Effect of the number of control points on the plan quality of intensity-modulated radiotherapy for nasopharyngeal carcinoma

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ABSTRACT
This study aimed to investigate the effect of the number of control points (CPs) on the plan quality, plan delivery efficiency, and gamma passing rate (GPR) of intensity-modulated radiotherapy (IMRT) for nasopharyngeal carcinoma (NPC). Twenty patients with NPC were selected. With all other optimization conditions unchanged, only the number of CPs in each field was changed and optimized to formulate four groups of IMRT plans (CP10, CP15, CP20, and CP25) for each case. An IMRT factor (IF) was used to evaluate the plan complexity, and the plan quality index (PQI) was employed to measure the plan quality. The MatriXX was used to measure each plan, and the plan delivery time (PDT) was recorded. The CP20 group had the lowest PQI (20.2%), while the CP10 group had the highest PQI (51.4%). The monitor unit (MU) values and PDTs gradually increased as the number of control points increased, while the MUs/segment significantly decreased. A negative correlation was observed between GPR and IF at the three commonly used criteria ($R^2 = 0.39$, 0.39, and 0.41, respectively). Considering the IMRT plan quality and the efficiency and accuracy of plan delivery, 20 CPs per field should be used in the IMRT planning for NPC.

1. Introduction
Nasopharyngeal carcinoma (NPC) is a malignant cancer commonly seen in southern China, with 15–50 cases per 100,000 individuals (Tang et al., 2016; Yang et al., 2017; Zong et al., 2016). Radiotherapy is one of the primary treatment options for NPC (Wu et al., 2017). The goal of radiotherapy is to maximize the probability of tumor control and reduce the probability of normal tissue complication. However, the anatomy of the nasopharynx is complex and the number of organs at risk (OARs) is large. In addition, some OARs may overlap with the target area, making it difficult to create an NPC radiotherapy plan (Chen et al., 2017; Hsin et al., 2016). In intensity-modulated radiation therapy (IMRT), the dose is optimized based on the tumor shape and anatomical structure in order to achieve a dose distribution that conforms strongly to the shape of the target region. IMRT is currently one of the most commonly used precision radiotherapy techniques and is the primary method that improves the cure rate of NPC and allows for the delivery of a higher radiation dose to the target region while reducing the absorbed dose to the surrounding normal tissues (Moon et al., 2016).

IMRT plan optimization is generally performed in two steps. In the first step, the optimal fluence map is created based on the target conditions and constraint functions. In the second step, the optimal fluence is converted into a multi-leaf collimator (MLC) sequence after accounting for the shape and physical limitations of the MLC. The IMRT plans for NPC are becoming increasingly complex. An NPC IMRT plan usually includes hundreds of segments. The setting of the optimization parameters, such as gantry angle increment and minimum segment width, during planning affects the dose distribution and the delivery efficiency of the radiotherapy plan, thereby affecting plan quality (Chen et al., 2019; Wang et al., 2018). The number of control points in the IMRT plan determines the number of segments; an increase in the number of control points results in an increase in the number of segments and the degrees of freedom for plan modulation, thus improving plan quality. Previous studies showed that using too many control points in the Eclipse treatment planning system (TPS) not only failed to improve the IMRT dose distribution and plan quality but also caused the executable file size to markedly increase, thereby reducing work efficiency (Goraj & De Boer, 2012). Sutton et al. defined the baseline numbers of segments in the Pinnacle system for different diseases by reducing the number of segments in each field (Sutton et al., 2012). The Monaco system is a widely used TPS, and our institution has used this system for radiotherapy planning in over 4,000 patients each year.
Its dynamic MLC (dMLC) IMRT is similar to that of the Eclipse system but differs in that the dose rate is dynamically modulated when the MLC of each field is scanned in one direction. Currently, a few studies have reported the number of control points selected for the Monaco system used in IMRT planning for NPC. In this study, the IMRT factor (IF) and plan quality index (PQI) were calculated to investigate the effect of the number of control points on the IMRT plan quality and the accuracy and efficiency of delivery in NPC, thus aiming to provide a reference for the clinical application of IMRT in NPC.

2. Materials and methods

2.1. Case selection

Twenty patients with NPC who underwent dynamic IMRT between September 2019 and March 2020 at the Department of Radiation Therapy of our center were retrospectively selected. Of them, 18 were pathologically diagnosed with non-keratinizing undifferentiated carcinoma and 2 had poorly differentiated carcinoma. The patients had the following clinical stages: 1, T1; 2, T2; 16, T3; and 1, T4. Of the 20 participants, 16 were men and 4 were women, and the median age was 41 years (range: 25–60 years). All patients were immobilized in a supine position with a head, neck, and shoulder thermoplastic material membrane and a Styrofoam, with the head facing the frame. A Siemens large-aperture computed tomography (CT) simulation scanner was employed for determining the patients’ accurate position and for scanning based on the following protocols: voltage, 120 kV; slice thickness, 3 mm; and scanning range, from the top of the head to 2 cm below the head of the clavicle. The reconstructed images were transmitted to the Monaco (V5.11) radiotherapy planning system.

2.2. Delineating the target region and organs at risk

According to the ICRU-62 report, the gross target volume (GTV) of NPC patients can be divided into GTVnx (primary tumor) and GTVnd (neck metastatic lymph nodes) based on the specific location and characteristics of the tumor. The clinical tumor volume (CTV) can be divided into CTV1 and CTV2 based on the extent of invasion. CTV1 is the high-risk clinical target region, including the primary tumor and the positive lymph nodes. CTV2 is the low-risk clinical target region. To account for the effect of dose deviation and positioning errors, the CTV was expanded uniformly by 3 mm in all three-dimensional directions to form the corresponding planning target volume (PTV). The OARs included the lens, optic nerve, optic chiasm, eyeball, spinal cord, brain stem, pituitary and parotid glands, temporal lobe, temporomandibular joint, and mandible. The target region and OARs were delineated on CT images by experienced senior oncologists.

2.3. Planning

All dynamic IMRT plans were designed and optimized using the Monaco (v5.11, Elekta, Sweden) system. The Monte Carlo algorithm was adopted to calculate the dose distribution, and the plan was delivered utilizing the Elekta Ltd (Sweden) Synergy linear accelerator with 6 MV X-rays. In each plan, nine evenly distributed coplanar radiation fields were used, and the angles were set to 160°, 120°, 80°, 40°, 0°, 320°, 280°, 240°, and 200°. The Pareto plan optimization method was adopted according to the following physical optimization parameters: beamlet width, 0.5 cm; target margin, tight (0.2 cm); minimum segment width, 0.6 cm; and fluence smoothing, low. The statistical uncertainty of each control point was 2%, and the dose calculation grid size was 3 mm. The number of control points of each field in the system could be set within the range of 2 to 1,024. For each case, the number of control points used per field was 10, 15, 20, and 25 (the total numbers of control points corresponding to the plan were limited to 90, 135, 180, and 225), and the corresponding plans were named as CP10, CP15, CP20, and CP25. All other parameters and constraint functions remained unchanged.

The prescribed doses for the target regions designated as PTVnx, PTVnd, PTV1, and PTV2 were 70 Gy, 66 Gy, 64 Gy, and 56 Gy, respectively, with each dose delivered in 32 fractions; the prescribed dose was required to contain at least 95% of the target region volume. The doses delivered to the OARs were kept at tolerable levels and based on the following requirements (Lee et al., 2019): lens, $D_{0.03CC} \leq 8$ Gy; optic nerve, $D_{0.03CC} \leq 54$ Gy; spinal cord, $D_{0.03CC} \leq 5$ Gy; brain stem, $D_{0.03CC} \leq 54$ Gy; pituitary gland, $D_{0.03CC} \leq 60$ Gy; optic chiasm, $D_{0.03CC} \leq 54$ Gy; parotid gland, $V_{50} \leq 50%$; temporomandibular joint, $D_{2%} \leq 70$ Gy; mandible, $D_{2%} \leq 70$ Gy; thyroid, $V_{50} \leq 60%$; eyeball, $D_{mean} \leq 5$ Gy; and temporal lobe, $D_{0.03CC} \leq 65$ Gy. Both the target region and the OARs were named in accordance with the rules set forth in the AAPM TG 263 report (Mayo et al., 2018).

2.4. Evaluation of plan quality

The following parameters were evaluated for the target region: target coverage (TC), homogeneity index (HI), conformity index (CI), $D_{2%}, D_{95%}$, and $D_{98%}$. According to the ICRU-83 report (Grégoire et al., 2010), TC, HI, and CI were calculated using equations (1), (2), and (3), respectively:
\[ TC = \left( \frac{TV_{p}}{TV} \right) \times 100\% \]  
\[ HI = \frac{D_{\text{ref}} - D_{\text{prescribed}}}{D_{\text{ref}}} \]  
\[ CI = \frac{(TV_{p})^2}{V_{T} \times V_{p}} \]  

Here, Dx% is the dose covering x% of the target volume. Lower HI values indicate greater target dose uniformity. TV is the volume of the target region PTV, TVp is the volume of the target area included in the prescribed dose, and Vp is the total volume included in the prescribed dose line. Values of CI closer to 1 indicate better conformity of the target region.

To evaluate the complexity of the IMRT plan, the IF concept was introduced (Glasgow, 2006). IF equals the ratio of MUIMRT to MOUNP. IF was calculated using equation (4).

\[ IF = \frac{\text{MU}_{\text{IMRT}}}{\text{MU}_{\text{ONP}}} \]  

Here, MUIMRT is the number of MUs in the IMRT plan; MOUNP is the number of MUs in the open plan, which uses the isocenter of the IMRT plan, a single field of 10 x 10 cm², and the same prescribed dose as the IMRT plan.

To quantify and compare the plan quality, the PQI (Bohnsung, Gillis, Arrans et al., 2005) was employed. A quantitative comparison of the degree to which different plans achieved the same target dose was performed using equations (5) and (6).

\[ S_i = \left| \frac{M_i - C_i}{C_i} \right| \times P_i \times 100\% \]  
\[ \text{PQI} = \sum_{i}^{n} S_i \]  

Here, M_i is the actual dose of the evaluation parameter of the i-th anatomical structure (target region or OAR) and C_i is the corresponding dose target. In this study, the best dose parameter result among the four groups of plans was selected as the target dose of that parameter. The dose parameter results of the other plans were compared with the target dose to determine the difference. P_i is the weighting factor of the evaluated item (the weight of all evaluated items in this study is 1), S_i is the quality score of the i-th evaluated item, n is the number of items evaluated, and PQI is the plan quality index of the plan. Smaller PQI values indicate a smaller deviation between the planned result and the target result, indicating better plan quality.

In addition, the MUs, the number of segments, and the plan delivery time (PDT) of each plan were recorded to evaluate and compare the execution efficiency of each group of IMRT plans.

2.5. Dose validation of plans

The MatriXX detector array (IBA, Germany) was adopted to validate the dose distribution of all plans in this study. The output of the accelerator was calibrated prior to validation. To eliminate the influence of the angular response, the angle of the gantry was set to 0° during validation. For each plan, the global absolute gamma value of the validation result was calculated and analyzed for all fields together. To eliminate the influence of low-dose signals, the lower limit of the dose threshold for γ calculation was set to 10%. The gamma passing rates (GPR) of the dose validation results at the 3%/3 mm, 3%/2 mm, and 2%/2 mm metrics were calculated.

2.6. Statistics

All statistical analyses were performed with the SPSS22.0 software. Data were expressed as mean ± standard deviation (x ± s). The Shapiro-Wilk test was used to assess the normality of data. Two-paired sample t-tests were used to analyze the data with a normal distribution, while Wilcoxon signed-rank tests were performed to analyze the data with non-normal distribution. The groups were evaluated to determine any significant differences. A p value of <0.05 was considered significant.

3. Results

3.1. Plan quality index

(Figure 1) shows the calculations of the PQI of the four groups of IMRT plans with different numbers of control points. The plans in the CP20 group had the lowest PQI of 20.2%, indicating that this group had the best overall quality. The CP10 group had the highest PQI of 51.4%, indicating that this group had the worst overall quality.
quality. (Figure 1) shows that the PQI score of the PTVs in the target region increased as the number of planned control points decreased. The CP10 group had the highest PQI, which indicated an extremely poor planned TC and a nonuniform dose; the CP25 group had the lowest PQI, which indicated excellent TC and dose uniformity, followed by the CP20 group. The PQI score of the OARs decreased as the number of planned control points decreased. The CP10 group had the lowest PQI, which indicated that the OARs were least exposed to radiation and were highly protected; in contrast, the CP25 group had the highest PQI, indicating that the OARs were not highly protected.

3.2. Target region dose

(Table 1) lists the dosimetric calculation results of PTVs in the target regions of the dynamic IMRT plans with different numbers of control points in the 20 patients with NPC. The CP20 group was assigned as the reference group; the average TC and $D_{50\%}$ doses of the PTVs in the four target regions of the CP10 group were lower than those of the CP20 group ($p < 0.05$). The HI of the PTVnx of the CP15 group was slightly lower than that of the CP20 group ($p = 0.01$). The $D_{50\%}$ and $D_{2\%}$ of PTVnx and the $D_{2\%}$ of PTV1 were 0.05 Gy, 0.13 Gy, and 0.10 Gy higher, respectively, than those of the CP20 group ($p = 0.01, 0.01$, and $0.01$, respectively); meanwhile, the average $D_{85\%}$ doses of PTV1 and PTV2 were 0.04 Gy and 0.35 Gy lower, respectively, than those of the CP20 group ($p = 0.00$ and $0.01$, respectively). No significant differences were observed in the other dosimetry parameters of the two planned PTVs ($p > 0.05$). No significant differences were also observed in the results of the planned PTVs in the CP25 and CP20 groups ($p > 0.05$). Compared with the CP20 group, no significant differences were found among the CI values of the other three groups. (Figure 2) shows the HI box plot of the IMRT plan for the 20 patients with NPC with different numbers of control points. When the number of control points per field was increased from 10 to 25, the average HI of the PTVnx and PTVnd target regions decreased, indicating that the uniformity of the target region dose improved, but the absolute difference was relatively small (Table 1).

3.3. Dose to the organs at risk

(Table 2) presents the results of OAR dosimetric calculations in the dynamic IMRT plans with different numbers of control points in 20 patients with NPC. The average planned dose to the eyes in the CP10 group was 0.21 Gy lower than that in the CP20 group ($p = 0.01$); no significant difference was found in the results of other OARs. No significant difference was also found when comparing the CP15 and CP20 plan groups ($p > 0.05$), except that the average maximum planned dose to the pituitary gland in the CP15 group was 1.5% higher than that in the CP20 group ($p = 0.01$). The average maximum dose to the temporal lobe in the CP25 group was 0.39 Gy lower than that in the CP20 plan group ($p = 0.01$). No significant difference was observed in the dose delivered to the other OARs between the CP25 and CP20 groups ($p > 0.05$).

3.4. Plan parameters and plan delivery efficiency

As shown in (Table 3), the actual number of segments in the optimized plan increases as the number of control points increases, and the number of MUs and the IF gradually increase, thus indicating an increase in the complexity of the plan. The number of segments in

### Table 1. Comparison of PTV dosimetry of dynamic IMRT plans with different numbers of control points (n = 20, x ± s).

| PTV  | Parameter       | CP10    | CP15    | CP20    | CP25    | p1    | p2    | p3    |
|------|----------------|---------|---------|---------|---------|-------|-------|-------|
| PTVnx| TC (%)          | 97.75 ± 1.12 | 98.08 ± 1.18 | 98.19 ± 1.20 | 98.26 ± 1.31 | 0.01  | 0.08  | 0.05  |
|      | HI              | 0.067 ± 0.02 | 0.064 ± 0.02 | 0.060 ± 0.02 | 0.060 ± 0.02 | 0.01  | 0.01  | 0.58  |
|      | CI              | 0.621 ± 0.05 | 0.617 ± 0.05 | 0.617 ± 0.05 | 0.616 ± 0.05 | 0.38  | 1.00  | 0.81  |
|      | D$_{2\%}$ (Gy)  | 72.84 ± 0.16 | 72.82 ± 0.15 | 72.77 ± 0.13 | 72.77 ± 0.15 | 0.01  | 0.01  | 0.79  |
|      | PTV2            | 97.59 ± 0.07 | 98.03 ± 0.10 | 98.40 ± 0.05 | 98.45 ± 0.09 | 0.01  | 0.01  | 0.49  |
|      | PTW1            | 55.68 ± 0.55 | 56.19 ± 0.90 | 56.54 ± 0.91 | 56.65 ± 1.04 | 0.01  | 0.01  | 0.25  |

p1, p-value of comparison between CP10 and CP20; p2, p-value of comparison between CP15 and CP20; p3, p-value of comparison between CP25 and CP20; PTV, Planning Target Volume; CP, Control Points; TC, Target Coverage; CI, Conformity Index; HI, Heterogeneity Index.
Figure 2. Heterogeneity index box plot of PTVnx and PTVnd target regions of dynamic IMRT plans with different numbers of control points in 20 patients with nasopharyngeal carcinoma.

each field of the dMLC plan is equal to the number of control points per field – 1, which means that the theoretical maximum numbers of segments in the CP10, CP15, CP20, and CP25 groups are 81, 126, 171, and 216, respectively. (Figure 3) shows the difference between the number of actual segments in the plan and the limit in the number of segments. For the CP20 and CP25 groups, the number of segments in some plans was redundant. The MU and IF values of the CP25 groups did not differ significantly from those of the CP20 group (p > 0.05). (Figure 4) shows a graph of the MUs/segment and a box plot of PDT for the dynamic IMRT plans with different numbers of control points in 20 patients. It is clear that the delivery efficiency gradually decreased, and the number of MUs per segment is significantly reduced; the number of segments with small MU segments is increased, which may also be an important reason for the decreased delivery efficiency.

### 3.5. Plan validation

(Table 4) shows the GPR validated and calculated using the 3%/3 mm, 3%/2 mm, and 2%/2 mm metrics for different numbers of control points. Using the different metrics mentioned above, the validation results of the CP10 group were found to be better than those of the other three groups, but no significant difference was observed in the validation results between the CP20 and CP25 groups (p > 0.05). The dose validation results of the four IMRT plan groups using the 3%/3 mm and 3%/2 mm metrics met the clinical requirements (GPR > 94%). The GPR using the three commonly used metrics showed a negative correlation with the IF (with coefficient values of determination R² of 0.39, 0.39, and 0.41, respectively, Figure 5).

### 4. Discussion

In theory, the higher the number of control points, the higher the number of degrees of freedom in IMRT plan optimization and the better the quality of the plan obtained from optimization. In the Monaco system, the number of control points for each field in dynamic IMRT plans must be manually set and range from 2 to 1,024 per field. In the present study, four groups of plans were created by changing the number of control points per field, that is, setting the maximum number of control points per field to 10, 15, 20, and 25, while keeping all other constraint functions unchanged. This process was used to optimize the four groups of

| OAR | Parameter | CP10 | CP15 | CP20 | CP25 | p1 | p2 | p3 |
|-----|-----------|------|------|------|------|----|----|----|
| Temporal Lobe | D_{max} (Gy) | 72.69 ±13.12 | 72.44 ±23.46 | 72.58 ±33.27 | 72.19 ±33.19 | 0.60 | 0.41 | 0.01 |
| TM joint | D_{max} (Gy) | 65.28 ±8.57 | 65.19 ±5.31 | 65.74 ±5.40 | 65.74 ±5.35 | 0.15 | 0.05 | 0.97 |
| Mandible | D_{max} (Gy) | 67.44 ±6.16 | 68.04 ±8.14 | 68.12 ±4.27 | 68.57 ±3.98 | 0.03 | 0.41 | 0.37 |
| Spinal cord | D_{max} (Gy) | 43.27 ±1.39 | 43.18 ±1.33 | 43.32 ±1.47 | 43.33 ±1.5 | 0.49 | 0.06 | 0.98 |
| Optic Nerve | D_{max} (Gy) | 44.36 ±13.62 | 45.58 ±12.69 | 44.96 ±13.26 | 45.73 ±12.75 | 0.25 | 0.43 | 0.46 |
| Optic Chiasm | D_{max} (Gy) | 40.12 ±16.54 | 41.64 ±16.54 | 40.81 ±16.7 | 41.56 ±16.48 | 0.19 | 0.15 | 0.21 |
| Brainstem | D_{max} (Gy) | 53.51 ±12.34 | 53.67 ±10.47 | 53.69 ±0.75 | 53.80 ±0.85 | 0.31 | 0.88 | 0.20 |
| Parotid | V30 (%) | 49.16 ±0.06 | 49.08 ±0.06 | 49.14 ±0.06 | 49.23 ±0.06 | 0.95 | 0.88 | 0.79 |
| PTV | D_{max} (Gy) | 56.74 ±7.39 | 57.61 ±7.89 | 56.75 ±7.82 | 56.91 ±7.51 | 0.88 | 0.01 | 0.74 |
| Lens | D_{max} (Gy) | 7.71 ±2.26 | 7.87 ±2.09 | 7.86 ±2.15 | 7.92 ±2.13 | 0.23 | 0.79 | 0.33 |
| Eyes | D_{min} (Gy) | 7.62 ±2.20 | 7.81 ±2.74 | 7.83 ±2.21 | 7.94 ±2.15 | 0.01 | 0.69 | 0.09 |

Table 3. Planning parameter statistics of IMRT plans with different numbers of control points (n = 20, x ± s).

| Parameter | CP10 | CP15 | CP20 | CP25 | p1 | p2 | p3 |
|-----------|------|------|------|------|----|----|----|
| MU | 697.37 ±58.50 | 738.60 ±54.88 | 763.17 ±57.52 | 768.43 ±40.56 | 0.01 | 0.01 | 0.97 |
| IF | 2.96 ±0.19 | 3.14 ±0.20 | 3.27 ±0.24 | 3.28 ±0.21 | 0.01 | 0.01 | 0.11 |
| PDT(s) | 306.25 ±18.85 | 331.53 ±18.44 | 354.70 ±22.11 | 375.75 ±18.02 | 0.01 | 0.01 | 0.01 |
| Segments | 80.95 ±0.22 | 125.70 ±0.66 | 170.40 ±0.88 | 214.05 ±2.48 | 0.01 | 0.01 | 0.01 |
| MUs/Segment | 8.61 ±0.47 | 8.88 ±0.36 | 4.51 ±0.23 | 3.59 ±0.19 | 0.01 | 0.01 | 0.01 |

Table 2. Comparison of OAR dosimetry of dynamic IMRT plans with different numbers of control points (n = 20, x ± s).

p1, p-value of comparison between CP10 and CP20; p2, p-value of comparison between CP15 and CP20; p3, p-value of comparison between CP25 and CP20; D_{max}, maximum dose; D_{mean}, mean dose; V_x, percentage volume of region of interest receiving at least X Gy.
the plan; employed finding maximum and respectively. (planning Figure Table dynamic Figure ), Table - Figure (A), Figure ).

276 carcinoma p 2% 3% 3% 3, 0.01 94.68 1, 0.01 94.62 2, 0.01 98.20 0.01 95.10 82.72 2 82.79 98.20 p-value CP20 CP15 CP25 CP10

Criteria p-value CP20 CP15 CP25 CP10 CP15 CP20 CP25 CP10 CP15 CP20 CP25 CP10 CP15 CP20 CP25
3% & 3 mm 98.20 ±1.03 97.74 ±1.19 97.47 ±1.30 97.45 ±1.19 0.01 0.08 0.87
3% & 2 mm 95.80 ±1.90 95.10 ±1.94 94.62 ±2.26 94.68 ±2.01 0.01 0.04 0.75
2% & 2 mm 87.48 ±5.60 83.95 ±4.62 82.72 ±4.98 82.79 ±4.55 0.01 0.01 0.83

\( p_1 \), p-value of the comparison between CP10 and CP20; \( p_2 \), p-value of the comparison between CP15 and CP20; \( p_3 \), p-value of the comparison between CP25 and CP20; GPR, gamma passing rate.

dynamic IMRT plans in order to analyze and evaluate the effect of the number of control points on IMRT planning for NPC. As presented in (Table 3) and (Figure 3), the actual numbers of segments of the four groups of plans were 81, 126, 170, and 214, respectively. The numbers of segments in the CP10 and CP15 plan groups were the values set in the plan; by contrast, the actual number of segments in the CP20 and CP25 plan groups was less than the maximum value set, and the degrees of freedom in the number of segments were not fully utilized. This finding shows that the value set is a relatively important constrained optimization parameter.

Quantitative plan quality evaluation indices can be employed to evaluate the quality of different plans in a relatively objective manner, especially in multi-center clinical radiotherapy plan quality studies (Bohsung, Gillis, Arrans et al., ; Santos et al., 2020). A quantitative PQI was calculated to evaluate the multiple groups of plans. As the exact optimal plan result was not known, the most satisfactory IMRT plan result was used as an approximate target. As can be seen from (Figure 1), the CP20 and CP25 groups had significantly lower PQI than the CP10 and CP15 groups, indicating that the setting of optimization parameters is associated with plan quality. The CP20 group had the highest overall quality and the smallest PQI (20.2%). This finding shows that increasing the number of control points beyond a certain point does not significantly improve the plan quality.

According to the data in (Table 3), the average numbers of segments in the CP15, CP20, and CP25 groups
increased by 55.3%, 110.5%, and 164.4%, respectively, compared with those in the CP10 group; the PQI of the corresponding PTV parameters gradually decreased (PQI of CP10 group = 50.2%; PQI of CP25 group = 2.8%), indicating a gradual increase in the coverage of the planned target region. Conversely, the PQI of the OAR parameters gradually increased (PQI of CP10 group = 1.2%; PQI of CP25 group = 17.9%), suggesting the gradual worsening of the protective effect. However, based on the data presented in (Tables 1 and 2), the absolute difference in the dose parameters between the target region and the OARs was relatively small; hence, the requirements of the clinical treatment plan were still met.

The results of this study showed that the planned MU and IF values increased as the number of control points increased, but the difference in MUs among the CP15, CP20, and CP25 groups was less than 15, and the difference in IF was less than 0.13 (Table 3). The MUs/segment decreased significantly as the number of control points increased. When the number of control points per field was increased from 10 to 25, the number of MUs/segment decreased from 8.64 to 3.58, and the delivery time increased significantly (Figure 4). The CP25 group had the longest PDT, which was 70 s, 45 s, and 22 s longer than those of the CP10, CP15, and CP20 groups, respectively. In the present study, the PDT of the CP10, CP15, and CP20 groups exhibited a strong positive correlation with the MUs/segment, with R² values of 0.61, 0.64, and 0.68, respectively (Figure 6), whereas the CP25 group exhibited a weak correlation (0.33). The CP25 group had the lowest plan delivery efficiency, which may be because the small number of MUs increased the complexity of plan delivery. In VMAT planning, an increase in the number of segments with a small area and a small number of MUs has been reported to increase the complexity of plan delivery; this may lead to inaccurate delivery of the planned VMAT dose and may even cause the plan delivery to be

![Figure 5](image-url). Correlation between GPR and the IMRT factor (IF). (A) 3%/3 mm GPR; (B) 3%/2 mm GPR; (C) 2%/2 mm GPR.

![Figure 6](image-url). Correlation of PDT and MU/segment in dynamic IMRT plans for NPC with different numbers of control points.
interrupted (Huang et al., 2016; Sutton et al., 2012). Our results show that reducing the number of segments and the number of MUs can shorten the time of radiotherapy without significantly reducing the plan quality; this may reduce uncertainty due to patient movement during radiotherapy and increase the biological efficacy of the treatment (Peguret et al., 2013; Zhang et al., 2017).

Increasing the number of control points not only reduces the plan delivery efficiency but also reduces the plan delivery dose accuracy (Table 4). When the number of control points in each field was increased from 10 to 25, the GPR using different metrics was reduced from 98.20% to 97.45% (3%/3 mm), from 95.80% to 94.68 (3%/2 mm), and from 87.48% to 82.79% (2%/2 mm), with decreases of 0.75%, 1.12%, and 4.69%, respectively. This may be because increasing the number of control points increases the plan complexity, which indicates an increased uncertainty in plan delivery. When different γ metrics were used, GPR showed a negative correlation with the IF (Figure 5). In the present study, the dose validation results of all the four groups of dynamic IMRT plans using the 3%/3 mm metric met the clinical requirements (GPR > 95%). Using the more stringent 2%/2 mm metric, the average GPR was less than 90%, indicating that this metric can be used to detect plan delivery errors more effectively.

5. Conclusion

In summary, the number of control points affects the quality, delivery accuracy, and efficiency of dynamic IMRT plans. Increasing the number of control points can improve plan quality while also increasing plan complexity. However, continued addition of CPs not only fails to improve the plan quality but also significantly reduces the efficiency and accuracy of plan delivery. Taken together, 20 control points per field are recommended for the Monaco TPS and are highly appropriate for NPC 9 F dynamic IMRT planning.

Disclosure statement

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