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Offline Plan Adaptation in Robustly Optimized CBCT Guided Pencil Beam Scanning Proton Beam Therapy: Lessons from a Real-world Cohort

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Objectives

Pencil beam scanning proton beam therapy (PBS-PBT) is highly sensitive to anatomical variations, necessitating inter-fraction adaptive replanning (ARP) to ensure accurate dose delivery. Although cone-beam CT scans (CBCT) is increasingly utilized, many institutions rely on periodic quality assurance CT scans (QACT) to trigger ARP. This study evaluates an offline adaptive PBS-PBT workflow in a real-world cohort

Methods

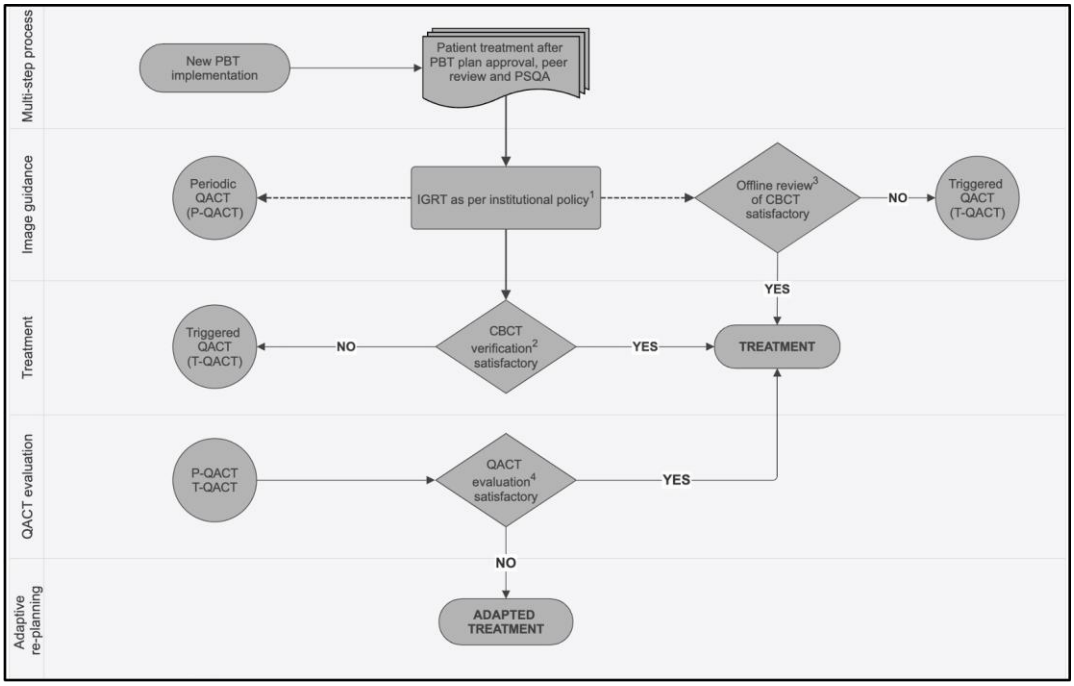
We retrospectively analysed 300 consecutive patients treated with robustly optimized PBS-PBT. All patients underwent CBCT guided treatments, with QACTs performed either periodically(P-QACT) or triggered by CBCT(T-CBCT) changes (Pic 1). We assessed ARP frequency, dosimetric and anatomic triggers, temporal patterns, indications, and workflow impacts across treatment sites. Strategic modifications were introduced after the first 100 patients and their effect on ARP frequency was evaluated.

Results

Of 761 QACTs performed, 541 were P-QACT and 220 were T-QACT. Overall, 94 ARP were done in 80 patients (27%), with the highest rates in head neck (62%) and thoracic (43%) cancers. The primary dosimetric trigger was organ-at-risk (OAR) overdosage (52%), followed by target under-coverage (32%) and a combination of both (16%). T-QACT demonstrated 97% sensitivity for triggering ARP with 41.4% (91/220) specificity as illustrated in Pic 2. Most ARPs (64%) occurred in the first half of the treatment, with 32% in week-3 as shown in the heatmap. Beam path changes (52%) were the most frequent anatomic trigger, followed by target deformation (29%) and setup inconsistencies (13%). Strategic modifications reduced ARP frequency from 35% in the first 100 patients to 22.5% in subsequent 200.

Conclusions

PBS-PBT frequently necessitates ARP. A CBCT-guided offline adaptive workflow, combined with stringent image review protocols, can largely eliminate the need for routine QACTs and streamline replanning. This approach offers practical guidance for PBS-PBT programmes.



Site	QACT Description	Number of QACT	Number of adaptive replanning	Number of ARP/QACT (%)	P value
All	P-QACT	541	3 **(3%)**	0.6	<0.0001
	T-QACT	220	91 **(97%)**	**41.4**	
Brain	P-QACT	152	0	0	<0.0001
	T-QACT	20	13	**65**	
Head Neck	P-QACT	122	0	0	<0.0001
	T-QACT	95	46	**48.4**	
Pelvis	P-QACT	110	0	0	<0.0001
	T-QACT	38	11	**28.9**	
CSI	P-QACT	60	1	1.7	0.002
	T-QACT	12	4	**33.3**	
Thorax	P-QACT	53	2	3.8	<0.0001
	T-QACT	30	15	**50**	
Abdomen	P-QACT	28	0	0	0.487
	T-QACT	20	2	**10**	
Misc	P-QACT	15	0	0	Cannot be evaluated
	T-QACT	6	0	0