Modulated Electron Therapy

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Purpose

- The purpose of this presentation is to introduce the clinical medical physicist to the principles of modulated electron therapy.
- This presentation will cover in 30 minutes what was covered for photons in 4 days!
- Therefore, the attendee is referred to the written chapter for greater detail.

Definition
Electron Conformal Therapy

Electron conformal therapy (ECT) is the use of one or more electron beams for the following purposes:

(1) containing the PTV in the 90% dose surface

(2) achieving as homogeneous dose distribution as possible or a prescribed heterogeneous dose distribution to the PTV

(3) delivering minimal dose to underlying critical structures and normal tissues

Definition
Modulated Electron Therapy

Modulated electron therapy (MET) is ECT achieved using:
- energy modulation and/or
- intensity modulation

Methods for Electron Modulation

- Energy modulation can be achieved through:
  - continuous steps (<0.2 MeV) using bolus
  - discrete steps (1.5-4.0 MeV) using a small number of beams on a current therapy machine
- Intensity modulation can be achieved through:
  - scanned electron beam (limited access)
  - multi-leaf collimator (limited development)
  - multiple field cutouts (simulating MLC, but impractical)

Methods for Modulated Electron Therapy

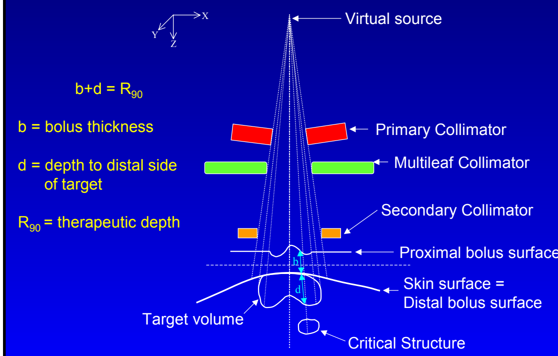
- Bolus ECT
- Segmented-field ECT
- Intensity-modulated Electron Therapy (IMET)

Relevant topics for each scheme are:
- Treatment planning
  - beam planning
  - dose calculation
- Treatment delivery
- Quality assurance
- Clinical utility

Bolus Electron Conformal Therapy

- Definition
  - Bolus ECT is the use of a single energy electron beam to deliver a dose distribution that conforms the 90% dose surface to the distal surface of the PTV.
  - Bolus ECT can be with or without intensity modulation.
- Treatment Planning
  - Design bolus using methods of Low et al. (1992)
  - Calculate dose using 3D-implementation of Hogstrom pencil beam algorithm (Starkschall et al. 1991)
  - Approved bolus file electronically transferred to bolus manufacturer

Bolus Creation Operator: Physical Depth



Electron bolus design operators

•Creation- provide the initial estimate of bolus shape
•Modification- modify initial bolus shape
•Extension- extend bolus to regions outside projection target volume and field

Operator	Description	Parameters	Type
P	Physical Depth	Δ, R_t	Creation
R	Effective Depth	Δ, R_t	Creation
I	Isodose Shift	R_t	Modification
S_t	Gaussian thickness smoothing	η,μ	Modification
S_h	Gaussian height smoothing	η,μ	Modification
T	Maximum coverage	η	Modification
C	Critical structure avoidance	η, D_c	Modification
H_t	Thickness extension		Extension
H_h	Height extension		Extension
O	Intensity modulation		

Low et al. (1992)

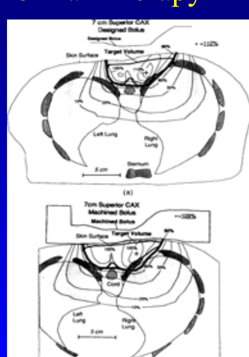
Bolus Electron Conformal Therapy

- Treatment Delivery
  - Bolus fabrication using machineable wax (.decimal, Sanford, FL)

  - Conventional electron beam delivery (single energy and irregular field cutout in applicator)

Bolus Electron Conformal Therapy

- Quality Assurance
  - Factory QA verifies thickness
  - CT scan and dose calculation with bolus verifies dose distribution



Low et al. (1994)

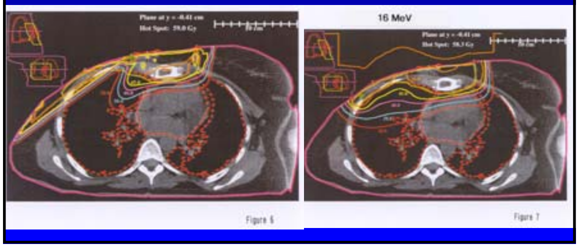
Bolus Electron Conformal Therapy

- Clinical Utility
  - Head and neck
    - parotid
  - Post-mastectomy chest wall
    - surgical defect
    - deformed surgical flap
    - recurrent disease at IMC-CW junction
  - Posterior wall sarcoma

Bolus Electron Conformal Therapy Chest Wall

- Recurrent disease at IMC-CW junction

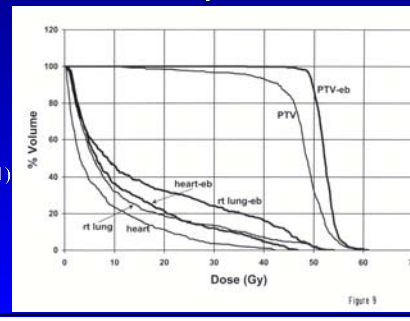
Perkins et al. (2001)



Bolus Electron Conformal Therapy Chest Wall

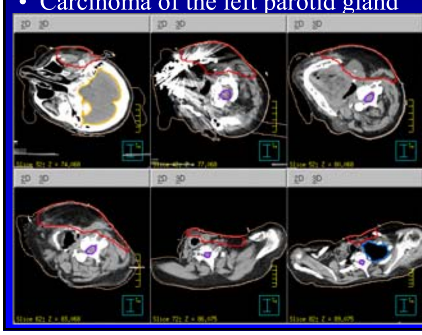
- Recurrent disease at IMC-CW junction

Perkins et al. (2001)



Bolus Electron Conformal Therapy Head and Neck-Parotid

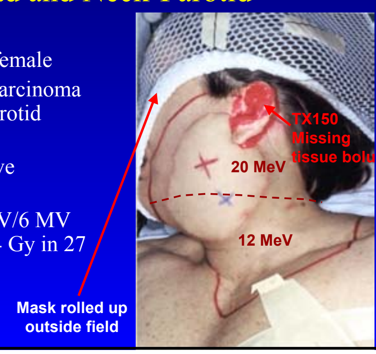
- Carcinoma of the left parotid gland



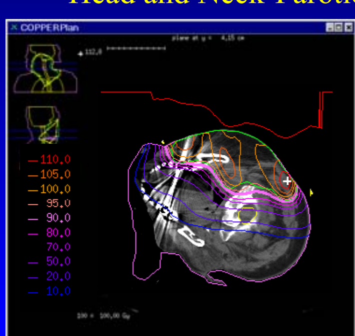
Kudchadker et al. (2002)

Bolus Electron Conformal Therapy Head and Neck-Parotid

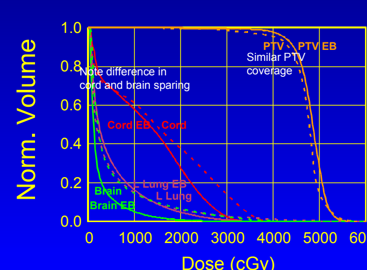
- 61 year old female
- Acinic cell carcinoma of the left parotid gland
- Post-operative radiotherapy
- Treat 20 MeV/6 MV (4:1) with 54 Gy in 27 fractions



Bolus Electron Conformal Therapy Head and Neck-Parotid



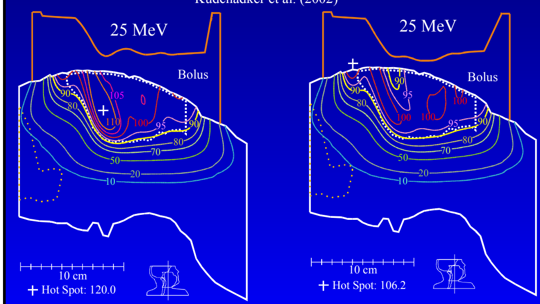
Bolus Electron Conformal Therapy Head and Neck-Parotid



Electron Bolus (EB)–solid lines
Patched Field plan–dashed lines

Bolus Electron Conformal Therapy with Intensity Modulation

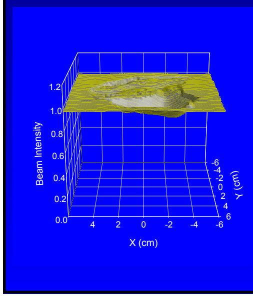
Kudchadker et al. (2002)

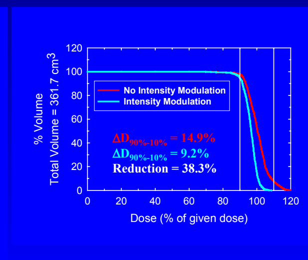


Without Intensity Modulation | With Intensity Modulation

Bolus Electron Conformal Therapy with Intensity Modulation

Kudchadker et al. (2002)

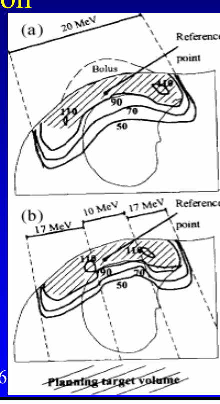




Dose volume histograms for PTV

Segmented-Field Electron Conformal Therapy

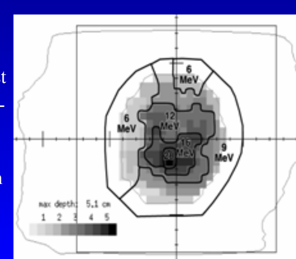
- Definition
  - Segmented field ECT is the utilization of multiple electron fields, each having a common virtual source but each having its own energy and weight, to deliver a dose distribution that conforms the 90% dose surface to the distal surface of the PTV.



Zackrisson and Karlsson, 1996

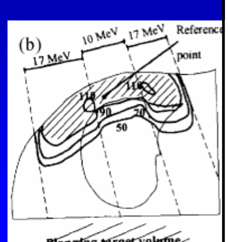
Segmented-Field Electron Conformal Therapy

- Treatment Planning:
  - Partition energy using BEV of depth to distal surface (Starkschall et al., 1994)
  - Such BEV tools do not exist
  - Calculate dose using pencil-beam or other 3D electron algorithm
  - Approve field segmentation and download beams to radiotherapy machine



Segmented-Field Electron Conformal Therapy

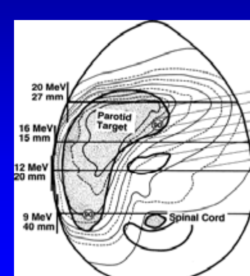
- Treatment Delivery
  - Multiple Cerrobend cutouts (limited to few fields)
  - ➔Isocentric with MLC (Scanditronix)
  - SSD with most MLC has too poor resolution
  - Electron multileaf collimator (eMLC)



Zackrisson and Karlsson, 1996

Segmented-Field Electron Conformal Therapy

- Treatment Delivery
  - Multiple Cerrobend cutouts (limited to few fields)
  - Isocentric with MLC (Scanditronix)
  - ➔SSD with most MLC results in too poor resolution
  - Electron multileaf collimator (eMLC)



Klein, 1998

Segmented-Field Electron Conformal Therapy

- Treatment Delivery
  - Multiple Cerrobend cutouts (limited to few fields)
  - Isocentric with MLC (Scanditronix)
  - SSD with most MLC has too poor resolution

➔Electron multileaf collimator (eMLC)

Antolak, Boyd, and Hogstrom, 2002

Segmented-Field Electron Conformal Therapy

- Quality Assurance
  - Not specified (similar to current electron therapy)
  - Could be modeled after IMXT
    - Calculate dose plan to cubical, water equivalent phantom in lieu of patient
    - Use film to measure dose in 3 othogonal planes of water equivalent phantom
    - Compare results to calculated dose

Segmented-Field Electron Conformal Therapy

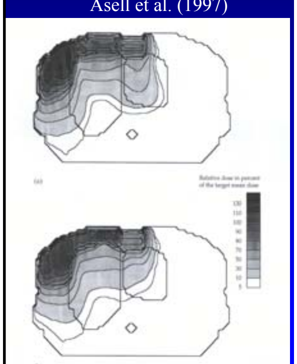
- Cinical Utility
  - Same as for bolus ECT

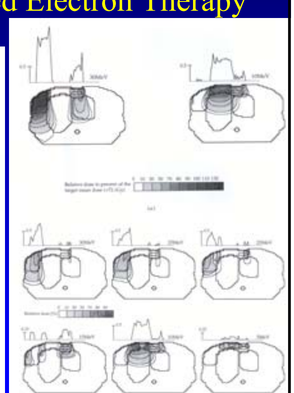
Intensity-Modulated Electron Therapy

- Definition
  - Intensity-modulated electron therapy (IMET) uses multiple electron beams, each of differing energy and intensity patterns, to deliver a dose distribution that conforms the 90% dose surface to the distal surface of the PTV.
- Pioneers in IMET
  - Hyödymnaa, Gustafsson, and Brahme (1996)
  - Åsell et al. (1997)
  - Ebert and Hoban (1997)
  - Lee, Jiang, and Ma, Ma et al., Lee et al. (2000)

Intensity-Modulated Electron Therapy

Åsell et al. (1997)





Intensity-Modulated Electron Therapy

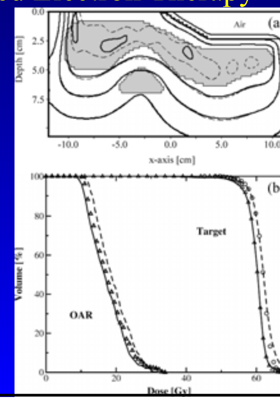
- Treatment Planning (Optimization)
  - Divide electron fields into beamlets.
  - Determine dose distribution for each beamlet, accounting for patient inhomogeneity, but ignoring collimator scatter.
  - Optimize beam weights to objective function.
  - Convert solution to MLC sequences.
  - Calculate dose distribution accounting for collimator scatter.
  - Optimize weights for each modulated beam energy

Intensity-Modulated Electron Therapy

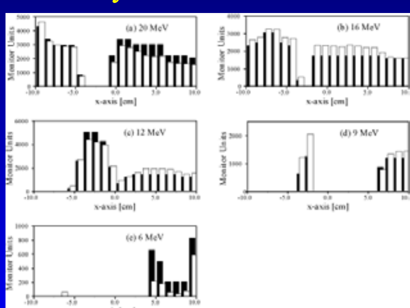
- Treatment Planning (Dose Calculation)
  - Monte Carlo algorithm or other algorithm that is more accurate than conventional PBA recommended for beamlet dose calculations (Ma et al., 2000)
  - Monte Carlo algorithm other algorithm that can account for collimator scatter and bremmstrahlung needed for final dose calculation (Lee et al. 2001)

Intensity-Modulated Electron Therapy

- Simulated 2D Plan (Lee et al., 2001)
  - 62.5, 50, 30, 10-Gy isodose contours
- Solid Curves
  - Plan ignoring leaf effects in planning
- Dashed Curves
  - Actual resulting plan delivered
- Triangles
  - DVH after second optimization



Intensity-Modulated Electron Therapy



Lee et al., 2001

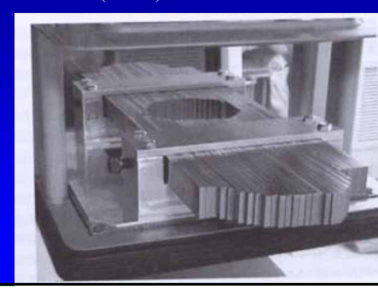
- Black bars- intensity maps after 1st optimization
- White bars- intensity maps after 2nd optimization

Intensity-Modulated Electron Therapy

- Treatment Delivery
  - xMLC has too poor resolution for treating at 100-cm SSD

  ➔Electron multileaf collimator (eMLC)

Ma et al. 2000



Intensity-Modulated Electron Therapy

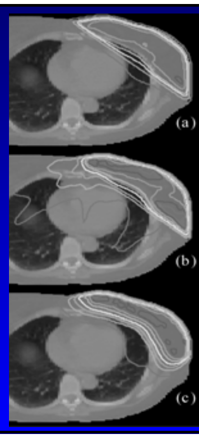
- Quality Assurance
  - Not specified
  - Could be modeled after IMXT
    - Calculate dose plan to cubical, water equivalent phantom in lieu of patient
    - Use film to measure dose in 3 othogonal planes of water equivalent phantom
    - Compare results to calculated dose

Intensity-Modulated Electron Therapy

- Cinical Utility
  - Same as for bolus ECT
  - Intact breast

Intensity-Modulated Electron Therapy

- Ma et al. 2003
- Isodose values
  - 55, 52.5, 50, 45, 40, 25, 15, 5 Gy
- Comparisons
  - (a) parallel opposed IMXT beams
  - (b) 4- field IMXT
  - (c) 8-field IMET



Bolus ECT Advantages and Disadvantages

- Advantages
  - + Continuous energy resolution
  - + Single treatment field
    - Fewer MU: Shorter treatment times and less x-ray leakage
    - No abutment issues due to dosimetry or patient motion
- Advantage/Disadvantage
  - ± Higher skin dose
- Disadvantages
  - Single energy requires greatest energy, resulting in greater $R_{90\text{-}10}$
  - Intensity modulation required to achieve optimal dose uniformity due to proximal bolus shape
  - Room entry required between fields

Segmented-Field ECT Advantages and Disadvantages

- Advantages
  - + Multiple fields of different energy, resulting in smallest possible $R_{90\text{-}10}$
  - + No room entry required if using eMLC to shape fields
- Advantage/Disadvantage
  - ± Lower skin dose
- Disadvantages
  - Greater MU: Longer treatment times and increased x-ray dose
  - Large energy intervals on linac (e.g. 3-4 MeV) can result in too deep of R_{90} over-irradiating normal tissue (e.g. lung)
  - Dose inhomogeneity from abutting fields of differing energy
  - Intensity modulation could be required to achieve dose uniformity due to patient heterogeneity

Intensity-Modulated Electron Therapy Advantages and Disadvantages

- Advantages
  - + Well suited for inverse planning
  - + No room entry required if using eMLC to shape and modulate fields
- Advantage/Disadvantage
  - ± Lower skin dose
- Disadvantages
  - Greater MU: Longer treatment times and increased x-ray dose
  - Large energy intervals on linac (e.g. 3-4 MeV) can result in too great of $R_{90\text{-}10}$ over-irradiating normal tissue (e.g. lung)
  - Patient motion could impact dosimetry of abutted beamlets

Conclusions- Clinical Availability

- Bolus ECT
  - Proven useful in clinic
  - Could be widely available if manufacturers included 10-y old bolus design tools in their TPS
- Segmented Field ECT
  - Proven useful in clinic
  - Could become widely available if manufacturers could provide adequate eMLCs
  - Treatment planning could be improved by manufacturers including beam energy partitioning tools in TPS

Conclusions- Clinical Availability (continued)

- Intensity Modulated Electron Therapy
  - Its potential has been demonstrated on TPS, but not in clinic
  - Availability requires manufacturers to provide
    - dynamic eMLCs on linacs
    - Monte Carlo method on TPS
    - Optimization and segmentation methods on TPS
  - Clincial implementation also requires development of methods
    - for quality assurance
    - to potenially deal with patient motion

Conclusions- Needed Developments

- Linear Accelerators
  - electron MLCs (static and dynamic capability)
  - coincident electron and x-ray source positions
  - maximum energy of 25 MeV
  - closer energy spacing, ~ 1 MeV
- Treatment Planning Systems
  - Tools for ECT planning
  - Monte Carlo dose algorithms
- Quality Assurance Methods
  - IMET methods similar to those in IMXT

Conclusions
Other Potential Applications

- Electron Arc Therapy
  - dynamic MLC for dose uniformity
  - multiple arcs of differing E for improved dose uniformity and conformality
- Mixed Beam Therapy
  - useful for both abutted and combined fields
  - optimized combination of IMXT and IMET will be better than either!