Bolus Electron Conformal Therapy (BECT)
Personalized Electron Beam Therapy Using Custom Treatment Devices

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Credited Content

Recognition to the following individuals for providing content/slides used within this presentation

- Dr. Kenneth Hogstrom (MBPCC/LSU)
- Dr. Robert Carver (MBPCC/LSU)
- Mitch Harrison, Nicole Hamm (Adaptiiv)
- Mary Snyder, Ivan Ramos (.decimal)
BECT at Siteman Cancer Center

- 12 Linear Accelerators
- 10 Radiation Oncologists who have used decimal
- First patient treated in 2010
- Treated 100+ patients
  - Head/face/neck
  - Extremities
  - Back
  - Shoulder
  - Breast/CW scars/Nodes

Outline

I. Fundamentals of Bolus Electron Conformal Therapy

II. Clinical Workflow
  - Simulations
  - Treatment Planning/Ordering
  - Treatment Delivery

III. Clinical Cases: Nose, Back, Foot

IV. Future – Potential for Intensity Modulation
Why use electrons?
- Optimal for treating superficial tumors (d ≤ 6cm)
- Characteristics of electron dose distribution
  1. 90% - 100% dose spread (d <R_{90})
     - Uniform dose to Planning Target Volume (PTV)
  2. Sharp distal fall off (R_{90}-R_{10})
  3. Finite penetration depth (R_{p})
     - Limited dose to critical structures distal to PTV

Objective:
- Conform 90% isodose surface to distal PTV surface.

Case 1: Uniform Thickness Bolus
- Issue: R_{90} > d_{PTV}
- Decreases depth of R90
- Increases skin dose
- SuperFlab, Aquaplast, red wax, wet gauze
Total Scalp Irradiation
Electron+X-ray Technique (Tung et al 1995)

- 6 MV X-rays + 6-9 MeV Electrons
- 0.6-cm Bee’s Wax Bolus
  Manually Constructed

Constant Thickness Bolus

- Useful for MV x-ray & electron beam dose buildup

- Postmastectomy CW 0.5-cm Bolus
- Reconstructed Breast
  (Lee and Archer)
- Partial Scalp irradiation
  (Szal & Purdon)

- 3D Printed PLA
  Courtesy of James Robar
- .decimal Machineable Wax
  http://dotdecimal.com/products/photons/uniform-thickness-bolus/
Standard Electron Therapy

Common Challenges
- Surface Irregularities
  - Create hot/cold spots
- Variable depth target volumes
  - Healthy tissue/OARs distal to shallow PTV treated to prescription dose
- Sloping surface creates oblique angle of incidence

Standard Electron Therapy

- Objective:
  - Conform 90% isodose surface to distal PTV surface.
- Case 1: Uniform Thickness Bolus
  - Issue: $R_{90} > d_{PTV}$
- Case 2: Variable Thickness Bolus
  - Issue: Variable $d_{PTV}$
  - Vary bolus thickness off-axis
  - Conform therapeutic range to distal surface of PTV
Bolus Electron Conformal Therapy (BECT)

BECT Definition: Use of a single electron beam with a variable thickness bolus designed to:

- shape the distal 90% dose surface to conform and contain the PTV,
- deliver minimal dose to adjacent (underlying) normal tissues, and
- achieve as homogeneous dose distribution as possible to the PTV.

• Established commercial BECT product (2009)
• Creates bolus using milling techniques
• Design process utilizes work by Low et. al from MD Anderson developed in 1992
• Blue machinable wax milled to create custom bolus
  • Density = 0.92 g/cc
  • Conforms to patient surface
Bolus Electron Conformal Therapy (BECT)

Adaptiiv (formally 3D Bolus)
- Established commercial product (2016), 510(k) cleared July 18th
- Creates bolus via additive 3D printing techniques
- Custom software that generates a STL file to be locally printed
- Various filament materials
  - Polylactic Acid (PLA): primary recommended
  - Thermoplastic polyurethane (TPU): Under evaluation

Terminology

- Plan Characteristics
  - 9 MeV electron beam
  - Rx: 800 cGy to 90% IDL
  - Goal: Spare healthy brain tissue

- Bolus Characteristics:
  - Distal bolus surface conforms to patient surface
  - Proximal surface shapes dose distribution.
Bolus Regions/Margins

- **Modulated region**
  - Bolus thickness milled to shape isodose to target

- **Inner Bolus Margin**
  - User specified distance in from target edge towards CAX.
  - Flat extension of modulated surface
  - Minimizes effect of rapid reduction of target thickness
  - Typically ~ 5mm

- **Outer Bolus Margin**
  - User specified extension of milled surface out from block edge
  - Allows for minor modifications of block after verification simulation
  - Typically 1cm – 1.5cm

- **Unmilled Margin**
  - Flat outer border
  - Provides structure and aids in daily setup
Bolus Regions/Margins

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**Design Operators**

- Uses a series of design operators (Low et al. 1992)
  1. Creation Operators
  2. Modification Operators
  3. Extension Operators

1. **Creation Operator**
   - Defines initial bolus thickness (b)
   - Dependent on target depth along rayline from target

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**Decimal Terminology**

- **Bolus Regions/Margins**
  - **Outer Bolus Margin**
    - User specified extension of milled surface out from block edge
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    - Provides structure and aids in daily setup

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**Virtual source**

Virtual source

\[ b = R_{90} - d \]
Design Operators

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  1. Creation Operators
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1. Creation Operator
   - Defines initial bolus thickness (b)
   - Dependent on target depth along rayline from target

Bolus Electron Conformal Therapy
Outline

I. Fundamentals of Bolus Electron Conformal Therapy

II. Bolus Electron Conformal Therapy Clinical Workflow
   • Simulations
   • Treatment Planning/Ordering
   • Treatment Delivery

III. Clinical Cases: Nose, Back, Foot

IV. Future – Potential for Intensity Modulation

General Clinical Workflow

• Patient consult (Ideally includes physicist for evaluation)
• Initial CT simulation (Day 1)
• Initial treatment planning (Day 2 – 5)
  • Multi-modality fusions
  • Contour creation
  • Beam selection
  • Virtual bolus creation
• Bolus fabrication and shipping (Day 5 – 7)
• Verification simulation (Day 8)
• Final treatment planning (Day 8 – 10)
• First treatment fraction (Day 10)
Selection Criteria

- Target volume depth less than 6cm
- Target volume depth varies throughout the field
  - Uniform thickness bolus not sufficient
- Critical structures distal to target volume
  - Modulation necessary to reduce dose to critical structure
- Patient skin surface has significant variation or defects
  - Bolus ECT can minimize hot/cold spots

Initial Patient CT Simulation (Day 1)

Patient setup

- Physician present to delineate treatment volume
  - Typically wires skin
- Oriented to maximize bolus stability
  - Gantry angle close to AP (0° ± 20°)
- Consider and minimize possible collision of patient anatomy with applicator
  - Shoulder issues when treating neck
  - Couch table when treating extremities
Initial Patient CT Simulation (Day 1)

Immobilization devices
- Dependent upon treatment site
- Mask used for head and neck treatments
  - Cutout mask 1 cm beyond delineated treatment volume
  - If using eye shields, remove mask above eyes
- Alpha cradle/vac loc for torso and extremities
  - Important when treating areas that can flex and bend
  - Register other devices with AC if used.

Special Considerations
- Slice thickness
  - Typically 3mm
  - Reduce to 1.5mm for small targets
- Scan length
  - Scan at least 5cm – 7cm beyond treatment volume
  - Especially important for superior or inferior extent of anatomy
- Eye shields
- Ear and nose taped/filled
- Patient marked for alignment
- Many setup images taken
Initial Treatment Planning (Days 2-5)

Contours creation in TPS
- External contour modifications
  - Includes mask/cradle
  - Extended to allow for breathing and above eyes
  - Smooth to minimize sharp edges
- Wire contour
  - Inside/Outside
  - Override densities
- PTV contour
  - Variations from transverse slice
  - Causes hotspots if not smoothed

Beam selection in TPS
- Angle should be perpendicular to distal PTV surface
- Determine energy from deepest part of target volume
  - \( d = \text{deepest target} + 3\text{mm} \)
- SSD typically set to 105cm
  - Allows for bolus to clear electron applicator
  - Extended SSD for large targets/clearance
- Transfer plan, structures, and CT to bolus creation software
Bolus Electron Conformal Therapy

**Initial Treatment Planning (Days 2-5)**

1. **decimal BolusECT**

   - Two Step Process (.decimal)
     - Distal bolus surface design
     - Proximal bolus surface design
   - For BECT, select “Optimized Thickness Bolus”
   - Verify plan configurations parameters and make changes as necessary

2. **Block Outer Border**
   - Defaults to 1cm to allow for block modifications
   - Increase for large targets

3. **Depth Beyond Target**

4. **Minimum Thickness:**
   - Minimum allowable thickness of the bolus
   - Measured along a beam aligned ray-line
Initial Treatment Planning (Days 2-5)

Step 1: Distal Bolus Surface Design

- **Point Spacing**
  - Spacing used for the bolus surface meshes.
  - 1mm, 2mm, 4mm

- **Rolling Ball Smoothing**
  - Equivalent to rolling a ball of radius $R$, across the patient surface.
  - Smaller $R = \text{less smoothing}$
Initial Treatment Planning (Days 2-5)

Step 2: Proximal Bolus Surface Design

- Begins with a flat top bolus.
- Iteratively reduces bolus thickness along ray lines intersecting the PTV.
- Max of 10 steps
  - Creation/Modification operators
  - Dosimetric damping (bolus smoothing)

Truncate Operator

- Reduces the height of the bolus in the unmilled region.
- Typically 2 – 6mm above peak proximal surface
Initial Treatment Planning (Days 2-5)

Bolus Electron Conformal Therapy

- P.D dose calculation uses Hogstrom Pencil Beam Redefinition Algorithm
  - Shiu and Hogstrom (1991); Boyd, Hogstrom, Rosen (1998); Boyd, Hogstrom, Starkschall (2001)
  - High degree of accuracy
  - PTV typically under covered at R_{90}
    - p.d reports 30% to 60%
    - Visually examine R_{88}
    - Plan normalization achieves coverage
  - Must assess plan quality using clinically commissioned electron dose algorithm

Initial Treatment Planning (Days 2-5)

Adaptiiv 3D Bolus

- Utilizes ray-tracing to determine off-axis bolus thickness
- Incorporates smoothing to minimize localized hot/cold spots
- Smaller bolus to reduce weight, printing time
- Includes modulated surface with margin to extend outside beam
Initial Treatment Planning (Days 2-5)

Adaptiiv 3D Bolus

**STEP 1:** Create a plan in the TPS

**STEP 2:** Create a bolus in 3DB software

**STEP 3:** Bolus verification in the TPS

**STEP 4:** Hot Spot Correction*  
*Adaptiiv's Hotspot Correction is an automated feature and typically requires no more than 1 additional iteration back into the TPS

**STEP 5:** Bolus verification in the TPS

**STEP 6:** Create an STL file in 3DB software

1-4 min  
Average time taken to create a modulated bolus in 3D Bolus software

Fabrication and Shipping (Days 5 - 7)

- **Bolus fabrication** by .decimal, LLC (Sanford, FL)
  - p.d sends bolus file to .decimal for fabrication
  - Bolus milled from machineable wax block (Low et al 1994)
  - Delivery: 1-3 days

**Custom Conformal Thickness**

Blank Block of Wax
**Fabrication and Shipping (Days 5 - 7)**

- QA for bolus treatment
- Examine bolus for defects
- Reduce sharp edges if needed
  - Only on patient side
  - Typically no alteration needed
- Prepare bolus for simulation
  - Add BBs on unmilled surface
- Useful printouts
  - 3D rendering of patient
  - Bolus in multiple orientations
  - Multiple axial slices with bolus
Verification Simulation (Day 8)

- Setup patient in treatment position
- Register bolus to patient
  - Align lasers to bolus X-hairs
  - Delineate lasers position on immobilization device
  - Draw bolus edge on mask/skin surface
- Measure bolus rotation
  - Transverse (within 1 degree of planned gantry angle)
  - Record sagittal angle
- Scan patient
  - Use same slice thickness as initial scan
  - Extend 5cm above and below bolus
- Examine bolus fit
  - Use lung window/level
  - Air gaps should be <3mm
  - Reposition and rescan if necessary
- Rarely alter bolus
  - Add red wax bolus to fill in large gaps
  - Bolus thickness for low energy beams

Bolus Electron Conformal Therapy
Final Treatment Planning (Day 8 – 10)

- Fuse verification and initial image sets
- Transfer structures
  - Compare bolus contour to bolus position
  - MD verifies accuracy of PTV
- Transfer initial plan
  - Adjust block and beam angle
  - Recalculate dose

Final Treatment Planning (Day 8 – 10)

- Record SSDs in R & V
  - Skin surface
  - Bolus Flattop
- Projection of light field to bolus surface
First Treatment Fraction (Day 10)

- Setup patient and bolus to marks
  - Compare to 3D printouts and setup images
- Record bolus rotation
  - Within 1 degree of verification simulation
- Align light field to bolus surface
- Verify SSDs
- Image
  - MV/KV/CBCT

ECT Costs

- .decimal (Milling)
  - Materials: $300-$995 per bolus, depending on size
  - Shipping: Costs based on location and timeframe
  - Software: Currently free for download
  - Hardware: None

- Adaptiiv (3D printing)
  - Materials: $5-$12 per bolus
  - Printing Fee: $75-$90 per print
  - Shipping: None
  - Software: Varies as company offers both upfront license and pay as you go
  - Hardware: $5000 - $10000 for 3D printer
ECT Reimbursement

- Bolus ECT requires additional medically necessary steps
  - **Re-CT** of patient with bolus in place
  - A **second plan** required for verification
  - A **second complex device** – the variable thickness bolus

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Case 1: Nose Initial Simulation

- 58 y/o F with cutaneous squamous cell carcinoma at nasion with extension towards R medial canthus.
- 12 MeV treated to 66 Gy in 2 Gy/fx

Marks align to bolus edge

Marks align to bolus x-hairs

Angle L to R: 21.5 degrees

Bolus Electron Conformal Therapy
Case 1: Nose Treatment Plan

- Eye shield considered but not used due to electron energy and uncertain impact on dose distribution near PTV

Case 1: Nose First Fraction

Response to Treatment
- Grade 2 skin reaction
- Completely cleared up at 6 week follow-up
Case 2: Back Initial Simulation

- A 34-year-old African-American male with dermatofibrosarcoma protuberans to the upper back
- Reversed prone pillow registered to Alpha Cradle

Case 2: Back Treatment Plan

- Treatment 80% using DD and 20 MeV, 20% using not bolus with 16 MeV.
  - Planning goals: 95% of PTV covered by 95% of Rx
  - RX = 54Gy @ 2 Gy fractions
  - Lung Dmean < 10Gy, V20 < 20%
  - Heart Dmean < 5 Gy, V20 < 5%
  - Mixed bolus with non-bolus to reduce dose to skin graft
  - 110cm SSD

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Case 2: Back Treatment Plan

Case 2: Back Verification Simulation

Bolus Electron Conformal Therapy
Case 2: Back Treatment

- Dry desquamation along surgical incision lines.
  - Went on 4 day break between 21<sup>st</sup> and 22<sup>nd</sup> fraction.
- 6 week follow up
  - Skin recovered from treatment

Case 3: Foot Initial Simulation

- 71 female with 2cm clear cell sarcoma of the right lateral foot
- Conservative local excision with positive margins.
- 2:1 BECT to 6X weighting
  - 95% of PTV covered by 95% Rx
  - 45Gy initial plan in 1.8 Gy fx.
  - PTV retracted 3mm from skin
  - 16 MeV (137MU) used and 6 X (61MU).
  - Mixed to reduce dose to skin, spare foot and ankle joints
Case 3: Foot Treatment Plan

BECT Isodose Distribution

BECT DVH

Case 3: Foot Verification Simulation

- 12 degree L/R
- 3.5 degree Sup/INF

Bolus Electron Conformal Therapy
Case 3: Foot First Fraction Treatment

- Results: Erythema resolved at time of 6 week follow-up.
- Patient has maintained an active life, retained ability to walk/hike.

Case 4: Face with 3D Printed Bolus

Case Details:

- 67-year-old female with mycosis fungoides of the forehead, eyelid and nose
- 3D modulated bolus resulted in better sparing of all the OARs while providing a similar PTV coverage compared to uniform thickness bolus
Case 4: Face with 3D Printed Bolus

- Adult patient with mycosis fungoides of the scalp
- Significant reduction of air gaps compared to handmade bolus
- Provided tailoring of the 90% isodose to follow the PTV contour, while limiting dose to the brain

Case 5: Partial Scalp with 3D Printed Bolus

- Adult patient with mycosis fungoides of the scalp
- Significant reduction of air gaps compared to handmade bolus
- Provided tailoring of the 90% isodose to follow the PTV contour, while limiting dose to the brain
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Bolus Electron Conformal Therapy
with Intensity Modulation

How can electrons be intensity modulated?

Bolus Electron Conformal Therapy

Department of Radiation Oncology
Division of Medical Physics
Electron Intensity Modulation
Proposed Method
(Hogstrom et al 2017, accepted, JACMP)

- Passive Radiotherapy Intensity Modulators for Electrons-
  PRIME (equivalent to compensators for x-rays)

Bolus Electron Conformal Therapy with Intensity Modulation

Bolus ECT

Intensity Modulated Bolus ECT
Bolus Electron Conformal Therapy with Intensity Modulation

- **Bolus Electron Conformal Therapy**
  - Bolus ECT
  - Penumbra matching of electron fields of differing energy (segmented-field ECT)
  - SSD and irregular surface effects of electrons

- **Passive Electron Intensity Modulators**
  - Under development by .decimal LLC & MBPCC
    - Planning software
    - Passive delivery device (intensity modulator)
    - Clinical QA methods
  - Potential Applications
    - Bolus ECT
    - Penumbra matching of electron fields of differing energy (segmented-field ECT)
    - SSD and irregular surface effects of electrons
Questions?

Thank you!

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