Hierarchical Spatial and Temporal Aggregation as Progressive Denoising for Longitudinal CBCT Radiomics

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1 Purpose

Daily CBCT during radiotherapy is **routine but dominated by noise** — individual scans are unreliable for radiomics.

Hypothesis: hierarchical spatial + temporal aggregation acts as **progressive denoising** (σ/√k), unlocking a clinically valuable signal.

Goal: robust survival prediction from **zero-added-burden** routine imaging in a clean full cohort of N=201.

2 Methods & Cohort

N=201 lung-cancer patients; weekly CBCT across 6 Tx weeks (TJUH, IRB #21F.644).

Features: 107 radiomic (1mm-iso, normalize=false) + **14 clinical** (TNM · age · PS · dose).

- Aggregation: contour (GTV/CTV/ITV/PTV) → image → CBCTc1-6 → course → patient.

Two geometry targets:
Frozen (planning mask → shape) vs
Re-segmentation (on-Tx contour → intensity).

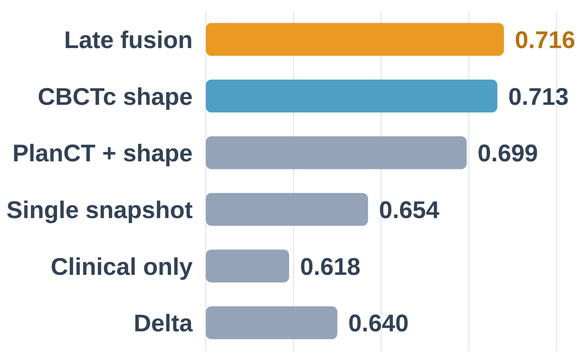
- Models: GBS / RSF / Cox-LASSO; 5-fold patient-level OOF C-index, seed-averaged (15 folds).

3 Aggregation ladder

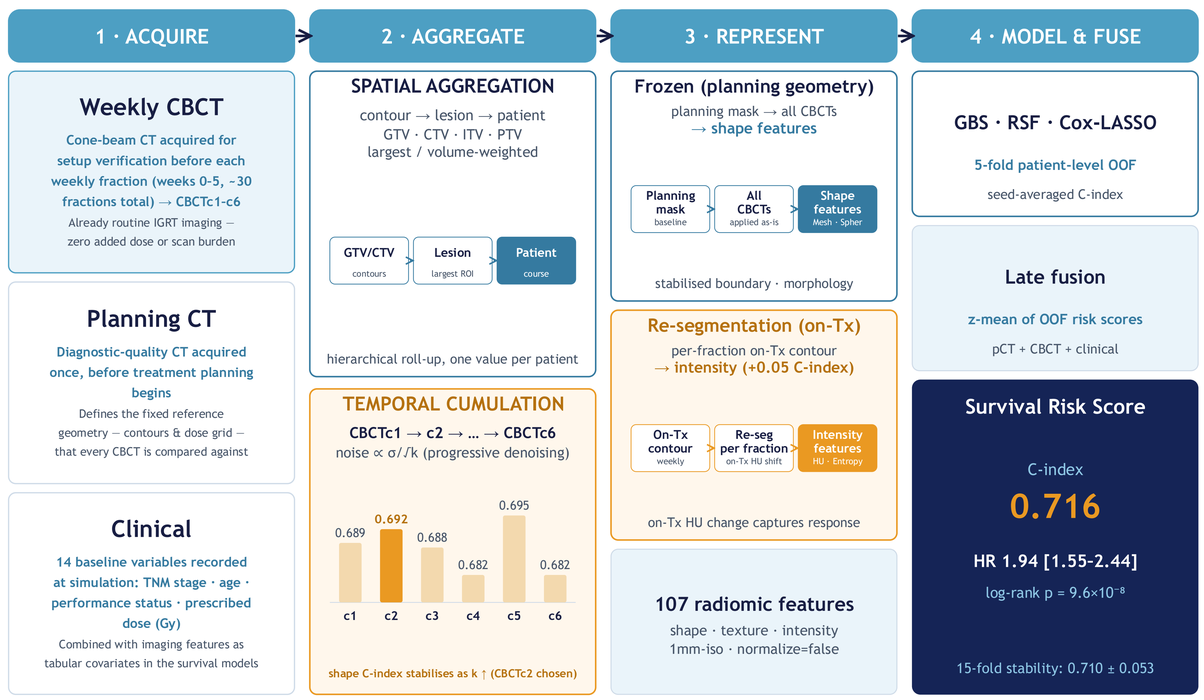
Level added	C-index
L0 — planning CT + clinical	0.661
+ contour / ROI	0.680
+ cumulation	**0.713**
+ course aggregation	0.718

Cumulation is the largest single step → drives +0.052.

4 Strategy comparison

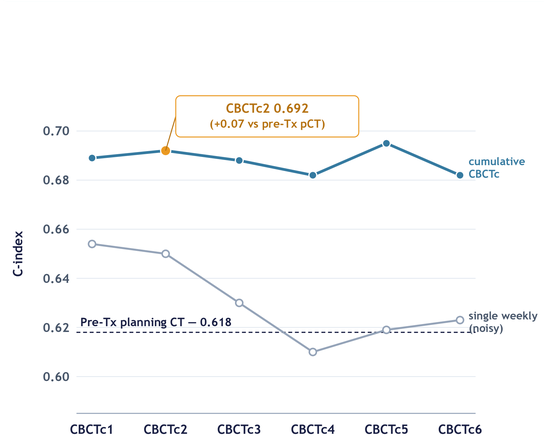


5 Method — hierarchical aggregation pipeline



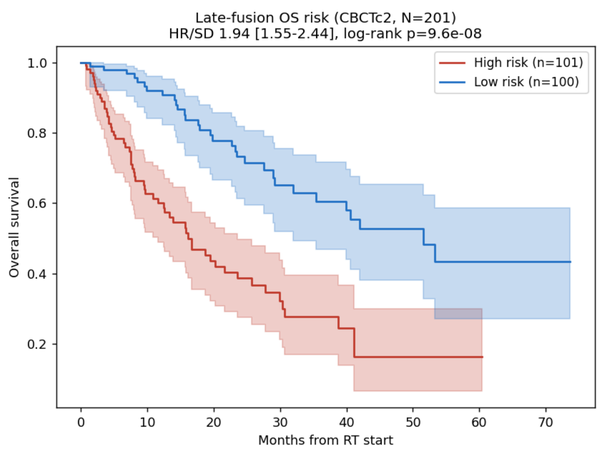
Spatial aggregation (contour→patient) + temporal cumulation (CBCTc1-6, σ/√k progressive denoising); frozen-shape & reseg-intensity targets fused via z-mean late fusion.

6 Cumulation ≫ single snapshot



CBCTc (+0.07 vs pre-Tx pCT): each cumulative point beats the corresponding single-week snapshot by +0.04-0.08 C-index.

7 Survival significance (KM)



Late fusion: C-index 0.716; HR 1.94 [1.55-2.44]; log-rank p=9.6×10⁻⁸; 15-fold stability 0.710 ± 0.053.

0.716 — Late-fusion C-index

1.94 — Cox HR / +1 SD

+0.07 — Cumulative vs pre-Tx CT

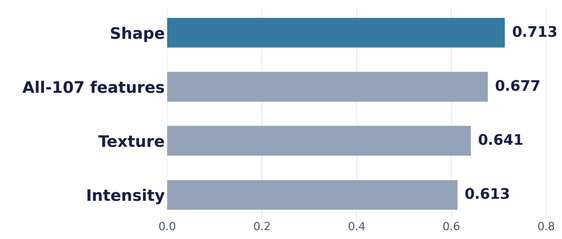
N=201 — Full cohort, no drops

Conclusion

Hierarchical aggregation of longitudinal CBCT radiomics enables **progressive denoising across treatment**.

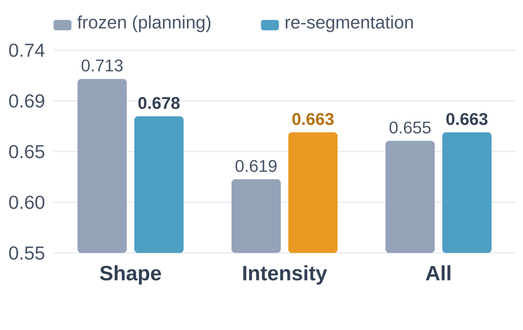
Cumulation stabilizes geometry; re-segmentation supplies on-treatment intensity; **late fusion integrates them (0.716, HR 1.94)** for early risk stratification — no added imaging burden.

8 Shape-primacy



Shape 0.713 ≫ all-107 features 0.677 > texture 0.641; pooling 107 features dilutes the signal.

9 Re-segmentation → intensity



Re-segmentation's model-independent value is intensity (+0.05, robust), not shape — on-Tx density matters.

10 Key findings

- **Cumulation overcomes CBCT noise:** CBCTc ≫ single snapshot by +0.04-0.08 C-index.
- **During-Tx CBCT ≥ pre-Tx pCT** from CBCTc2 onward (no wait needed).
- **Shape primacy:** **shape 0.713 ≫ all-107 features 0.677** (pooling dilutes the signal).
- **Re-segmentation's value** is **intensity (+0.05)**, not shape — on-Tx tumor density over geometry.
- **Late fusion 0.716, HR 1.94,** log-rank $p=9.6\times10^{-8}$. 15-fold 0.710±0.053.

11 Code & reproducibility

qradiomics (open source)
Atomic radiomics primitives — foundation of this pipeline.
github.com/choilab-jefferson/qradiomics

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