New Performance Standard: Multi-channel and One-scan Radiochromic Film Dosimetry

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What is Radiochromic Film?

A film that instantly changes color upon exposure to ionizing radiation and needs no chemical or physical processing

WHAT FOR DOSE MEASUREMENT?



With acknowledgements to Slobodan and Nada Devic, Samuel Trichter, Eduardo Villarreal, Jeffrey Guild, Gary Arbique and Scott Sample

WHAT FOR BEAM LOCATION?

- Primarily for radiotherapy (MV photons, electrons, protons)
 - RTQA2 2 cGy to 8 Gy
- Primarily for radiology (kV photons)
 - XRQA2 1 mGy to 20 cGy
 - XRCT2 1 mGy to 20 cGy
 - XRM2 1 mGy to 20 cGy







Gantry : Diafragama :





With acknowledgements to: Slobodan Devic, Theo van Soest, Andre Wopereis and Zheng Lu

EBT3 AND EBT2 COMPARED

EBT2	EBT3	Comment
Active layer 26-28 µm	Active layer 26-28 µm	Active layer composition and response unchanged
Asymmetric structure	Symmetric structure	Scan EBT3 from either side
Smooth polyester substrate	Matte polyester substrate	Change prevents Newton's Rings formation
Density (unexposed) ~0.10 – 0.12	Density (unexposed) ~0.12 – 0.14	Matte polyester slightly hazy
Total thickness: ~ 0.28 mm	Total thickness: ~ 0.27 mm	

CONFIGURATION CHANGE EBT2 TO EBT3

Polyester Laminate , 50 µm

Adhesive Layer, 25 µm Active Layer, ~28 µm

Polyester, 175 µm

EBT2

Matte Polyester, 120 µm

Active Layer, ~28 µm

Matte Polyester, 120 µm

EBT3

MATTE POLYESTER SURFACE



EBT3 ELIMINATES NEWTON'S RINGS ARTIFACT



EBT2



RESPONSE OF EBT3 SIMILAR TO EBT2



EBT2 – Lot A011411

EBT3 – Lot A071111

COMPARISON EBT SERIES OF FILMS

- Gafchromic EBT film was well regarded in market
- × Early EBT2 film had occasional problem
- Current EBT2 and EBT3 films are as good as if not better than original EBT
- Superior solution especially if combined with FilmQA Pro software
- New protocol will make dosimetry easier and faster

RADIOCHROMIC FILM DOSIMETRY THE ADVANTAGES

- × Handle in light
- × Cut to size
- × Bend to shape
- Immerse in water
- × Wide dynamic range
- High spatial resolution

Specially valuable for new conformal therapies

RADIOCHROMIC FILM AND NEW THERAPY MODALITIES

- × Trends in conformal therapy
 - + Less fractions
 - + Higher doses per fraction
 - + Tighter conformity
- Trending to a higher value on
 - + Spatial resolution, spatial resolution, spatial resolution
 - + Dynamic range

SMALL FIELD – HIGH SPATIAL RESOLUTION



With acknowledgements to: Steve Sorensen, Stefan van Hoof, Mark Oldham, Frank Verhagen, Guillaume Landry, Shane White and Sha Chang

PRESENT/FUTURE OF FILM DOSIMETRY



ASHIAND

GarChromic

- Post-exposure waiting
- × Film artifacts
- × Scanner artifacts
- × Environmental

How we turn film from a hassle to a snap?

NEW PERFORMANCE STANDARD

× Simplify calibration

- + Less films and all scanned together
- + Fitting functions that act like film
- Combine verification with calibration
 - + Every patient film scanned with reference films
 - + Eliminates environmental effects
 - + Eliminates inter-scan variability
- Reduce post-exposure waiting to minutes
- Introduce multi-channel dosimetry
 - + Eliminates or mitigates film and scanner artifacts

ONE SCAN CALIBRATION

- Expose three calibration films doses approx.
 D(>maximum possible dose), 0.4D and 0.16D
- Scan the exposed films and an unexposed film all together
- Fit response data to a rational function like
 X(D)=a + b/(D-c) where a, b and c are constants
- × Defines the shape of the calibration function
- × Once per production lot

Typical completion time <~20 minutes

ONE SCAN CALIBRATION



FITTING CALIBRATION-BASIS FOR FEWER POINTS

Polynomial Functions

 $X(D) = A_1.D^n + A_2.D^{n-1} + \dots + A_n.D + C$ D = dose, X(D) = response



Rational Functions

X(D)= A + B/(D-C) D = dose; X(D) = response



Not consistent with fundamental properties of film ***** Function can oscillate between values ***** Cannot be inverted ***** Consistent with the behavior of film \checkmark Easily inverted - D = C + B/(X(D)-A) \checkmark

COMPARISON OF 3 POINT CALIBRATION VS 7 POINT CALIBRATION





ONE SCAN DOSIMETRY-TWO POINT SCALING

- Set up patient film and expose treatment plan
- Expose a reference film (same lot as patient film) to dose similar to maximum dose on patient film
- Scan patient film, reference film and an unexposed film all together
- Convert to response to dose and analyze

Typical completion time ~20 minutes

ONE SCAN DOSIMETRY-TWO POINT SCALING

ISP FilmQA Pro - RapidArc - 2 arcs A012412 for web - Image viewer and editor

Pile Panel Data Help 53 2 R 13 1 Curtor region Full image Union of all frames ÷ Case description 111 x (16 bpch)= <(16 bpch)> <(16 appeh) = 43302 47384 33636 Film calibration (ordinary) • 65 14824 10645 R and deviation 43183 3646 22328 Data - Calibration film R min Brias 43461 85533 44983 41832 48238 35445 G average A Tool - Image viewer and editor G and deviation 127 13623 7085 Gmin 41612 4219 27658 A Tool - Calibration tool 1 42003 65534 43407 Gmax E Dose map (single scar) 80 23915 38965 221.43 B average 224 B std deviation 84 20380 2140 Data - dose tiles 1102.41 10000 38.03 10 Feet statestics (631 . 319) 100 lata - dose map (read only) Aminten-t 336 Histogram 'down film' (de - consistency map (seed only) Ħ Color channel: Red Region: Rectangle (326, 484) x (85 x 168) - (W-158, H-80) 0 Dependence - Film calibration (ordinary) 55. t 10 + Dote to plan comparison 50 4 + Case object management 4.5 *** 560 . 4.0 -# 35 100 3.0 672 20 \$ 25 2.0 794 1.5 1.0 0.5 896 0.0 42000 42500 43000 43500 44000 44500 Color channel / (16 book) Histogram Gooe Mrv 4 1008 B 44 Care data relector H ÷ 100 ** Selected, first or full frame 1120 troage 'dose film' - 70 to Image histogram region 8:32 APL> Auto scale continue paiette is off 🔁 🕼 🖉 🕼 🐨 🐼 🧭 The brands. 🔁 Sep Fanga P. 🙀 Microsoft G. 🚽 🐨 Fanga P. 🙀 Microsoft G. 🚽 🗮 Microsoft G. 🚽 💭 Hicker Physic. 📅 Addand Prest. 👘 Addand Prest. # Start

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BASIS FOR 'ONE-SCAN' DOSIMETRY

- × All dose response curves have similar shape
- × Scan the patient and reference films together
- Two-point re-scaling one exposed reference plus an unexposed film - applies to most situations
 - + Post-exposure change
 - + Inter-scan variation
 - + Ambient temperature/moisture change
 - + Photon energy
 - + Type of scanner used
 - + Film-scanner orientation
- Three-point re-scaling for lot-to-lot differences

DIFFERENT SCANNERS OF THE SAME TYPE



- Normalize responses to the response
 of unexposed film
- Scale normalized responses to the net response at a selected dose (480 cGy)



DIFFERENT SCANNER TYPES

Absolute Response - Different Scanner Models EBT3 A101711, red color channel



SCANNER TEMPERATURES





PHOTON ENERGY

EBT3 Responses at 6MV and 160kVp





Relative/Scaled Responses at 6MV and 160kVp



FILM ORIENTATION





Relative Responses after Scaling EBT3 A101711; 10000XL scanner



POST EXPOSURE

Post-Exposure Changes, Absolute, red channel - EBT3 A101711



RECALIBRATION LOT-TO-LOT: CURVES HAVE DIFFERENT SHAPE



GOOD TIME MANAGEMENT: THE EXPOSURE WINDOW FOR PATIENT AND REFERENCE FILMS



Time after exposure, minutes	Exposure window, minutes	Dose error
10	5	1.0%
20	5	0.5%
40	5	0.25%

EXAMPLES - RESULTS VS. TIME

Calibration films scanned 2 hours after exposure Patient/reference films scanned at different times







30 min. after

4 hours after

3 days after

EXAMPLES - RESULTS VS. TIME

Time after exposure		Gamma passing rate for 2%@2mm
Calibration	Patient film and reference	Red Channel
2 hr	30 min.	97.9
2 hr	60 min.	97.6
2 hr	4 hr	97.7
2 hr	24 hr	97.9
2 hr	72 hr	97.9

NEW PERFORMANCE STANDARD

VUI

Film is time-co

ASHLAND

Gai Chromic

Why One-scan dosimetry?

Fast – results in minutes

Less exposures and scanning

Uncomplicated

Easy use

Economical

Less film consumption

Reliable and Accurate

Multi-Channel Dosimetry

SINGLE CHANNEL DOSIMETRY

- Calibration Curve X=R $R_{ave} = R_{ave}(D) \leftrightarrow D_{R} = D_{R}(R_{ave})$
- Color channels X=RGB
 D_X = D(X_{ave})
 correlates average response of film-scanner system
- Robust method any X value delivers dose D_X(X)

 $D=D_{x}$



300

Every measured response maps directly to a dose Every response artifact maps to a dose artifact 1% response artifacts map to 3% dose artifacts

40.0

80: 100 120

MULTI-CHANNEL FILM DOSIMETRY

- RGB Calibration Curves
 + Dose induced color C C(D) = {R(D),G(D),B(D)}
- Dose exposure generates only 'certain' colors C
 + Not all C deliver dose value



Observed color C_{scan}
 is superposed with disturbance ΔC
 + C_{scan} = C(D) + ΔC

Solution: Optimize dose D value, *i.e.* minimize ΔC + $|C_{scan} - C(D)| \rightarrow min_D$

MULTI-CHANNEL FILM DOSIMETRY

- Model: Scanned optical density d_{X,scan}
 - + $d_{X,scan}(D) = d_{X,D}(D) * \Delta d$

 $d_X = -\log(X)$ for X = RGB

- + d_{X,D} is calibration function (average behavior)
- + ! disturbance Δd independent of dose + X (wave length) ! but $\Delta d = \Delta d$ (film, scanner, noise, environment, artifacts)

Solution:

+ Minimized function ϕ vs. disturbance Δd :

 $\phi(\Delta d) = (D_R - D_B)^2 + (D_B - D_G)^2 + (D_G - D_R)^2 \rightarrow \min_{\Delta d}$

WHY THE MARKER DYE?

 Red channel signal dominated by dose information

 Blue channel signal dominated by uniformity information

Facilitates correction of film non-uniformities
 + U.S. Patent 6,285,031 September, 2001
 + U.S. Patent Application ??????

SPECTRA OF EBT2/EBT3 COMPONENTS

Active component + Signal in red channel

Marker dye + Signal in blue channel



Visible Spectrum of Active Component after Exposure

DOSE MAP- SINGLE CHANNEL

📰 ISP FilmQA Pro - Poor uniformity - Image viewer and editor

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DOSE MAP- DISTRURBANCE



DOSE MAP- MULTI CHANNEL

ESP FilmQA Pro - Poor uniformity - Image viewer and editor

File Panel Data Help



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WHAT DO I NEED TO KNOW ABOUT SCANNING? DISABLE ALL THE IMAGE ADJUSTMENT FEATURES







DOSIMETRY METHOD AND LATERAL DISPLACEMENT





Central placement

Lateral placement

CLINIC EXAMPLES OF MULTI CHANNEL ONE SCAN DOSIMETRY



SYNERGY

Gafchromic Films

and FilmQA Pro 3.0





CONVENTIONAL FILM DOSIMETRY



Typically >90% pixels passing gamma test of 3% at 3mm

SINGLE IMRT FIELD- MULTI-CHANNEL, ONE-SCAN

SP FilmQA Pro - A101711 IMRT-different post exposure times - Image compares



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COMPOSITE IMRT-MULTI-CHANNEL, ONE-SCAN

FilmQA Pro - Case 2011-06-03 - Image comparer - B × Panel. Data Help + × Case description Ino-Lines Red Ø Background (none) 190 185 111 190 Film calibration (mosaic scans) + 150 175 230.0 cGy 215.0 cGy 178 Images only (multiple scans) + 200.6 cGy + 165 170.0 cGs 135.0 cGy 160 -Dose map (single scan) 100.0 cGy 60.0 cGy 285 155 150 0 Data - doze tim 145 140 ata - dose map (read only) 644 135 130 1 ata - consistency map (read only) 125 120 Dependence - Film calibration (mosaic a 115 -------598 110 105 E Dose to plan comparison E 100 95 90 Data - Treatment plan 743 85 ata - Dose map (read only) 80 75 70 05 898 lata - Dose map registered (emptyreac 60 Data - Comparison dose to plan (empty 65 1048 50 Dependence-Dose map (single scan) 45 0 40 1 Tool - Image viewer and editor 35 30 25 1198 1 Tool - Image comparer 20 15 -Case objectmanagement 1347 Add new case ubject 95.6% for 2%/2mm 0 110 120 130 140 New treatment case 1497 legistrant treference overlagt 🕶 🖙 📗 Ý. 🥥 🐴 357 NaN Case data selector 2 offinit -X7 A Schuial -X7 95.64 % 4 238.9 cGv - NaN patising tale Yed 430 offeet -Y. rase relevance A telucial -Y / 26% 2 mm 0.0 % 100:0.% default value distance Inin theshold NaN **I**oletance -0.2.1 2 totation angle Atducal-1.1/

3:17 PM> Contour palette with 7 levels assigned.

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RAPIDARC™, ONE ARC-MULTI-CHANNEL, ONE-SCAN

ISP FilmQA Pru - Kelowna Rapid arc scan 6 point cal A101711 - bmage compare



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RAPIDARC™, TWO ARCS-MULTI-CHANNEL, ONE-SCAN



SRS ONE FIELD – MULTI-CHANNEL, ONE-SCAN

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ISP FilmQA Pro - Yout Exposure Case.2012-05-11.2 - Image comparer



The New Film Dosimetry Standard



New Film Dosimetry Standard

95% pixels passing 2% at 2mm

NEW PHYSICS QA TOOLS

🚟 ISP FilmQA Pro - Anonymous - Star shot physics QA





MULTI-CHANNEL AND ONE-SCAN DOSIMETRY IS THE NEW STANDARD

- Application and calibration films scanned simultaneously
 - + Inter-scan variability is avoided
- Multi-channel dosimetry corrects/mitigates film and scanner artifacts
- × Simplicity goes up and errors go down
- Komma evaluation with 95% passing 2%/2mm

FILM DOSIMETRY SUMMARY OF ADVANTAGES

- × Post-exposure timing rules are relaxed
- No concern whether a calibration is still valid
- Don't need large number of calibration films
- x Don't need multiple scans
 - × Entry costs Film/Software/scanner
 - Much less than an array device
 - × Running costs
 - Less film consumption
 - Less working time

EBT2/3 + FILMQAPRO 3.0-A COMPLETE SYSTEM

× Provides millions of measurements

- Arrays only make 100 1000 measurements missing 99.9% of the picture
- Nothing is missed with film
- Shoot film from any angle
 - + Shoot the whole plan on one film
 - + Just like the patient gets it

DOSE MONITORING WITH GAFCHROMIC® XR-R



Immediate visualization of patient exposure – magnitude and location
 Detailed dose distribution

IAEA STUDY RESULTS

	Coronary	Non- Coronary
# of patients	400	250
% > 2Gy	12	10
Repeat	40%	40%

×	Gafchromic [®] XR Film
	+ Easiest
	+ Simple
	× Visual Reference
	× Feedback during procedure
	+ Consistent and Reliable Results

- × DAP/KAP
 - + Difficult to correlate to peak skin dose
- × Importance of Dose Monitoring

COMPARISON OF GAFCHROMIC XR-R WITH DIODES



*Data provide by Les Hopitaux Universitaires de Strasbourg, used with permission

FILMQA-XR SCREEN SHOT

SP FilmQA XR 2010 File Help Data 20 mm 180 mm 210 mm 239 mm 269 mm 299 mm 50 mm 90 mm 260.522 R 30 mm 60 mm 0 mm 0 mm average dose (2916 values, 0.000 m²) 26 mm 34.138 R 69.525 R 429.379 R dose standard devia dose minimum dose maximum 52 mm Iso-Lines 'Application image 001' 77 mm Color channel: Red 600.000 R 250 500.000 R 103 mm 400.000 R 200 300.000 R 129 mm 200.000 R 100.000 R ε 150 ε /λ 100 50.000 R 155 mm 10.000 R 1.000 R 181 mm 50 206 mm 0 232 mm n 50 100 150 200 250 ×/mm 258 mm dose contour lines scanned image View 31 % ## 🛦 🌅 2.5 Gy 3.0 Gy scan image image stack Calibration (xvu) 2010-02-12 15-51 (EPSON Expression 168 calibration

10:38 AM> View 31 %

FUTHER QUESTIONS?

× For more information

- + www.gafchromic.com
- + www.FilmQApro.com
- + www.FilmQAXR.com

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ASHLAND



With the New Protocol and Your Efforts