Small-Vault Total Body Irradiation Using Jaw-Defined Sweeping Arc Delivery

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

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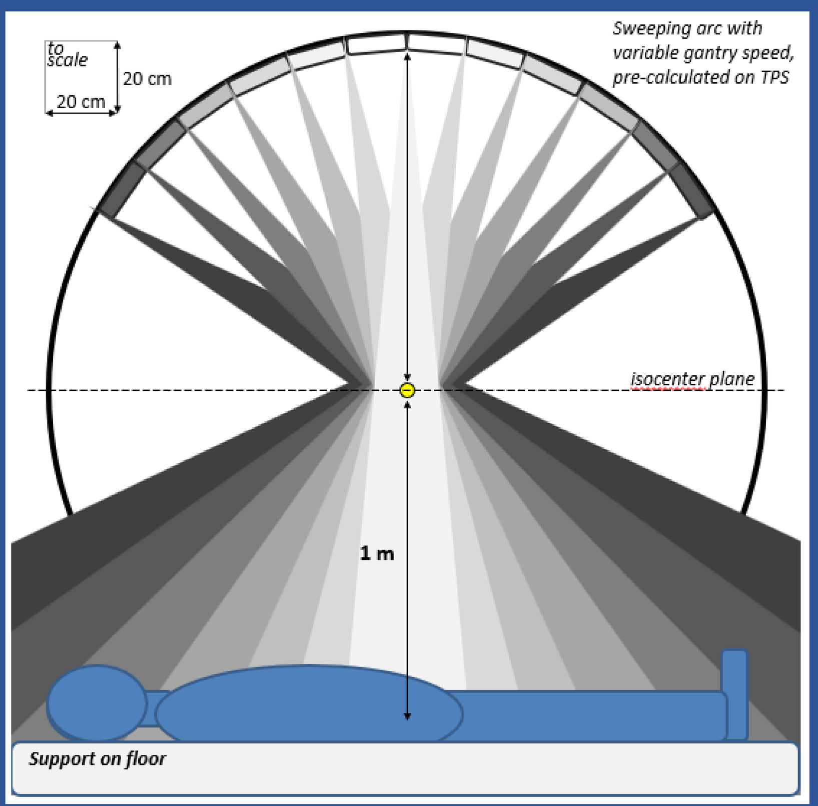

Figure 1. Sweeping arc TBI schematic

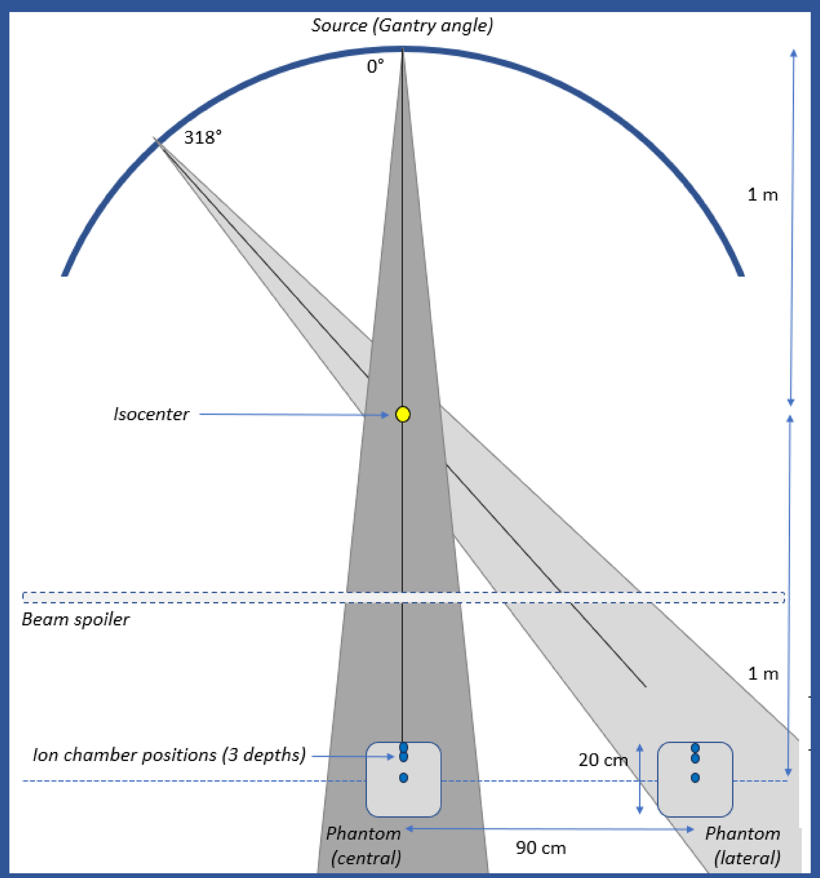

Figure 2. Prior study showed that ion chamber measurements are within 3% of TPS calculations at the extended distance of approximatly 200 cm.

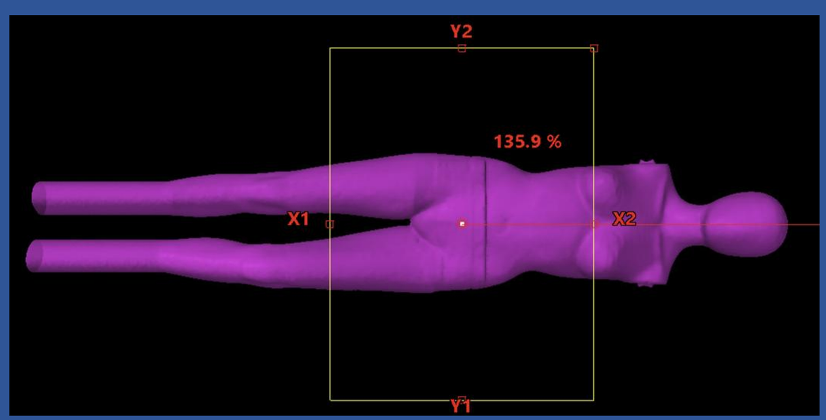

Figure 3. The beam's eye view of a 30 x 40 cm² field at gantry 0° provides a snapshot of the sweeping arc.

Figure 5. Irradiation of homogeneous anthropomorphic phantom with diodes. Supine position (left). Prone position (right).

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INTRODUCTION

Total Body Irradiation (TBI) delivers a uniform, prescribed dose to the entire body as conditioning for bone marrow transplantation in patients with hematological malignancies. Current TBI methods are complex and resource-intensive. We present a simpler approach using Treatment Planning System (TPS)-optimized jaw-defined arcs, suitable for a small treatment vault.

Following a geometry used from the University of Heidelberg (Jahnke et al. 2014), the patient is treated in both supine and prone positions on a stretcher close to the floor, aligned in the gantry's rotation plane, at a source-to-surface distance (SSD) of approximately 200 cm. (Figure 1.) A full-body beam spoiler is placed approximately 20 cm above the patient. The linear accelerator (linac) delivers partial arcs.

In previous studies we have verified that our clinical TPS accurately predicts dose delivery at a SSD of 200 cm, with the difference between measured and calculated doses consistently well within 5% (Figure 2.) Optimal parameters were identified as 10 MV energy, a 30 × 40 cm² field size, and a 110° arc with field weight adjustments every 5°. (Figure 3.) In slab phantom studies, 96% of the target volume was covered within ±10% of the prescription dose using the TPS.

This project aims to verify TPS accuracy in an anthropomorphic phantom, assess the effect of extending the scan inferiorly to accommodate patient height due to scan length limitations, and test the robustness to setup uncertainty.

METHODS

A. TPS Accuracy

We built a homogeneous anthropomorphic phantom by filling a mannequin with rice and inserting eight diodes throughout. We then scanned it with 5 mm CT slice thickness. The CT scanner's maximum scan length is 144 cm, so the lower shin and feet were not included in the scan. The CT dataset was extended to match the phantom height as proposed by the University of Calgary group (Pierce et al 2019).

In Eclipse, a dual-isocenter plan was created in which each isocenter group was comprised of 20 arcs of 5° each, spanning from 310° to 50°. The initial weight of each 5° arc was based on prior research. The fixed field size was 30×40 cm², covering the mannequin laterally while sweeping longitudinally. Dose rates were 100 MU/min for arcs that irradiated lungs (325°-5°), and 600 MU/min for the rest. (Figure 4)

After calculating the plan (AAA Ver16, 0.5 cm calculation grid size), weights were manually adjusted for optimal coverage, ensuring the maximum dose remained below 110% of the prescription and that 95% of the body contour received 90-110%.

Plan was delivered on a TrueBeam using automation feature with a 0.5" acrylic beam spoiler in place above the phantom while measuring dose with the eight diodes. (Figure 5.)

B. Robustness to setup uncertainty

A robustness analysis was performed within the TPS by shifting the isocenter to simulate setup variations. The initial shift was 2 cm in the superior/inferior direction from the original isocenter, followed by a second shift of 4 cm in the same direction. The doses from the two plans were compared to the dose in the original plan.

C. CT scan length limitation

Due to the CT scan length limitations, it was necessary to extend the scan inferiorly. To verify the appropriateness of this approach, the plan was duplicated onto a half-body scan that included the entire foot. The dose was calculated and compared with the original plan, in which the CT was extended inferiorly to match phantom height.

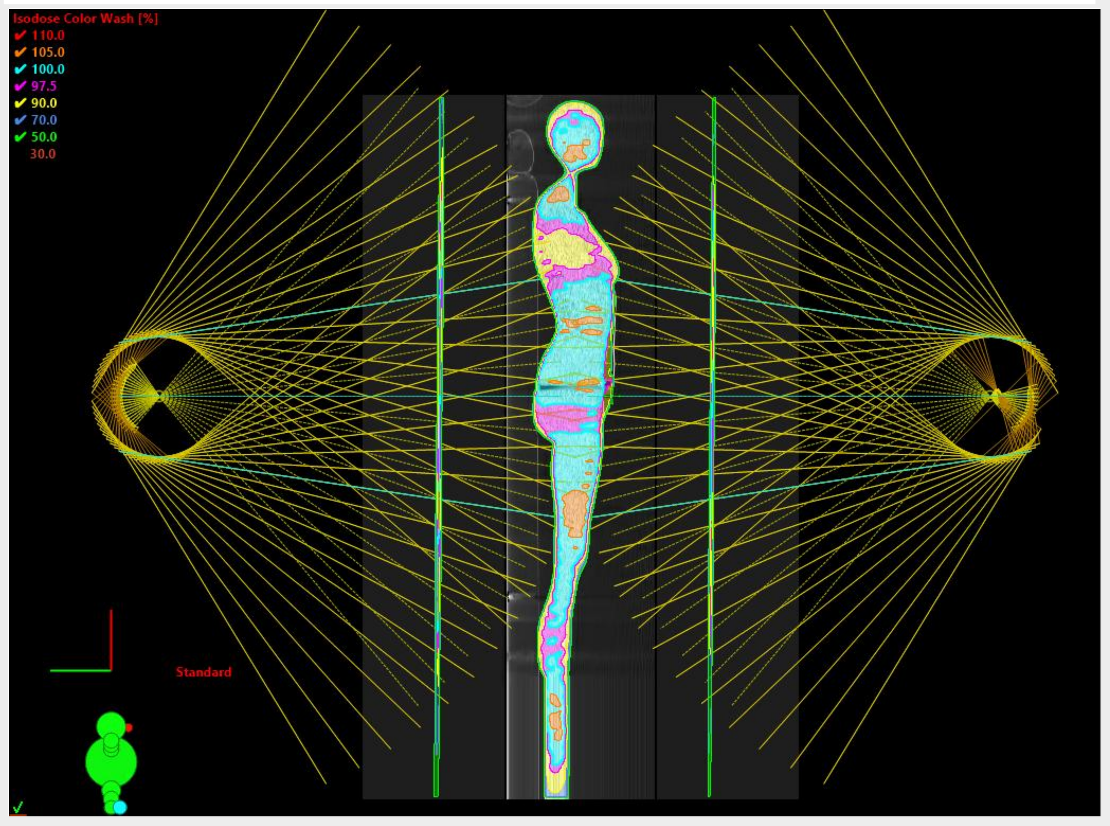

Figure 4. Dual-isocenter plan with 40 arcs of 5°. 95% of phantom volume receives the prescription dose ±10%. Lung region is intentionally kept approximately 5% cooler. Beam spoiler included in the dose calculation.

RESULTS

A. TPS Accuracy
There is good agreement between TPS and measurement in the phantom. Most of the dose differences are within 5%, with the average difference of 3%. (Table A.)

B. Robustness to setup uncertainty
In both cases the coverage to Body-5mm changed by less than 1%. The robustness analysis incorporating the isocenter shifts demonstrated that the treatment plan is robust to setup variations of at least 4 cm in the superior/inferior direction. (Table B.)

C. CT scan length limitation analysis
When the plan is optimized to produce a uniform dose in the extended leg, the dose delivered to a 'real' ankle and foot is slightly hotter (more 105% and some 110%). This is the case because the ankle and foot are thinner than the axial cut of the shin that was extended. For future patient treatments the planned dose to the extended leg should be about 95% so that the ankles and feet will receive approximately 100%. (Table C.)

Table A.

TPS Accuracy	Diode msmt (cGy)	TPS calc (cGy)	% Difference
Head	383.4	401	-4.4%
Neck	426.6	418.9	1.8%
Thorax	375.4	388.8	-3.5%
Lt elbow	414.9	435.4	-4.7%
Navel	393.7	409.3	-3.8%
Pelvis	383.4	398.6	-3.8%
Rt knee	403.1	429.7	-6.2%
Rt ankle	351.0	358.1	-2.0%
		Average(%)	-3.3%

Table B.

Robustness	Max Dose (%)	Mean Dose (%)	V90% (%)
Original Iso	111.2	100	98.77
2 cm Sup Shift	111.5	99.9	98.47
4 cm Sup Shift	111.7	99.7	98.17

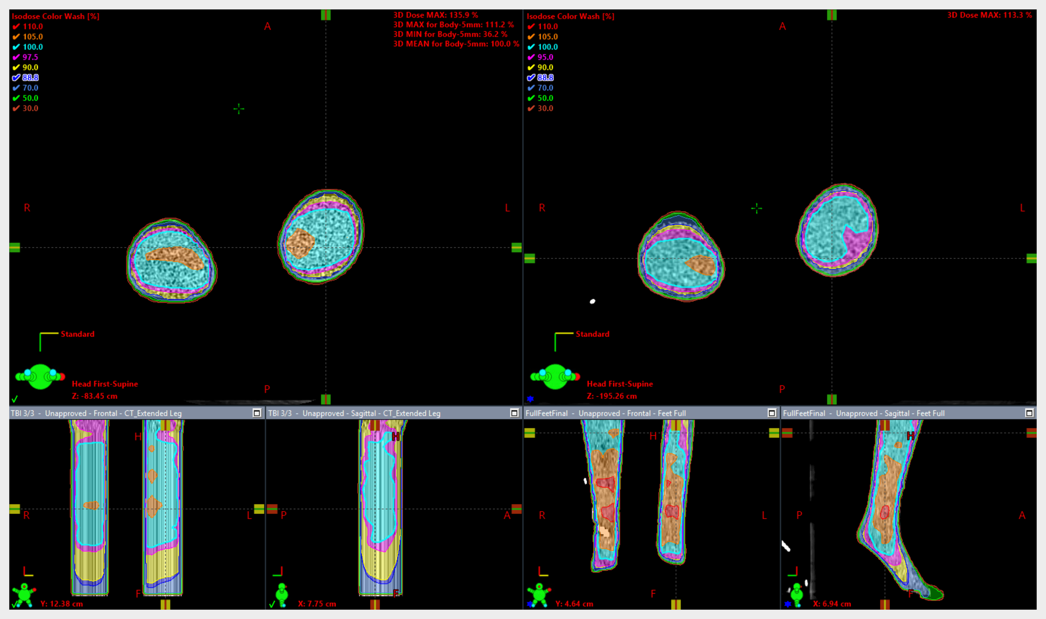

Figure 6. Left: plan optimized on phantom with artificially extended leg. Right: same plan applied to realistic anatomy shows similar coverage but more 105-110%. Table C provides the dose statistics.

Table C.

Dose to lower leg	Extended CT (%)	Real Feet (%)	Difference (%)
V95%	90.0	88.4	-1.6
D95%	92.9	88.4	-4.5
D90%	95.0	94.0	-1.0
Dmean	99.4	100.3	0.9
D0.03cc	111.2	113.0	1.8
V110%	0.04	0.56	0.52

DISCUSSION

Sweeping arc plans are a practical and robust solution for TBI. It is less resource-intensive and more robust than VMAT-TBI, and provides more information than traditional AP-PA or Lateral irradiation methods.

In a separate study on an anthropomorphic thorax phantom with lung inserts, we found that it was possible to optimize weights so as to not overdose the lungs. There is thus no need for additional shielding devices to spare lungs.

Unfortunately, arc-TBI has found limited adoption: we are aware of five centers in Germany (see review by Shariff et al, 2025) and a few in North America (McGill, Ottawa Universities and Medical University of South Carolina). We present these results for other centers that are looking to renew/start TBI. Users need simply to verify the accuracy of their TPS at extended SSD and adapt a low support couch for patients' CT and treatment.

CONCLUSIONS

TPS accuracy was within 5%, demonstrating reliable calculations. The 10 MV with a 30 x 40 cm² arc configuration provided excellent coverage and homogeneity. In the anthropomorphic phantom plan, over 95% of the body received the prescribed dose within ±10%.

When CT scan length is limited, extending the slices to match the patient's height is recommended.

The patient setup can accommodate at least a 4 cm superior-inferior error with minimal impact.

Sweeping arc TBI is a practical solution that may benefit many patients and clinics.

REFERENCES

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