MEDICAL PHYSICS

Optimization meets Medical Physics for improved Arc-Therapy treatments delivery

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Background

The latest generation of linear accelerators for radiotherapy treatment allows the simultaneous motion of gantry and couch leading to highly noncoplanar arc trajectories as illustrated in Fig.1. The use of noncoplanar trajectories in arc radiotherapy combines the benefits of arc treatment plans, such as short treatment times, with the benefits of step-and-shoot noncoplanar intensity-modulated radiation therapy (IMRT) treatment plans, such as improved organ sparing.

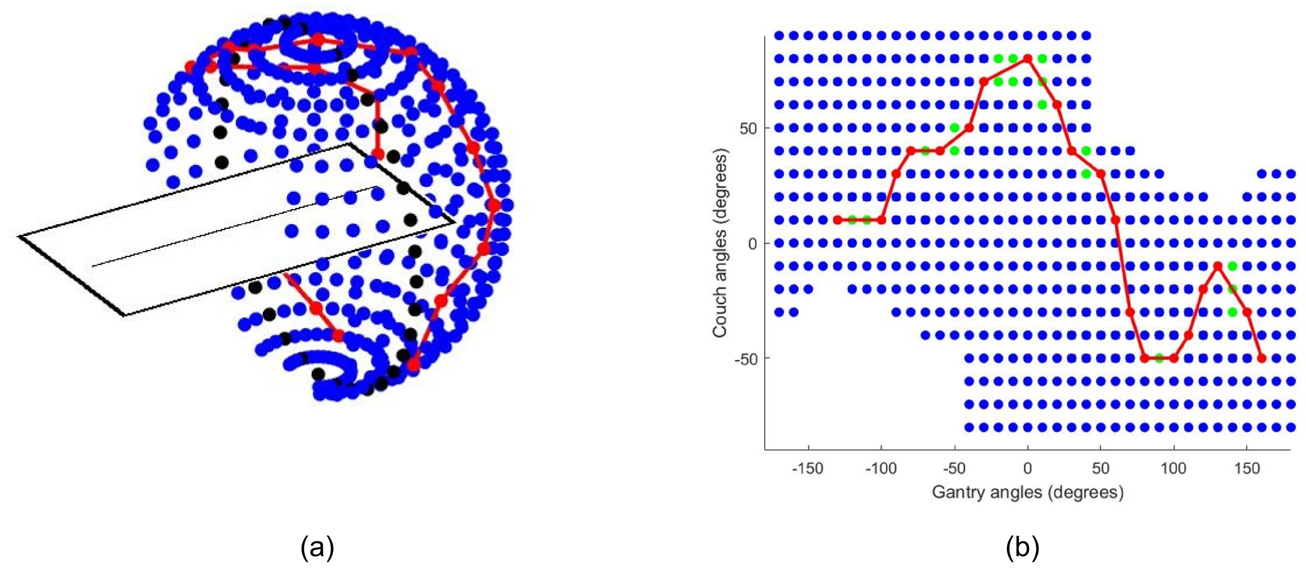

Fig. 1. The noncoplanar arc trajectory is displayed in red in 3D - 1(a) and in 2D - 1(b).

Methodology

A two-step approach, illustrated in Fig. 2, is proposed and tested considering a nasopharyngeal tumor case. In the first step, a set of noncoplanar beam directions is calculated resorting to beam angle optimization (BAO). In the second step, anchored in the points calculated in the first step, more anchor points are iteratively calculated, considering the dosimetric criteria used for the noncoplanar BAO search rather than geometric or time criteria commonly used.

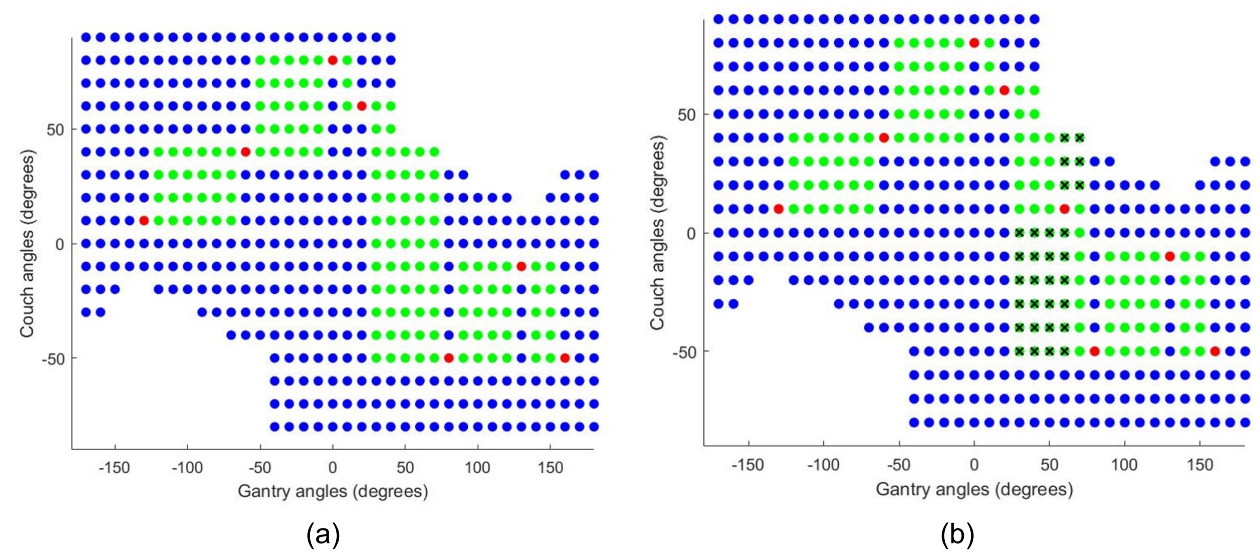

Fig. 2. The noncoplanar BAO solution is displayed in red and the feasible points to consider when calculating a new anchor point are displayed in green - 2(a). Novel anchor point belonging to the largest set of green candidate beams is added and green candidate beams that became infeasible are removed - 2(b).

Results

Computational tests depicted in Tables 1-3 show that the resulting noncoplanar arc therapy plan has undoubtedly greater overall quality compared to both the coplanar arc therapy plan and the typically used coplanar equidistant step-and-shoot IMRT plan. It is possible to achieve a proper coverage of the volumes to treat, being able to obtain a better sparing of the organs at risk. More tests are needed, in an enlarged set of patients.

Table 1. Comparison of treatment plans: Optimal FMO value.

Equi	$2\pi VMAT$		$4\pi VMAT$	
FMO value	FMO value	%decrease	FMO value	%decrease
560.33	522.19	6.8	473.92	15.4

Table 2. Comparison of treatment plans: Target coverage.

Target parameters	*Equi*	$2\pi VMAT$	$4\pi VMAT$
PTV_{70} Coverage	0.863	0.849	0.919
PTV_{70} Conformity	0.505	0.466	0.555
PTV_{70} Homogeneity	0.880	0.873	0.892
$PTV_{59.4}$ Coverage	0.930	0.928	0.937
$PTV_{59.4}$ Conformity	0.554	0.551	0.562
$PTV_{59.4}$ Homogeneity	0.856	0.857	0.867

Table 3. Comparison of treatment plans: Organ sparing.

	Mean Dose (Gy)			Max Dose (Gy)		
OAR	*Equi*	$2\pi VMAT$	$4\pi VMAT$	*Equi*	$2\pi VMAT$	$4\pi VMAT$
Spinal cord	–	–	–	34.9	33.6	30.8
Brainstem	–	–	–	44.8	42.3	33.9
Right parotid	23.0	22.9	21.6	–	–	–
Left parotid	24.4	19.3	15.4	–	–	–
Oral Cavity	17.5	12.9	10.9	–	–	–

Conclusions

In this approach, we take advantage of all the quality work already produced for the noncoplanar BAO problem and propose an optimization strategy, anchored on the solution calculated by the BAO problem, that also considers dose metrics to guide the optimization procedure but simultaneously embeds the goal of obtaining an efficient dose delivery time, which is one of the main features of rotational treatments.

Better treatment plans will lead to better overall survival probabilities, and less complications induced by radiotherapy treatments. This will have an enormous impact at the patient's level, their families but also a significant positive impact to society. Furthermore, the developed methodologies can also be applied to new treatment modalities, like the use of protons.