerated Go Live), the time to start treatments after installation is reduced up to 70% and Monaco beam models can be quickly compared with measured data for validation before clinical use. With Monaco HD, you have a complete system to support all major treatment modalities, including 3D conformal radiation therapy, IMRT, VMAT, Stereotactic Radio-Surgery (SRS), Stereotactic Body Radiotherapy (SBRT), and MR Planning. Monaco uses the Monte Carlo algorithm that is the most accurate dose calculation available on the market. Multi-criterial optimization (MCO) takes the patient's biology into account and ensures organs at risk (OAR) are spared while maintaining target coverage. The system's Predictive Insights tools enable real-time interaction during and after optimization, facilitating efficient trade-off decisions without the need to optimize multiple plans. The Monaco treatment planning system unlocks: 1,024 dynamic control points for superior and efficient treatment Performance of highly modulated deliveries with faster arc treatments.

2.1.4. MOSAIQ

MOSAIQ image-enabled electronic medical record provides tools to streamline the radiotherapy process as a whole, while delivering secure access to the patient information and images that drive clinical decision-making. MOSAIQ performs pretreatment checks—including patient identification, positioning, and site setup. MOSAIQ and your Elekta linear accelerator together provide the quality assurance that the delivered plan matches the prescribed plan, through continuous verification and recording of treatments.

2.2. Method

In this study, a number of patients were diagnosed with medulloblastoma disease are selected for this study. All Patients were simulated using a C.T-simulator of type siemens somatoms. patients were immobilized in the treatment positions using customized thermoplastic masks on a head rest. The C.T cuts for each patient were transferred to Monaco sim workstation where all organs at risk and targets (brain and spine) were delineated. All patients C.T cuts were transferred to monaco treatment planning workstation where two different techniques, 3D-Conformal and IMRT, were designed for Craniospinal Irradiation (CSI) with prescription dose of 3600 cGy/18 fraction. In the 3D technique, two different isocenters were used, one isocenter was used with cranium and the other isocenter was used with spinal field. two lateral parallel opposed fields were used for the cranium irradiation and with respect to spine, two different techniques were used, one technique was used adirect posterior field, and another technique was used obliques fields for spine irradiation as shown in figure1 a,b. in some cases, the spine was long so two isocenters were used with the spine and the spinal area was divide to upper spine from C4 to L2 and lower spine from L2 to S2-S3 junction and lower spine match upper spine through couch angle adjustment. In cranial fields, the collimator and couch were adjusted to match the divergence of cranial fields with spinal fields in all previous tecniques. In IMRT technique, the plan were designed using a seven field with inverse treatment planning facility. The beams in IMRT technique were distributed around the target with equidistant gantry angles with gantry angles of 0°, 50°, 100°, 150°, 210°, 260°, and 310° as shown in figure 2 and the mode of multi-leaf collimator movement was step and shoot. The dose received by the targets and OARs in the two techniques were compared in terms of mean dose and maximum point dose. V2%, V95%, V50% and V98% for targets were estimated from the dose volume histogram on treatment planning workstation. The homogeneity index (HI) and Conformity index (CI) are calculated for all targets. HI is defined as $HI = D2\%/D95\%$

Where D2% and D95% correspond to the dose received by 2% and 95% volume of the PTV, respectively, and smaller HI implies a better plan. It was calculated using the RTOG equation.

CI is defined as

CI = Volume covered by the reference isodose (95%)/total target volume

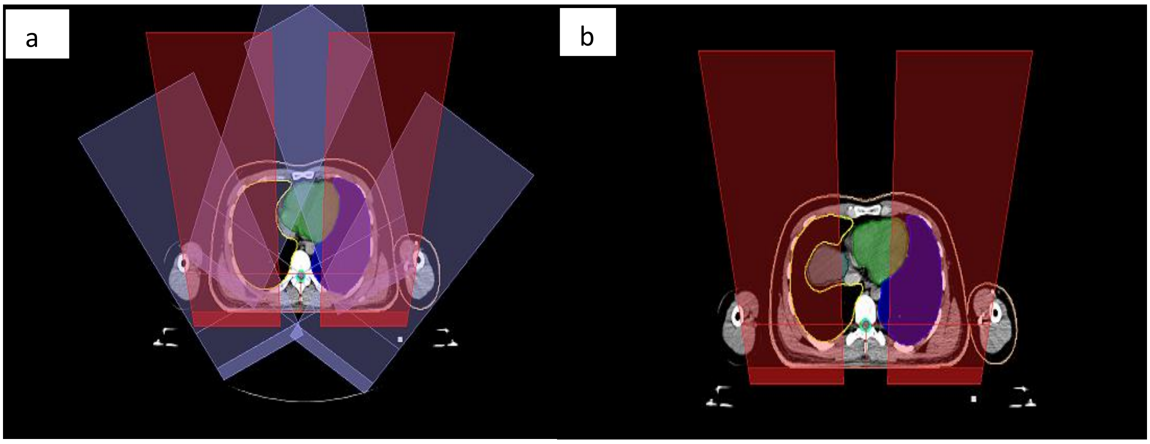

Figure 1 (a,b). the obliques and direct posterior fields in 3D technique, respectively in spine irradiation

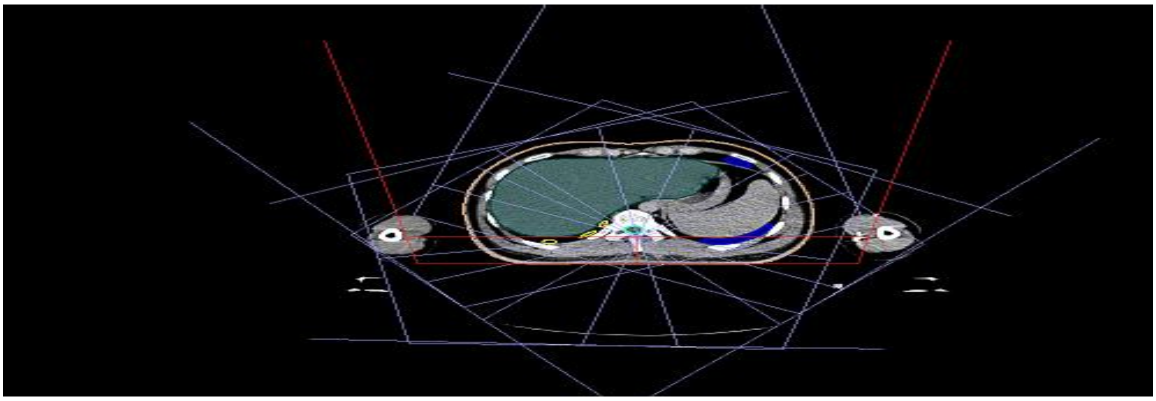

Figure 2. beam arrangement in IMRT technique in spine irradiation

3. Results and Discussion

Figures 3,4 and 5 show the maximum dose (D2%) and minimum dose (D98%, D95%) respectively, that are delivered to the brain, from this figure, it is clear that there is a sharp decrease in brain maximum dose with IMRT techniques in comparison to both 3D conformal techniques opposing and obliques techniques that show similar brain dose where there is a significant difference between 3D conformal and IMRT techniques (p-value <0.05). on the other hand the IMRT achieve good coverage for the brain (D98% and D95%) in comparison to the two 3D conformal techniques where (p-value <0.05) between the two 3D conformal techniques and IMRT techniques.

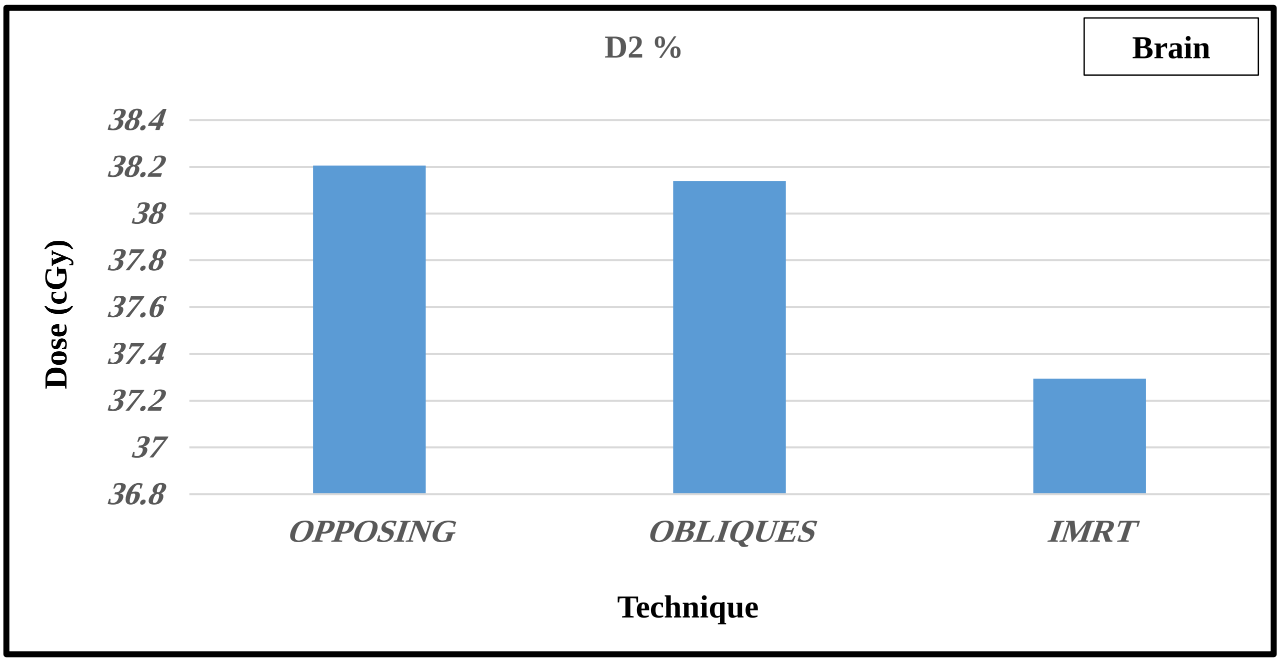

Figure 3. maximum brain dose (D2) with different 3D and IMRT techniques.

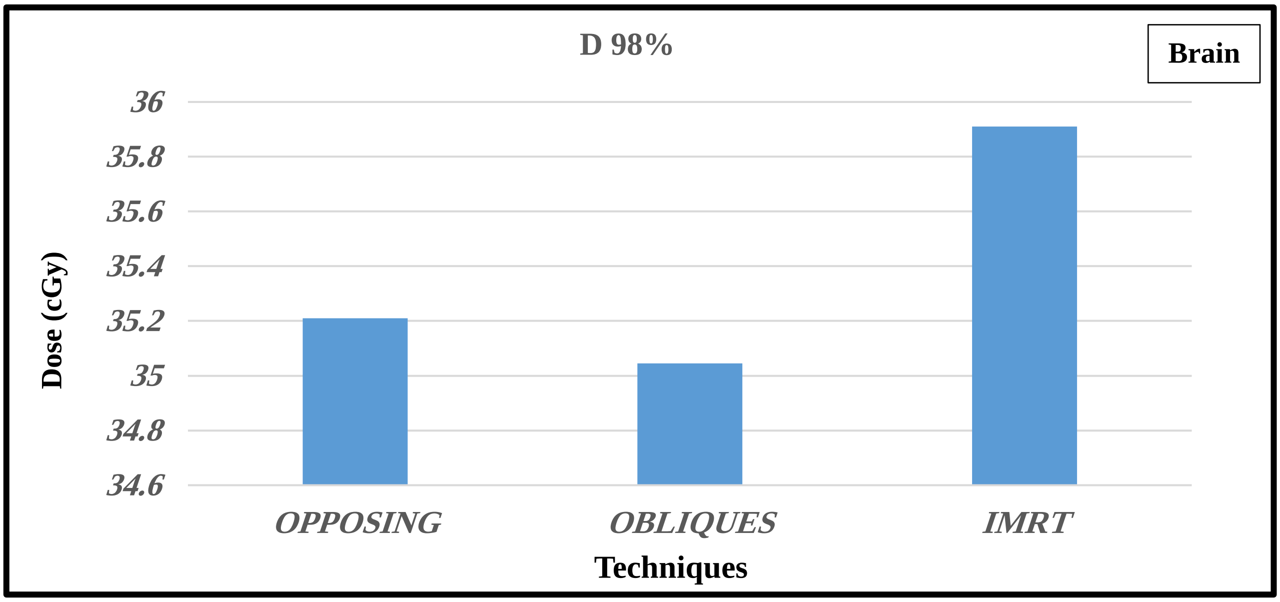

Figure 4. Minimum brain dose (D98) with different 3d and IMRT techniques.

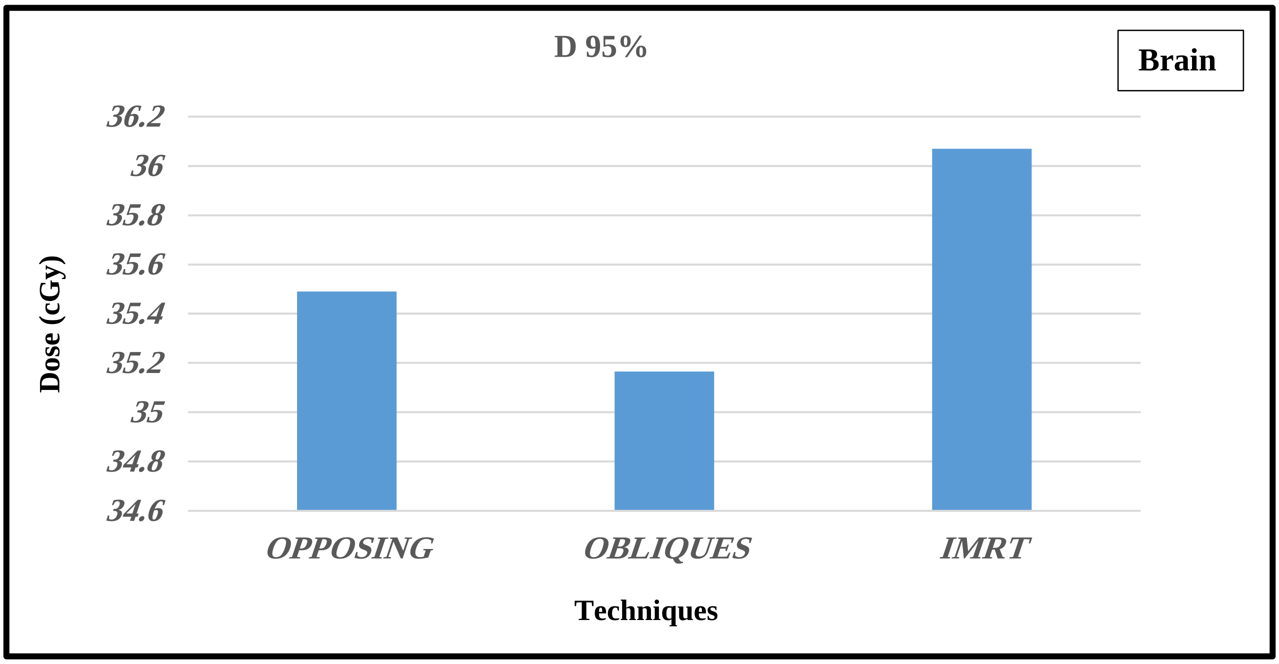

Figure 5. D95% brain dose with different 3d and IMRT techniques

Figures 6,7 show the brain conformity and dose homogeneity inside the brain, from these figure it can be observed that there is a slight variation between 3D techniques (opposing and obliques techniques) and IMRT in confirmty index and homogeneity index and there is insignificant difference ($p>0.05$) between conformity index and homogeneity index in the previous techniques where the conformity index is 0.94%, 0.94% and 0.95%, respectively and homogeneity index is 1.1%, 1.08% and 1.1%, respectively.

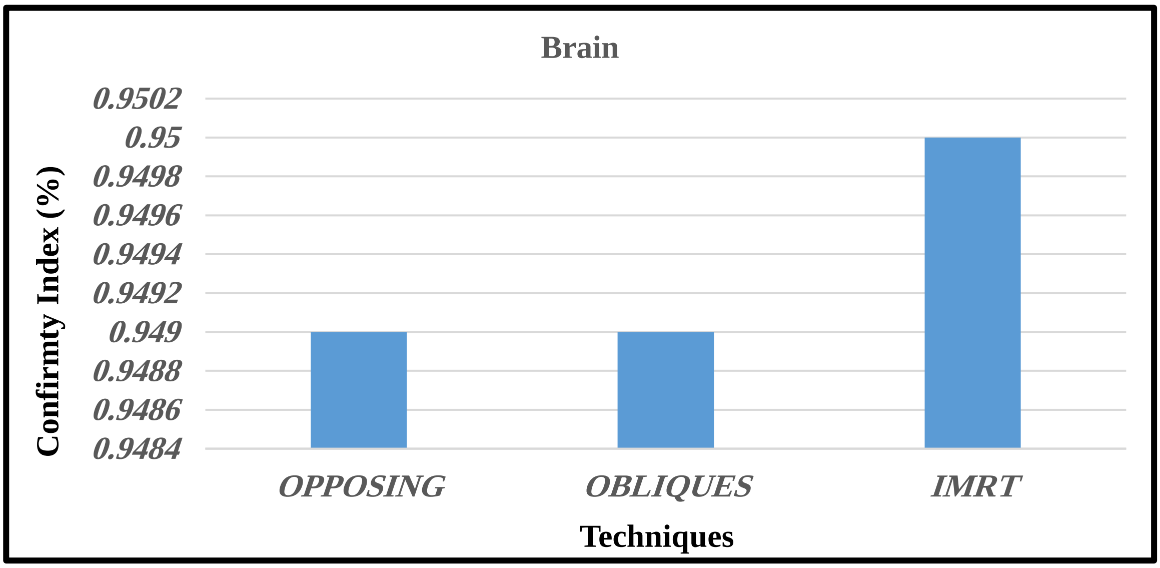

Figure 6. Conformity of brain dose with different 3d and IMRT techniques

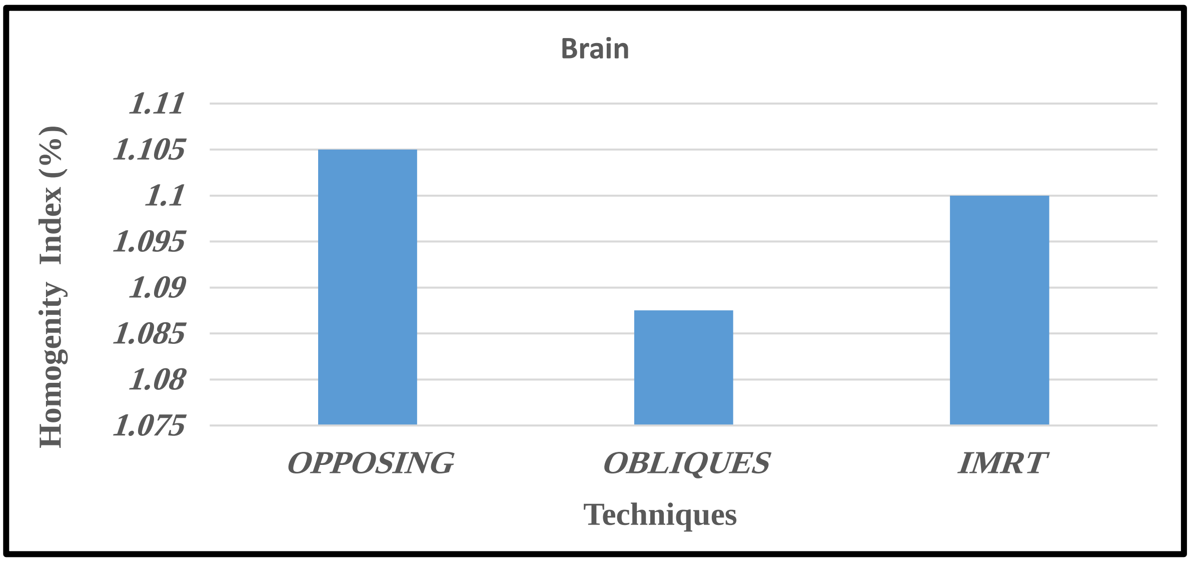

Figure 7. Homogeneity of brain dose with different 3d and IMRT techniques

Figures 8, 9, and 10 show the maximum dose (D2%) and minimum dose (D98%, D95%) respectively, that are delivered to the spinal cord, from figure 7, there is slight increase in D2% from the opposing technique to the oblique technique where there is a sharp decrease in D2% with IMRT and there is a significant difference ($p<0.05$) in D2% between 3D and IMRT techniques. In figures 8 and 9, D98% and D95% show similar behavior where there is a slight increase in D98% from opposing to obliques techniques then there is a sharp increase with IMRT where D98% and D95% achieve significant difference between 3D and IMRT technique ($p<0.05$).

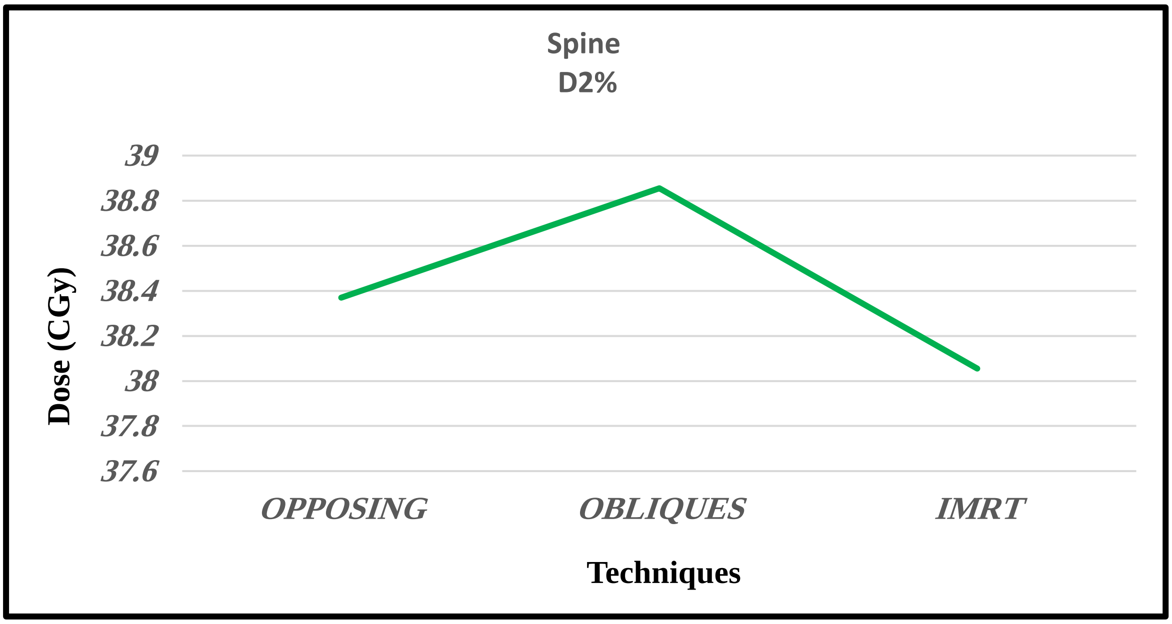

Figure 8. D2% of spine with different 3d and IMRT techniques

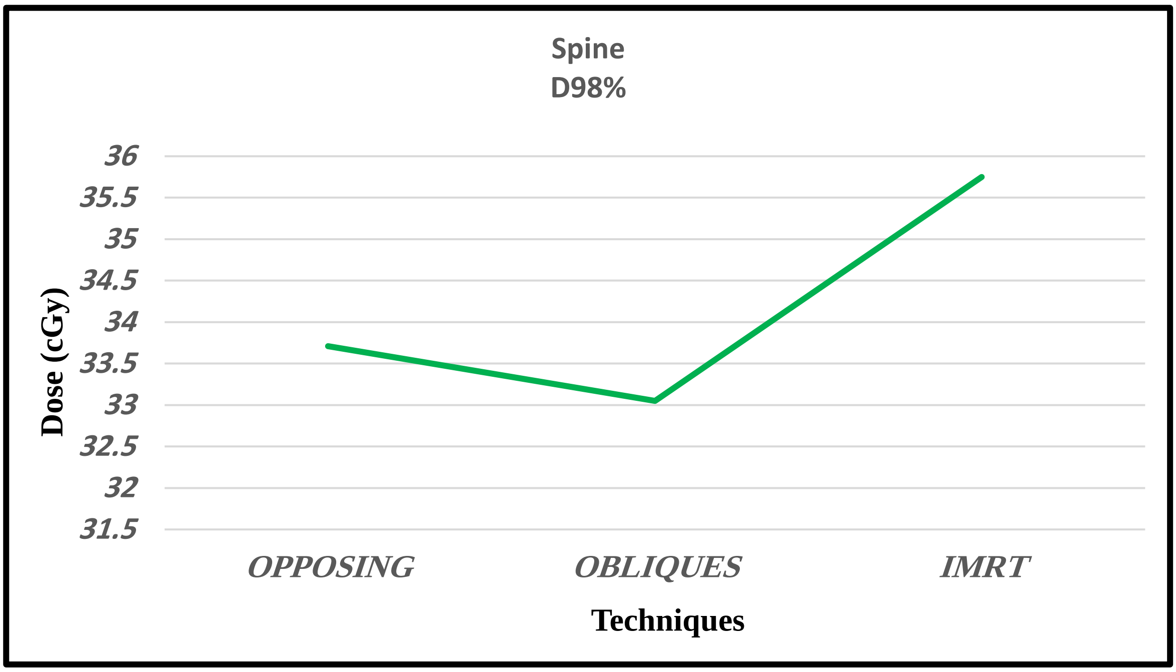

Figure 9. D98% of spine with different 3d and IMRT techniques

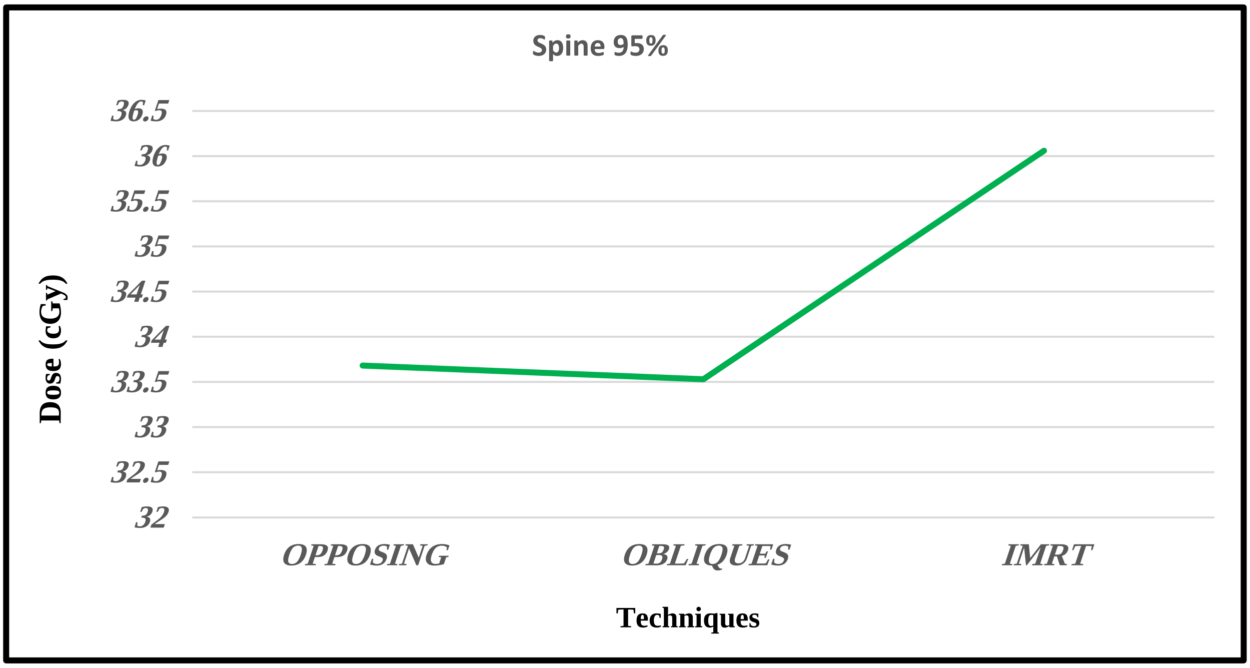

Figure 10. D95% of spine with different 3d and IMRT techniques

The conformity index and homogeneity index in the spinal cord are shown in figures 11 and 12 that show insignificant difference ($p>0.05$) between 3d and IMRT techniques in The conformity index and homogeneity index where the conformity index in (opposing and obliques techniques) and IMRT are 0.94%, 0.94%, and 0.95%, respectively and homogeneity index are 1.11%, 1.10%, and 1.11% respectively.

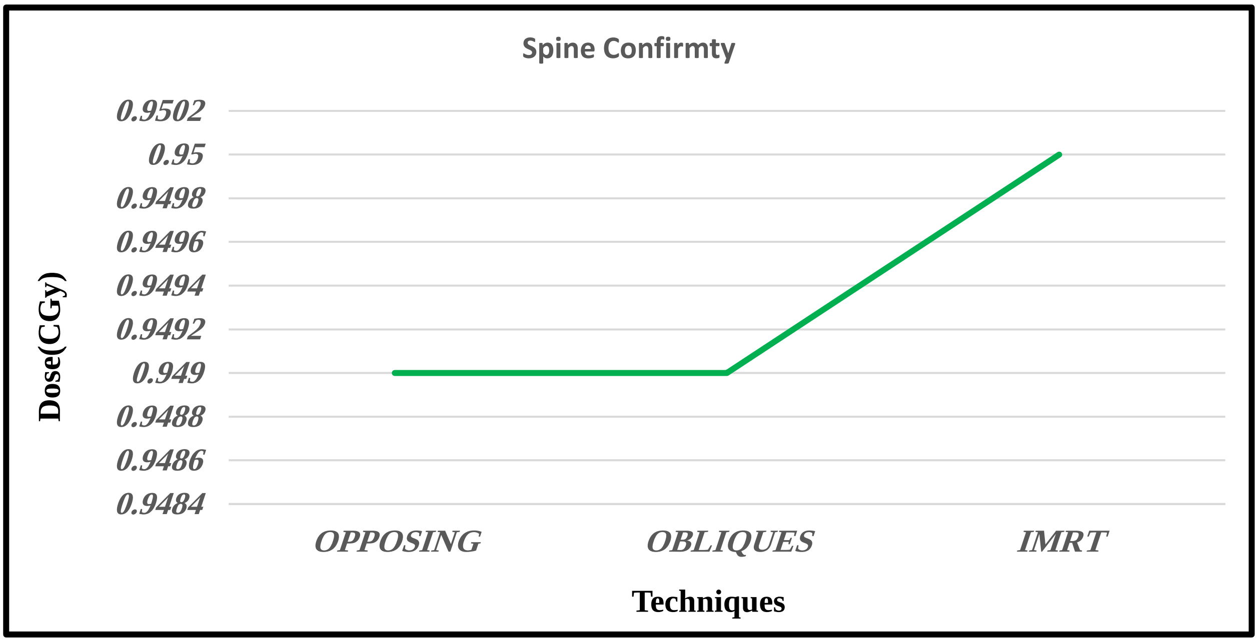

Figure 11. Confirmty index of dose in spine with different 3d and imrt techniques

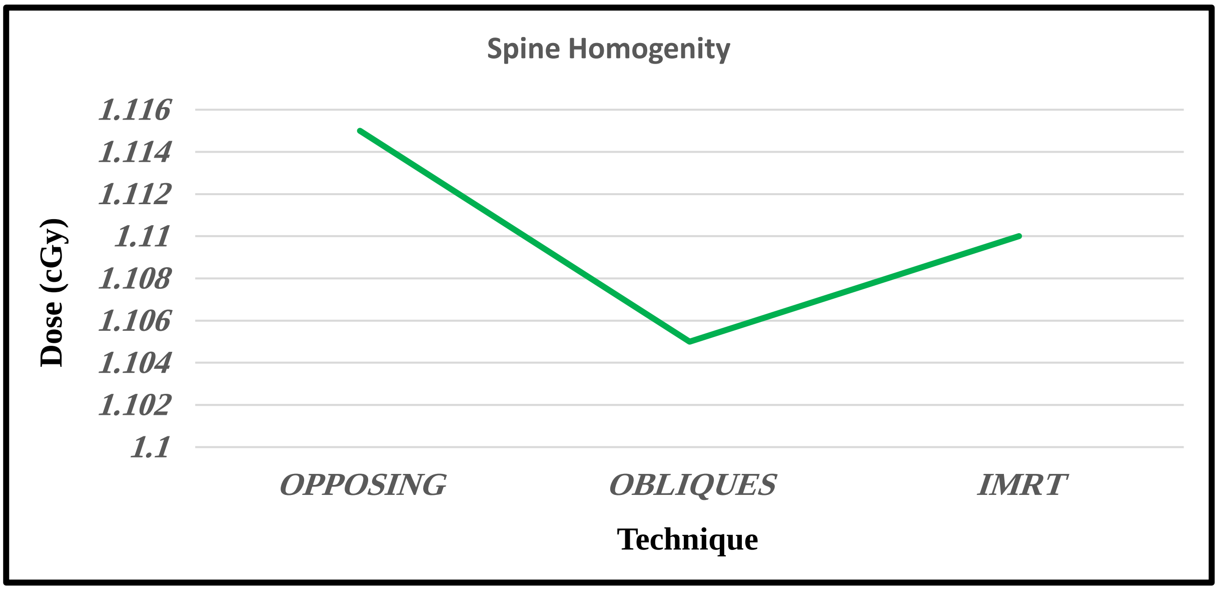

Figure 12. Homogeneity index of dose in spine with different 3d and IMRT techniques

Figure 13 and figure 14 show the doses that were reached to rt cochlea and lt cochlea, from these figure it is clear that there is a sharp drop in rt cochlea and lt cochlea dose with IMRT in comparison to 3d techniques that show similar doses where there is significant difference (p >0.05) between IMRT cochlea dose (rt and lt) and 3d techniques cochlea dose (rt and lt).

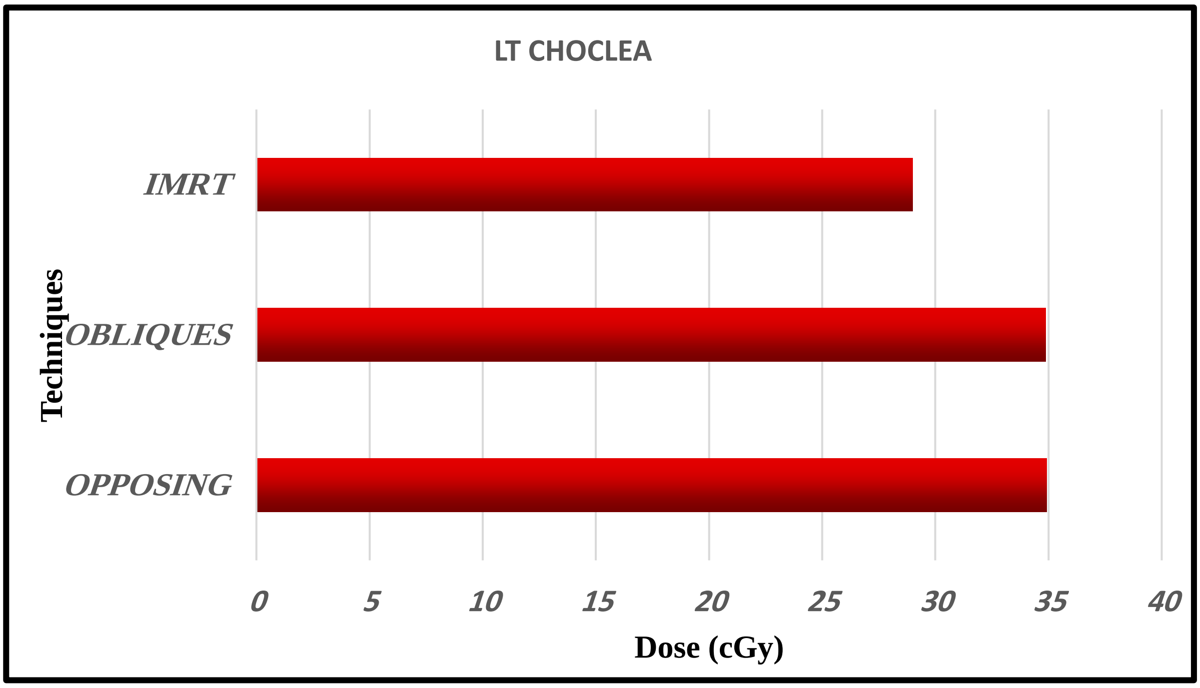

Figure 13. Dose of lt cochlea with different 3d and IMRT techniques

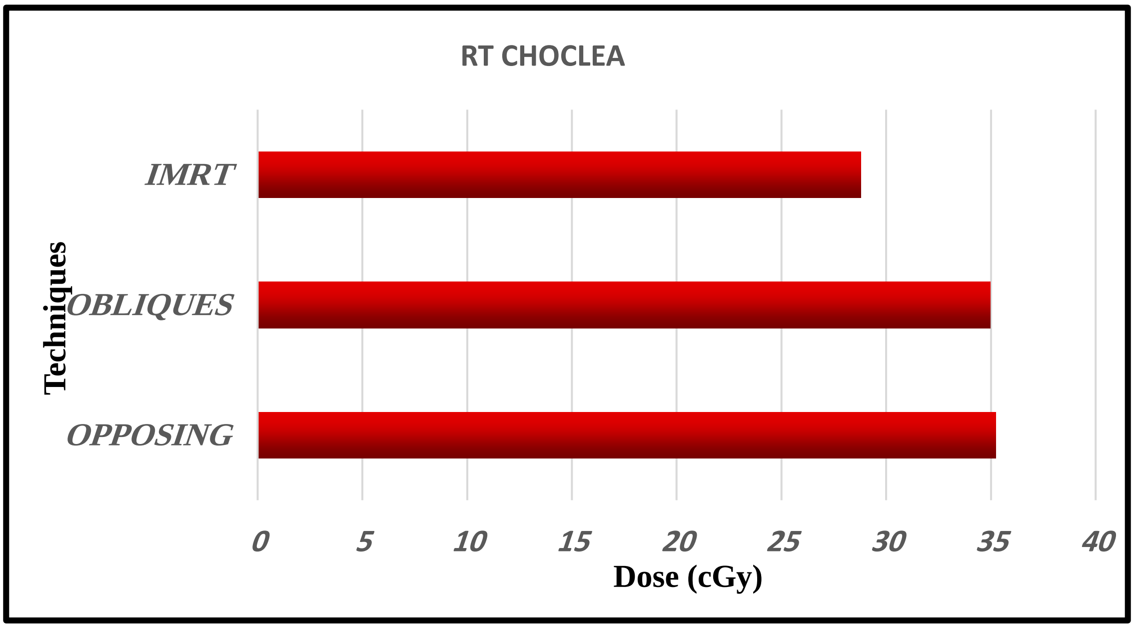

Figure 14. Dose of rt cochlea with different 3d and IMRT techniques

Figure 15 shows the liver dose in 3D and IMRT techniques, from the figure it can be observed that there is a large decrease in liver dose with IMRT (4.8 cGy) in comparison to 3d techniques where there is a significant difference ($p < 0.05$) between IMRT and 3D techniques in liver dose while there is little difference between 3d techniques (obliques and opposing) that are 7.5 cGy and 7.1 cGy, respectively with the liver dose.

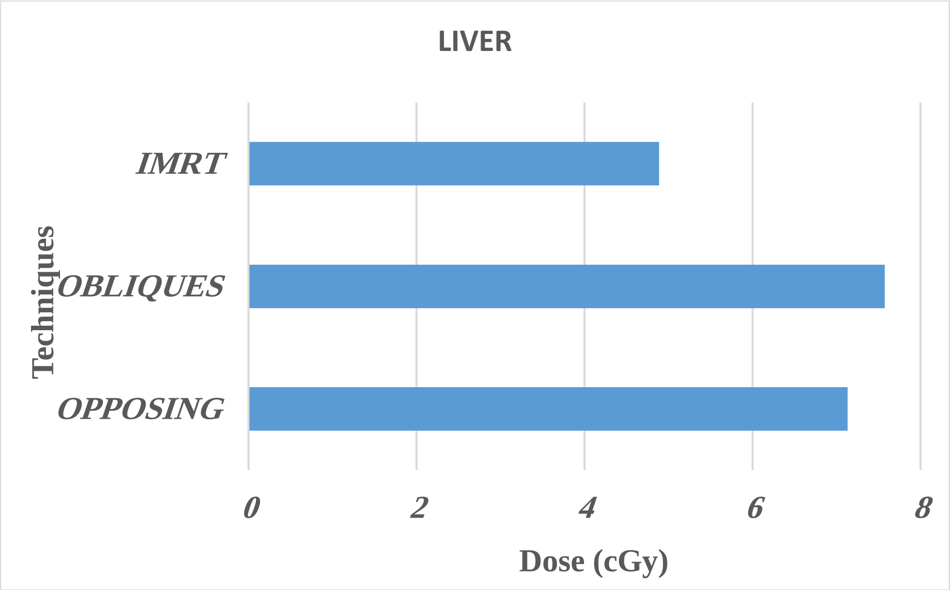

Figure 15. Dose of liver with different 3d and IMRT techniques

Similar behavior is achieved with lt parotid and rt parotid as liver where the IMRT technique shows a large decrease in lt parotid and rt parotid dose in comparison to 3d techniques as shown in figures 16 and 17.

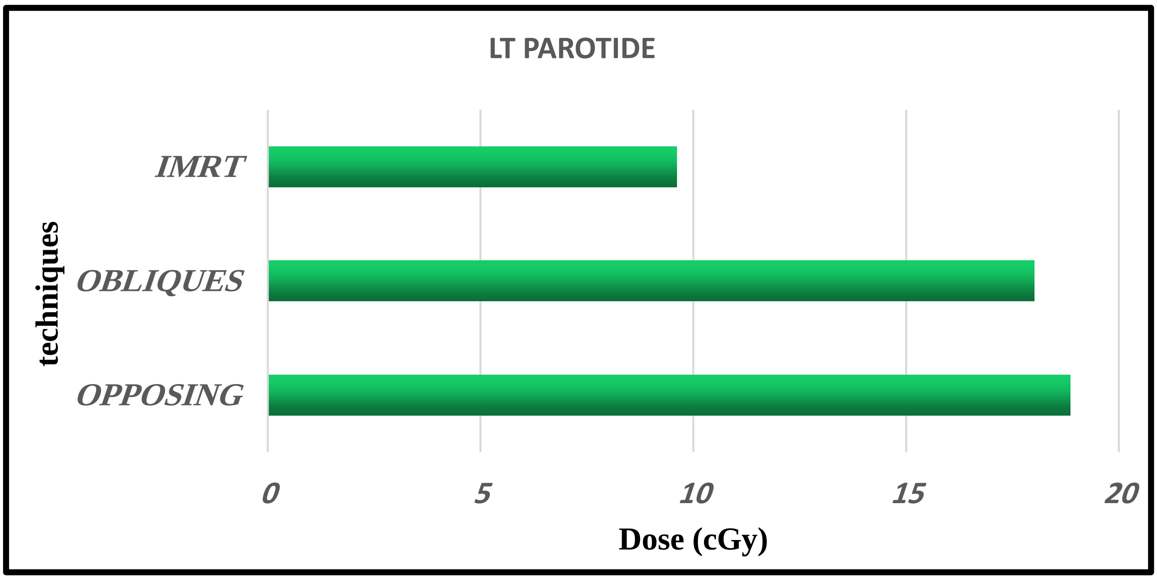

Figure 16. Dose of lt parotid with different 3d and IMRT techniques

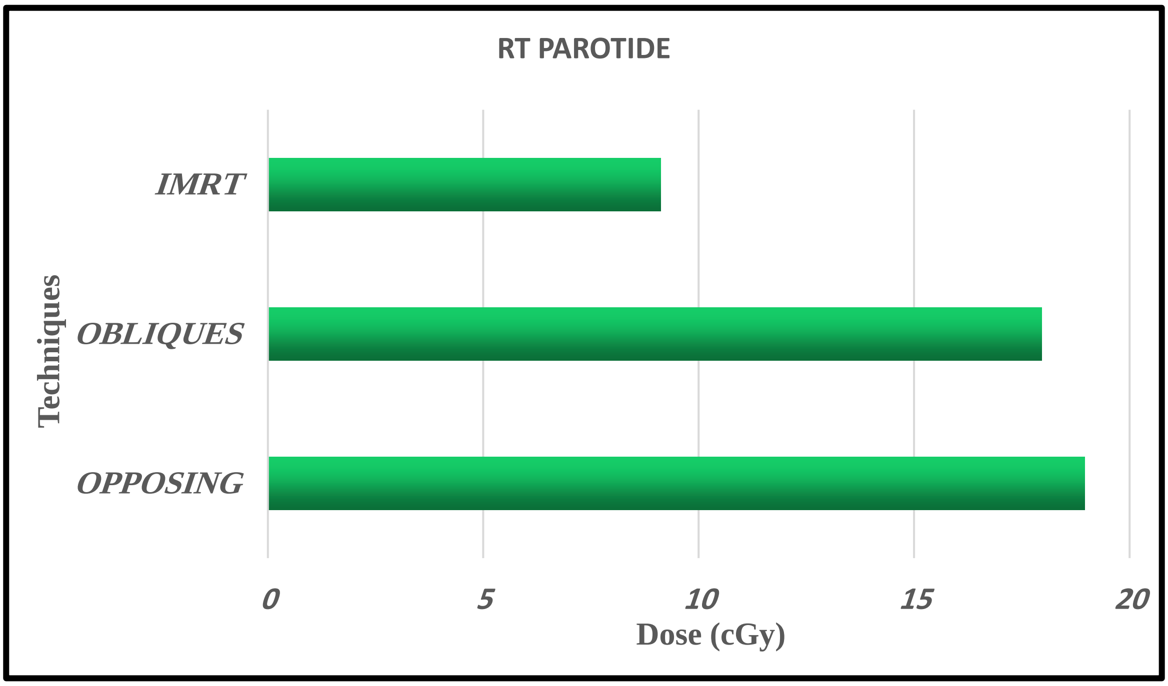

Figure 17. Dose of rt parotid with different 3d and IMRT techniques

IMRT achieve a sharp drop in dose reaching the heart in comparison to 3d techniques that show a small difference between 3d technique and there is a significant difference ($p<0.05$) between IMRT and 3d techniques with heart dose as shown in figure 18.

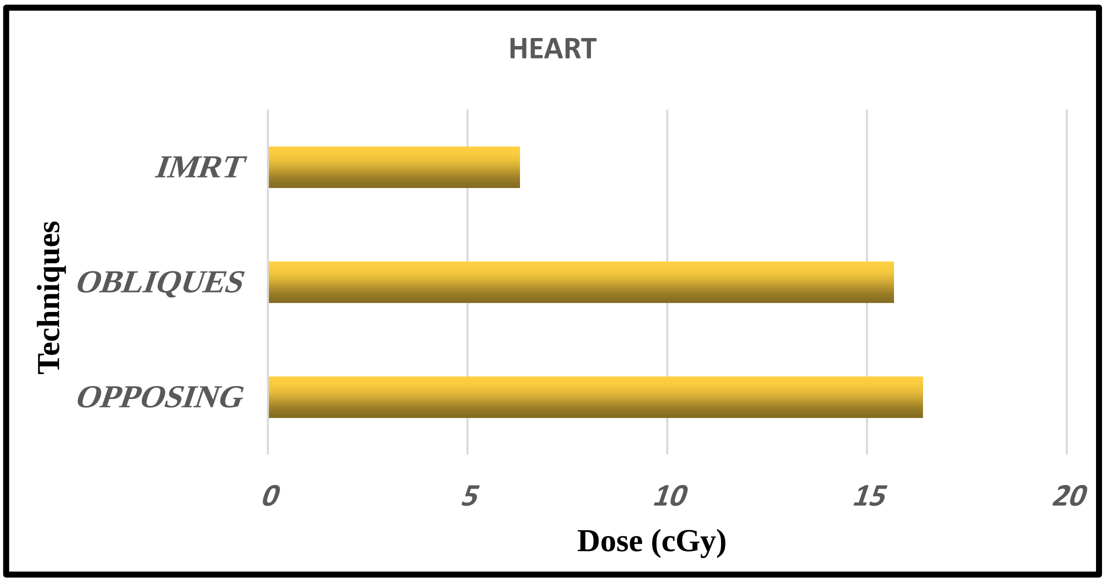

Figure 18. Dose of rt parotid with different 3d and IMRT techniques

To sum up the results,The technique most commonly used for treating the craniospinal is a combination of two lateral opposed photon beams for the brain, matched to one or more posterior photon fields to treat the spine [31,32]. This approach results in dose inhomogeneity, especially at the beam junction(s), and a significant dose anterior to the spinal target volume. Over the last decade, other techniques for CSI have been investigated in order to decrease the dose to the organs outside the target volume, in particular the thyroid, heart and intestines [33, 34].

From the total dose it can be observed that there is good coverage and low maximum dose in the brain with IMRT in comparison to 3d techniques, while the conformity and homogeneity index of the brain dose and spinal dose is nearly the same in IMRT and 3d techniques.IMRT an advanced form of 3D-CRT. It employs inverse planning algorithms and iterative, computer-driven optimization to generate treatment fields with varying beam intensity. Combinations of intensity modulated fields produce custom-tailored, conformal, dose distributions around the tumor with steep dose gradients at the transition to adjacent normal tissues [35]

On the other hand, with respect to organs at risk doses, IMRT achieves the lowest dose for all organs at risk while the 3D techniques show little difference. Intensity-Modulated Radiation Therapy (IMRT), R are highly conformal techniques, which can reduce the dose to the structures anterior to the vertebrae at the expense of a larger volume of low-dose irradiation to the entire body. [36,37].

4.Conclusion

From all results in this study, it is recommended to use the IMRT technique in the treatment of medulloblastoma cases to achieve good coverage for the target (brain and spinal cord) and more sparing to organs at risk but it is important to take into consideration the accurate set up due to the high dose gradient in IMRT in comparison to 3d techniques.

5.Conflict of Interest: None

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الملخص العربي

مقارنة الجرعات بين العلاج الاشعاعي ثلاثي الابعاد والعلاج الاشعاعي متغير الشدة في العلاج الاشعاعي لاورام النخاع الشوكي

ساره اشرف عبد الفتاح [١]، احمد موسي محمد عبد العال [١،*] ،طارق محمد الدسوقي حجازي [٢]

[١] قسم العلاج الاشعاعي- معهد ناصر للبحوث والعلاج
[٢]استاذ الفيزياء الاشعاعية- كلية البنات للاداب والعلوم والتربية -جامعة عين شمس

الملخص العربي

العلاج الاشعاعي لاورام المخ مع الحبل الشوكي اصبح طريقه هامه لعلاج الاورام الابتدائيه. يستخدم العلاج الاشعاعي ثلاثي الابعاد ومعدل الشده في علاج هذه الحالات. تم اختيار عدد من المرضي الذين يعانون من اورام المخ مع الحبل الشوكي لاجراء هذه الدراسه. في العلاج الاشعاعي ثلاثي الابعاد و تم استخدام حقلين اشعاعيين جانبيين للعلاج الاشعاعي للرأس متماشي مع الحقل الاشعاعي المستحدم في العلاج الاشعاعي للحبل الشوكي. في العلاج الاشعاعي معدل الشده تم استخدام الحقول الاشعاعيه بزوايا مسافات متساويه حول منطقه الورم ذات 0°, 50°, 100°, 150°, 210°, 260°, 310°

معامل التجانس ومعامل التماثل تم حسابهم لكل الاورام في منطقه الراس والحبل الشوكي. يوجد تغطيه اشعاعيه جيده لمنطقه الورم من خلال تقنيه معدل الشده مقارنه بالعلاج الاشعاعي ثلاثي الابعاد. بينما معامل التجانس ومعامل التماثل تقريبا نفس القيمه

معدل الشده يحقق اقل جرعه اشعاعيه للانسجه الطبييعيه المحيطه بالورم لذلك هذه الدراسه توصي بأستخدام تقنيه معدل الشده لكي نحقق تغطيه اشعاعيه جيده لمنطقه الورم وحمايه الانسجه الطبيعيه المحيطه بالورم