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Calibration, dosimetry, and radiation safety for a directional brachytherapy source

AAPM Spring Clinical Meeting

Kissimmee, FL

3/31/2019

IT'S HOW MEDICINE SHOULD BE®

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Disclosures

- Rush University is participating in a pancreatic cancer study sponsored by CivaTech and funded by the NIH.

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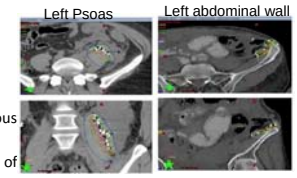
Who needs a directional IORT brachytherapy source?

- Treat positive margins without treating adjacent tissue
- Our experience
  - 9 patients planned in previous three years
  - 3 patients cancelled at time of surgery
- Clinical trial NCT02843945



First two patients treated with CivaSheet at RUMC, treating resection margins in left psoas and left abdominal wall (Zhen et al 2018)

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Outline

- Description of the CivaDot
- Review of CivaDot and CivaSheet dosimetry
- CivaDot calibration procedure
- Radiation safety concerns

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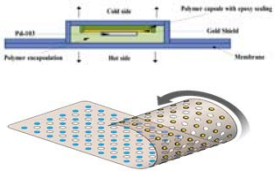
Description of CivaDot/CivaSheet

- CivaDot
  - ^{103}Pd source
  - Gold shield
- CivaSheet
  - Bioabsorbable polymer sheet
  - Source spacing 8 mm
  - Can order
    - 5x10 cm (6x12 sources)
    - 5x15 cm (6x18 sources)



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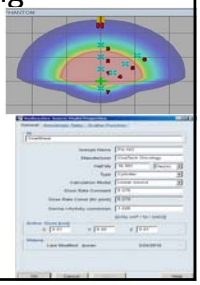
Review of CivaDot and CivaSheet Dosimetry

- Source modeling
- Verification of source model
- Source strength nomogram
- Pre-and-post implant dosimetry of a directional source

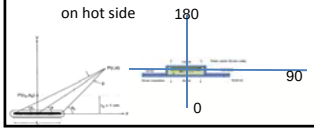
Source Modeling

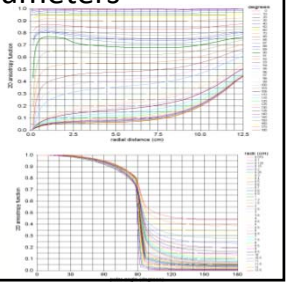
- Source specified for dose calculation according to modified version of TG-43 protocol
- Source parameters provided by vendor
- Modeled, E.g., in Brachyvision



TG-43 Parameters

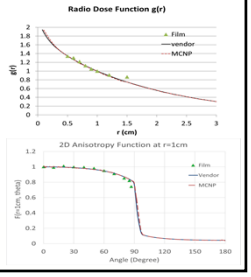
- TG-43 parameters described by Rivard, *Brachytherapy* 16(2):421-432 using MCNP6
- Anisotropy functions shown
- Shows, e.g., at 10 cm from source, dose on shielded side is 20% dose on hot side



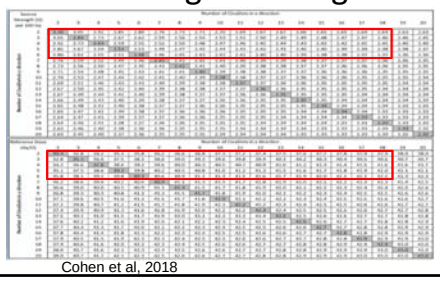


Verification of Source Model

- We independently compared TG-43 model to both MC simulation and film
- Λ within 1.7%
- g(r) within 0.5% for MC, 2.7% for film
- F(r,θ) within 0.9% (0-85° 100-180°)



Source Strength Nomogram



Cohen et al, 2018

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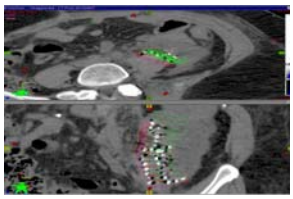
Pre-and-post implant dosimetry of a directional source

- Difficulty of performing treatment planning in commercially available TPS (e.g., Brachyvision)
  - Determining source orientation
  - Specifying source orientation within the TPS



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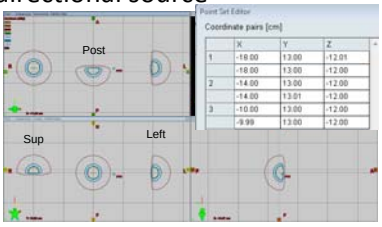
Pre-and-post implant dosimetry of a directional source

- In Brachyvision, the source is modeled with finite size
- Relative location of two coordinates gives source position
- Manual method: orient viewing plane orthogonal to intended source direction, and click-and-drag source



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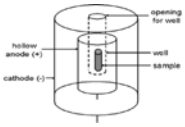
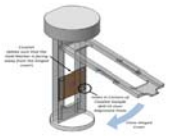
CivaDot calibration procedure

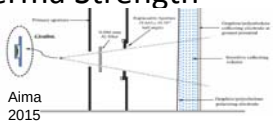
- NIST → UW ADCL → RUMC
- An HDR 1000 plus Well-typed Ion Chamber with a CivaDot-specific insert was sent to Wisconsin ADCL
- An AKS calibration factor was obtained (7.912×10^{11} U/A)





Reference Air Kerma Strength

- Measurement performed at UWM using VAFAC (Aima 2015)
- Tested for repeatability, compared to NIST WAFAC, and further investigated (Aima 2018)

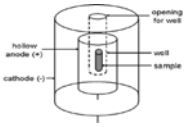


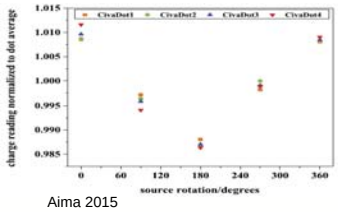
Aima 2015

NIST Source ID	UW VAFAC	u	NIST WAFAC	u	Difference
#	S_K (U)	(%)	S_K (U)	(%)	(%)
005 A	5.27	1.82	5.27	1.74	-0.1%
005 B	5.30	1.80	5.28	1.78	0.4%
005 C	5.17	1.82	5.16	1.79	0.2%
CSH-010-1	4.22	1.80	4.20	1.69	0.4%
CSH-010-5	4.21	1.82	4.16	1.76	1.1%
CSH-010-7	4.21	1.79	4.20	1.80	0.3%
CSH-010-13	4.13	1.80	4.13	1.75	0.0%
CSH-010-14	4.16	1.80	4.15	1.86	0.2%

Aima 2018

CivaDot calibration procedure





Aima 2015

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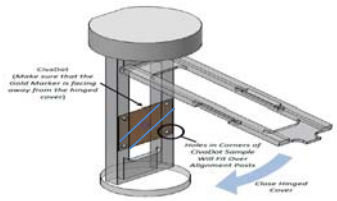
CivaDot calibration procedure



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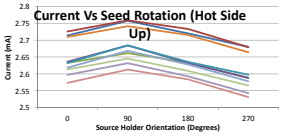
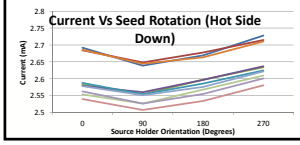
CivaDot calibration procedure





	Charge Collected (nc)		
Seed	Hot Side Up	Hot Side Down	% Difference
1	54.36	53.64	1.32%
2	54.48	53.62	1.58%
3	52.58	51.84	1.41%
4	52.70	51.86	1.59%
5	52.75	51.76	1.88%
6	54.15	53.52	1.16%
7	52.46	51.63	1.59%
8	51.51	50.81	1.35%
9	52.17	51.29	1.69%
10	51.82	51.22	1.16%
Average	52.90	52.12	1.47%

RUMC data

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EXAMPLE CALIBRATION

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CivaTech ONCOLOGY P.O. Box 14310, Research Triangle Park, NC 27709

CivaTech® Oncology Certification Palladium-103 Sealed Source for Medical Use

Sales Order Number: 1902501

The radioactive sources listed below are certified to have the following characteristics for the reference date:

Reference Date: 2019/02/12 (YYYY/MM/DD) 1100 Eastern Time USA

[illegible]

EXPIRES: 11/30/2019 LIMIT: 37 GBq

ALL CIVADOT SOURCES HAVE PASSED A LEAK TEST SHOWING <5 nCi (<185 Bq) OF REMOVABLE Pd-103 ACTIVITY

VALUES LISTED ARE BASED ON CORRECTED NIST WAFAC CALIBRATION ($S_{K,NIST}$)

Package: [illegible] | Lot ID: CSH-154 | Product: CivaSheet | Area of CSH (mm²): 7500 | # CH Sources: 10

SOURCE STRENGTH VIA NIST 2017 WAFAC CivaDot® Standard for Pd-103*	
Total Activity – mCi (A)	158.56
Mean CSH Activity per Dot – mCi/Dot (A)	1.344
Activity Range per Dot – mCi/Dot (A)	1.313 – 1.408
Total Activity – MBq (A)	5866.2
Mean CSH Activity per Dot – MBq/Dot (A)	49.713
Activity Range per Dot – MBq/Dot (A)	48.595 – 52.100
Mean CSH Air Kerma Strength per Dot – μGy·m²h⁻¹/Dot ($S_{K,NIST}$)	2.049
Air Kerma Strength Range per Dot – μGy·m²h⁻¹/Dot ($S_{K,NIST}$)	2.003 – 2.148

*Guidance from the AAPM cautions the use of appropriate dose rate constant as recommended by the AAPM in reference 1.

NOTE: The contained activity (A) is used here because of the anisotropic emission from the sources due to gold shielding, and should be used for shipping and storage purposes only. A is calculated by dividing $S_{K,NIST}$ by 1.525.

References to guidance from the American Association of Physicists in Medicine, The American Brachytherapy Society and CivaTech® Oncology consultants.

[illegible]

CivaTech® Oncology (919)314-5515

02/08/2019 Date

Low Dose Rate Brachytherapy Measurement Data

Calibration Completed: 25/APR/2018 Report Date: 25/APR/2018

Re-Entrant Chamber

Standard Imaging
Model: HDR1000 Plus
S/N: A960811

Electrometer used in Calibration

Standard Imaging, Inc.
Model: SUPERMAX
S/N: P111024

Type	Well-type
Atmospheric Communication	Open
Calibration Source	Pd-103 CivaTech Oncology model CivaDot

For detailed source parameters, please refer to the Joint AAPM/IROC Registry at: rpc.mdanderson.org

Source Activity	1.147 mCi
Source Holder Used	CivaDot source holder, S/N 201601-11
Source Reference Point	Gold marker faced away from hinged cover
Collecting Electrode Bias	+300 V
Charge Collected	Negative
Pre-Irradiation Leakage	-6.0×10^{-15} A
Calibration Uncertainty	3.5 %

Calibration Coefficient (at 22 °C and 101.325 kPa)

Air Kerma Strength Calibration Coefficient: **7.970×10^{11}** μGy m²/h/A

Comments: *This calibration is based on the average of four charge readings at source holder rotational orientations of 0, 90, 180 and 270 degrees. This calibration is valid only for the specific source holder referenced above and is considered to be an integral part of the reported calibration coefficient. The calibration coefficient as reported above has been determined using the 01/DEC/2013 NIST Wide-Angle Free Air Chamber calibration for this model seed.*

Rush University Medical Center

CivaSheet Pd-103 Source Strength Calibration

Patient Name: [redacted] MRN [redacted]

Source Information :

Manufacturer	Civa	
Vendor Calibration Ref Date	2/12/2019	
Vendor Calibration Ref Time *(24h)*	11:00	*Central*
Vendor Stated Source Strength	2.049	*U*

Measurement Devices:

	manufacturer	Model	Serial Number	Calibration Date
well chamber	Standard Imaging	HDR 1000 plus	A960811	4/25/2018
Source Holder	CivaTech	CivaDot holder	201601-11	3/17/2016
electrometer	Standard Imaging	SuperMax	P113204	

Chamber Calibration Factor : N_{Sk}	7.970E-01	*U/pA*
Electrometer correction factor: P_{EL}	0.999	*pA/* Rdg

Measurements:

$S_k = M_{raw} \cdot P_{EL} \cdot C_{T,P} \cdot N_{Sk}$

Temperature	23.1	°C	$C_{T,P}$ =	*T/(273.15+22)*1013/P*
Pressure	997.4	*mbar*	$C_{T,P}$	1.020

Important: Gold Marker faced away from the hinge cover. Rotate the holder to measure at four cardinal angles.

Readings @+300V	Dot 1	Dot 2	Dot 3	Dot 4	Dot 5	Dot 6	Dot 7	Dot 8	Dot 9	Dot 10
Rdg1 (0°)	2.714	2.726	2.633	2.636	2.632	2.710	2.619	2.574	2.613	2.597
Rdg2 (90°)	2.758	2.759	2.662	2.685	2.685	2.741	2.668	2.613	2.646	2.632
Rdg3 (180°)	2.720	2.733	2.634	2.632	2.636	2.715	2.628	2.584	2.609	2.593
Rdg4 (270°)	2.680	2.679	2.588	2.588	2.598	2.664	2.578	2.531	2.566	2.543
Average (pA)	2.718	2.724	2.629	2.635	2.637	2.707	2.623	2.575	2.608	2.591
Source Strength (U)	2.206	2.212	2.134	2.139	2.141	2.198	2.130	2.091	2.118	2.104

Mean Source Strength	2.15	*U*	Standard deviation of the Batch	0.04	*U*

Comparison:

Date of User Calibration	2/11/2019		Time of User Calibration *(24h)*	13:45	*Central*
Expected source strength:	2.13	*U*	Decay from Vendor Calibration	1.038	
Difference between Vendor and User Value	**0.95%**				

Radiation Safety Concerns

- Establish a policy and procedure

Contents

Radiation Safety Concerns

- Policy and procedure should include training/instructions for all required parties
- Training includes safe practices

XI. Radiation Protection Instructions

a. **Nursing Instructions**
The OR nurses should be provided with instructions regarding this device. The instructions are not different than those provided for any interstitial implants and should conform to our institutional radiation safety policies and procedures.

b. **Surgeon Instructions**
The surgeon and the radiation oncologist will perform the cutting of the sheet to conform to the intended target. The surgeon(s) and the RO will be instructed to follow the manufacturer provided guidelines as discussed during the training and outlined in the document entitled "CivaSheet Guide for Dose to Surgeon". The following paragraph is presented here: "When working with the CivaSheet, it is recommended to face the gold shielded side of the device towards your body when possible. Additionally, use forceps when handling the CivaSheet to reduce the dose to your hands and increase the distance of the source from your body. Hand dose can also be reduced by wearing shielded radiation gloves. Employing these simple steps can increase the number of implantations per year that are below the annual radiation limit recommended by the NRC."
The surgeon shall wear a sterile ring radiation badge during the procedure. The badge will be provided by the RSO office as a temporary badge. Following the procedure it will be returned to the RSO for processing. The identity of the surgeon will be provided to the RSO by the Medical Physicist prior to the procedure.

c. **Patient Instructions**
At the completion of the procedure the patient will be surveyed to ensure that the level of exposure does not exceed 2.0 mRem/hr at 1.0 m away. A form will be provided to the patient instructing him/her regarding sleeping arrangements and time spent around children and spouse.

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Radiation Safety Concerns

- Policy and procedure should include training/instructions for all required parties
- Training includes safe practices

Table 1: Measurements of dose rates to the hands for the radioactive and shielded sides of the CivaSheet. Note that the gold shielding reduces the dose rate by 10x. The annual hand dose limit for a radiation worker is 5,000 mrem per year.

Side of the CivaSheet	Touching device (mrem/hr per mCi)	Using tweezers (10cm) (mrem/hr per mCi)	Stapling device (20cm) (mrem/hr per mCi)
Radioactive	4600	14	1.8
Shielded	4.90	5.7*	0.20

* Calculated value based on TLD measurements.

Table 2: Measurements of dose rates to the body for the radioactive and shielded sides of the CivaSheet. Note that the gold shielding reduces the dose rate by 10x. The annual body dose limit for a radiation worker is 5,000 mrem per year.

Side of the CivaSheet	Touching device (mrem/hr per mCi)	Removing from packaging (30cm) (mrem/hr per mCi)	Attaching in open surgical cavity (30cm) (mrem/hr per mCi)
Radioactive	1,900	0.93	0.62
Shielded	450	MDL**	MDL**

** MDL = below minimum detectable limit.

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Radiation Safety Concerns

- PHYSICIST performs calibration on 10 seeds
  - 3 mCi/dot maximum activity -> 30 mCi
  - 420 mrem/hour at 10 cm, it would take 120 hours to reach hand dose maximum
  - Can easily spend less than one minute per seed -> 720 calibrations
- Compare to surgeon dose
- Remember: Time / distance / shielding!
- NB: Use the tweezers, not your fingers!

Table 1: Measurements of dose rates to the hands for the radioactive and shielded sides of the CivaSheet. Note that the gold shielding reduces the dose rate by 10x. The annual hand dose limit for a radiation worker is 50,000 mrem per year.

Side of the CivaSheet	Touching device (mrem/hr per mCi)	Using tweezers (10cm) (mrem/hr per mCi)	Wiping device (20cm) (mrem/hr per mCi)
Radioactive	4600	14	1.8
Shielded	430	1.7*	0.20

* Calculated value based on TLD measurements

Table 2: Measurements of dose rates to the body for the radioactive and shielded sides of the CivaSheet. Note that the gold shielding reduces the dose rate by 10x. The annual body dose limit for a radiation worker is 5,000 mrem per year.

Side of the CivaSheet	Touching device (mrem/hr per mCi)	Removing from packaging (30cm) (mrem/hr per mCi)	Attaching in open surgical cavity (50cm) (mrem/hr per mCi)
Radioactive	1900	0.93	0.62
Shielded	450	MDL**	MDL**

** MDL = below minimum detectable limit.

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Radiation Safety Concerns

- Be prepared for the OR
- Communicate with surgery team to minimize exposure time to staff
- Take pictures to document everything

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References

- M.J. Rivard, A directional ^{103}Pd brachytherapy device: Dosimetric characterization and practical aspects for clinical use, *Brachytherapy* 16(2):421-432
- M. Aima et al, Air-kerma strength determination of a new directional ^{103}Pd source. *Med. Phys.* 42(12):7144-7152
- Aima et al, Dosimetric characterization of a new directional low-dose rate brachytherapy source. Med. Phys. 45(8):3848-3860
- G.N. Cohen et al, Intraoperative implantation of a mesh of directional palladium sources (CivaSheetTM): Dosimetry verification, clinical commissioning, dose specification, and preliminary experience. Brachytherapy 16(6): 1257-1264
- H. Zhen et al, Initial clinical experience using a novel Pd-103 surface applicator for the treatment of retroperitoneal and abdominal wall malignancies. Adv. Rad. Oncol. 3(2): 216-220

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Thanks to RUMC Physics group (J. Turian, D. Bernard, Y. Liao, A. Templeton, J. Van Schelt, K. Jones, J. Paul, J. McCorkingdale), RUMC physicians (D. Wang), CivaTech assistance (R. Babcock, K. Perez)

THANK YOU FOR YOUR ATTENDANCE

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