# *Bolus Electron Conformal Therapy (ECT)*

Personalized Electron Beam Therapy
Using Custom Treatment Devices

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Kenneth Hogstrom, PhD

Senior Medical Physics Advisor, Mary Bird Perkins Cancer Center
Professor Emeritus, LSU Medical Physics & Health Physics Program
Professor Emeritus, The University of Texas M D Anderson Cancer Center

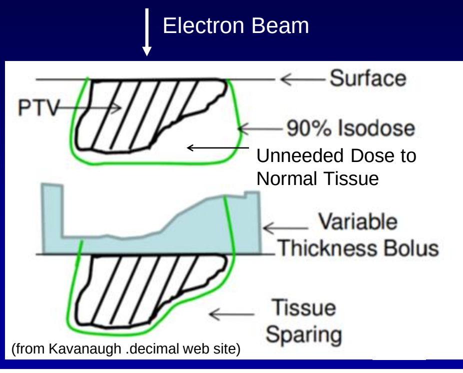
## *Bolus Electron Conformal Therapy*

I. What is Bolus ECT?
II. Clinical Utilization of Bolus ECT
III. Planning Bolus ECT
IV. Bolus ECT Dose Calculation Accuracy
V. Delivering Bolus ECT (Fabrication & QA)
VI. Future – Potential for Intensity Modulation

## Types of Electron Boluses

- Uniform-thickness bolus (e.g. chest wall, scalp)
  - Increases surface dose (low energy beams)
  - Spares distal tissues by providing continuously varying energies (6-20 MeV) from set of typically 7
- Flat-top bolus (e.g. nose or ear)
  - Smoothes skin surface (perpendicular to beam direction) reducing dose heterogeneities
- Variable-thickness bolus (all sites)
  - Thickness varies with off-axis position conforming therapeutic range (e.g. $R_{90}$) to distal PTV surface.

## Utility of Variable Thickness Bolus

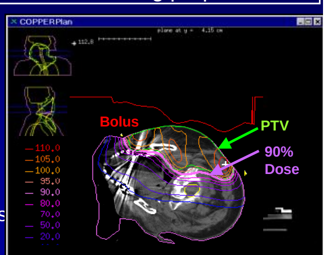


(from Kavanaugh .decimal web site)

## What is Bolus Electron Conformal Therapy? (Hogstrom et al 2003)

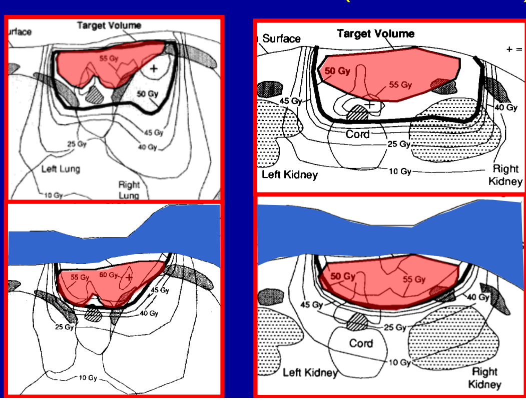
Bolus Electron Conformal Therapy (ECT) is the use of a single electron beam with variable thickness bolus that is designed for the following purposes:

- shaping the distal 90% dose surface to conform and contain the PTV,
- delivering minimal dose to adjacent (underlying) critical structures and normal tissues, and
- achieving as homogeneous dose distribution as possible to the PTV.



(Starkschall et al. 1994, 1995)

## Bolus: Posterior Wall Sarcoma (Low et al. 1995)



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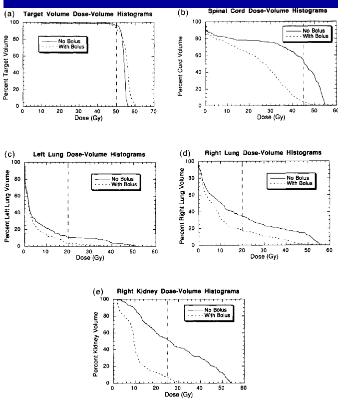


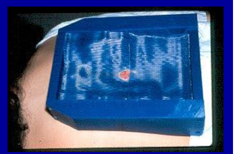

- Conclusions (bolus ECT vs. e⁻ only):
  - Bolus ECT greatly reduces dose to normal tissue.
  - Dose heterogeneity to PTV is increased.

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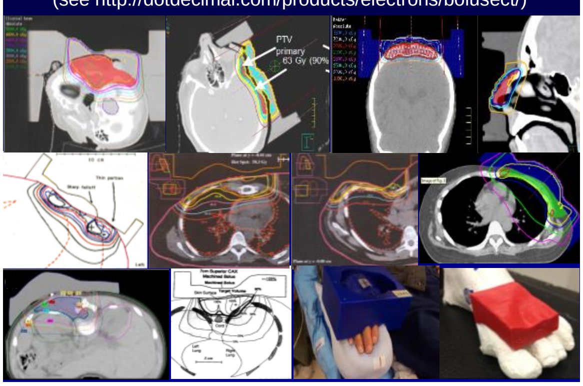
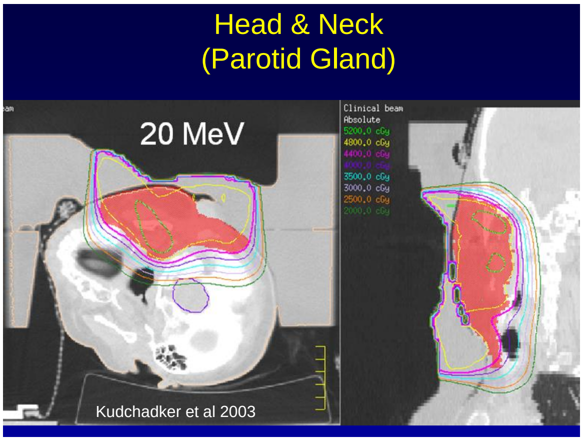
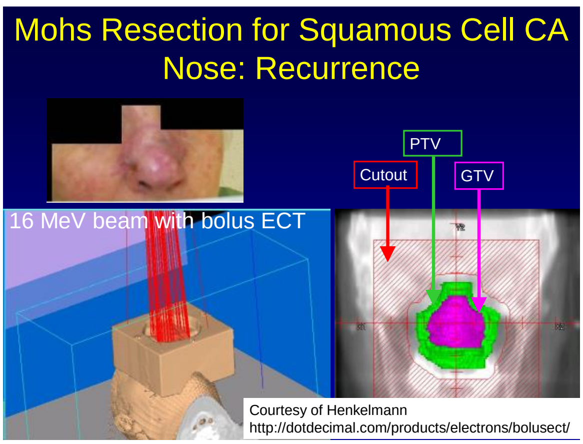
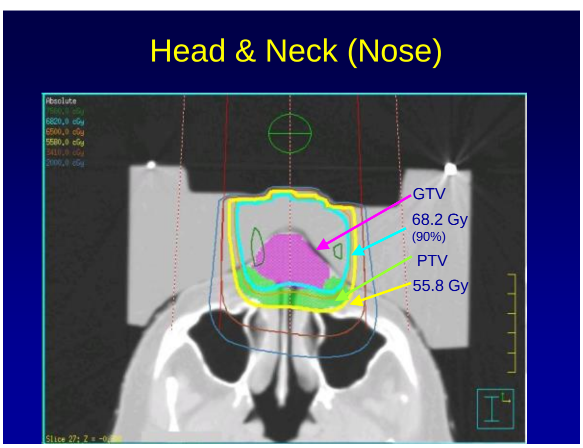
## Bolus ECT: Clinical Examples by Treatment Sites

(see http://dotdecimal.com/products/electrons/bolusect/)

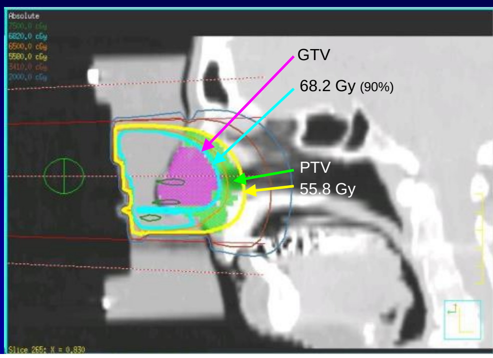



Head & Neck
(Parotid Gland)
20 MeV
Clinical beam
Absolute
5200.0 cGy
4800.0 cGy
4400.0 cGy
3500.0 cGy
3000.0 cGy
2500.0 cGy
Kudchadker et al 2003

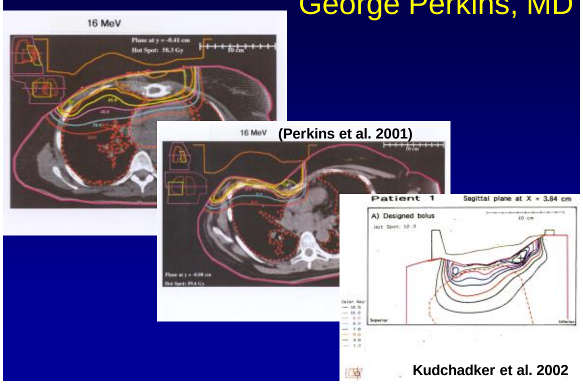

Mohs Resection for Squamous Cell CA
Nose: Recurrence
PTV
Cutout
GTV
16 MeV beam with bolus ECT
Courtesy of Henkelmann
http://dotdecimal.com/products/electrons/bolusect/


Head & Neck (Nose)
Absolute
GTV
68.2 Gy
(90%)
PTV
55.8 Gy

## Head & Neck (Nose)

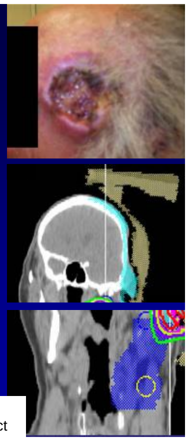



## Bolus ECT: Post Mastectomy Chest Wall
George Perkins, MD



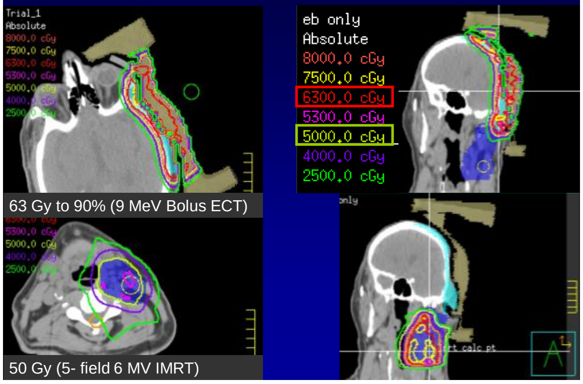

## Mixed Beam
L Temple & Upper Neck

- Patient History
  - Recurrence (1 year post-resection) differentiated squamous cell CA: 7-8 cm tumor resection (+ margins)
- L Temple Prescription
  - 63.0 Gy (28 fx) to 90% isodose surface
  - Bolus ECT using L oblique 9-MeV $e^-$ field
- L Upper Neck Prescription
  - 50 Gy (25 fx)
  - IMXT using 5-fields of 6MV x-rays
  - Abuts bolus ECT field (w/o bolus)



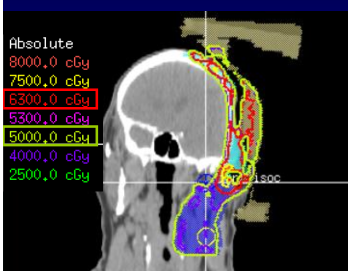
Courtesy of Henkelmann
http://dotdecimal.com/products/electrons/bolusect

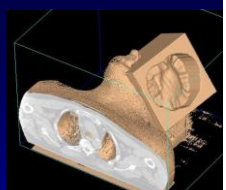
## L Temple & Upper Neck: Mixed Beam Plan




## L Temple & Upper Neck: Mixed Beam Plan

9 MeV Bolus ECT + 6 MV IMRT



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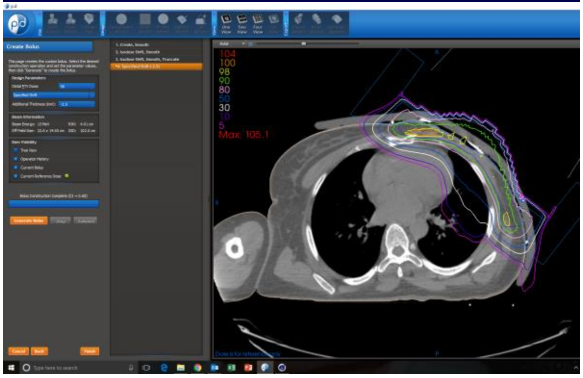
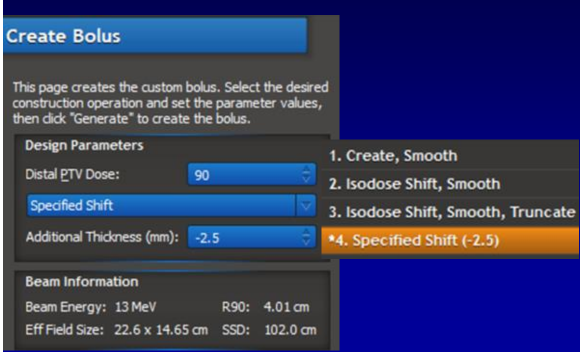
## Bolus ECT Treatment Planning Process
(highlighted steps are bolus specific)

- Perform planning CT scan of patient
- Plan w/o bolus in clinical TPS (e.g. Pinnacle or Eclipse)
  - Delineate PTV and prescription
  - Specify e⁻ beam angle (⊥ to distal PTV surface)
  - Specify e⁻ beam energy ($R_{90}$>max PTV depth)
  - Determine field shape (PTV + margin)
  - DICOM transfer plan w/o bolus to bolus design system
- Design bolus with .decimal p.d software (Low et al. 1992)
  - Create initial bolus (thickness = $R_{90}$ – depth to distal PTV)
  - Calculate dose using PBRA and modify as needed
  - Transfer bolus to TPS for dose calculation & .decimal for milling

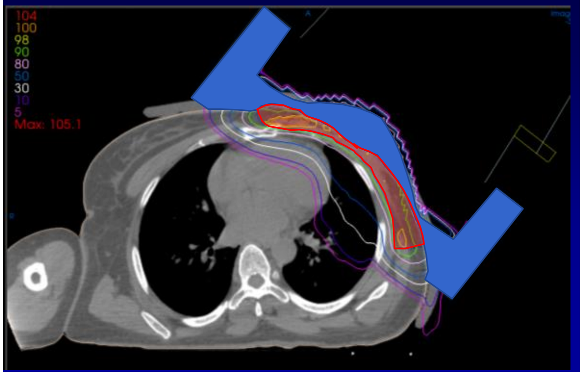
## .decimal p.d BolusECT® Software



## Bolus Design Using Operators (Low et al 1992)



## Bolus ECT Dose Distribution

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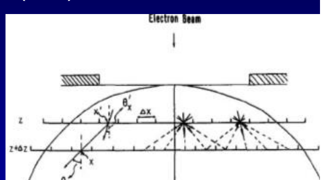
## Pencil Beam Redefinition Algorithm (PBRA)

p.d uses PBRA for Dose Calculations

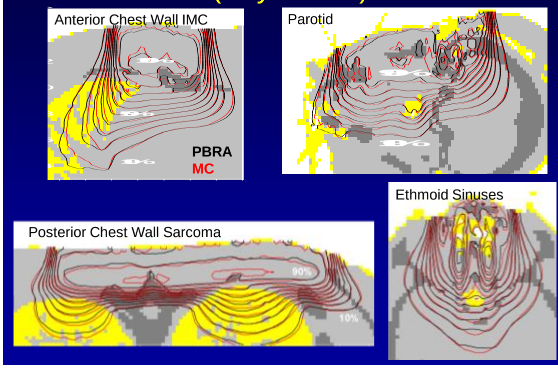
- Shiu and Hogstrom (1991); Boyd, Hogstrom, Rosen (1998); Boyd, Hogstrom, Starkschall (2001)



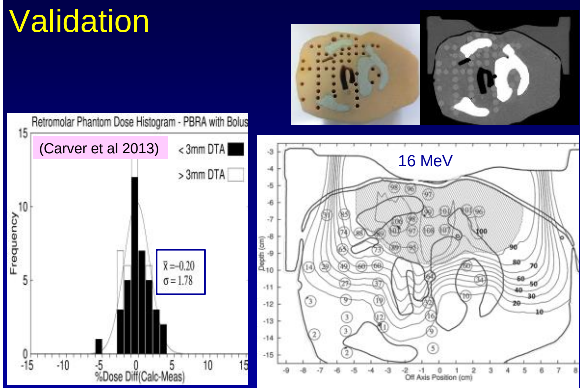

Advantages of PBRA

- Self commissioning for bolus design
- Faster, more precise, and more accurate than fast MC algorithm
- Accuracy is well documented

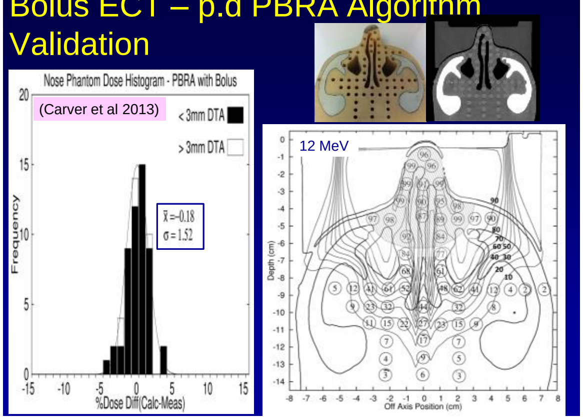
## PBRA & EGS MC Dose Comparison (Boyd 2001)



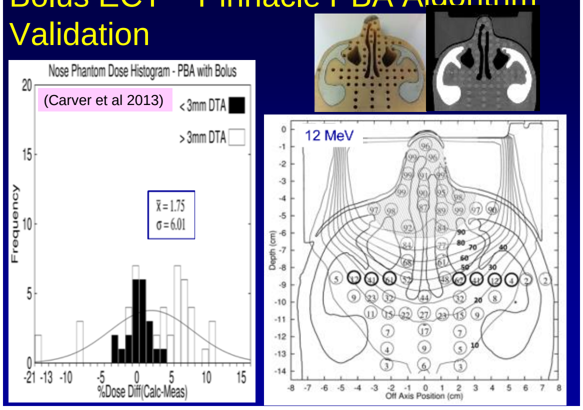

## Bolus ECT – p.d PBRA Algorithm Validation



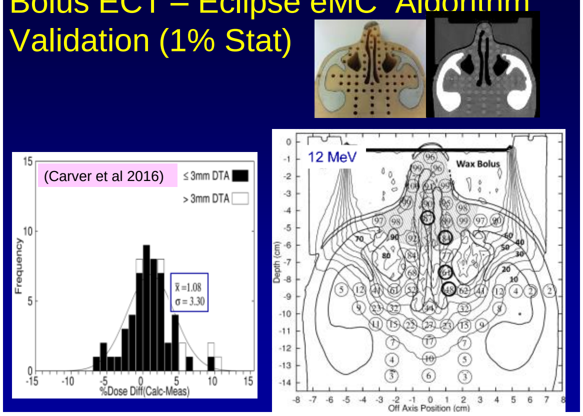

## Bolus ECT – p.d PBRA Algorithm Validation



## Bolus ECT – Pinnacle PBA Algorithm Validation




## Bolus ECT – Eclipse eMC Algorithm Validation (1% Stat)




## Bolus ECT: Dose Calculation Accuracy

Dose differences (Calculated – Measured): Mean ± 1 SD

| | Retromolar Trigone | Nose |
|---|---|---|
| p.d PBRA[1] | -0.20% ± **1.54%** | -0.18% ± **1.22%** |
| Eclipse eMC[2] | +0.01% ± **2.38%** | +1.30% ± **3.35%** |
| Pinnacle PBA[1] | -0.05% ± **3.14%** | -1.75% ± **5.94%** |

[1]Carver et al. 2013 [2]Carver et al. 2016

### Conclusions

- p.d PBRA is most accurate for bolus ECT planning.
- Eclipse eMC is sufficiently accurate for bolus ECT.
- Pinnacle PBA is marginally accurate for bolus ECT.

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## History of .decimal LLC Bolus Fabrication (Machineable Wax)

- MD Anderson Bolus ECT (Low et al 1992)
  - 1992-2000 in-house fabrication
  - 2000-2004 .decimal fabrication
- .decimal, LLC Offers BolusECT® (2009)
  - Free p.d device designing system (integrates with TPS)
  - Fabrication cost: $300-$1,000 (size & delivery)
- US Market
  - 350 institutions to date
  - 2,200+ boluses delivered to date (500 in 2016)

## BolusECT® - Bolus Fabrication

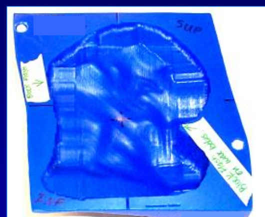
- Bolus fabrication by .decimal, LLC (Sanford, FL)
  - p.d sends bolus file to .decimal for fabrication
  - Bolus milled from machineable wax block (Low et al 1994)
  - Delivery: 1-2 days


Blank Block of Wax


.decimal Farm of Milling Machines

## BolusECT® - Bolus Fabrication

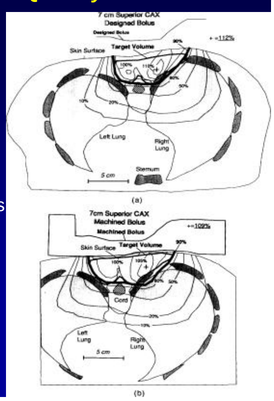
Patient Surface



Beam Surface

## Bolus ECT: Pre-treatment Quality Assurance (Low et al. 1995)

- Quality Assurance (factory)
  - .decimal verifies thickness before shipping
- Quality Assurance (clinic)
  - Acquire patient CT scan w/ bolus
    - Initially: CT simulator
    - Daily: Cone beam CT
  - Calculate dose with bolus on patient
  - Verify bolus fabrication and localization by comparing dose calculation with dose plan

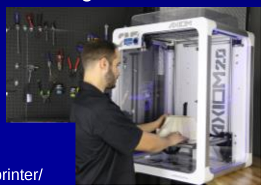



## Bolus Fabrication (3D Printing)

- Under development by 3D Bolus, Inc.
  - Bolus design using Su, Robar et al (2014) algorithms
  - Alternative business model for bolus ECT
- Planning
  - User purchases bolus ECT planning software
  - Compatible with TPS, but all dose calculations done in TPS
- Fabrication
  - User purchases 3D printer
  - User sets up 3D printing lab
  - User 3D prints bolus

## Bolus Fabrication (3D Printing) Challenges

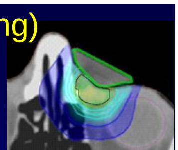
- Cost, space, & maintenance of 3D printer & supplies
- Long printing time for large boluses (0.5-2 days)
- Printing with accuracy and homogeneity
- Availability of commercial bolus design software



AXIOM 20 DUAL Direct Drive 3D Printer
$9,995.00
https://airwolf3d.com/shop/tall-desktop-3d-printer/

## Bolus Fabrication (3D Printing) Clinical Bolus

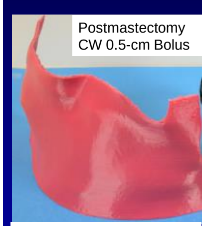
- Patient Boluses
  - Limited published clinical examples
  - Primarily smaller boluses/field sizes
- Small Bolus
  - Inner canthi (Lukowiak et al 2017)
  - Pinna ( Zhao et al 2017)
- Medium Bolus
  - Rhabdomyosarcoma (Su et al 2014)



## Constant Thickness Bolus

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

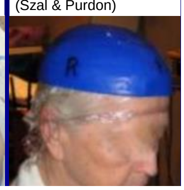
Postmastectomy
CW 0.5-cm Bolus



3D Printed PLA
Courtesy of James Robar

Reconstructed Breast
(Lee and Archer)

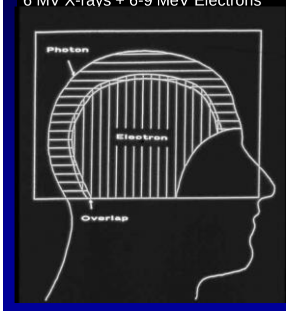
Partial Scalp irradiation
(Szal & Purdon)



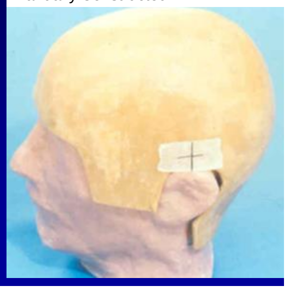
.decimal Machineable Wax
http://dotdecimal.com/products/photons/uniform-thickness-bolus/

## 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



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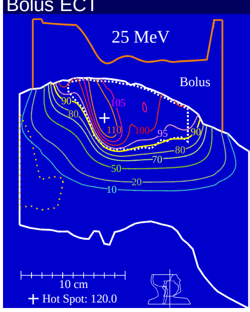
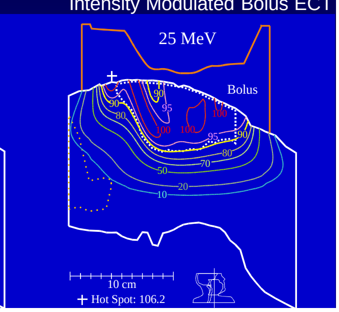
## Bolus Electron Conformal Therapy with Intensity Modulation

(Kudchadker et al 2002)

Bolus ECT



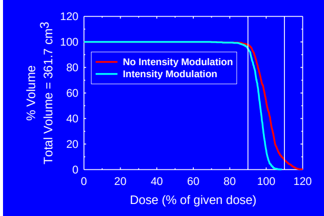

Intensity Modulated Bolus ECT

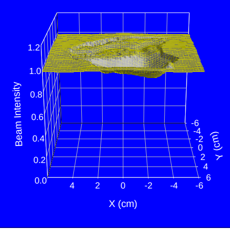


## Bolus Electron Conformal Therapy with Intensity Modulation

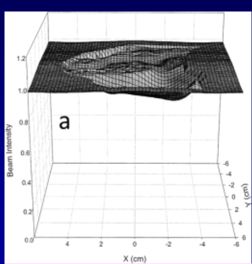
(Kudchadker et al 2002)

How can electrons be intensity modulated?

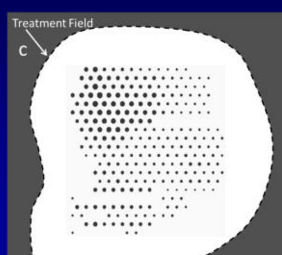



## Patient Example Intensity Modulator (Chambers 2016)



Desired Intensity Modulation 20 MeV

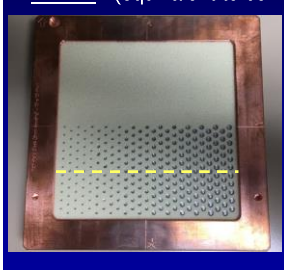


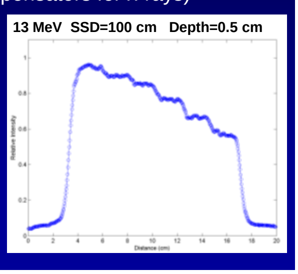
Intensity Modulator Design

## Electron Intensity Modulation Proposed Method

(Hogstrom et al 2017, accepted, JACMP )

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





## 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

## Impediments to Bolus ECT Utilization

- Lack of equitable billing codes
- Competition with IMXT, which has
  - Slightly better PTV dose homogeneity
  - Comparable doses to nearby normal tissues
  - Greater chance of secondary cancer to distal tissues
  - Greater revenue stream
- Decreasing knowledge of electron therapy amongst radiotherapy staff
- Antiquated electron planning tools in TPS
- Greater ease of use of bolus design tools
  - e.g. managing unsmoothed juts in distal PTV surface

## Summary: Bolus ECT

- Bolus ECT conforms the 90% dose surface to the PTV, significantly improving sparing of normal tissue.
- The utility of Bolus ECT for head and neck, postmastectomy chest wall, posterior chest wall, and extremities, is well documented in the literature (1995-present).
- BolusECT® has been commercially available for 8 years and used by ≈350 treatment centers. Free p.d software is compatible with most commercial TPS.
- PBRA and eMC algorithms are sufficiently accurate for bolus ECT; PBA algorithms are marginally accurate for some sites.
- Primary impediments to bolus ECT are lack of equitable billing codes, antiquated TPS tools, and IMXT.
- Future electron intensity modulators should improve PTV dose homogeneity.

## Summary
## Personalized Electron Beam Therapy Using Custom Treatment Devises

- Electron therapy can offer significant advantages, particularly for normal tissue sparing and reduced risk of 2° cancers (poor man's proton beam).
- Many tools (collimating inserts, skin collimation, eye shields, conformal bolus, and accurate dose calculations) exist for delivery of highly personalized electron therapy.
  - Most tools are commercially available
  - Treatment planning systems have failed to provide software that easily manages such tools and accurately calculates dose in their presence.