A Simulation-Based Radiobiological and Dosimetric Feasibility Study of Conceptual Kilovoltage X-ray VMAT for Skin Field Treatment

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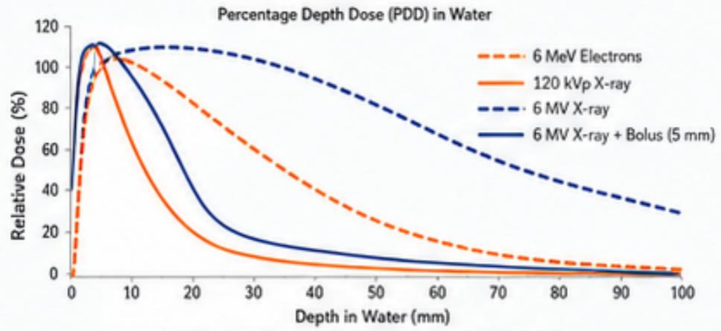
TAKE-HOME MESSAGE

CT-source 120 kVp kV-VMAT may improve superficial target uniformity while reducing adjacent-tissue dose in simulated skin-field treatment.

1. Clinical Need & Radiobiological Rationale

- Superficial skin cancers require high surface dose and rapid distal fall-off.
- Electrons need bolus and can suffer from lateral scatter.
- MV-VMAT has buildup region and higher integral dose.



Simulated depth-dose curves (water). kV X-ray shows high surface dose with rapid fall-off, minimizing dose to deeper tissues.

1.21 — RBE_DSB at 5 mm, vs 6 MV photons

1.12 — RBE_DSB at 2 cm, vs 6 MV photons

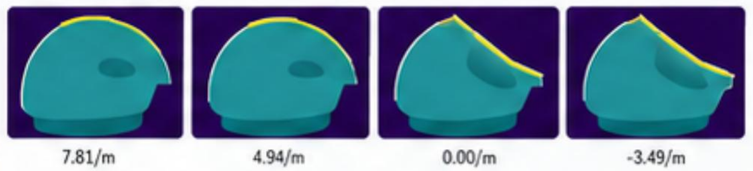
No bolus — conceptual surface-dose advantage, vs electron-based

2. Study Design & Planning Pipeline

SIMULATION-TO-PLANNING WORKFLOW

120 kVp CT-source spectrum (Tube voltage, filtration) → Monte Carlo beam model (Source model, particle transport) → DNA damage model (Local effect dose model) → Inverse planning (Fluence + Collimator + VMAT arcs)

EVALUATION COHORTS



Phantom curvature (1/m): Positive = convex, 0 = flat, Negative = concave

Phantom plans
Curved slabs with uniform 5 mm skin target

Patient cases
11 cutaneous malignancies, 2–5 cm targets

Endpoints
HI, CI, OAR composite dose

TECHNICAL ASSUMPTION

kV aperture and fluence modulation were idealized for theoretical feasibility and to isolate radiobiological and dosimetric potential.

3. Principal Results

1.088 — Patient HI by kV-VMAT (lower = more uniform)

0.445 — Patient CI by kV-VMAT (higher = less hot)

3.85 Gy — Mean composite OAR dose (n = 11, 2–5 cm lesions)

PHANTOM RESULT

- kV-VMAT achieved average HI 1.61 and CI 0.38 in phantom scenarios.
- Electron+bolus had best phantom HI/CI in simple geometry but lacked modulation flexibility.
- kV-VMAT leverages arc shaping for superior surface conformity.

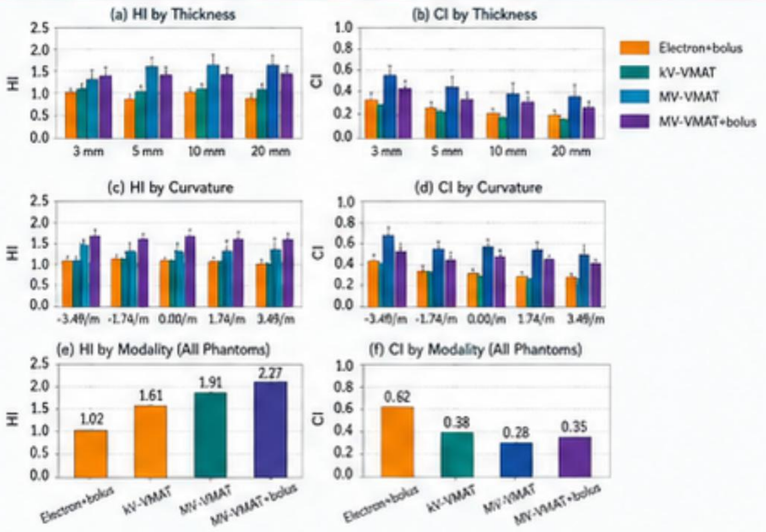
PATIENT RESULT

- Across 11 cases, kV-VMAT produced significantly improved HI compared with all comparators.
- Rapid kV attenuation reduced integral dose to nearby healthy tissue.
- Dose dose beyond target for kV-VMAT was consistently lower.

BOTTOM LINE

Conceptually, kV-VMAT combines the superficial-dose physics of kilovoltage X-rays with arc-based fluence modulation, supporting further development for skin-field carcinoma.

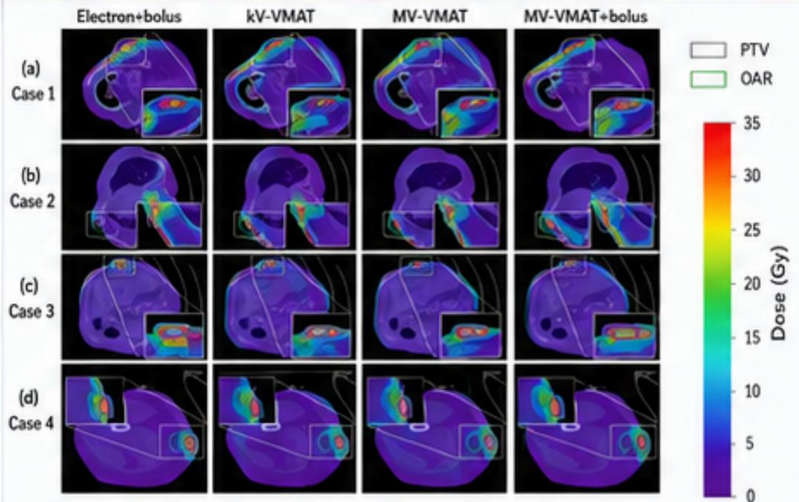
4. Phantom Dosimetry: Curvature & Thickness Sensitivity



INTERPRETATION

kV-VMAT outperformed fixed-beam plans on average in simulated phantoms, especially where deeper penetration from MV beams increased normal-tissue dose; electrons remained favorable in uniform-thickness phantom setups.

5. Clinical-Geometry Evaluation: Dose Distribution

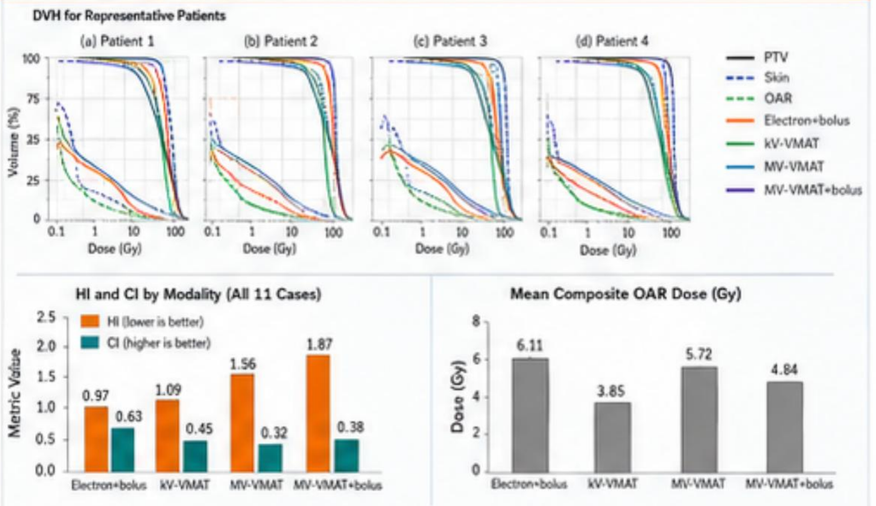


Representative patient case comparing Electron+bolus, kV-VMAT and MV-based VMAT.

What changes clinically?

- More homogeneous PTV dose distribution compared with MV-based plans.
- Lower composite OAR dose due to rapid kV attenuation.
- Requires implementation-aware validation of field shaping, dose rate, leakage, and heat management.

6. Cohort DVH Summary & Conclusions



CONCLUSIONS

- kV-VMAT supports simulated feasibility of a CT-source-based 120 kVp VMAT concept for superficial skin-field treatment.
- Compared with MV-based approaches, it improved PTV homogeneity and reduced dose to surrounding tissue in the simulated cohort.
- Electron+bolus retained advantages in some simplified phantom settings, but kV-VMAT offers greater modulation flexibility.

KEY LIMITATIONS

- Conceptual delivery model, not yet a clinical hardware.
- Idealized collimation and fluence modulation.
- Small superficial lesion cohort.
- Requires hardware validation.

Keywords: Kilovoltage X-ray • VMAT • Non-melanoma skin cancer • Superficial radiotherapy • Monte Carlo • Treatment planning • Dosimetry

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