Evaluate clinical cases using commercially available systems and compare to TG-43 dosimetry

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Disclosure

- My institution is an Elekta's Center of Excellence in Brachytherapy
- I am the Chair of the AAPM/ESTRO/ABG Working Group on Model-based Dose Calculation Algorithms.
  - Our WG is working with all brachytherapy TPS vendors.
- Further acknowledgements to Mark J. Rivard, Firas Mourtada and many others in the fields who works on advanced dosimetry for brachytherapy over the years and contributed to the literature.

Learning Objectives

- For commercially available Model-based dose calculation algorithms:
  - Understand their performance relative to MC and TG43.
  - Understand the perturbation factors influencing dosimetry for key tumor sites.
  - Review current evidence of impact for key tumor sites.

Two commercial algo. (^{192}Ir)

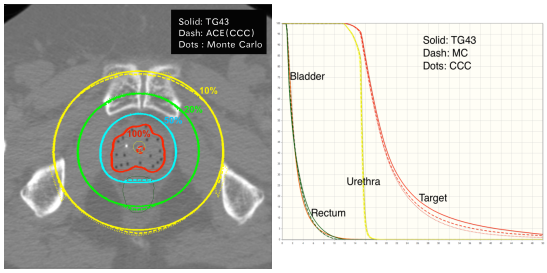
- Acuros (GBBS) from Varian and ACE (Collapsed-code) from Elekta
- Performs on par with Monte Carlo in most clinical situations
- Some limitation due to handling of mutltiple scatter component (e.g. far from the source) and discretization (e.g. angles)

Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					←
	low	XXX	XXX	XXX		
breast	high				XXX	
	low	XXX	XXX	XXX		
GYN	high			XXX		
	low	XXX	XXX			
skin	high			XXX	XXX	
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

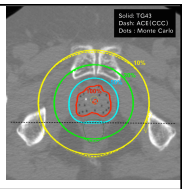
Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)

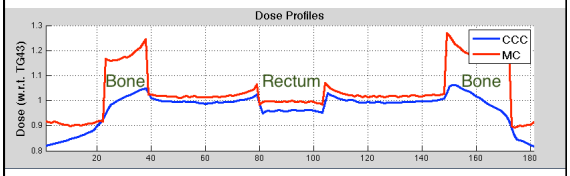
HDR Prostate implants



17 catheters; rectum set to air!

HDR Prostate implants





- Remaining issue with the multiple scatter point-kernels

Summary for Prostate Brachytherapy

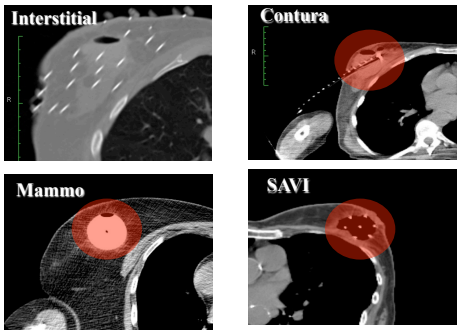
- Minimal impact for
  - CTV-PTV
  - OARs: rectum, bladder, urethra

Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

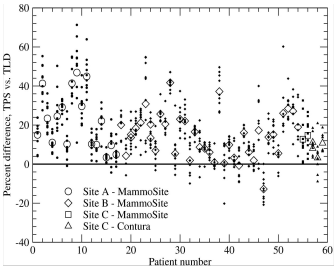
anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					
	low	XXX	XXX	XXX		
breast	high				XXX	←
	low	XXX	XXX	XXX		
GYN	high			XXX		
	low	XXX	XXX			
skin	high			XXX	XXX	
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)

One size does not fit all!
Same for the dosimetry …



Skin Doses: study on 59 patients

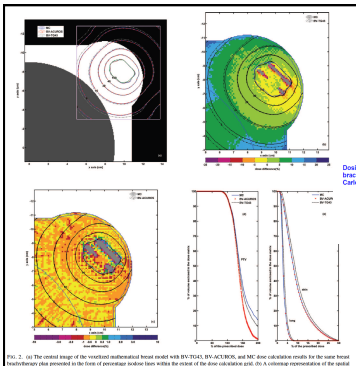


TLD skin dose meas.

- TPS-TLD: -13% to 47%
- Average: 16% overestimation
- MC or Acuros: < 5%

Raffi JA et al, Med. Phys. 37 (2010).

ACUROS benchmark



Dosimetric accuracy of a deterministic radiation transport based ^{192}Ir brachytherapy treatment planning system. Part III. Comparison to Monte Carlo simulation in voxelized anatomical computational models

- Negligible effect on PTV coverage
  - Difference V150, V200
- Overestimation for skin and lung doses

Abstracts / Brachytherapy 10 (2011) S14–S101

Balloon-Based Accelerated Partial Breast Irradiation With Contura™: Comparison Between Conventional TG-43 and Brachyvision Acuros™ Dose Calculation Methods

Ruben Ter-Antonyan, PhD[1], Paul W. Read, MD, PhD[2], Bernard F. Schneider, MD, PhD[1], Anneke T. Schroen, MD, MPH[2], Stanley H. Benedict, PhD[1], Bruce P. Libby, PhD[1]. [1]Radiation Oncology, University of Virginia Health System, Charlottesville, VA; [2]Surgery, University of Virginia Health System, Charlottesville, VA.

- 5 Contura patients

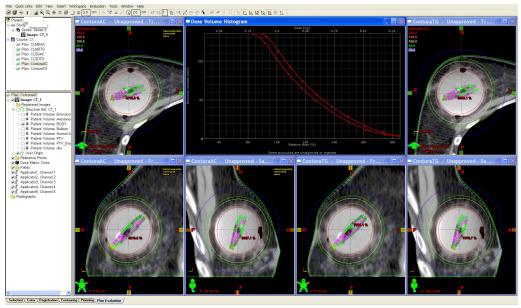
	TG-43	Acuros™	Difference
PTV_eval D95 (cGy)	322.7	311.9	(3.4 ± 0.5) %
PTV_eval D1 (cGy)	816.4	806.6	(1.2 ± 0.6) %
PTV_eval D_{min} (cGy)	238.4	254.1	(-7.1 ± 7.1) %
PTV_eval V150 (cm^3)	26.5	24.0	(9.2 ± 1.3) %
Skin D_{max} (cGy)	439.0	420.1	(4.6 ± 1.2) %
Skin D_{mean} (cGy)	242.8	226.6	(6.7 ± 0.6) %
Skin D_{skin_pt} (cGy)	297.1	278.1	(6.7 ± 1.7) %

courtesy of F. Mourtada

Abstracts / Brachytherapy 9 (2010) S23–S102

Comparison between Two Dose Calculation Methods, Acuros and TG43: Implications for Accelerated Partial Breast Irradiation

Jill P. Heffernan, M.D., Lynn Gilbert, C.M.D., Douglas W. Arthur, M.D., Dorin A. Todor, Ph.D. Radiation Oncology, Virginia Commonwealth University, Richmond, VA.



courtesy of D. Todor

Abstracts / Brachytherapy 9 (2010) S23–S102

Comparison between Two Dose Calculation Methods, Acuros and TG43: Implications for Accelerated Partial Breast Irradiation

Jill P. Heffernan, M.D., Lynn Gilbert, C.M.D., Douglas W. Arthur, M.D., Dorin A. Todor, Ph.D. Radiation Oncology, Virginia Commonwealth University, Richmond, VA.

- 30 patients evaluated $Skin_{max}$, Rib_{max}, D90, V100, V150, V200
- Variety of applicators including interstitial
  - Results for interstitial were within 3% or 3cc
- Balloon based:
  - $Skin_{max}$ – 8% including >10% if only using central lumen/single dwell
  - Rib_{max}- 5% on average
  - Target coverage less (3.5% – 8%)
  - Larger balloons had greater differences in V100, etc.

courtesy of F. Mourtada

Summary for Breast Brachytherapy

- The experts agree that in using TG43 for APB:
  - If you are using high levels of contrast – your overall dose is decreased
  - Skin dose is decreased ~ 4-10%
  - Dose to ribs is decreased ~ 5 -7%
  - Dose coverage is probably slightly reduced
- New methods of dose calculation are promising and show we have gains to be made in accuracy

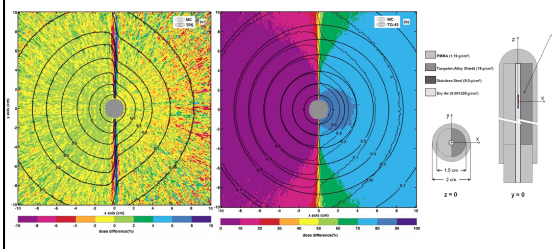
Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					
	low	XXX	XXX	XXX		
breast	high				XXX	
	low	XXX	XXX	XXX		
GYN	high			XXX		←
	low	XXX	XXX			
skin	high			XXX	XXX	
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)

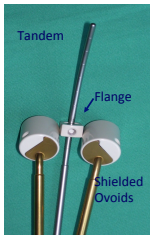
Shielded Geometry

Petrokokkinos *et al*., MedPhys 38, 1981-1992 (2011)

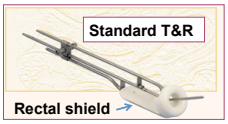


GYN Standard Applicators too many to list

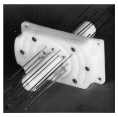
Fletcher-Williamson T&O



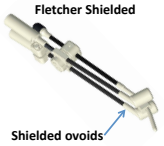
Standard Cylinder
Regular or shielded



Interstitial



Fletcher Shielded



courtesy of F. Mourtada

Impact of Heterogeneity-Based Dose Calculation Using a Deterministic Grid-Based Boltzmann Equation Solver for Intracavitary Brachytherapy

Justin K. Mikell, B.S.,*,† Ann H. Klopp, M.D., Ph.D.,† Graciela M.N. Gonzalez, M.P.H.,‡ Kelly D. Kisling, M.S.,†,§ Michael J. Price, Ph.D.,** Paula A. Berner, B.S.,* Patricia J. Eifel, M.D.,† and Firas Mourtada, Ph.D.*,†,††

*Departments of *Radiation Physics, †Radiation Oncology, ‡Biostatistics, §Radiation Physics—Patient Care, and ¶Experimental Diagnostic Imaging, The University of Texas MD Anderson Cancer Center, Houston, Texas; ||University of Texas Graduate School of Biomedical Sciences at Houston, Houston, Texas; **Department of Physics and Astronomy, Louisiana State University and Agricultural and Mechanical College, Baton Rouge, Louisiana, and Mary Bird Perkins Cancer Center, Baton Rouge, Louisiana; and ††Department of Radiation Oncology, Helen F. Graham Cancer Center, Newark, Delaware

Summary

This study investigated the use of a grid-based Boltzmann solver (GBBS) for cervical cancer patients treated with unshielded CT/MR applicators. The GBBS was found to have minimal impact on clinical dosimetric parameters for these patients. GBBS differences from standard TG-43 dose estimates were mainly due to source, boundary, and applicator model differences. CT-to-material mapping of rectal and balloon contrast did not impact clinical dosimetry. Rectal dose parameters may be affected by incorrectly mapping packing material.

Purpose: To investigate the dosimetric impact of the heterogeneity dose calculation Acuros (Transpire Inc., Gig Harbor, WA), a grid-based Boltzmann equation solver (GBBS), for brachytherapy in a cohort of cervical cancer patients.

Methods and Materials: The impact of heterogeneities was retrospectively assessed in treatment plans for 26 patients who had previously received ^{192}Ir intracavitary brachytherapy for cervical cancer with computed tomography (CT)/magnetic resonance–compatible tandems and unshielded colpostats. The GBBS models sources, patient boundaries, applicators, and tissue heterogeneities. Multiple GBBS calculations were performed with and without solid model applicator, with and without overriding the patient contour to 1 g/cm^3 muscle, and with and without overriding contrast materials to muscle or 2.25 g/cm^3 bone. Impact of source and boundary modeling, applicator, tissue heterogeneities, and sensitivity of CT-to-material mapping of contrast were derived from the multiple calculations. American Association of Physicists in Medicine Task Group 43 (TG-43) guidelines and the GBBS were compared for the following clinical dosimetric parameters: Manchester points A and B, International Commission on Radiation Units and Measurements (ICRU) report 38 rectal and bladder points, three and nine o'clock, and D_{2cm3} to the bladder, rectum, and sigmoid.

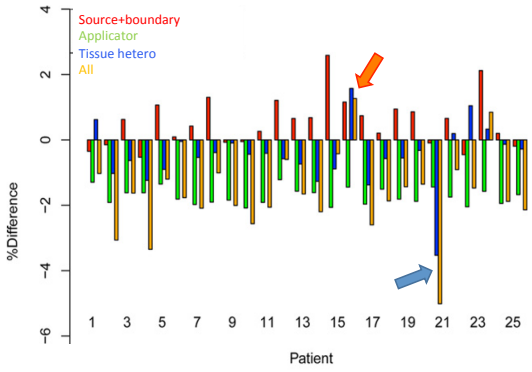
Results: Points A and B, D_{2cm3} bladder, ICRU bladder, and three and nine o'clock were within 5% of TG-43 for all GBBS calculations. The source and boundary and applicator account for most of the differences between the GBBS and TG-43 guidelines. The D_{2cm3} rectum ($n = 3$), D_{2cm3} sigmoid ($n = 1$), and ICRU rectum ($n = 6$) had differences of >5% from TG-43 for the worst-case incorrect mapping of contrast to bone. Clinical dosimetric parameters were within 5% of TG-43 when rectal and balloon contrast were mapped to bone and radiopaque packing was not overridden.

Conclusions: The GBBS has minimal impact on clinical parameters for this cohort of patients with unshielded applicators. The incorrect mapping of rectal and balloon contrast does not have a significant impact on clinical parameters. Rectal parameters may be sensitive to the mapping of radiopaque packing. © 2012 Elsevier Inc.

- ✓ VS-2000 source
- ✓ Applicator part #: AL07334001

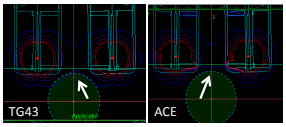
IJROBP, vol 83, No 3, pp e414-e422, 2012

ICRU Rectal Point Dose Impact of GBBS relative to TG-43



MDACC Clinical Outcomes (n=12)

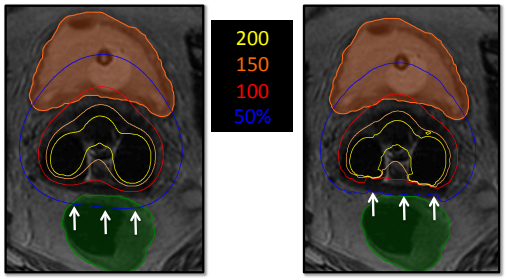
- Enrolled on prospective protocol of image based brachytherapy
- PDR brachytherapy with Fletcher CT/MR Shielded Applicator



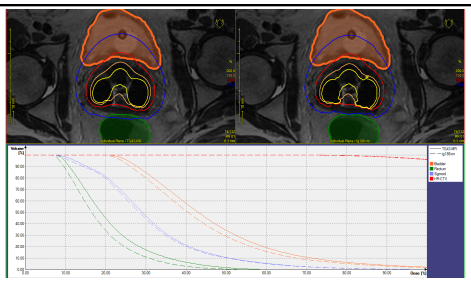
Castle KO, Mourtada F, Klopp AH, Rechner LA, Cunningham MG, Bruno TL, Berner PA, Jhingran A, Allen PK, Lawyer A, Eifel P, "Dose reduction to rectum and bladder using the Fletcher CT/MR shielded applicator for cervical cancer brachytherapy", **ABS Annual Meeting, San Diego, CA, April 3-5, 2014**

Dose Distribution at Ovoids

TG43 (no shields) TG186 (shields modeled)



courtesy of F. Mourtada



Rectum: Mean (Range)	Bladder: Mean (Range)	Sigmoid: Mean (Range)
– D2cc 15% (5-22)	– D2cc 6% (3-12)	– D2cc 2% (1-14)
– D1cc 15% (4-22)	– D1cc 6% (3-11)	– D1cc 2% (1-13)
– D0.1cc 13% (3-22)	– D0.1cc 6% (1-11)	– D0.1cc 2% (1-12)

courtesy of F. Mourtada

Summary for GYN Brachytherapy

- The new brachy dose calculation algorithms provide more accurate dose distributions for GYN brachytherapy than the standard TG-43.
- Unshielded GYN CT/MR applicators impact is within +/-5%
- Shielded GYN Applicator significantly reduces dose to rectum, bladder, and sigmoid (up to 25%)

Sensitivity of Anatomic Sites to Dosimetric Limitations of Current Planning Systems

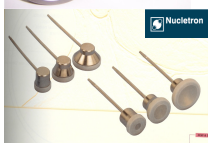
anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					
	low	XXX	XXX	XXX		
breast	high				XXX	
	low	XXX	XXX	XXX		
GYN	high			XXX		
	low	XXX	XXX			
skin	high			XXX	XXX	←
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)

HDR ^{192}Ir Skin Molds/Flaps

courtesy J. Perez-Calatayud

HDR ^{192}Ir Shielded (Leipzig) Applicators

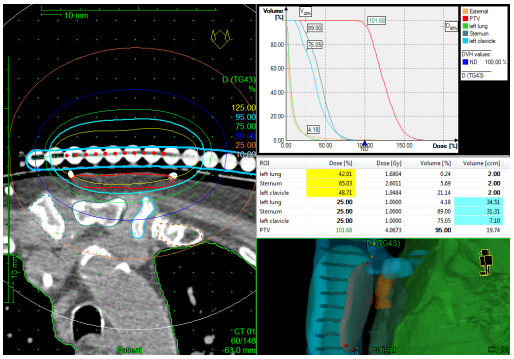


Cup-shaped of tungsten
Horizontal and Vertical
Diameters 1 cm, 2 cm, 3 cm

Plastic cap 1 mm, to reduce skin dose due to electrons

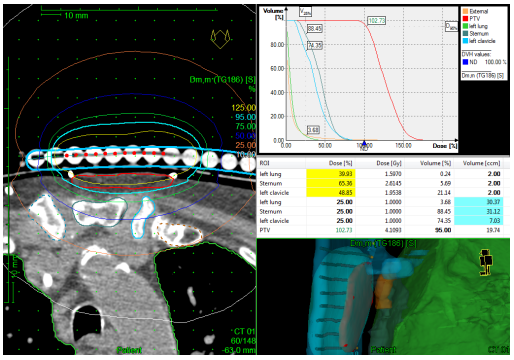
courtesy J. Perez-Calatayud

Oncentra® ACE TG-43



courtesy Y. Niatsetski

Oncentra® ACE TG-186



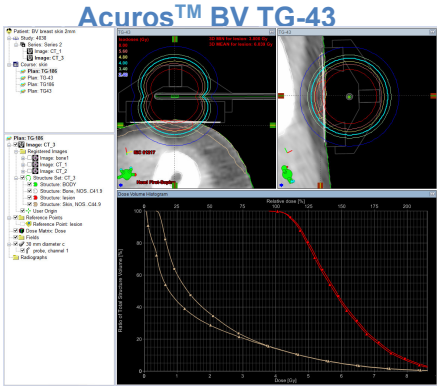
courtesy Y. Niatsetski

Oncentra® ACE Skin Mold Differences

target	TG-43 D_{95} (Gy)	TG-186 D_{95} (Gy)	TG-43 Dose (%)	TG-186 Dose (%)
PTV	**4.07**	**4.11**	**101.7**	**102.7**
no big deal for skin mold				
ROI	TG-43 V_{25} (cm^3)	TG-186 V_{25} (cm^3)	TG-43 V_{25} (%)	TG-186 V_{25} (%)
sternum	**31.31**	**31.12**	**89.00**	**88.45**
clavicle	**7.10**	**7.03**	**75.05**	**74.35**
lung	**34.51**	**30.37**	**4.18**	**3.68**

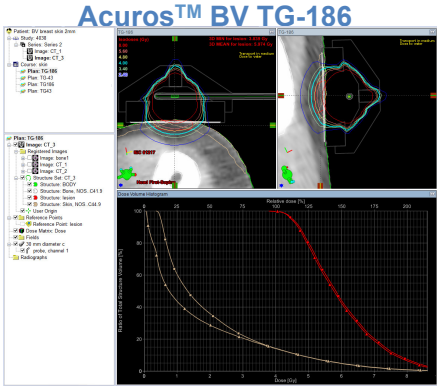
courtesy of M Rivard

Acuros™ BV TG-43



courtesy R. Park

Acuros™ BV TG-186



courtesy R. Park

Acuros™ BV Shielded Applicator

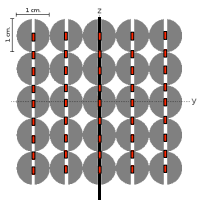
target	TG-43 D_{95} (Gy)	TG-186 D_{95} (Gy)	TG-43 Dose (%)	TG-186 Dose (%)
PTV	**4.50**	**4.50**	**100.0**	**100.0**
collimation is important				
ROI	TG-43 V_{25} (cm^3)	TG-186 V_{25} (cm^3)	TG-43 V_{25} (%)	TG-186 V_{25} (%)
skin	**3.97**	**2.88**	**60.1**	**43.7**
bone	**3.32**	**5.85**	**3.88**	**6.83**

courtesy of M Rivard

Comparing TG-43 and MC for Skin BT

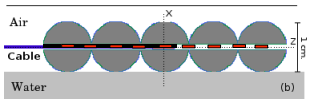
Dosimetry comparison between TG-43 and Monte Carlo calculations using the Freiburg flap for skin high-dose-rate brachytherapy

Javier Vijande[1,2,*], Facundo Ballester[1], Zoubir Ouhib[3], Domingo Granero[4], M. Carmen Pujades-Claumarchirant[5], Jose Perez-Calatayud[5]



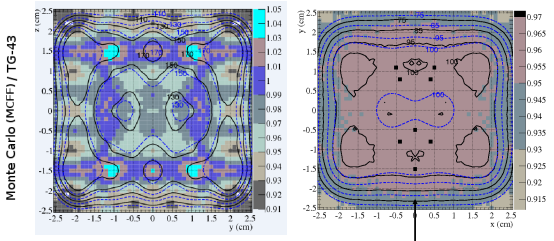
⇨evaluate scatter defect, air gap

⇨5x5 cm^2 clinical mesh



Vijande et al, *J Contemp Brachy* 4, 34-44 (2012) courtesy J. Perez-Calatayud

Comparing TG-43 and MC for Skin BT



surface

+5% to -7%

5 mm depth

-4% to -7%

over/under dose compensation between adjacent spheres

Vijande et al, *J Contemp Brachy* 4, 34-44 (2012) courtesy J. Perez-Calatayud

Summary for Skin Brachytherapy

- Challenges due to irregular surface
  - Interplay between scatter and shielding effects
- Departure from TG43 calculated dose depends on shielding and/or presence of air gaps
  - Small for PTV with unshielded geometry
  - Need further doe recalculation studies of (large) patient cohorts

Head and Neck?

anatomic site	photon energy	absorbed dose	attenuation	shielding	scattering	beta/kerma dose
prostate	high					
	low	XXX	XXX	XXX		
breast	high				XXX	
	low	XXX	XXX	XXX		
GYN	high			XXX		
	low	XXX	XXX			
skin	high			XXX	XXX	
	low	XXX		XXX	XXX	
lung	high				XXX	XXX
	low	XXX	XXX		XXX	
penis	high				XXX	
	low	XXX			XXX	
eye	high			XXX	XXX	XXX
	low	XXX	XXX	XXX	XXX	

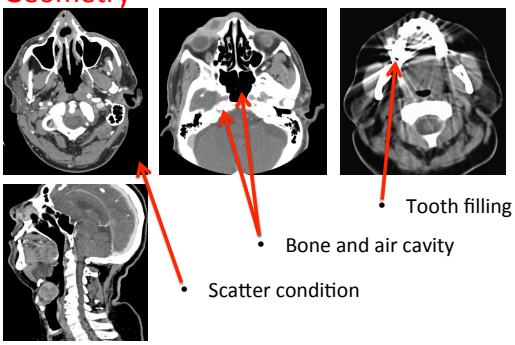
Rivard, Venselaar, Beaulieu, *Med Phys* 36, 2136-2153 (2009)

References

- Poon E, Verhaegen F. A **CT-based analytical dose calculation method for HDR ^{192}Ir brachytherapy**. Med Phys 2009;36:3982–94.
- Siebert F-A, Wolf S, Kóvacs G. **Head and neck ^{192}Ir HDR-brachytherapy dosimetry using a grid-based Boltzmann solver**. jcb 2013;5(4):232–5.

Comparative dose calculation data sets limited

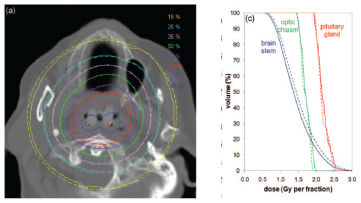
Geometry



- Tooth filling
- Bone and air cavity
- Scatter condition

TG43 vs MC

Poon *et al*, Med Phys 36 (2009)



MC = solid lines; TG43= dashed lines

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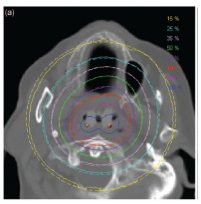
TG43 vs MC



- Target dose unaffected
  - Dominated by primary
- $D_{TG43} > D_{MC}$ brain stem
  - Screening by bones
- $D_{TG43} > D_{MC}$ close to skin

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AcurosBV vs TG43

Siebert *et al*, J Contemp Brachytherapy 2013

- 49 consecutive patients, 2001-2009
- floor of mouth carcinoma
- larynx carcinoma
- parotid carcinoma
- 2.5 Gy/Fx
- BV 8.8 and Acuros 1.3.1

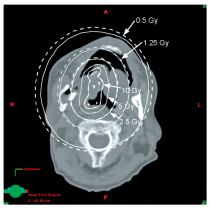

Fig. 1. Transversal CT slice of a patient with mandibular cancer with infiltration of the floor-of-mouth and tongue using a single prescription dose of 2.5 Gy. Dotted isodose lines represent doses of TG-43 formalism, whereas straight lines show isodose lines of computations of the GBBS algorithm

AcurosBV vs TG43

Siebert *et al*, J Contemp Brachytherapy 2013

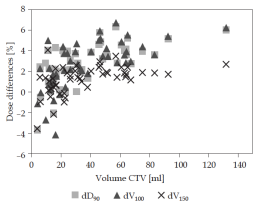

Fig. 2. Dose differences in percent between TG-43 formalism and the GBBS (TG-43 minus GBBS) for D_{90}, V_{100}, and V_{150} of the CTV versus volume of the CTV. A positive dose difference means that TG-43 result was larger than the GBBS results

- $D_{TG43} > D_{MC}$ by ≈ 3%
- CTV D90 and V100
  - Range -4% to +7%
- Larger volumes lead to larger differences
  - Primary vs scatter contributions to total dose important

Summary for H&N Brachytherapy

- Limited data set available from H&N brachytherapy dose recalculation
  - Almost nothing beyond CTV data
- Differences small on average for CTV
  - Over and under dosage is patient specific(!)
  - Effects greater at distance from CTV

Conclusion

- Advanced dose calculation algorithms offer significant advantages for many commonly encountered clinical situations
  - From a few % to many tens of % for shielded geometries
- Algorithms desperately needed for low energy brachytherapy: seeds or eBx
  - Much larger effects expected
- Only for dose recalculation for now
  - Plan optimization with TG43 remains the std of care