Dosimetric effects related to collimator angle optimization in intensity-modulated radiotherapy planning for gastric cancer

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Abstract

Objective: To investigate the dosimetric impact of different collimator angle optimization methods in intensity-modulated radiotherapy of gastric cancer.

Methods: A total of 10 gastric cases were retrospectively selected in this study. Three sets of plans were generated with different collimator angle optimization: setting the collimator angle to 0° (CL0), applying Eclipse automatic collimator angle optimization (CLA), and setting the collimator angle corresponding to the minimum X-jaw gap (CLX). Different dosimetric metrics were applied in comparison of the target volume and normal tissues. Delivery efficiency was accessed in terms of control points, split fields, monitor units, and treatment time. All plans were verified using the 2-D array MatriXX, and the γ-index analysis was carried out by using different criteria.

Results: There was no significant difference in dosimetric comparison of planning target volume and organs at risk. Compared with CL0, both CLA and CLX can significantly reduce control points, split fields, and monitor units, except that CLA increased treatment time. For dose verification, the γ passing rate showed a tendency of CLX > CLA > CL0.

Conclusion: For intensity-modulated radiotherapy for gastric cancer, CLA and CLX can obtain comparable dosimetry distribution in respect to CL0. However, CLX can significantly increase the dose delivery efficiency and verification passing rates. It was suggested that CLX was beneficial in intensity-modulated radiotherapy for gastric cancer.

KEYWORDS

collimator angle optimization, gastric cancer, intensity-modulated radiotherapy

1 INTRODUCTION

Gastric cancer is one of the most common malignant tumors worldwide, with one study reporting that there were up to 1,033,701 gastric cancer diagnoses in 2018 alone.1 Furthermore, the mortality rate of gastric cancer has been reported to be as high as 75%.2 The incidence of gastric cancer remains high in East Asia, intermediate in Latin America, and low in developed countries.3 Gastric cancer is responsible for one of the highest cancer burdens, and it is believed that the reduced incidence of gastric cancer is largely due to improvements in sanitation and food preservation, as well as a decline in Helicobacter pylori infections.3 Furthermore, a reduction in tobacco smoking remains an important modifiable risk factor in gastric cancer. The treatment of gastric cancer usually includes surgery,4 chemotherapy,5 and...
Advantages of collimator rotation. (a) Increasing irradiation range. (b) Reducing dose leakage out of the field. (c) Improving the conformity between the target and the multi-leaf collimators.

Radiotherapy, whereas intensity-modulated radiotherapy (IMRT) has also become an important therapeutic means in gastric cancer. The goal of treatment planning is to create a conformal radiation dose distribution throughout the patient's body by optimizing, among others, the number of fields, beam orientation, beam energy, couch rotation, and collimator rotation. Among the aforementioned degrees of freedom, collimator rotation has been shown to have an important impact on the quality of the IMRT planning.

Collimator angle rotation optimization has several theoretical advantages. First, increasing the range of exposure. The range of exposure would be 56 cm after rotating the collimator 45°, as shown in Figure 1a. Second, minimizing the conformal distance. When the Eclipse 13.5 treatment planning system was used to design the plan, split fields (SF) occurred automatically once the distance between the X-jaws exceeded 14 cm. In fact, high doses may occur at the junction of the SF as a result of system errors, as shown in Figure 1b. Third, improving the conformity. Rotating the collimator allowed critical structures to be better isolated from tumor irradiation, as shown in Figure 1c. Fourth, reducing the leakage between multi-leaf collimators (MLC). The tongue and groove effect between the MLC leads to a certain amount of ray leakage, as confirmed previously; although other studies reported that rotating the collimator would contribute to a reduction in the influence of leakage on the overall dose distribution. Finally, improving the spatial resolution of fluence. The spatial resolution was limited by the leaf width; however, the spatial resolution was approximated by a circle with a diameter equal to the minimum leaf displacement when the collimator was rotated.

Although some scholars have studied the influence of collimator angle optimization (CAO) in IMRT planning, CAO has not yet been systematically exploited. Furthermore, we found few studies about CAO in gastric cancer IMRT planning, and even fewer using the automatic CAO technology of the Eclipse Planning System (Varian Medical Systems, Palo Alto, CA, USA). Moreover, no previous study has provided an analytical standard-based CAO technique for IMRT planning. In the present study, the innovative technique of collimator angle corresponding to the minimum X-jaw gap (CLx), when the distance of the X-jaw was shortest around the planning target volume (PTV), was obtained by processing the pictures of beam's eye view of the PTV with MATLAB programming (MathWorks; Natick, MA, USA). In this study, the dosimetric differences between the other two CAO techniques and the conventional 0° (CL0) in PTV and organs at risk (OARs) of gastric cancer were systematically studied for clinical reference.

2 METHODS

2.1 Computed tomography simulation

A total of 10 patients with gastric cancer without distant metastasis were included in this comparative planning study, and all of the selected target areas were single target areas. All patients underwent computed tomography (CT) scanning with a 3-mm slice thickness (German Siemens Somatom sensation CT; Siemens, Erlangen, Germany). For CT scanning, the patients were placed in the supine position, and immobilized with their arms raised above the neck by a vacuum cushion. The images were transferred to the Eclipse 13.5 treatment planning system (Varian Medical Systems, Palo Alto, USA) through DICOM.

This study was approved by the institutional review board at the Zhongnan Hospital of Wuhan University. All methods were carried out in accordance with the relevant guidelines and regulations.
TABLE 1  Dose constraints used in planning

| Structure     | Parameters | Requirement |
|---------------|------------|-------------|
| PTV           | $V_{100\%}$ | >95%        |
| CTV           | $V_{100\%}$ | =100%       |
| Liver         | $V_{20\text{Gy}}$ | <60%        |
| Kidney        | $V_{22.5\text{Gy}}$ | <33%        |
| Small intestine | $V_{22.5\text{Gy}}$ | <50%        |
| Spinal cord   | $D_{\text{mean}}$ | <40 Gy      |
| Liver         | $D_{\text{mean}}$ | <15 Gy      |
| Kidney        | $D_{\text{mean}}$ | <15 Gy      |
| Small intestine | $D_{\text{mean}}$ | <18 Gy      |
| Spinal cord   | $D_{\text{mean}}$ | <22 Gy      |

CTV, clinical target volume; $D_{\text{max}}$, maximum dose; $D_{\text{mean}}$, minimum dose; PTV, planning target volume; $V_{\text{ref}}$, relative volume of the target or organ of interest received at least x% of the prescribed dose; $V_{\text{xy}}$, relative volume of organ of interest covered by the x Gy isodose line.

2.2  |  Delineation of the target volumes and OARs

All of the target volumes and OARs were contoured on individual axial CT slices in all patients by the same radiation oncologist. The clinical target volume was planned to encompass the remaining stomach, tumor bed, and draining lymph node stations (perigastric, pancreaticoduodenal, porta hepatitis, celiac, and suprapancreatic). The PTV was defined by adding an isotropic margin of 5 mm from the clinical target volume in the 3-D directions. The range of the PTV volume was 496–931 cm$^3$, the mean target volume was 653 ± 148 cm$^3$, and the OARs included the liver, kidneys, small intestine, and spinal cord.

2.3  |  IMRT planning

The treatment planning system of the Eclipse was used for the planning design. All of the IMRT plans were delivered using a Varian Clinac IX accelerator (Varian Medical Systems). The accelerator was equipped with 120 multi-leaves; 80 leaves comprising 20 cm of the isocenter (5-mm width), and the other 40 leaves were 1 cm on both sides. The maximum speed and transmission of a leaf was 2.5 cm/min and 2.5%, respectively. The IMRT plans (dynamic IMRT) were generated with five coplanar radiation fields, the beam angles of which were 330°, 10°, 45°, 90°, and 180°. A 6 MV photon beam was used, and for all collimator angle optimization (CAO) techniques, a 2.5-mm grid size and analytical anisotropic algorithm were applied to the planning calculation. Heterogeneity corrections were turned on during all dose calculations. The dose constraints used in planning were according to the research of relevant scholars and the experience of staff at Zhongnan Hospital in Wuhan, as detailed in Table 1.7,21–23 The prescribed dose to the PTV was 45 Gy in 25 fractions; the dose rate was 400 MU/min. The aim of the target was to deliver at least 95% and 100% of the prescribed dose to the PTV and clinical target volume, respectively. Care was taken to maintain a difference between the maximum and prescribed doses of <10%. The accepted dose constraints for OAR were as follows: 60% of the liver was to receive <30 Gy, the mean dose ($D_{\text{mean}}$) for the liver was <18 Gy; 33% of each kidney was to receive <22.5 Gy, the $D_{\text{mean}}$ for each kidney was <15 Gy; 50% of the small intestine was to receive <25 Gy; and the maximum spinal cord dose was <40 Gy. IMRT planning for all patients was initially produced with collimator angle zero (CL0), and then later reoptimized at different collimator angles using the same dose constraints and normalization parameters as the original plan to avoid human interference.

2.4  |  CAO

Three plans were generated for each patient with different CAO techniques as follows: CL0, the collimator angle of each field was set to 0°; CLx, each field was set to optimize the collimator angle using the Eclipse algorithm; and CLx: the orientations of the collimator angles were obtained automatically by processing the pictures of the beam’s eye view of the PTV with MATLAB programming. The CLx process is shown in Figure 2, the yellow line represents the simulated X and Y-Jaws, in which the X-Jaws distance corresponding to the rotation angle changes with the rotation of the collimator. Therefore, the collimator angle is established when the distance of the X-Jaws was the shortest around the PTV. The PTV conformability of the three collimator angles is shown in Figure 3. To make it convenient for clinical physicists or dosimetrists to call the program to acquire the corresponding angle of CLx, we used a graphical user interface to visualize the program, importing the image using the “Import images” button, and then clicking “Compute best angels” to calculate the optimal angle of CLx (the original procedure is shown in the Appendix). It should be noted that it was not necessary to make the Jaws tangent to the PTV in the actual planning, and the work was only to determine the optimal angle of CLx.

2.5  |  Plan evaluation

All plans were analyzed using a dose–volume histogram. The PTV was evaluated in terms of minimum, maximum, and mean dose. The conformity index (CI) and homogeneity index (HI) were calculated to analyze the PTV dose coverage and uniformity, respectively. Specific evaluation metrics for different organs were used, including the $D_{\text{mean}}$ and volume receiving ≥5 Gy (or 30 Gy) of the prescribed dose ($V_{5\text{Gy}}$, $V_{30\text{Gy}}$) for the liver; $V_{12}$, $V_{22.5}$, and mean dose for the kidneys; $D_{50\%}$ and maximum dose ($D_{\text{max}}$) dose for the small intestine; and the $D_{\text{max}}$ for the spinal cord. The CI was defined according to Paddick as follows: $CI = (TV_{\text{ref}} / TV) \times (TV_{\text{ref}} / V_{\text{ref}})$, where $TV_{\text{ref}}$ is the target volume (cm$^3$) covered by the reference isodose, $TV$ is the target volume (cm$^3$), and $V_{\text{ref}}$ is the volume (cm$^3$) covered by the reference isodose. The CI ranged from 0 to 1, with values closer to 1 indicated higher dose conformity to the target. The HI was recommended by the ICRU 83 report: $(D_{2\%} - D_{98\%}) / D_{50\%}$, where $D_{2\%}$ indicated the maximum dose received by 2% of the PTV, $D_{98\%}$ indicated the minimum dose received by 98%
FIGURE 2  Schematic diagram of the optimal collimator angle corresponding to the minimum X-jaw gap angle selection process. The normalized X-jaw gap is plotted as a function of the collimator angle. The global minimum of the graph is picked out automatically and selected as the angle to be used for the collimator angle corresponding to the minimum X-jaw gap.

FIGURE 3  A depiction of the three optimizations for a single field. (a) The collimator angle was set to 0° by default (CL0). (b) Collimator selected by Eclipse automatic optimization (CLA). (c) Collimator angle with the shortest X-jaw gap (CLX). The multi-leaf collimator leaves are outlined on the inside of the box, with the solid yellow lines representing the jaw positions. The multi-leaf collimator leaves move in the direction from X1 to X2.

of the PTV, and D50% indicated the dose received by 50% of the PTV. A lower HI value equated to a more homogeneous dose distribution; for example, HI = 0 indicates that the target has perfect uniformity. For each plan, we also studied the number of treatment monitor units (MU) under different CAOs, as well as the control points (CP), treatment time (Time), volume receiving 50% of the prescribed dose (V50%), and SF. The treatment time included the time of irradiation and the time of rotation between the head and the collimator. To verify the delivery efficiency, planned fluence was delivered to the IBA I’mRT MatriXX ionization chamber array detector. The measured fluence was compared with the planned dose using OmniPro-I’mRT software (IBA Dosimetry; Scanditronix Wellhofer, Germany) using the 2-D Gamma index (γ), as proposed by Low et al.24 The plan was only accepted if >95% pixels had the value of γ ≤1, and was rejected when γ >1. Repeated measurements of the Varian Clinac IX linear accelerator showed that the average gantry speed was approximately 5.9°/s, whereas the collimator speed was approximately 3.5°/s.

2.6  Statistical analysis

All statistical analyses were performed using SPSS Statistics 22.0 software (IBM, Armonk, NY, USA). One-way ANOVA was used for multiple comparisons of target and critical organs in different CAO. P-values <0.05 were regarded as statistically significant.

3  RESULTS

3.1  PTV

All IMRT plans met the dose constraint requirement for gastric cancer radiotherapy. For CI, CL0 was larger, whereas CL0 was not significantly different from CLA and CLX. For HI, CLX had the best homogeneity, CL0 was the smallest, CLX was 3.2% larger than CL0 (P > 0.05), and there was no significant difference in target homogeneity between
| Par               | Collimator angle optimization (mean ± SD) | P-value |   |   |   |
|------------------|------------------------------------------|---------|---|---|---|
| CL0              | CLA                                      | CLX     | $P_1$ | $P_2$ | $P_3$ |
| PTV               |                                           |         |     |     |     |
| CI               | 0.85 ± 0.02                              | 0.84 ± 0.02 | 0.84 ± 0.02 | 0.22 | 0.31 | 0.84 |
| HI               | 0.06 ± 0.02                              | 0.06 ± 0.02 | 0.06 ± 0.02 | 0.97 | 0.83 | 0.87 |
| $D_{\text{min}}$ (Gy) | 39.10 ± 2.85                            | 38.37 ± 2.69 | 38.96 ± 2.72 | 0.57 | 0.91 | 0.64 |
| $D_{\text{max}}$ (Gy) | 48.86 ± 1.30                            | 49.00 ± 1.27 | 49.16 ± 1.38 | 0.81 | 0.60 | 0.79 |
| $D_{\text{mean}}$ (Gy) | 46.32 ± 0.35                            | 46.50 ± 0.31 | 46.64 ± 0.34 | 0.24 | 0.04 | 0.36 |
| Liver            |                                           |         |     |     |     |
| $V_5$            | 89.25 ± 5.83                             | 89.59 ± 5.39 | 88.97 ± 5.52 | 0.89 | 0.91 | 0.81 |
| $V_{30}$         | 25.33 ± 5.24                             | 25.06 ± 4.95 | 24.94 ± 4.92 | 0.90 | 0.86 | 0.96 |
| $D_{\text{mean}}$ (Gy) | 18.78 ± 2.27                            | 18.84 ± 2.14 | 18.75 ± 2.17 | 0.95 | 0.98 | 0.93 |
| Left kidney      |                                           |         |     |     |     |
| $V_{12}$         | 31.68 ± 13.38                            | 32.21 ± 12.98 | 31.67 ± 13.00 | 0.93 | 0.99 | 0.93 |
| $V_{22.5}$       | 18.45 ± 10.46                            | 19.12 ± 10.14 | 18.41 ± 10.46 | 0.89 | 0.99 | 0.88 |
| $D_{\text{mean}}$ (Gy) | 11.57 ± 3.32                            | 11.68 ± 3.32 | 11.61 ± 3.19 | 0.94 | 0.98 | 0.96 |
| Right kidney     |                                           |         |     |     |     |
| $V_{12}$         | 39.04 ± 19.31                            | 39.34 ± 19.70 | 38.47 ± 18.49 | 0.97 | 0.95 | 0.92 |
| $V_{22.5}$       | 17.59 ± 8.30                             | 17.83 ± 8.38 | 17.86 ± 8.10 | 0.95 | 0.94 | 0.99 |
| $D_{\text{mean}}$ (Gy) | 11.80 ± 4.10                            | 11.93 ± 4.14 | 11.90 ± 4.00 | 0.95 | 0.96 | 0.99 |
| Small intestine  |                                           |         |     |     |     |
| $D_{50\%}$ (Gy)  | 14.44 ± 10.06                            | 14.54 ± 10.06 | 14.58 ± 10.03 | 0.98 | 0.98 | 0.99 |
| $D_{\text{max}}$ (Gy) | 48.26 ± 1.18                            | 48.50 ± 1.15 | 48.74 ± 1.38 | 0.65 | 0.38 | 0.66 |
| Spinal cord      |                                           |         |     |     |     |
| $D_{\text{max}}$ (Gy) | 34.91 ± 2.02                             | 34.92 ± 2.03 | 35.12 ± 1.93 | 0.99 | 0.81 | 0.83 |
| Body             |                                           |         |     |     |     |
| $V_{50\%}$ (cc)  | 2588 ± 465                               | 2593 ± 456 | 2577 ± 452 | 0.98 | 0.96 | 0.94 |

$P_1$ is the P-value for the collimator angle set to $0^\circ$ (CLA) versus collimator selected by Eclipse automatic optimization (CL); $P_2$ is for CL0 versus collimator angle corresponding to the minimum X-jaw gap (CLX); and $P_3$ is for CLA versus CLX.

CTV, clinical target volume; $D_{\text{max}}$, maximum dose; $D_{\text{mean}}$, minimum dose; PTV, planning target volume; $V_x\%$, relative volume of the target or organ of interest received at least $x$% of the prescribed dose; $V_xGy$, relative volume of organ of interest covered by the $x$ Gy isodose line.

3.2 | OAR

For IMRT plans of gastric cancer, we focused on OARs, such as the liver, left and right kidneys, small intestine, and spinal cord. Under different CAOs, there were no significant differences in the dosimetric parameters of OAR ($P > 0.05$). However, CLx optimization has the ability to reduce the dose to the liver, and left and right kidneys, albeit with a slight increase in the maximum dose to the small intestine and spinal cord. CLA optimization would increase the dose to OAR. For $V_5$ of the liver, CLx decreased by 0.32%, whereas CLA increased by 0.38%. For $V_{30}$ of the liver, CLA and CLx were reduced by 1.09% and 1.54%, respectively. For $V_{12}$ and $V_{22.5}$ of the left kidney, CLA increased by 1.68% and 3.66%, respectively. For $V_{12}$ of the right kidney, CLx decreased by 1.46%, whereas CLA increased by 0.76%. For the maximum dose to the small intestine, CLA and CLx increased by 0.50% and 0.99%, respectively. For the maximum dose to the spinal cord, CLx increased by 0.6%. The results are summarized in Table 2.

3.3 | MU, CP, Time, and SF

Under different CAOs, there were significant differences in parameters, such as treatment MU, the number of CPs, and the number of
TABLE 3 Comparison of the control points, split fields, monitor units, and dose delivery times for the three optimizations

| Parameters | Collimator angle optimization (mean ± SD) | P-value |
|------------|------------------------------------------|---------|
|            | CL₀                                      | CLₐ     | CLₓ     | P₁     | P₂     | P₃     |
| CP         | 838.4 ± 103.9                            | 773.4 ± 91 | 618.5 ± 37.8 | 0.60   | <0.01  | 0.01   |
| SF         | 4.1 ± 1.3                                | 3.9 ± 1.6 | 2.8 ± 2.1 | 0.99   | 0.01   | 0.01   |
| MU         | 820 ± 176.0                              | 743 ± 106.0 | 615 ± 106.0 | 0.18   | 0.01   | 0.03   |
| Time (s)   | 158.6 ± 26.5                             | 166.6 ± 26.5 | 142.7 ± 14.7 | 0.41   | 0.11   | 0.02   |

P₁ is the P-value for the collimator angle set to 0° (CL₀) versus collimator selected by Eclipse automatic optimization (CLₐ); P₂ is for CL₀ versus collimator angle corresponding to the minimum X-jaw gap (CLₓ); and P₃ is for CLₐ versus CLₓ.

CP, control point; MU, monitor unit; SF, split field; Time, dose delivery time.

SFs; the results are summarized in Table 3, and the error bar chart is shown in Figure 4. For the MU, CLₐ and CLₓ were reduced by 9.34% and 25.02%, respectively (P < 0.05), compared with CL₀. For the CP, CLₐ and CLₓ were reduced by 7.75% and 26.23%, respectively (P < 0.05), compared with CL₀. For the SF, CLₐ and CLₓ were reduced by 0.2 and 1.3 SFs, respectively, compared with CL₀. For the treatment time (Time), CLₓ decreased by 10.03%, whereas CLₐ increased by 5.04%.

3.4 | γ Passing rates

The γ passing rates of all plans were > 95%. For the same γ criteria, CLₓ > CLₐ > CL₀, CLₓ and CLₐ were 3.1% and 2.22% larger than CL₀ for 2 mm/2%, respectively; for 2 mm/3%, CLₓ and CLₐ were 1.63% and 1.3% larger than CL₀, respectively; CLₓ and CLₐ were 1.05% and 0.89% larger than CL₀ for 3 mm/2%, respectively; and for 3 mm/3%, CLₓ and CLₐ were 0.38% and 0.34% larger than CL₀, respectively. The results are summarized in Table 4, and the error bar chart is shown in Figure 5.

4 | DISCUSSION

In the current study, we systematically analyzed the dosimetric effects of different CAOs on gastric cancer. It was evident that non-0° CAO could obtain comparable dosimetric distribution to the conventional 0° CAO, as well as reduce the number of treatment MUs, CPs, SFs, and Time. Fewer treatment MUs will contribute to a reduction in radiation leakage, treatment time, and intrafractional movement, as well as an improvement in the accuracy of the radiation dose and treatment efficiency. Fewer MUs also lead to less total body scatter and less...
MLC transmission. Other investigators have argued that higher MUs result in an increased probability of long-term complications, including secondary malignancies.25–29 Furthermore, a reduced number of CPs made it easier to complete IMRT planning, as did CLx optimization. Badusha et al. showed that the use of a feasible collimator angle could reduce the number of treatment MUs, which is consistent with the present findings.17,19,20 Wang et al. found that the number of MUs was largely reduced without compromising plan quality when collimator angles were determined with a new algorithm.30 Furthermore, Millette suggested that comparable dose distributions and better delivery efficiency were possible with the rotating aperture optimization technique.31 Additionally, the innovation of the current study was that it proposed to adopt MATLAB to write code, combined with analytical methods to obtain the best collimator angle (CLx) in gastric cancer for the first time.

The dosimetric parameters of OAR were compared for different CAO techniques, whereas the automated angle optimization tool (CLA), which has been rarely studied in the Eclipse planning system, was also discussed. The results showed that CLx had the lowest number of treatment MUs, because when the distance of the X-jaw was shortest around the PTV, the conformal distance of the MLC would also be shortest, therefore reducing the difficulty of planning. For a large target area over 14 cm, SFs will occur if the conventional 0° collimator angle is used to optimize the planning. SFs might result in hot or cold spots at the junction due to the uncertainty of the daily position; in this regard, CLx optimization is a good choice, because it can minimize the conformal distance.7 In the current study, to verify the delivery efficiency, the measured fluence on the IBA ImRT MatrixXX ionization chamber array detector was compared with the treatment planning system dose plan with 2-D \( \gamma \) evaluation. The 2-D \( \gamma \) index evaluation of planned and delivered fluence showed that the \( \gamma \) passing rates of each planning was >95%, and CLx > CLA > CL0 in the same \( \gamma \) index; thus, these results showed that the delivery efficiency of CLx was better.

We determined the collimator angle based on 2-D beam’s eye view images; in further studies, it might be useful to obtain the collimator angle in 3-D directions according to the shape of the target, because it might be better to irradiate the target area and protect the OAR. Conventionally, volumetric modulated arc therapy (VMAT) plans generally only use one fixed collimator angle; however, the quality of VMAT plans are also related to the collimator angles.32–42 More recently, dynamic collimator optimization has been proven to have a positive influence on dosimetric distribution in VMAT.43–47 Similarly, acquiring multiple collimator angles during gantry rotation using the CLx technique in VMAT plans also warrants further investigation.

CLx optimization might not be suitable for all cancers, and might be more suitable for cancers with relatively regular single target shapes, such as rectal cancer and conventional lung cancer.

In summary, CAO could play an important role in improving the quality of treatment plans. The CAO techniques of CLA and CLx could achieve comparable dose distribution to conventional CAO (CL0) in IMRT for gastric cancer, and could reduce the number of treatment MUs, CPs, and SFs, as well as the likelihood of second cancer, leakage. Furthermore, the CAO techniques of CLA and CLx could also reduce the tongue and groove effect, and improve the conformity of the target volume dose and the spatial resolution. Different CAO techniques increase the possibilities for the choice of radiotherapy planning, and it has been suggested that CLx optimization should be used in gastric cancer IMRT planning to obtain higher-quality IMRT planning. Thus, CAO increases the freedom to create a conformal radiation dose distribution in the patient. The results of the present study set the groundwork for guiding the CAO with regard to PTV dose distribution and sparing of OARs in gastric IMRT planning.

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### CONFLICT OF INTEREST

The authors declare that they have read the article and there are no competing interests.

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