Dosimetric Considerations for VMAT Total Body Irradiation in Adult Patients: A Single-Institution Implementation Experience

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ABSTRACT

Purpose:
Total body irradiation (TBI) is a key component of myeloablative conditioning before hematopoietic stem cell transplantation. Modern TBI techniques are increasingly moving towards multi-isocentric VMAT approaches to improve dose homogeneity and organ sparing while reducing bunker space constraints. Published implementations have focused predominantly on pediatric patient populations. This study describes the clinical implementation of VMAT-TBI in an adult population and evaluates size-related dosimetric challenges and limiting factors.

Methods:
From December 2022 to September 2025, 50 adult patients underwent VMAT-TBI. Prescriptions were 200 cGy given for 1 (n=27), 2 (n=18), or 6 (n=5) fractions. Mean patient height was 169 cm (range 148-195 cm) and mean weight was 85 kg (range 46-148 kg). Automated script-based plans were created using 5-7 isocenters, 2-4 arcs per isocenter, to deliver homogenous dose to the entire body, excluding lungs and kidneys. Treatment plans were evaluated based on dose coverage and high-dose volumes.

Results:
All planned treatments met guidelines for TBI target coverage, however, substantial variability in high-dose volumes was observed. Average(±SD) maximum dose to 1 cubic centimeter (D_{1cc}) was 128.7%±7.6%, and average volume receiving 110% prescription dose (V110%) was 17.4±12.1%. PTV V110% and D_{1cc} demonstrated positive correlations with patient weight (R^2 = 0.76, 0.74) and maximum patient separation (R^2=0.73, 0.64), while minimal correlations were observed relating to patient height (R^2 = 0.29, 0.27). Doses to lungs and kidneys showed no correlations to patient size.

Conclusion:
VMAT-TBI is feasible in adults with a wide range of body sizes. Patient weight and separation, rather than height, appear to be the primary factors for dose inhomogeneity. Unlike pediatrics, adult bodies may limit achievable high-dose control despite optimization and additional isocenters. These findings suggest that patient size–based planning considerations and acceptance criteria may be necessary when extending VMAT TBI techniques from pediatric to adult populations.

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INTRODUCTION

Background:
- Total body irradiation (TBI) remains an important component of conditioning regimens before hematopoietic stem cell transplantation
- Multi-isocentric VMAT-based TBI techniques have emerged over recent years as an alternative, providing:
  - Standard couch-based treatment geometry
  - Elimination of large bunker requirements
  - Improved dose homogeneity
  - Increased OAR sparing

Local Motivation:
- In 2022, Saskatoon Cancer Centre implemented VMAT-TBI as one of the earliest Canadian community-centre programs for adult patients
- Implementation was driven primarily by limited bunker space and availability due to linac upgrades
- Goal was to develop a technique to reproduce established conventional TBI dosimetry while providing a sustainable long-term TBI program

Study Objectives:
- Evaluate dosimetric performance across a broad range of adult patient sizes
- Identify patient characteristics associated with increased dose inhomogeneity

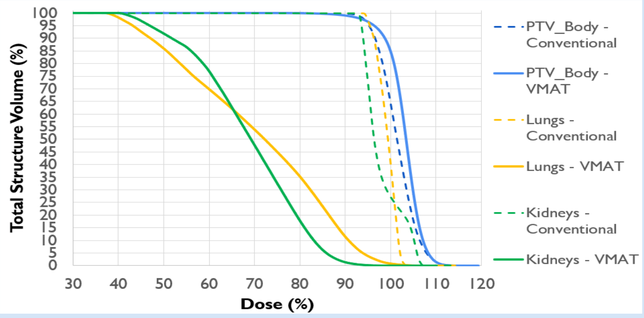

Figure 1. Example comparison of conventional and VMAT TBI DVHs. TBI provides improved coverage with significant OAR sparing

METHODS AND MATERIALS

Planning Workflow:
- Script planning technique to help automate planning structures, field placement and optimization
- 5-7 isocenters depending on patient length
- 2-4 arcs per isocenter
- PTV defined as whole body excluding lungs and kidney
- Optimization objectives prioritized for whole-body coverage over OAR sparing
- Limit modulation to reduce MLC motion and MUs

Treatment Delivery:
- Full body vac-loc and mask on rotating platform (CDR)
- Imaging at each isocenter and global shifts applied
- Upper-body isocenters imaged and treated, then rotate and repeat for lower-body isocenters

Patient Population:
50 adult patients (Dec. 2022- Sept. 2025)

Characteristic	Value
Mean height (range)	169 cm (148-195 cm)
Mean weight (range)	85 kg (46-148 kg)
1 fraction (2 Gy)	27
2 fractions (4 Gy)	18
6 fractions (12 Gy)	5

Our clinical population included numerous large adult patients, providing a challenging opportunity to evaluate technique limitations

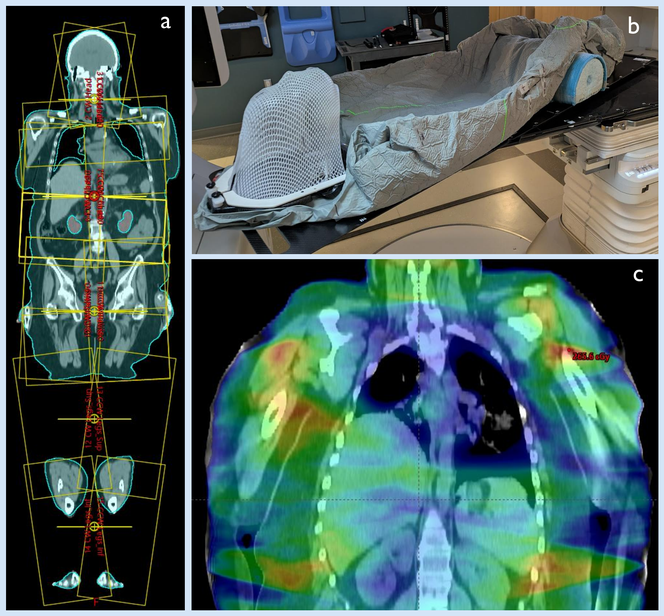

Figure 2. (a) TBI field arrangement for an average adult patient (5 isocenter, 14 field). (b) Treatment setup with mask and full body vac-loc on rotating platform. (c) Coronal dose distribution for a large patient showing sparing of lungs and high dose at periphery.

RESULTS

Clinical Performance:
- All patients were successfully treated
- All plans achieved institutional coverage objectives
- Lung and kidney dosimetry acceptable and consistent improvement over conventional technique

Dosimetric Outcomes & Impact of Patient Size:
- Dosimetry varied substantially across the population:

Metric	Mean ± SD
PTV V90%	99 ± 1%
PTV D1cc	129 ± 7%
PTV V110%	17 ± 12%

- Increasing patient weight and maximum body separation (shoulder width) were associated with larger high-dose volumes and higher dose maxima
- Increasing patient size resulted in progressively larger regions of elevated dose despite equivalent optimization objectives
- Correlations related to patient height or scan length were substantially weaker due to the addition of increased number of isocenters
- No correlations between patient size and OAR doses

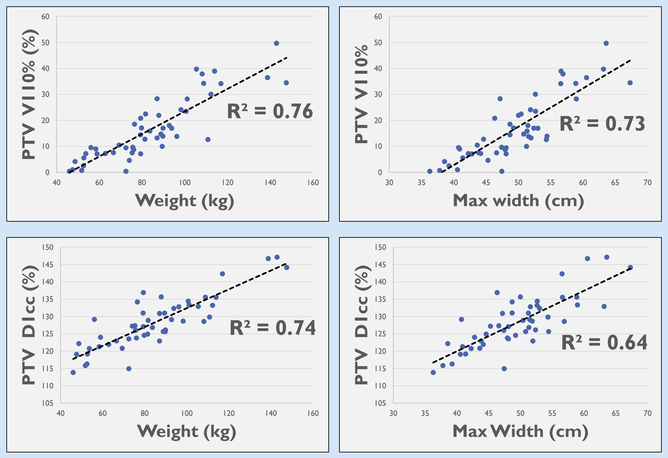

Figure 3. Patient high dose volumes (PTV V110%, D1cc) reported as a percentage of the prescription dose as a function of patient weight and patient maximum width, with linear fits applied

DISCUSSION

Key Findings:
- VMAT-TBI was successfully implemented in a community cancer centre
- Clinical technique was feasible across a wide range of adult body sizes
- Dose coverage objectives were achieved, and displayed consistent improvement over the traditional TBI procedure
- Larger patients resulted in significant high-dose volumes

Adult Patients Present Unique Challenges:
- Published VMAT-TBI experiences have primarily focused on pediatric and smaller adult populations
- Patient body separation rather than patient height was the dominant factor influencing dose heterogeneity
- Larger adults exhibited increasing high-dose volumes

Planning Trade-offs & Relevance to Fractionation:
- Treatments in this cohort primarily consisted of **single-fraction 2 Gy** conditioning regimens
- While observed dose inhomogeneities were clinically acceptable in this setting, higher-dose multi-fraction treatments may require more aggressive planning strategies and tighter dosimetric control
- High-dose volume reduction and improved OAR sparing have been observed with:
  - Additional isocenter placement and field overlaps
  - Increased number of fields in large separation areas
  - Increased field modulation and extended optimization with greatly increased MUs
- Improvements in homogeneity must be balanced against treatment complexity, planning time, delivery efficiency, and robustness

Recent Developments:
- VMAT-TBI continues to evolve rapidly, with increasing adoption and growing clinical experience worldwide
- Expanding reports from academic centres provide greater insight into planning strategies, workflow, and dosimetric considerations for adult patients
- **AAPM Grace Kim Memorial Challenge** has highlighted the complexities associated with planning large patients and the trade-offs between dosimetric quality and treatment complexity
- The forthcoming **AAPM TG-379** (Technical Guidelines for Total Body Irradiation, Total Marrow Irradiation, and Total Lymphoid Irradiation) is expected to provide further guidance and standardization for modern TBI techniques

CONCLUSIONS

- VMAT-TBI was successfully implemented and clinically deployed in a community cancer centre
- Acceptable target coverage and organ sparing was achieved across a diverse adult population
- Patient weight and body separation were the strongest predictors of dose inhomogeneity
- Larger patients receiving higher dose prescriptions may require individualized planning approaches to balance dose homogeneity and treatment deliverability
- Size-dependent planning considerations should be incorporated when extending VMAT-TBI from pediatric to adult populations

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