Development of an Aperture Shape Displacement Score In Online Adaptive Radiation Therapy for Pancreatic Cancer

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ABSTRACT

Purpose: In online adaptive radiation therapy (oART), a new treatment plan is generated using three-dimensional images acquired before irradiation. However, no metric exists for evaluating the extent of day-to-day plan changes. This study aimed to develop a novel aperture shape displacement score (ASDS) to quantify aperture shape deviations in oART plans for pancreatic cancer and to evaluate its relationship with plan complexity and isocenter displacement relative to the CT simulation-based plan (CTS plan).

Methods: A total of 135 oART plans from 15 patients with pancreatic cancer treated with IMRT using the ETHOS therapy system (Varian) from December 2022 to March 2024 were analyzed. The ASDS was quantified by calculating (1) the difference in corresponding leaf positions, (2) the difference in paired leaf widths, and (3) the Dice similarity coefficient of the corresponding aperture shape between the CTS and oART plans for each control point. The ASDS was defined on a scale of 0 to 1. Correlations between the ASDS and the modulation complexity score (MCS) and isocenter positional deviation from the CTS plan were evaluated using Pearson correlation coefficients (CCs).

Results: The mean ± standard deviation of the ASDS between the CTS and oART plans was 0.59 ± 0.06. The MCS and isocenter positional deviation were 0.22 ± 0.02 and 8.1 ± 3.1 mm. There were moderate correlation between MCS of oART plans and ASDS with CC of 0.63, and strong correlation between the isocenter positional deviations of oART plans and ASDS with CC of -0.71.

Conclusion: We developed a novel metric to quantify aperture shape displacement between an oART plan and the CTS plan. This ASDS may serve as a new indicator for evaluating geometric variations in oART plans.

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INTRODUCTION

Online adaptive radiation therapy (oART) generates a new treatment plan based on daily three-dimensional imaging to account for anatomical changes. This approach is particularly valuable for pancreatic cancer, where substantial interfractional variations are frequently observed. However, no quantitative metric currently exists to evaluate the degree of plan modification relative to the CT simulation-based plan (CTS plan). This study aimed to establish a novel aperture shape displacement score (ASDS) to quantitatively assess aperture shape deviations in pancreatic cancer oART plans and to examine its relationship with plan complexity and isocenter displacement from the CTS plan.

METHODS AND MATERIALS

A total of 135 oART plans from 15 patients with pancreatic cancer treated with IMRT using the ETHOS therapy system (Varian Medical Systems, Palo Alto, CA, USA) from December 2022 to March 2024 at a single institution were retrospectively selected. The treatment planning was performed using the ETHOS treatment planning system (TPS) with dose calculation algorithm of Acuros XB (AXB) algorithm, and a 2.0 mm dose grid size.

The ASDS is a metric for quantitatively evaluating differences between treatment plans. The ASDS integrates TPS–derived information, including leaf position variability, field shape irregularity, segment weight, and area, into a single score ranging from 0 to 1.0 that is applicable to any IMRT and VMAT plan. The ASDS is primarily composed of the following two components of leaf position displacement (LPD) and dice similarity coefficient (DSC) as shown in figure 1.

Correlations between the ASDS and the modulation complexity score (MCS)[1)] and isocenter positional deviation from the CTS plan were evaluated using Pearson correlation coefficients (CCs).

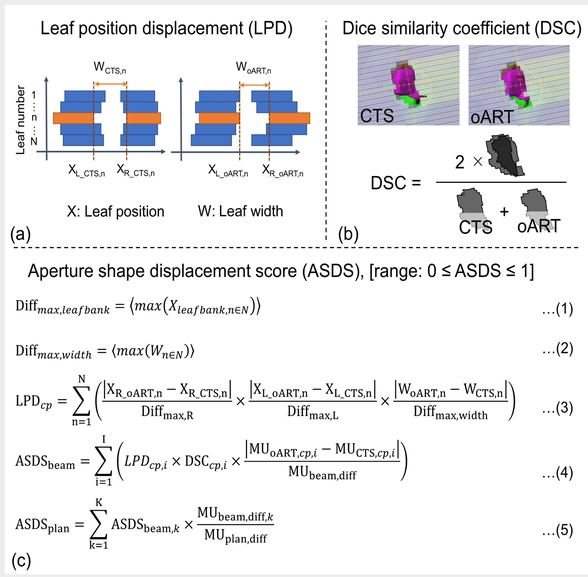

Figure 1. Calculation process of the ASDS.

RESULTS

The mean ± standard deviation (SD) of the ASDS between the CTS and oART plans was 0.59 ± 0.06 (ranges; 0.43 to 0.74). As the fraction-by-fraction changes, a mean highest score of 0.64 ± 0.05 was achieved at the 7th fraction, while a low value of 0.55 ± 0.05 was observed at the 15th (figure 2).

The mean ± SD of MCSs were 0.25 ± 0.03 (ranges; 0.20 to 0.29) for CTS plan and 0.25 ± 0.03 (ranges; 0.19 to 0.30) for oART plan, respectively. Overall, the MCS values were comparable between the CTS and oART plans. There was moderate correlation between MCS of oART plans and ASDS with CC of 0.63 (figure 3a).

The isocenter positional deviations between the from the CTS plan and that in the corresponding oART plans was 8.1 ± 3.1 mm (ranges; 1.1 to 19.2 mm. There was strong correlation between the isocenter positional deviations of oART plans and ASDS with CC of -0.71 (figure 3b). Namely, ASDS tended to decrease as the isocenter positional deviation increased. The lowest ASDS value was 0.43, corresponding to an isocenter positional deviation of 13.7 mm (figure 4). These results suggest that larger positional discrepancies were associated with greater deviations between the CTS and adapted treatment plans.

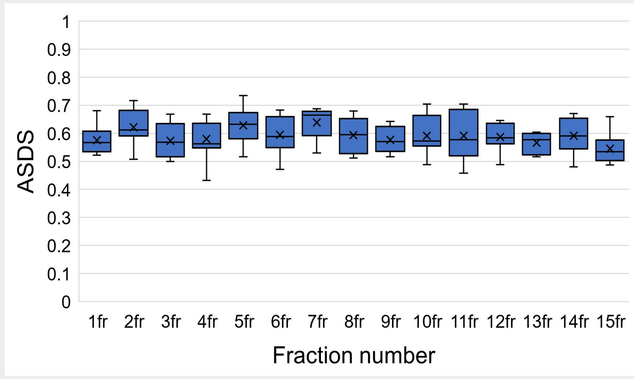

Figure 2. Box plots of the ASDS for each fraction.

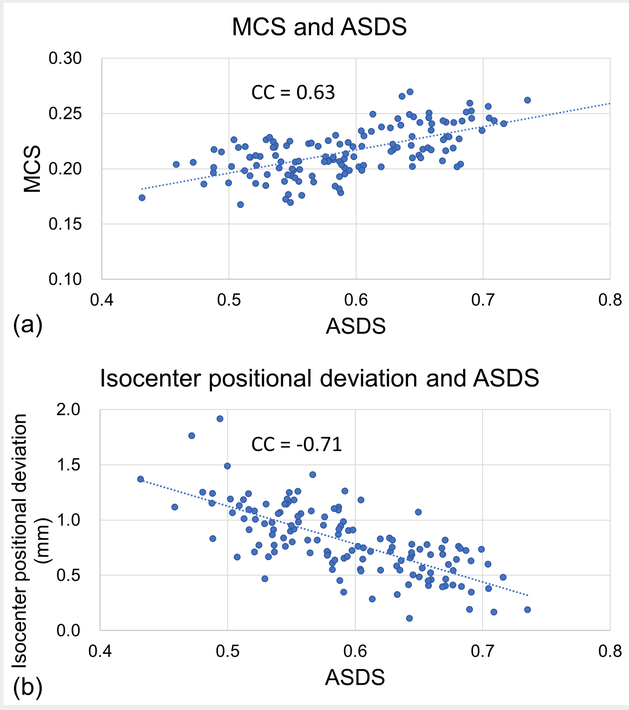

Figure 3. Scatter plots of the ASDS versus MCS (a) and isocenter positional deviations (b).

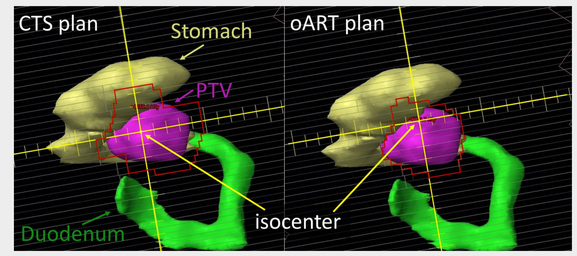

Figure 4. Beams eye views of CTS plan and oART plan for the lowest ASDS value.

DISCUSSION

Treatment plan changes are inevitable during oART. Tanny et al. reported substantial MU variability in CBCT-guided pelvic oART but found no significant association with anatomical changes and suggested that optimizer randomness may contribute to these variations[2)]. However, no practical method was proposed to objectively quantify plan modifications. The ASDS developed in this study provides a quantitative measure of deviations between the original CTS plan and the adapted oART plan, offering a novel indicator of plan changes and potentially providing additional insight into oART plan quality beyond MU variation alone.

In oART, daily anatomical variations are accommodated through online plan adaptation rather than conventional couch shifts[3)]. Nevertheless, this study demonstrated that larger isocenter positional deviations were associated with greater plan modifications. Given that substantial plan changes may be a concern in on-couch adaptive workflows, objective evaluation of such changes is important. The observed correlation between ASDS and MCS further indicates that ASDS may not only quantify plan deviations but also provide insight into changes in plan complexity during oART.

CONCLUSIONS

This study proposes ASDS, a novel metric for quantifying fraction-by-fraction plan variations in oART. ASDS reveals trends in adaptive plan changes and their relationship with isocenter position, providing information beyond conventional QA results and serving as a potential new indicator for oART plan evaluation.

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