Conformity and Homogeneity Indices for Brain Cancer Patients Using 3DCRT Technique

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Abstract

Background: 3D conformal radiotherapy 3DCRT technique are used to treat patients with brain cancer.
Goal: this study aims to compare conformity and homogeneity indices for eight patients of brain cancer by using three-dimension conformal radiotherapy (3DCRT) technique on planning target volume (PTV) located in brain.
Methods: Comparative study of Conformity and Homogeneity indices for ten brain cancer patients during period from October 2019 to March 2020 that carried out at ZCC (Zhianawa Cancer Center) in Sulaimany-Iraq. 3DECRT technique was applied to get the heist dosage to the target volume (tumor) and lowest dose to the healthy structures around the tumor. By using Linear Accelerator machine- LINAC, Elekta synergy type with 6MV photon beam. SPSS-version 22 was applied for analyzing and caring out the data measurements.
Results: It has been observed from the results, in both techniques the highest conformity and homogeneity indices have the acceptable values, in this study with 3D-CRT plan technique showed that the mean conformity and homogeneity indices were (0.1999 ± 0.03, 0.9457 ± 0.05) respectively. The mean dose values for organs at risk spinal cord and brain stem were (41.98 ± 2.23, 26.01 ± 16.62) respectively, for ten right and left parotid glands were (23.52 ± 3.99, 23.34 ± 3.93) respectively. In both plans, the average dose values for all organs at risk mentioned above were less than tolerance radiation doses.
Conclusion: This study also supports that indices of homogeneity and conformity are important tools for improving the long-term quality of life of brain cancer patients using 3DCRT technology.

Key Words: Treatment-planning Techniques, Dose Volume, Organs at Risk, Brain Cancer.
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Introduction

For treating brain cancer by the radiation it needs a perfect and accurate technique in order to save healthy structures such as a spinal cord, brain steam, and so on, in order to save these healthy organs, the 3DCRT technique is a good technique among many other available techniques to solve this problem. Radiotherapy is the use of high x-ray energy or some particles to shrink cancer cells. It can give internally and externally, an external radiation therapy is using high-energy x- rays to the affected area using a huge instrument termed (LINAC) and an interior radiation therapy technique use a radioactive substance has placed near the cancer tumor in the body which is called (brachytherapy) (Isaacson, 2000).

The treatment of neck and head (N & H) is the most difficult to plan because of the anatomy of the patient, various goals with different dosages recipe, extensive expansion of the therapy area, as well as the number of organs at hazard. Since, dosages up to 70–72 Gy with a classical fragmentation can be described.

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To control difficulties of planning, very much developed techniques such as intensity-modified radiotherapy (IMRT), or volumetric Modulated Arc Therapy (VMAT) have been developed, that get a lot greater product than (3DCRT) three dimension conformal radiation therapy, exactly in the spare of the healthy tissues. (Herrassi, 2013). Therefore, these technologies cannot be applied globally, as a result of unavailability of suitable apparatus, or sick person case; the 3DCRT technique is still widely used for the treatment of H&N cancers, despite its obvious limitations when compared to highly modified techniques. Some more advanced 3DCRT handling design techniques have been progressing to get better the dosage divide to designing goal volumes and OARs, such as, Bellinzona, Forward-Planned Multi-segments (FPMS), and field-in-field (FIF) technique etc.

Intensity-modulated radiotherapy (IMRT) is a technique of high- accuracy radiotherapy that uses computer- planned linear accelerator to transport eradiation dosage to tumor or specified areas in the tumors. IMRT allows the eradiation dosage to adjust more precisely to the three-dimensional form of the swelling by modify concentration of the radiation beam in multiplied tiny dimension. (India, 2006).

Three-dimensional conformal irradiation therapy, include producing a 3D computer images and deliver very focus irradiation to swelling whilst plain near healthy tissue. 3D-CRT is a form of extrinsic beam radiotherapy (EBRT), who is the generality concerted kind of irradiation treatment planning. The procedure of radiation therapy begins with scanning of the patient's body, delineating areas of expecting to exist tumor, construction the handling plans and collecting and dispatch commonalty the information to the tool out of an investigation system; mosaiq. An important portion of this series, which is formed in the handling plan system. This method is able to produce 3DCRT & VIMAT…. Etc. treatment scheme. Until everything processes of these two ways looks like in a design plan and difference in technique. (Bakiu, 2013).

Traditional 3D treating plan is manually optimum, this means that the physician selects whole packet data, such as beam directions, numbering of packets, shape of multi-leaf collimators, using wedges or not, weightiness etc., and the computer calculates distribution of the resulting dose.

The 3DCRT technique has been revised to use MLC originally proposed. It consists of 5 – 10 fields depend on form and site of the tumor inside the body of patient. The rearward domain can be divided in two separate areas in the case of the spinal cord, brain steam, or parotid glands can't be perfectly protected due to the restriction of the leaving distances of MLC leaves. In the main paper, a dosage of 50 GY was specific to the PTV at the ICRU point. (Teoh, 2011).

For treating the neck and head cancers by an irradiation, it needs an ideal and accurate mechanism in order to split organs at risk in this area, in order to save healthy organs such as parotid glands IMRT technique is very important technique to solve this problem.

Simulation

It is a procedure that explains the field of radiotherapy and is marked outside your skin. The simulator is a great-cavity of computed tomography (CT) scanner that is used to define the location of tumor inside the body. Pictures are then sent to the treatment planning room wherever the doctors contour the tumor and organs at risk nearby the tumor in order the beams will arrange according of this contouring and make a custom plan. Hence it is up to the appointed sponsor to make placement as easy as possible while making sure that treatment can be provided consistently at every appointment. Patients come in all shape and size of tumors, patient measurements must be obtained. (Yun, 2012).

Treatment plan factors are recorded and all ranking entries are validated to ensure that treatment history is complete. This is an important portion of the planning procedure. The CT scan itself is not used as a diagnostic examination but instead to determine the shape of your body and see its structures. The treatment planner can then set the type of packet, numbers & the direction of beams to make a plan using a computer system.

Qualitative Plan Evaluation

Quality assurance in radiation therapy is all procedures that ensure the accuracy of the medical prescription, and safe fulfillment of that prescription, and the dose to the target volume, together with minimal doses to normal tissue nearby the tumor, minimal exposure of personnel and adequate patient monitor aimed at determining the result of the treatment, also it must be stressed that quality assurance in radiotherapy is concerned with all aspects of the radiotherapy process and should involve all groups of staff's cancer center, since quality activities are interdependent. (Saw, 2008).

All radiation therapy involves a risk since even a small error in the treatment planning, delivery, or great amount of radiation energy can lead to series consequences. This is because the human anatomy is a complex organism and tumors are mostly located in close of sensitive normal tissues and critical organs. For this reason, modern technologies that allow us to treat, and cure patients with minimal adverse effects are very important. Unfortunately, the newer techniques are highly complex, thus increasing the potential for error.

All modern radiotherapy techniques are heavily reliant not only on a technology, but on the input from human experts: the radiation oncologist must locate and contour the target volume area as accurately, then the medical physicist needs to design an optimal treatment plan which deliver the required radiation dose while sparing healthy organ; finally, the technicians must make sure that the patient is correctly positioned before treatment begins. (Malicki, 2012).

Comparative Evaluation of Treatment Plans

The plans with 3DCRT are done in two phases for head or brain. In the first phase, the plan is a simple which consists of two lateral beams each beam has the energy 6 MV and in the second phase it is created a plan with three beams, two lateral beams and one vertex beam again with energy 6 MV. The second plan uses in more time since decreasing the dose energy to the healthy organs surrounding the tumor cells in such a way to protect better the organs at risk. The beams are conformed with the help of MLC to the treatment planning volume PTV. It has to be mention that in both plans the PTV is delineated and the isocenter putted in the center of the PTV in order to pass all beams among the tumor and to limit the dose energy to the organs at risk. When the plans are finished, they are compared, for both methods, first according to dose-volume histogram and then according to time-consuming for quality control procedures. The checks for the position of the patients, so the giving of the right dose to the right part of the body.

Theory

This study was conducted at ZCC Cancer Center in Sulaymaniyah between October 2019 and March 2020.

Ten patients with brain cancer were chosen for this study, ELEKTA linear accelerator a collimator of 80 leaves was used as shown in the fig. (1). 3D-DRT was used all measurements. The organ at risk spinal cord, brain steam, parotid glands, cochlea, etc. for all patients was contoured by CT images. And then for each patient, treatment plans were generated using the superposition algorithm of XIO planning system and 6MV photon beams of radiation energy was used.

The prescription dosage was 50 Gy, to a reference point in the PTV, which could fulfill most recommendations of ICRU organization in radiotherapy. Note that for all patients only one phase of treatment calculated which (50 Gy) is. Reference point was selected in the center of PTV area with low dose gradient. Other doses points in PTV were usually added in order to check the homogeneity of doses. The main goal planning was to minimize the energy doses to the OAR's and maximum dose to the target volume (tumor).

Figure 1. Linear Accelerator (LINAC)

1. The General Strategies to Treat the Ten Brain Cancer Patients

All patients were treated at the (ZCC) cancer center. Treatment consisted of the following planning process.

- Assessing the case of the patient before taking radiation.
- Diagnosing the type of cancer (malignant or benign), also the location and the size of the tumor.
- Deter mining the type of cancer stages (first, second, third or fourth) stage.
- Delineation organs at risk (spinal cord, brain steam, etc.)
- C.T. scanner simulation, contouring tumor cell and organs at risk, prescribing dose and number of fraction doses per day.

- Treatment planning process (3D-CRT) technique.
- The procedure of the Quality Assurance process.
- Delivery of the radiation doses in the treatment room.
- Following up the patient during the treatment.

In 3D-CRT, the tumor and all organs are viewed in three dimensions and radiation is delivered using irregular beams with uniform intensity according to the shape of the tumor from different directions, and the radiated volume corresponds to the shape of the tumor. This compatibility increases the ability to safely deliver higher doses to the tumor, and reduce radiation exposure to surrounding healthy tissue.

2. Types of Treatment Planning

First plan: is two lateral beams in the left and right side of head, this plan depends on collimator and gantry angles to apply a beam of radiation on brain, the amount of these angles depend on the location and size of the tumor in the brain, so the gantry and collimator angles for each patient are difference.

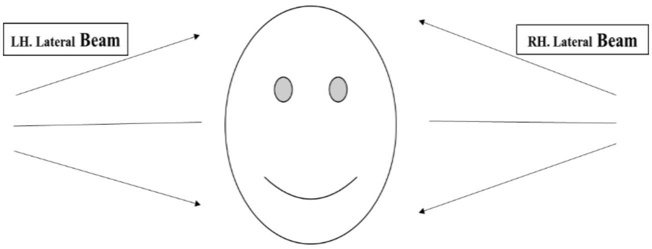

Figure 2. The schematic illustration of first planning

Not that it is not condition for the first plan to use full beam of radiation, in some time half beams will be used also, and this plan approximately consider (25 to 35)% of brain cancer patients and mostly uses for (palliative cases).

Second plan: it consists mainly of three beams right and left lateral breams a one vertex beam, the third beam is very important to brain cancer treatment planning since it reduces the radiation energy to the normal tissues surrounding the tumor cell and increase the radiation energy to the tumor which is the main goal of each treatment planning. However, the amount of collimator a gantry angles depends on the location and the size of the tumor in, also in most time half beam uses in this type planning Figure (3). In most treatment planning of brain cancer radiotherapy is applying the second type of brain treatment planning especially in (cure treatment cases).

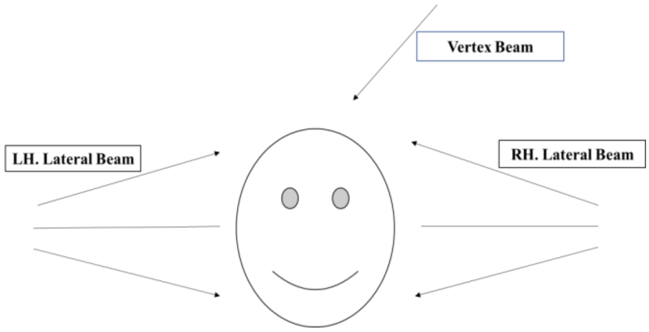

Figure 3. The schematic illustration of second planning

In 3DCRT technique, Elekta's XiO computer program has great ability to provide a powerful radiotherapy planning system. XiO is a perfect system For accurate planning and fluent workflow and can meet the expectations of Elekta treatment planning, Such as easy integration, advanced dosing calculations, high degree of flexibility, automation tools, etc. XiO has a variety of workflow tools for planning with the ability to select fonts, virtualization, fusion, and revision.

For PTV, the average dose D95%, D98%, and D2% were taken into account, while, for the OAR oar, the maximum point dose and the median dose for several organs of the brain, spinal cord and brain vapor were taken.

Treatment regimens use MLCs not only to shape the radiotherapy area so that it perfectly matches the shape of the tumor, but also to adjust the intensity of the radiation beam during each treatment.

Statistical Analysis

Data analysis was carried out using the statistical package available from SPSS-22 (Statistical Packages for the Social Sciences-Version 22). It is presented in simple measures of frequency, percentage, mean, standard deviation, and range (minimum and maximum values).

The significance of the variance for the different means (quantitative data) was tested with a paired t-test for variance in paired observations (or two dependent means). Statistical significance was considered when the P-value was equal to or less than 0.05.

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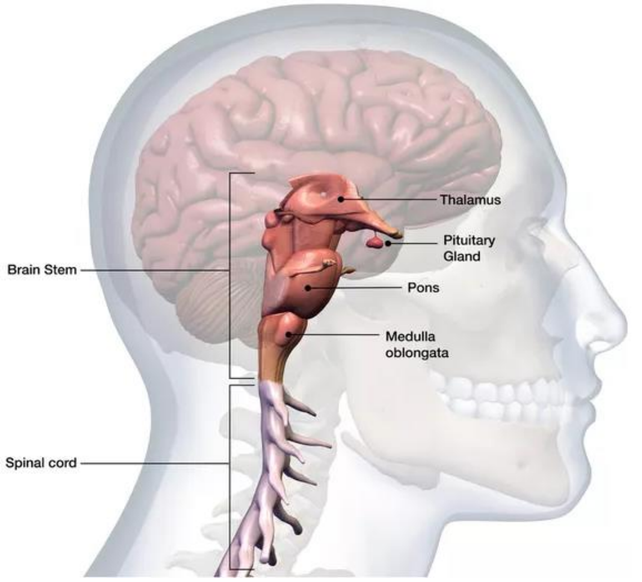

Figure 4. The structure of side head anatomy

Cancers extend through 4 major ways as follows:

i. Direct extension from its primary site to proximate regions.
ii. Extension via lymphatic channels to lymph nodes.
iii. extend along nerves (neural extension) to other regions of head and neck, and
iv. Extension via blood vessels to distant areas of the body. The second phenomenon is more common in head-and-neck cancer.

In the case of cancer, some special cells of the body reproduced out of control. Head-and-Neck cancers begin in various places of head and throat, and differ from brain and eye cancers. The term "head-and-neck cancer" refers to various malignant tumors that infect sinuses, throat, mouth, larynx, and nose of patients. Head-and-neck cancers are further classified by the initial region of infection. In order to gain the highest cure probability, development of conformal treatment plans with the ability to deliver high doses to the target volume while sparing of healthy tissue are essential. In the case of head-and-neck cancer, there are several healthy structures or organs-at-risk (OARs) close to the disease sites, which complex the treatment process.

Conformal radiotherapy refers to modalities (techniques) which radiation beams are "shaped" to cover the tumor volume plus sparing the surrounding tissues nearby the target volume. We present here a brief overview of the different types of conformal radiation therapy modalities to fulfill the objective of this research which is comparing the radiotherapy treatment plans between this two above techniques and its effect on organs at risk (OARs) in patients with head and neck cancer, also to compare the clinical outcomes of both plans in terms of dosimeter optimization and sparing organs at risk near the target volume (PTV). (Taylor, 2004).

Results

According of ICRU protocol the dose distribution requires a minimum dose of 95% and minimum dose of (105 -107)% of the dosage prescription in to the (PTV) target volume. Most of the target volumes (PTV) of this ten patients close to brain steam a spinal cord in some cases close to parotid glands, (more than 90%) are close to the spinal cord or parotid glands, so a minimum dose of the prescribed dose (95%) in to the target volume is difficult to achieve. However, the minimum dose radiation is (88%) and the mean dose is (100.02%) as shown in the table (1) below.

Table (1). Doses into PTV D_{min}, D_{max}, and D_{mean}

Patients	D_{min} (98 %)	D_{max} (2 %)	D_{mean} (50%)
1	4310	5390	5031
2	4515	5355	5128
3	4289	5387	5060
4	4532	5827	5277
5	4189	5323	5017
6	4480	5365	5058
7	4510	5280	5066
8	4390	5413	5286
9	4390	5312	5074
10	4365	5410	5065

The minimum doses of ten patients are illustrated bellow the fig.(5). One patient has taken lower value of dose radiation (4189 cGy). The 55% of the minimum dose is less than 90 %. One of the interests of the minimum dose is to reduce the exposure dose to the healthy tissues nearby the tumor.

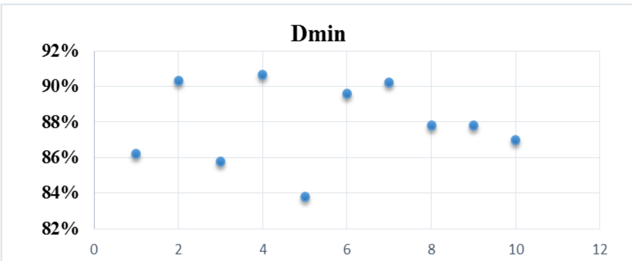

Figure 5. Minimum dose (98%)

As shown in fig.(6) below nine cases where the maximum dosage radiation pass 107%, but is lower than 109 % and located in target volume (PTV). Maximum doses value is very important for series organs such as spinal cord and brain steam since the tolerance doses of radiation energy for this type of organs maximum dose take in to account.

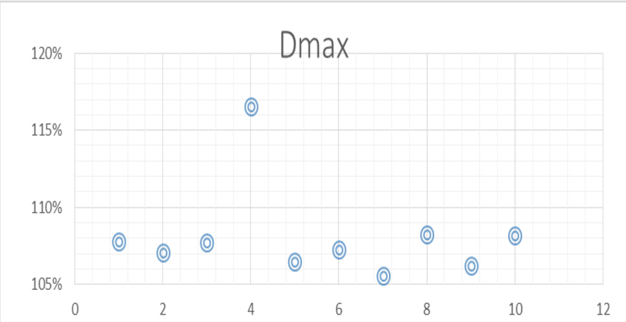

Figure 6. Maximal dose (2%)

Conformity and Homogeneity indices are an important quantitative tool for assessing the dose homogeneity and conformity of treatment plan in radiotherapy procedures. By these two tools the doctors or physicians be sure while the treatment plan is acceptable or not. Accordingto radiotherapy oncology group (RTOG) conformity index suggested in 1993 and it is considered a good quantitative tool for checking the plan quality of treatment planning process, and has been explained in ICRU (international commission and radiation units) explained by this equation:

$$CI\ (RTOG) = VRI / TV$$

Where, the VRI is the volume reference dose, and TV is the target dose volume (PTV). In RTOG guideline defined the range of conformity index as follows:

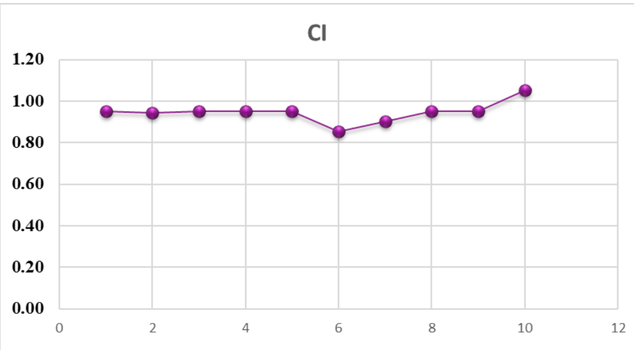

Figure 7. Conformity Index (%)

Homogeneity index is a simple quantitative tool to analyze and quantifying dose homogeneity in the target volume (PTV). It can be used to estimate the dose distributions of radiation energy in each point in the target volume or to know while each point in the target volume (PTV) take approximately the same amount of radiation energy. A more descriptive formula is:

$$HI = D_2 - D_{98} / D_p$$

Where D_2 = minimum dosage to 2%, D_{98} = minimum dosage and D_p = prescribed dosage.

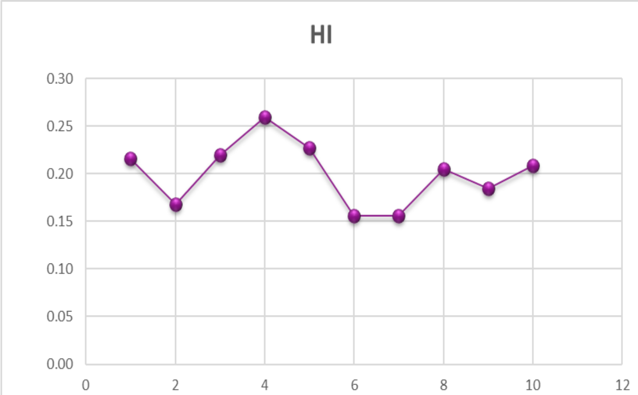

Figure 8. Homogeneity Index (%)

Discussion

If the value of conformity is equal to 1, it means the value is ideal or perfect and in the same time the treatment planning quality is ideal and acceptable, if the CI value is less than 1, this means the regret volume (PTV) is partially irradiated, it is not good treatment plan because two things, first the coverage of the target volume is less than legal percentage (95% - 107%) and there is cold spot during the treatment planning process, this is clinically unacceptable.

If the conformity index value is greater than 1, this means that the volume irradiation is greater than the target volume (PTV) and organs at risk nearby the target volume are included, this is not acceptable clinically also, since this healthy tissues close to tumor take radiation doses more than its tolerance dose, so doctors or physicians never accept this type of plan. (Petrova, 2017).

Note that the value of CI in range of 1 to 2 acceptable in most of radiotherapy cancer centers in condition not be more than 2, and the value of CI less than 1 is accepted in condition not be less than (0.80).

In the results Fig. (7) presented below, it can be seen that in one case the conformity value is greater than 1 by (1.05), and most of the cases are (0.95) except in one case it is value is (0.85). In this two case the value of the CI difference because of the location of tumor or target volume may some sensitive organs close to the tumor and the treatment plan may be difficult so the conformity of the target volume is not been perfect and the healthy tissue nearby the target volume either take more radiation dose or less radiation energy that its tolerance dose.

Note that in if the conformity index value is very lower than its ideal value such as in our case (0.85) this means that the shape of the target volume is not more suitable for the shape of the target volume inside the patient's body, this treatment planning cases medically accepted in rare states.

The values of both D 98% and D 2% for target volume (PTV) were obtained from DVH (dose volume histogram). A low value of HI indicates a better quality plan and more regular distribution of doses in PTV that can be achieved in the target.

The effect of receiving doses by organs at risk like the spinal cord, brain steam, and the parotid glands has consisted with the planning technique. The major aims of these organs at risk above were to achieve a lower radiation dose value than their tolerance doses; (tolerance dose for spinal cord and brain steam are less than 48 Gy and 54 Gy respectively and for parotid glands are less than 26 Gy as proposed by RTOG (radiation therapy oncology group).(5)

For the estimated ten patients, the plans indicate that OAR values were below established dose limits except in one patient where the doe value of right and left parotid glands a little above tolerance dose (29.65 and 29.70)Gys as shown in the table (1) below.

The mean and standard deviation of both HI and CI were (0.1999 ± 0.03, 0.9457 ± 0.05) respectively. The conformity value is clinically acceptable and it's close to ideal value 1 according of RTOG, and homogeneity index mean value also acceptable since its value near the RTOG value which is equal to zero. Standard deviation of all ten patients is good and the values of CI and HI were statistically acceptable.

Table 1. Minimum dose, Maximum dose, Organs at risk, Conformity and Homogeneity indices for ten patients

cases	Dmin	Dmax	HI	CI	Cord	Brainstem	Rt parotid	Lt parotid
1	43.10	53.90	0.2160	0.9510	39.88	41.25	18.76	21
2	45.15	53.55	0.1680	0.9450	37.49	22.36	20.13	22.39
3	42.89	53.87	0.2196	0.9509	42.39	45.96	29.65	29.7
4	45.32	58.27	0.2590	0.9500	43.75	36.5	24.21	24.9
5	41.89	53.23	0.2268	0.9510	41.46	3.3	20.63	24.92
6	45.84	53.65	0.1562	0.8541	43.92	26.87	26.56	26.59
7	45.10	52.89	0.1558	0.9025	43.01	5.04	18.47	17.08
8	43.90	54.13	0.2046	0.9499	42.48	30.15	22.84	17.72
9	43.90	53.12	0.1844	0.9505	44.99	43.72	25.7	25.74
10	43.65	54.10	0.2090	1.0518	40.45	4.91	28.28	23.34
Mean value	**44.07**	**54.07**	**0.1999**	**0.9457**	**41.98**	**26.01**	**23.52**	**23.34**
Standard Deviation	**1.26**	**1.53**	**0.03**	**0.05**	**2.23**	**16.62**	**3.99**	**3.93**

Conclusion

We can see that from the results: CI and HI of ten brain cancer patients who worked in this paper within the framework of RTOG recommendations; the best value of this two indices was (1.0518 and 0.1558) respectively, in the case of the best target volume (PTV) coverage. It can be concluded that the matching and homogeneity indices are necessary tools to assess the adequacy of a treatment plan, but not a sufficient factor to optimally evaluate a radiotherapy plan. To be able to evaluate and estimation acceptance of some treatment plan methods into daily practice, further experience and data as max., min, and average dose values for required size, In addition to covering healthy organ tissues should be taken into account. For other assessment tools (DVH, isodose assay etc).

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