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Impact of Slice Thickness and Grid Size on Dose Calculation in Intensity Modulated and Volumetric-Modulated Arc Radiotherapy in Head and Neck Cancer

N. Ayman[1], A. Abdelaal[1], H.H. Amer[2], H.S. Mohammed[2*]

[1]*Radiotherapy Department, Nasser Institute, Cairo, Egypt*
[2]*Biophysics Department, Faculty of Science, Cairo University, Giza, Egypt*

► ***Original article***

***Corresponding author:**
Haitham S. Mohammed, Ph.D.,
***E-mail:** haitham@sci.cu.edu.eg*

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ABSTRACT

Background*:** The grid size in radiotherapy can have an impact on dose values. When calculating the dose, slice width is a crucial component to consider. A thinner slice provides for a more precise mean dose estimate than a thicker slice. ***Materials and Methods: For this study, 35 patients with Head and Neck (H&N) cancer were chosen. Planning Target Volume (PTV) and Organ At Risks (OARs) were optimized using the same criteria. Intensity Modulated Radiation Therapy (IMRT) and volumetric-modulated arc therapy (VMAT) plans, which were designed with slice thicknesses (3,5,7 mm) and grid sizes (2,3,5, 7 and 8 mm). Homogeneity (HI) and Conformity Index (CI), dose points, such as D2%, D50%, and D98% for each OAR, assessed in relation to slice thickness and grid size. ***Results:*** There is a substantial difference ($p<0.05$) between grid sizes 3mm, 5mm, 7mm, and 8mm in IMRT and VMAT, but no significant difference ($p>0.05$) in target and OAR dose between grid sizes 2mm and 3mm. Conversely, the target dosage and OAR dose are significantly affected by variations in the Computed Tomography (CT) slice thickness, with a significant difference ($p<0.05$) seen in the target dose between 3mm, 5mm, and 7mm slice thickness and an insignificant difference ($p>0.05$) between 5mm and 7mm in OAR dose. ***Conclusions:*** According to this study, using the grid size of 2 mm is not recommended because it generates memory issues in the treatment planning system (TPS) and takes a lot of time, neither of which have a practical clinical effect.

INTRODUCTION

For many cancer patients, radiation therapy is a crucial form of treatment. While it can be very successful in identifying and eliminating cancer cells, there is a chance that organs far from the original tumor location can acquire secondary malignancies. Ionizing radiation, including charged particles or X-rays, can harm normal cells genetically in addition to cancerous ones [1].

A crucial part of radiation treatment planning is precisely delineating normal structures to reduce the risk of treatment-induced secondary cancers. It enables more accurate delivery of radiation therapy by radiation oncologists, optimizing tumor control and reducing damage to adjacent healthy tissues. As a result, patients receiving radiation therapy benefit from better treatment outcomes and higher-quality care overall [2].

The accuracy of volume calculations for the target and Organ At Risks (OAR) regions is influenced by the thickness of the CT imaging slice, which in turn affects the outcomes of the dosage calculation. The target and OAR regions' size, shape, and volume, among other factors, may affect the ideal slice thickness [3].

To treat H&N cancers, two advanced radiation therapy techniques that are frequently used include Intensity Modulated Radiation Therapy (IMRT) and volumetric-modulated arc therapy (VMAT). Both techniques offer more focused and accurate radiation administration, reducing harm to nearby healthy tissues and OARs [4]. The abundance of OARs near diseased organs, such as the salivary glands, spinal cord and brainstem, larynx, pharyngeal constrictors, oral mucosae, tongue and lips, masseter, eyes, and inner ears, presents a significant challenge when it comes to irradiating Head and Neck (H&N) cancer [5].

Several small radiation beams are used in IMRT, and their shapes and intensities can be adjusted to match the size and shape of the tumor. By adjusting the beam's intensity, IMRT enables more accurate delivery of radiation at varying doses to distinct areas within the treatment field. This reduces the possibility of difficulties and negative consequences by protecting critical tissues and OARs near the tumor [6-9]. In contrast, VMAT is a type of IMRT where a rotating gantry is used to administer radiation to the patient in a continuous arc. Throughout treatment, the apparatus revolves around the patient,

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continuously adjusting the radiation beam's intensity. A range of distribution angles for VMAT radiation allow for highly conformal and effective therapeutic delivery [10, 11].

IMRT and VMAT are superior to traditional radiation therapies in terms of precise dosage contouring, preservation of healthy tissues, and improvement of therapeutic outcomes. They are particularly helpful in the treatment of H&N cancers, where it is crucial to protect vital organs such the spinal cord, salivary glands, and ocular structures. It's crucial to remember that the radiation oncology team's expertise, the patient's condition, and the characteristics of the tumor all play a role in the treatment decisions that are made. Depending on the specific circumstances and the resources and technology available at the treatment center, either IMRT or VMAT is chosen [12-14].

The TPS's dose calculation algorithm's resolution and speed are influenced by the size of the dose calculation grid. Previous studies have shown that the TPS's computation of the dosage distribution is dependent on grid size, especially in areas with significant dose gradients or intricate beam arrangements. Therefore, choosing the appropriate grid size is essential to guaranteeing the effectiveness and caliber of treatment planning for radiation [12, 15]. Numerous investigations have shown a correlation between dosage variations and the size of the calculating grid [16]. Determining the volume of contour for the target and OAR requires calculating the grid size dose by specifying the resolution of the dosage distribution [17].

The purpose of this study was to investigate the effects of dose calculation grid size on radiation treatment planning accuracy and efficiency. For various clinical settings such as IMRT and VMAT, we want to determine the optimal grid size that can both compute quickly and provide high dose calculation accuracy. The Consideration of both grid size and slice thickness effect in the same study, study of grid Size (5, 7 and 8mm) which aren't mentioned in the previous studies, and grid size and slice thickness effect in VMAT and IMRT while the previous studies consider IMRT only.

MATERIALS AND METHODS

Patient Selection

Data was retrospectively obtained from planning ststem for 35 male patients of ages 40-50 years diagnosed with H&N cancer (nasopharynx cancer were selected for this study, these patients underwent CT scan with CT machine of SOMATOM (Siemens, Germany) to acquire the CT images with a slice thickness of a 3 mm, 5mm and 7mm in the same treatment position. These CT images were transferred to the Monaco Sim workstation (Elekta, Sweden) where the targets and organs at risks as the spinal cord, the right (rt) parotid gland, and the left (lt) parotid gland were delineated. On the various CT data sets (3,5, and 7 mm slice thickness), PTV was produced by extending the Clinical target volume (CTV) by a consistent margin.

Treatment Planning

After delineation step was completed, the CT images were sent to the Monaco Planning System workstation (Elekta, Sweden) where dynamic IMRT and VMAT techniques are designed for each patient using 6 MV photon beam from synergy linear accelerator with 160 Multi-Leaf Collimator (MLC). for both IMRT and Vmat techniques, montcarlo simulation algorithm was used to calculate the dose distribution. The prescription dose for prostate tumor was 60Gy with daily dose of 2Gy (30 fraction) delivered by Linear accelerator of type Synergy (Elekta, Sweden).

In IMRT technique, nine fields of gantry angles (0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, and 320°) are used to design the plan for each patient while in VMAT technique,Two coplanar arcs (clockwise and counterclockwise) are used.

In IMRT and VMAT techniques, the Monte Carlo uncertainty method is adjusted to per calculation method with different calculation values as 1, 5, 7, and 10 in all previously designed plans as shown in figures 1,2. Then, the different dosimetric plan parameters (D95%, D98%, D2%) of each target and the acceptance criteria doses to each OARs were evaluated. The Monte Carlo uncertainty method is adjusted another time to per the control point method with different calculation values as 1, 5, 7, and 10 in all previously designed plans and the previous dosimetric parameters as per calculation method are evaluated to estimate the effect of different uncertainty methods in Monte Carlo algorithm on dose calculation and doses reach targets and organ at risks in the previous patients.

Using the same optimization settings in all these parameters, these treatment plans were recalculated for a 2, 3, 5, 7, and 8 mm grid size with various slice thicknesses (3, 5, 7 mm) to evaluate the effect of grid size and slice thickness on dose calculation in each previous technique. The following equations were also used to assess ICRU-83 dose points, such as D2%, D50%, and D98%, as well as specific dose-volume points for each OAR, HI, and CI in relation to slice thickness and grid size as shown in equations 1, 2 respectively.

$$HI = \frac{D2\% - D98\%}{D50\%} \quad (1)$$

$$CI = \frac{VRI}{TV} \quad (2)$$

Where; VRI = Reference isodose volume and TV = Target volume [18].

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Statistical Analysis

The association between changes in computed parameters and alterations in CT slice thickness and grid size for each plan, in both IMRT and VMAT procedures, was investigated in this study using a t-test with independent samples (SPSS, V.26). A statistically significant p-value was defined as one that was less than 0.05.

RESULTS

Figures 1 and 2 depict the spectrum of PTV (D95%) and PTV (D98%) doses for Head and Neck (H&N) cancer patients undergoing Intensity-Modulated Radiation Therapy (IMRT) across various grid sizes (2, 3, 5, 7, and 8 mm) and three different slice thicknesses.

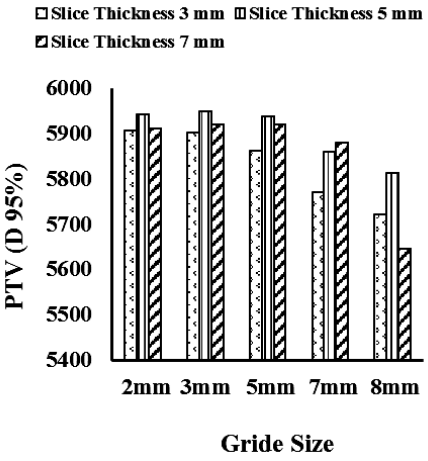


Figure 1. Variation of PTV (95%) dose (cGy) as a function of grid size at different slice thicknesses (3,5,7 mm) using the IMRT technique.

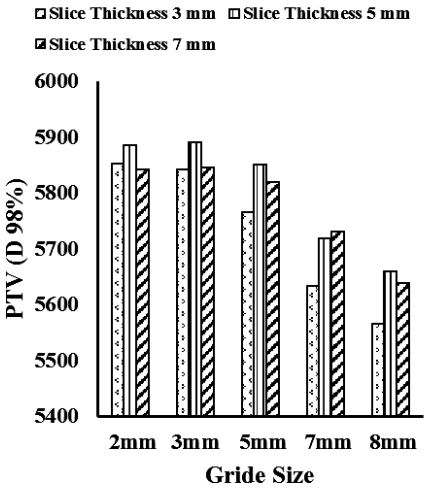


Figure 2. Variation of PTV (98%) dose (cGy) as a function of grid size at different slice thicknesses (3,5,7 mm) using the IMRT technique.

The utilization of the IMRT technique revealed statistically significant differences ($p<0.05$) in the reported PTV doses (D95% & D98%) among patients with Head and Neck (H&N) conditions. These differences were influenced by modifications in both grid size and slice thickness. Comparable patterns were noted while utilizing various grid sizes in conjunction with a slice thickness of 5 mm. In contrast, the findings regarding a slice thickness of 7 mm exhibited a significant disparity ($p > 0.05$) just at the 8 mm grid size, whereas no statistically significant alterations ($p > 0.05$) were seen at grid sizes of 2 mm, 3 mm, 5 mm, and 7 mm.

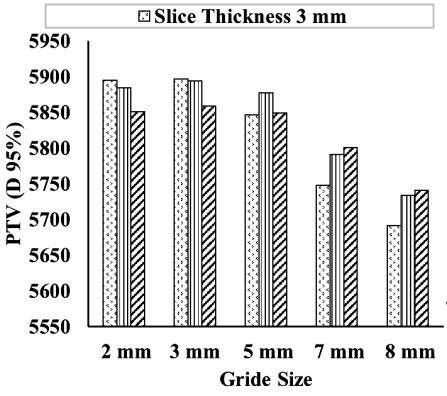


Figure 3. Variation of PTV (95%) dose (cGy) as a function of grid size at different slice thicknesses (3,5,7 mm) using VMAT technique.

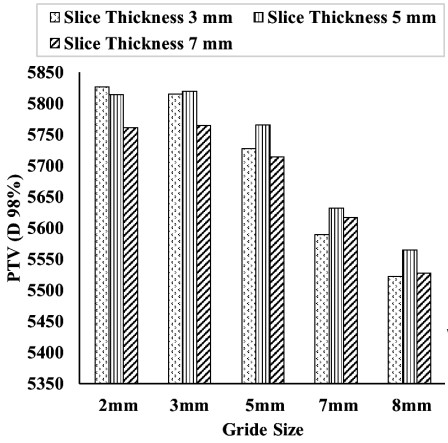


Figure 4. Variation of PTV (98%) dose (cGy) as a function of grid size at different slice thicknesses (3,5,7 mm) using VMAT technique.

Figures 3 and 4 represent notable differences in PTV D95% and D98% with different slice thicknesses in utilizing the IMRT technique with varying grid sizes, particularly at a consistent grid size of 3 mm. Here, the PTV doses exhibited a gradual increase from 3 mm to 5 mm, followed by a sharp decrease from 5 mm to 7 mm, indicating statistical significance ($p < 0.05$) among slice thickness values. At a grid size of 5 mm and slice thicknesses of 3 mm, 5 mm, and 7 mm, statistically significant differences ($p < 0.05$) were noted in both PTV D95% and D98%, with a steady decline from 5 mm to 7 mm and a rapid rise from 3 mm to 5 mm. Conversely, at a grid size of 7 mm, significant differences ($p < 0.05$) were observed among different slice thicknesses, particularly between slices measuring 3 mm, 5 mm, and 7 mm in thickness. This disparity stemmed from a marked increase in PTV D95% & D98% from 3 mm to a slice thickness of 5 mm, succeeded by a gradual rise in PTV D95% & D98% values from 5 mm to 7 mm.

By utilizing the VMAT technique, as depicted in figures 5 and 6, it was observed that the PTV D95% and D98% doses remained relatively stable at slice thicknesses of 3mm and 5mm, respectively. However, a notable fluctuation ($p < 0.05$) was evident among different slice thicknesses, particularly with the PTV D95% dose experiencing a sudden decline from 5mm to 7mm at the consistent grid size of 3mm. Significant

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differences ($p < 0.05$) were observed between various slice thicknesses, with a sharp increase noted from 3 mm to 5 mm and a subsequent decrease from 5 mm to 7 mm in both PTV D95% and D98% dose values.

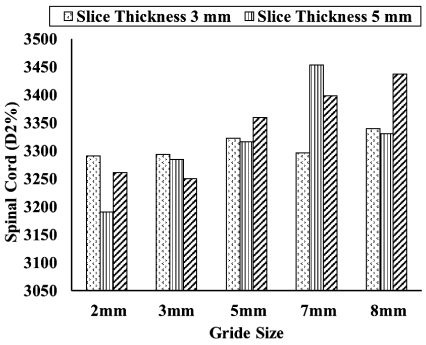


Figure 5. Variation of spinal cord dose with slice thickness 3,5,7 mm as a function in different grid sizes using IMRT technique.

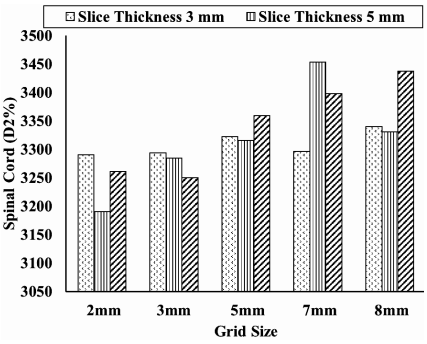


Figure 6. Variation of spinal cord dose with slice thickness 3,5,7 mm as a function in different grid sizes using VMAT technique.

This study uses Top of Formthe spinal cord and parotid as an example of OAR in H&N to assess the impact of slice thickness and grid size variation on the OAR dose calculation because the spinal cord is one of the primary OAR in H&N cases in radiotherapy.

Figure 5 depicts the variation in spinal cord dosage corresponding to slice thicknesses of 3 mm, 5 mm, and 7 mm, respectively, employing the IMRT approach. The grid sizes utilized in the study were 2 mm, 3 mm, 5 mm, 7 mm, and 8 mm. There is a significant difference ($p<0.05$) in the spinal cord doses observed when comparing grid sizes of 3 mm, 5 mm, and 7 mm, with corresponding slice thicknesses of 3 mm, 5 mm, and 7 mm at various grid sizes. However, the disparity in spinal dose between 2 mm and 3 mm at different grid sizes was found to be statistically insignificant ($p>0.05$). The VMAT technique demonstrates comparable levels of significance ($p<0.05$) and insignificance ($p>0.05$) throughout the same slice thickness and grid size, as depicted in figure 6. There is no statistically significant difference ($p>0.05$) observed in spinal cord doses when employing the VMAT technique.

The variation in doses received by the right (RT) parotid gland, utilizing slice thicknesses of 3 mm, 5 mm, and 7 mm, across different grid sizes ranging from 2 mm to 8 mm, as analyzed through the IMRT technique, is presented in figure 7. Examination of this figure indicates significant differences ($p<0.05$) in RT parotid doses among grid sizes of 3 mm, 5 mm, 7 mm, and 8 mm at slice thicknesses of 3 mm, 5 mm, and 7 mm. Conversely, differences in RT parotid doses between 2 mm and 3 mm grid sizes were not found to be statistically significant ($p>0.05$). Furthermore, employing the VMAT approach at the same slice thickness and grid size revealed comparable significant ($p<0.05$) and inconsequential ($p>0.05$) trends, as demonstrated in figure 8.

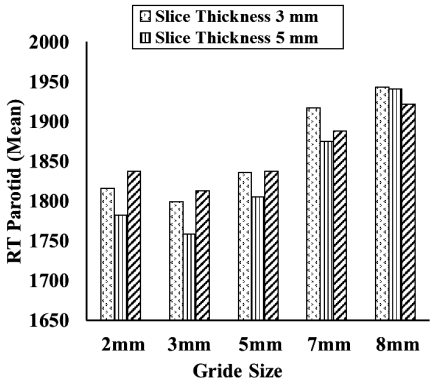


Figure 7. Variation of RT Parotid with slice thickness 3,5,7 mm as a function in different grid sizes using IMRT technique.

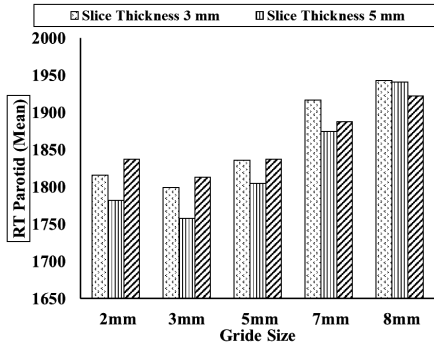


Figure 8. Variation of RT Parotid with slice thickness 3,5,7 mm as a function in different grid sizes using VMAT technique.

Figures 9 and 10 present the variations in doses received by the left (LT) parotid gland across slice thicknesses of 3 mm, 5 mm, and 7 mm, considering different grid sizes (2 mm,3 mm, 5 mm, 7 mm and 8 mm) for both IMRT and VMAT approaches respectively. These figures demonstrate that LT parotid doses exhibit significant differences ($p<0.05$) at slice thicknesses of 3 mm, 5 mm, and 7 mm across various grid sizes of 3 mm, 5 mm, 7 mm, and 8 mm.

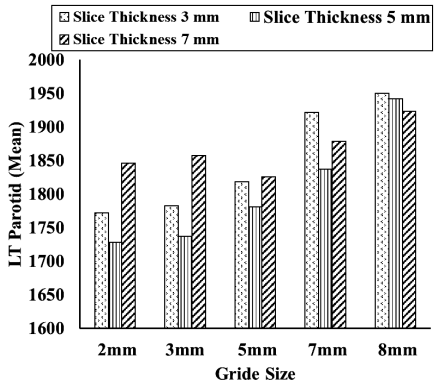


Figure 9. Variation of LT parotid with slice thickness 3,5,7 mm as a function in different grid sizes using IMRT technique.

Utilizing the IMRT technique, figure 11 depicts the variations in Homogeneity Index (HI) across slice thicknesses of 3 mm, 5 mm, and 7 mm, considering different grid sizes ranging from 2 mm to 8 mm. Analysis of this figure reveals significant differences ($p<0.05$) in HI results at a slice thickness of 3 mm

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among various grid sizes of 5 mm, 7 mm, and 8 mm. Conversely, negligible differences (p>0.05) were observed with a grid size of 3 mm at the same slice thickness. Furthermore, HI results with 5 mm and 7 mm slice thicknesses only displayed significant differences in grid sizes (7 and 8 mm at 5 mm slice thickness, and 2 mm at 7 mm slice thickness, respectively).

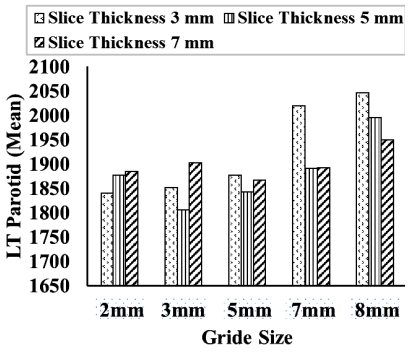


Figure 10. Variation of LT parotid with slice thickness 3,5,7 mm as a function in different grid sizes using VMAT technique.

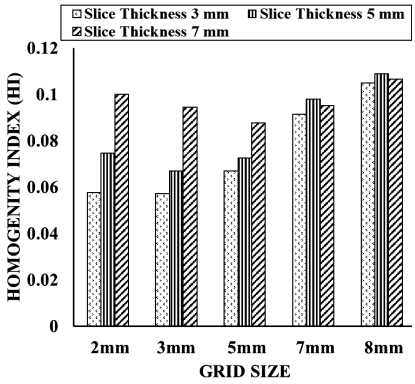


Figure 11. Variation of Homogenity Index (HI) with slice thickness 3,5,7 mm as a function in different grid sizes using IMRT technique.

Similar trends were observed with the VMAT approach (figure 12) across multiple grid sizes and slice thicknesses. However, when employing the IMRT technique, results with a slice thickness of 5 mm exhibited significant differences (p<0.05) with grid sizes of 2 mm, 5 mm, 7 mm, and 8 mm, as well as at 7 mm and 8 mm.

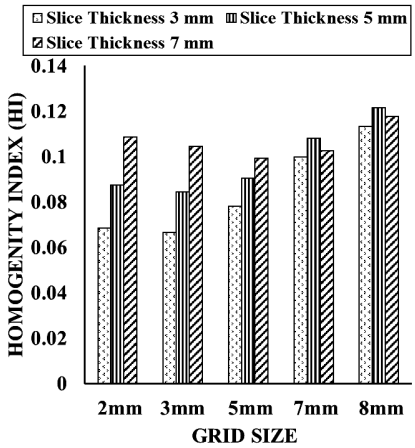


Figure 12. Variation of Homogenity Index (HI) with slice thickness 3,5,7 mm as a function in different grid sizes using VMAT technique.

DISCUSSION

The calculation grid size, is entirely different from the CT-pixel size that is dependent on the imaging system. Commercial TPSs generally offer a range of grid size from 1-10 mm for dose calculation. The commonly used grid size in most clinics is between 2.5-5.0 mm as a compromise of computational time and dose calculation accuracy [19]. As reported in figure 1,2 where no statistically significant alterations (p > 0.05) were seen at grid sizes of 2 mm, 3 mm, 5 mm, and 7 mm.

The calculated dose distributions of treatment planning system (TPS) are affected by the dose grid size, and the presence of a dosimetric influence according to the calculated grid size has been reported in IMRT and VMAT [20]. The outcomes of the VMAT method in comparison to IMRT for slice thicknesses of 3, 5, and 7 mm are shown in figures 3 and 4. With the exception of grid widths of 7 mm and 8 mm for slices 3 mm and 5 mm, respectively, where there is a significant difference (p<0.05), the results are similar for all slice thicknesses.however using the VMAT technique at the same slice thickness and grid size, A statistically significant difference (p>0.05) was not found between LT parotid dosages with slice thicknesses of 7 mm at different grid sizes of 2 mm and 3 mm in the VMAT approach, with the exception of those results at 7 mm. Nonetheless, using the VMAT approach, there is a statistically significant difference (p<0.05) in spinal cord doses between slice thicknesses of 5 mm and 7 mm as shown in figures 6 and 10, respectively. Nevertheless, using the VMAT approach, there is no statistically significant difference (p>0.05) between the rt parotid dosages with slice thicknesses of 7 mm and 8 mm at various grid sizes of 3 mm, 5 mm, and 8 mm as shown in figure 8. The current study used IMRT and VMAT approaches to determine the CI and discovered that there is no significant difference (p>0.05) in the CI values at different slice thicknesses and varied grid sizes.

A quick summary of the study's main conclusions is as follows: altering the computation grids will change the OAR dose as well as the target dose distribution. An reliable evaluation of the doses received by the target and OAR can be obtained by using a calculation grid of the right size [21]. In general, using VMAT and IMRT procedures, there is little variation in PTV doses and OAR doses between grid sizes of 2mm and 3mm. Additionally, it takes a long time to calculate doses using the 2mm grid size. Although a smaller grid size can yield a more accurate and conformal dose calculation, particularly in regions of high dose gradient, dose calculations using a finer calculation grid size require a longer computational time [22]. Additionally, there are analogous significant and insignificant results for HI at various grid sizes and slice thicknesses, as well as insignificant results for CI at the same parameters as shown in figures 11, 12 with IMRT and VMAT techniques. Affine grid size dosage calculations take a long time to compute and might not be feasible. In

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case the grid is too small, it would have memory issues. The most significant discovery was that the dose was almost grid-independent. This shows that changing the grid size in the plan while keeping the Monitor Unit (MU) constant has no effect on the dosage due to its straightforward shape and lack of a gradient area [23]. Based on the results of this study, it is not recommended to utilize a grid size of 2 mm for the dose calculation in IMRT and VMAT. When choosing the default grid size for new plans, one must always make an equilibrium between speed and accuracy. In order to achieve the desired coverage, larger grid sizes necessitated higher MUs and an increase in dose to the structures [24]. For this reason, using grid sizes larger than 3 mm when using IMRT and VMAT is not advised.

Slice thickness has a significant influence on the OAR dose as well as the dose computation; nevertheless, the variation in thickness between 5 and 7 mm is not very great. The slice thickness used for sites with tiny OARs, like the brain, head, and neck, should be 3mm, as opposed to the transition between 3mm and 5mm, which is based on the treatment site and the OAR volume [25].

CONCLUSION

Variations in slice thickness and grid size play pivotal roles in radiotherapy, particularly with advanced techniques like VMAT and IMRT, because they greatly affect target and OAR doses. Based on these findings, a grid size of 2 mm is not recommended due to its limited clinical utility, takes a long time to compute, and may produce memory problems in the TPS. While differences in OAR doses between slices of 3 mm and 5 mm are minimal, variations become significant between slices of 5 mm and 7 mm, with the OAR volume notably impacting this transition.

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***Consent to Participate*:** Non Applicable.
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***Authors' contributions*:** N.A.: performed the practical part of the paper and data collection; A.A.: Wrote the paper draft and shared in data analysis; H.A.: Shared supervision; H.S.M.: Revised the paper, data analysis, and supervised the workflow.

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