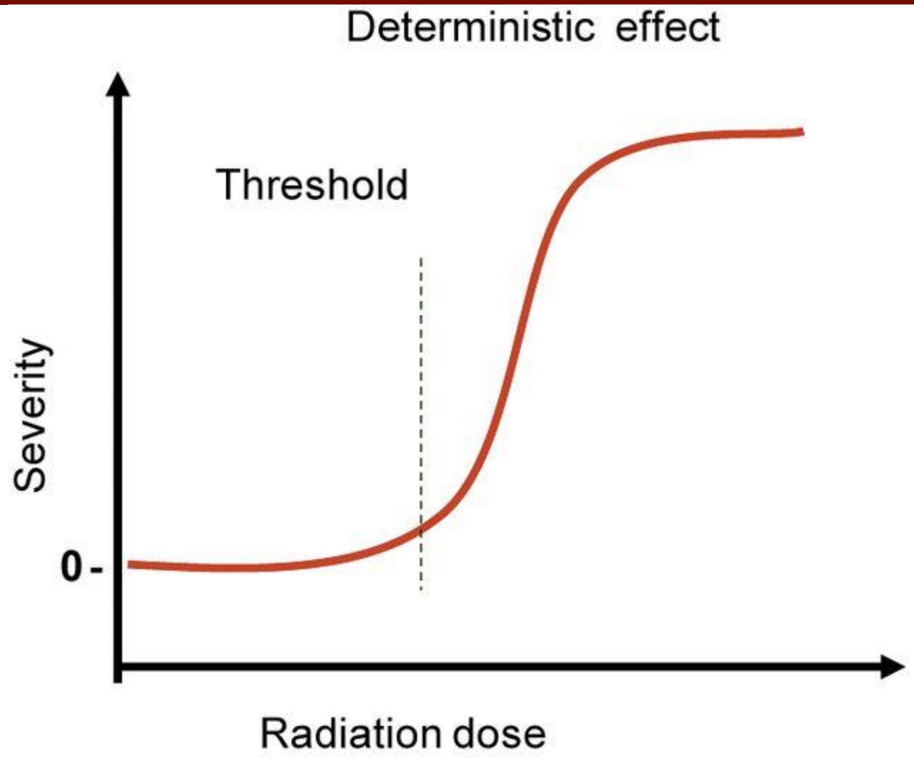
How Do I Reduce Radiation Exposure During 3DRA?

Shyam K. Sathanandam

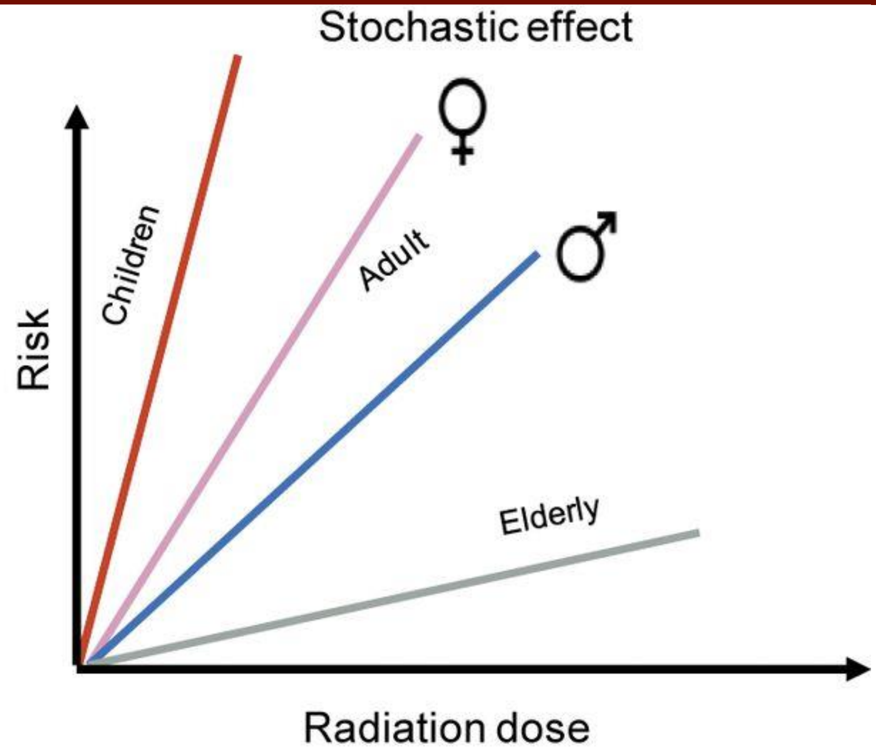
Disclosures

I have no financial relationships with any commercial interest related to the content of this presentation.

Radiation Exposure – Cancer Risk



- Due to cell killing.
- Have a dose threshold–typically several Gy.
- Specific to particular tissues.
- Severity of harm is dose dependent.



- Due to cell changes (DNA) and proliferation towards a malignant disease.
- Severity (example cancer) independent of the dose.
- No dose threshold–applicable also to very small doses.
- Probability of effect increases with dose.

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RISK: Deterministic versus Stochastic

Single-Site Acute Skin-Doses:

0-2 Gy

< 2 Weeks: None

2 – 52 Weeks: None

Permanent: None

2-5 Gy

< 2 Weeks: Erythema

2 – 52 Weeks: Epilation

Permanent: None

5-10 Gy

< 2 Weeks: Erythema

2 – 52 Weeks: Prolonged/Permanent Erythema/Epilation

Permanent: Dermal Atrophy

>10 Gy

< 2 Weeks: Erythema/Ulceration

2 – 52 Weeks: Desquamation

Permanent: Surgery

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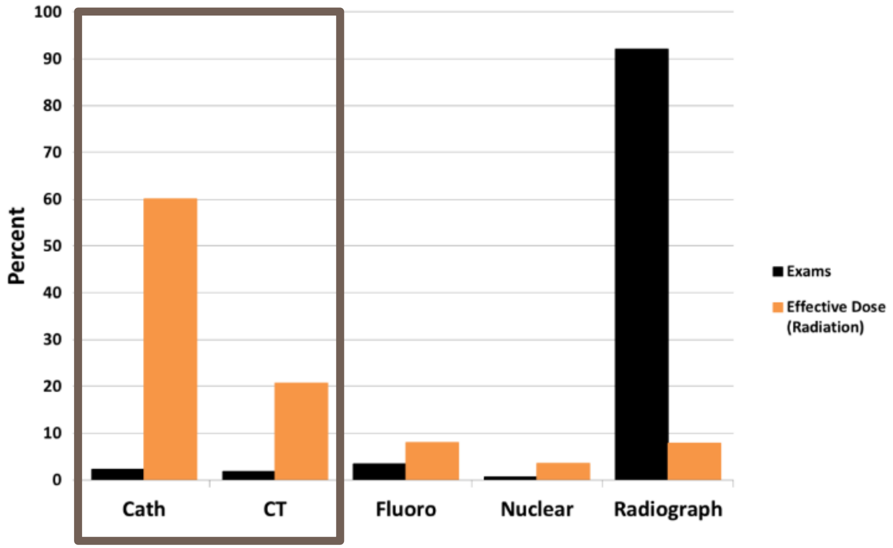
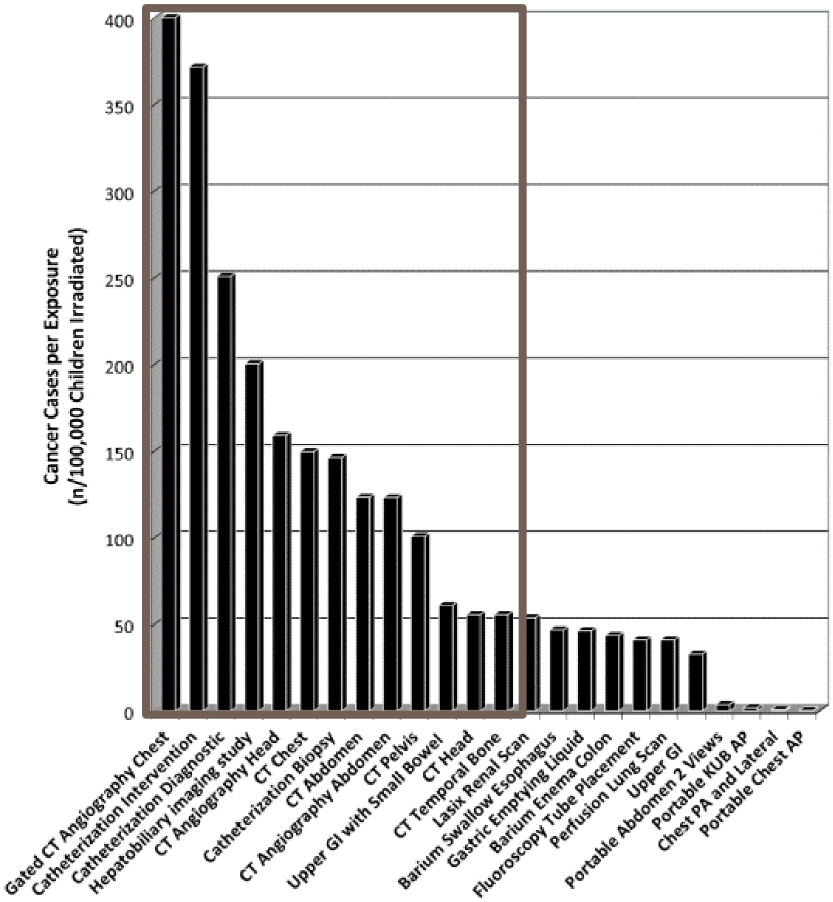
Radiation Exposure – Cancer Risk





Johnson JN, et al. *Circulation*. 2014;130:161-167.

Radiation Exposure – Fluoro Time

Inadequate Estimation of Radiation Exposure

	Est. Impact on Dose	
30 Minutes	2x >	15 Minutes
Patient Weight: 70 kg	10x <	Patient Weight: 100 kg
Fluoro Pulse Rate: 7.5 pps	2x <	Fluoro Pulse Rate: 15 pps
Cine Frame Rate: 15	2x <	Cine Frame Rate: 30
Cumulative Air Kerma (mGy): 250	15x <	Cumulative Air Kerma (mGy): 3750

Definitions

♥ **Air Kerma (Gy)** - **K**inetic **E**nergy **R**eleased per unit **Ma**ss
Sum of the kinetic energies of all the charged particles liberated by ionizing radiation absorbed in a sample of matter, divided by the mass of the sample.

♥ **Dose Area Product (Gy·cm^2)** – Absorbed dose multiplied by the area irradiated.

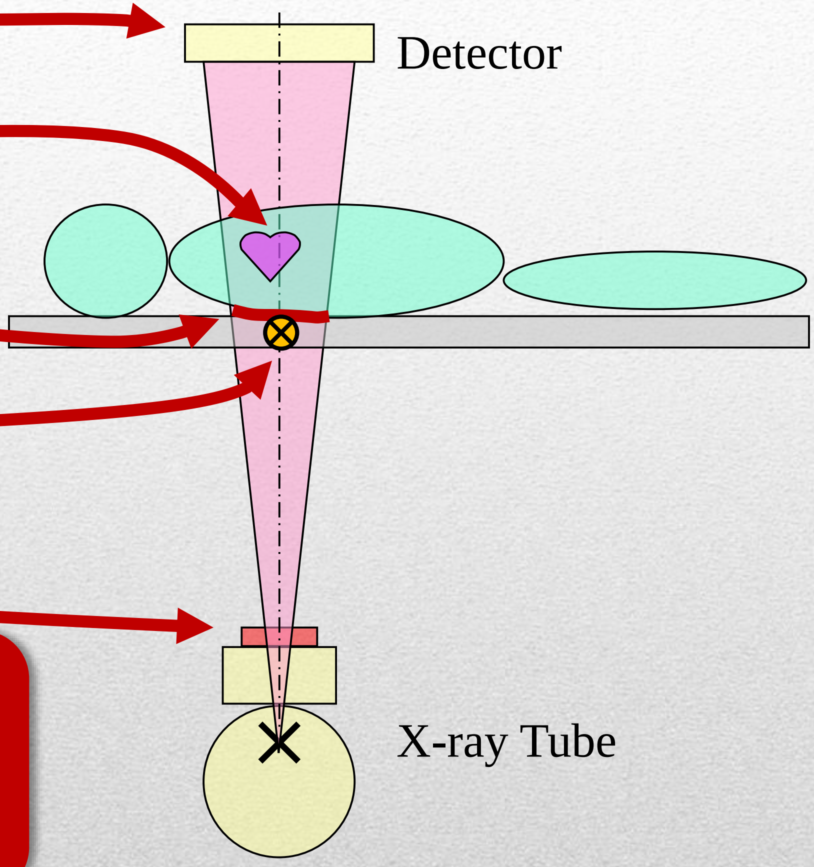
♥ **Effective Dose (Sv)** – Multiplying the average organ dose by tissue weighting factor and summing the results over the whole body. Used by ***ICRP*** – Probability of cancer.

1Gy (A physical quantity) = 1Sv (A biologic effect)

- 1 Gy is the deposit of a joule of radiation energy in a kg of tissue.
- The Sievert represents the equivalent biological effect of the joule of radiation energy in a kilogram of tissue.

Dose Metrics: Air Kerma and DAP

- Detector Exposure – *R*
  (Drives AEC Techniques)
- Organ Dose / Effective Dose – *mSv*
  (Patient Dose)
- Peak Skin Dose (PSD) – *mGy*
  (Patient Dose)
- Air Kerma at Reference Point†* - *mGy*
  (Machine Output)
- Dose Area Product (DAP) – *Gy cm²*
  (Machine Output)



†Reference Point = Patient Entrance Reference Point = 15cm From Isocenter Towards Focus (IEC Standard)

*

Inverse Square Law:

$$\text{Intensity} \propto \frac{1}{\text{distance}^2}$$

Per Inverse Square Law: 5cm Results in Approximately 20% Deviation

†Assumes Patient Surface is Equivalent to 30cm Sphere

*21CFR1020.32 – Air Kerma Mandatory for Fluoroscopic Equip. after 6/10/2006
Accuracy Tolerance: ± 35%

Actual Patient Location May Deviate from the Reference Point Location

Summary of Reference Point Locations

IEC Patient Entrance Reference Point

[15cm from the isocenter in the direction of the focal spot]

Always Implemented on Lateral Arm

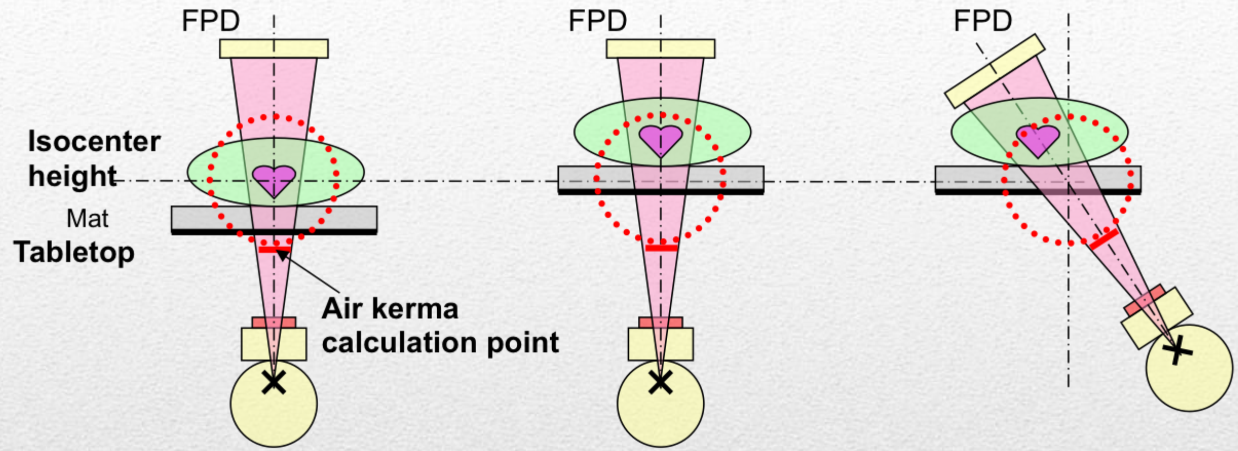
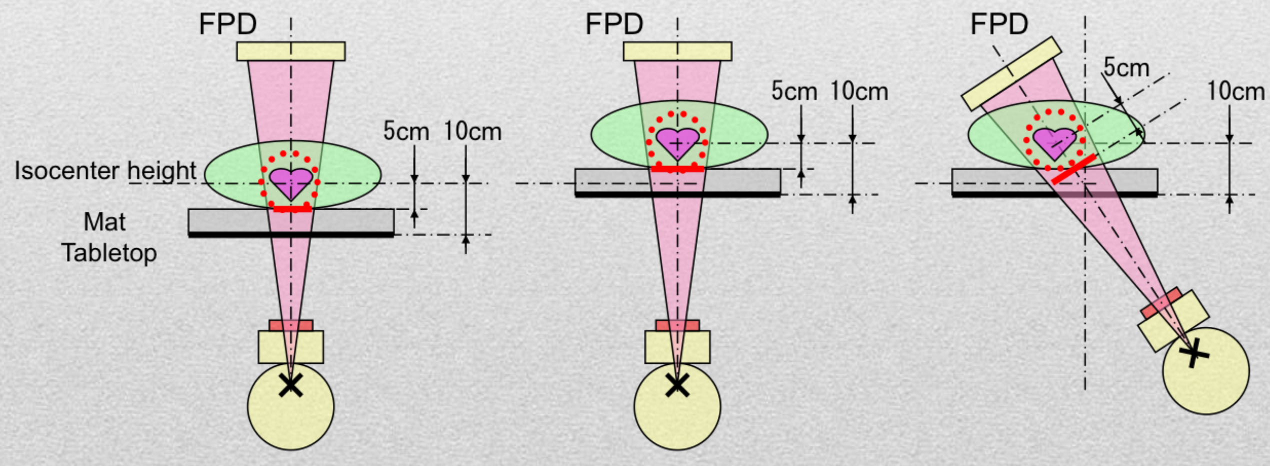


Table Tracking Method

[Configurable setting to track with the table (e.g. 5cm above tabletop to account for mattress)]



Summary of Reference Point Locations

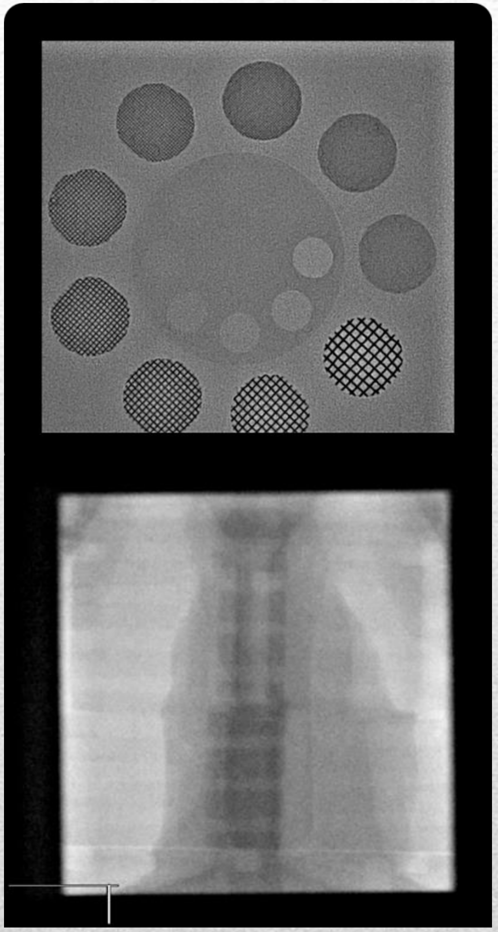
ORIGINAL ARTICLE

Congenit Heart Dis. 2016;00:00–00

Radiation Protocol for Three-Dimensional Rotational Angiography to Limit Procedural Radiation Exposure in the Pediatric Cardiac Catheterization Lab

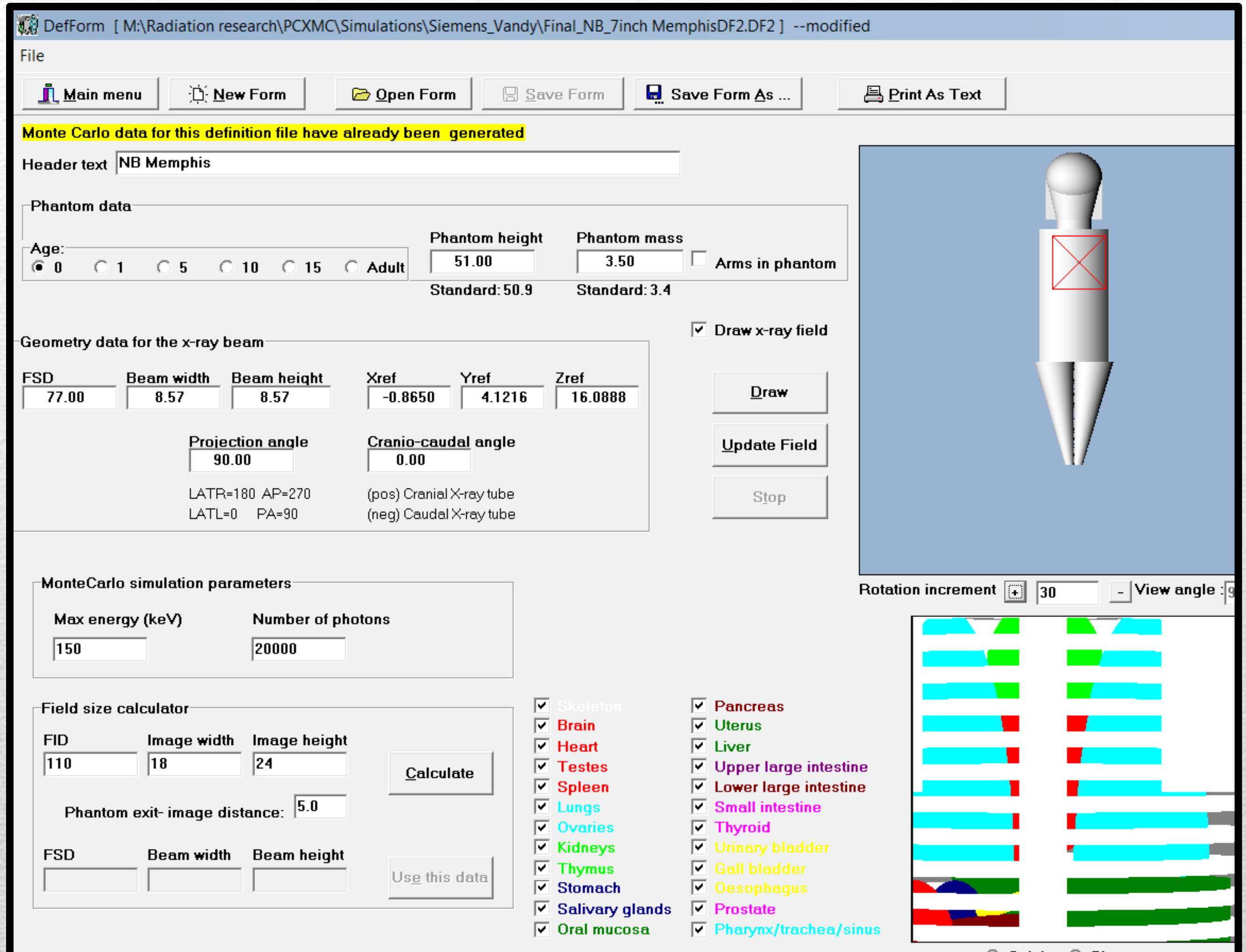
Lauren Haddad, MD,* B. Rush Waller, MD,[†] Jason Johnson, MD,[†] Asim Choudhri, MD,[‡]
Vera McGhee, BS,[§] David Zurakowski, PhD,[¶] Andrew Kuhls-Gilcrist, PhD,** and
Shyam Sathanandam, MD[†]

Protocols to Decrease Radiation During 3DRA



- 2 Anthropomorphic phantoms of different sizes were used to set up our 3DRA protocols

Protocols to Decrease Radiation During 3DRA



Protocols to Decrease Radiation During 3DRA

Protocol	**≤ 30 kg**	**> 30kg**
Frame Rate (frames/sec)	25	25
C-Arm rotation	206º	206º
Tube Voltage (kV)	73	73
Tube Current (mA)	564	564
Pulse Width (ms)	3.7	3.7
Field of View (inches)	8	12
Source to image distance (cm)	110	120
Delay time (sec)	1	1
Rotation Time (sec)	4.1	4.1
AEC dose (µR)	150 dose rate ≈ 0.033 mGy/sec	250 dose rate ≈ 0.055 mGy/sec

PHANTOM IMAGING

Comparison of radiation to perform rotational and bi-plane imaging

Table 1. Phantom Imaging: Comparison of Radiation and Parameters to Perform Rotational and Biplane Imaging

Phantom Data	3DRA, Mean ± SD	2DDA, Mean ± SD	*P* Value
DAP (cGy/cm^2)	32.8 ± 16.8	23 ± 14.8	.24
Air Kerma (mGy)	1.6 ± 0.7	1.2 ± 0.46	.15
Measured skin dose (mSv)	0.16 ± 0.04	0.15 ± 0.03	.76
Effective radiation dose calculated by Monte-Carlo simulation (mSv)	0.13 ± 0.01	0.1 ± 0.02	.31
Tube voltage (kV)	87.6 ± 1	67.2 ± 4.2	.30
Tube current (mA)	39.75 ± 15.5	115.25 ± 6.1	.001

- 2 Anthropomorphic phantoms of different sizes were tested using the two 3DRA protocols and five 2DDA protocols, twice on each phantom.
- The 2DDAs were performed at 15-frames/s for 5-seconds.
- This generated eight 3DRA and twenty 2DDA datasets for comparison.

PATIENT STUDY AND CONTROL GROUPS

Comparison of demographics, angiographic sites and procedure types

Table 2. Patient Study and Control Group: Comparison of Demographics, Angiographic Sites, and Procedural Types

Variable	3DRA Group ($n = 100$)	2DDA Group ($n = 100$)	*P* Value
Age (years)	10.2 (1.12–43.87)	9.98 (0.33–39.52)	.239
Sex, M:F (n)	59:41	53:47	.114
Height (cm)	145 (69–181)	135.5 (59–181)	.207
Weight (kg)	39.8 (8.3–118.2)	35.6 (5–115.6)	.146
Body surface area (m^2)	1.23 (0.4–2.33)	1.09 (0.28–2.3)	.103
Site			.420
Aorta	16	10	
BDG/Fontan	18	24	
Right/left ventricle	66	66	
Diagnosis			<.001*
CTA	52	36	
COA	15	6	
SV	14	48	
PPS	19	10	
Intervention			.007†
Melody valve	18	5	
COA stent	12	6	
PA stent	21	12	
PA plasty	24	33	
Other	4	19	
None	21	25	

*Significantly more single ventricle patients in the 2DDA group.
†Significantly more stent implantation procedures in the 3DRA group.
BDG, bidirectional Glenn; COA, coarctation of aorta; CTA, conotruncal anomalies; PA, pulmonary artery; PPS, peripheral pulmonary artery stenosis; SV, single ventricle.

- During a 2 year study period, a total of 144 3DRAs (19% of all cardiac catheterizations) were performed; 100 were included in the study.
- The 2DDAs were performed at 15-frames/s.

PATIENT STUDY

Comparison of radiation to perform a 3DRA vs. a 2DDA and total procedural radiation

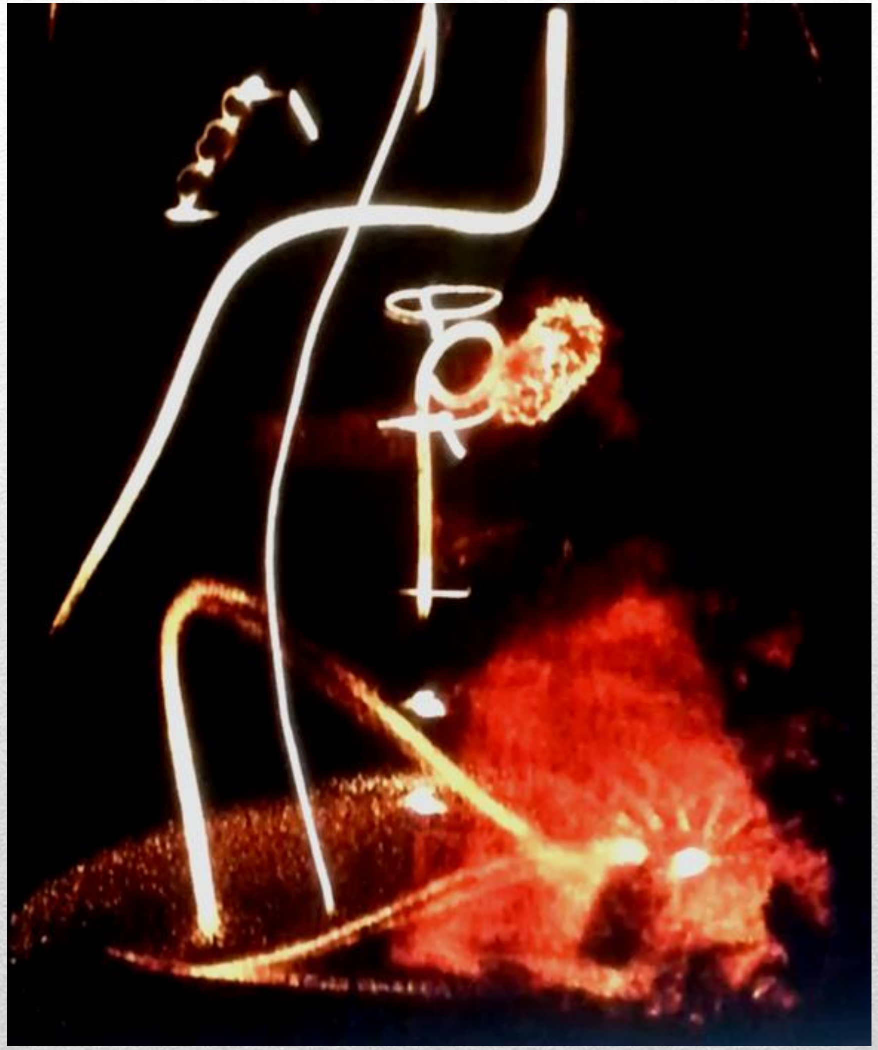
Table 3. Patient Study and Control Group: Comparison of Radiation and Parameters to Perform Rotational and Bi-plane Imaging and Total Procedural Radiation

Radiation Parameters	3DRA Group, Median (IQR), $n = 100$	2DDA Group, Median (IQR), $n = 100$	P Value
Duration of single 3DRA/2DDA (seconds)	4.1	4.9 (3.8-6.2)	.12
DAP for a single 3DRA/2DDA (cGy/cm^2)	278 (107–595)	241 (124–760)	.14
Indexed DAP for a single 3DRA/2DDA ($cGy/cm^2/m^2$)	237 (147–428)	218 (130–732)	.42
Effective dose by Monte-Carlo simulation (mSv)	0.8 (0.2–1.8)	0.67 (0.08–3.7)	.22
Total procedural DAP (cGy/cm^2)	3605 (1679–18 033)	3544 (1186–10 761)	.45
Total procedural indexed DAP ($cGy/cm^2/m^2$)	3248 (1885–9383)	3176 (1537–7778)	.48
Total procedural Air Kerma (mGy)	250 (146–816)	265 (121–531)	.21
Total procedural indexed Air Kerma (mGy/m^2)	244 (170–578)	249 (174–500)	.79

Table 5. Patient Study and Control Group: Comparison of Contrast Volumes and Other Procedural Data

Contrast and Procedural Data	3DRA Group, Median (IQR), $n = 100$	2DDA Group, Median (IQR), $n = 100$	P Value
Single 3DRA/2DDA contrast volume (mL/kg)	1.59 (1.0–1.9)	1.01 (0.5–1.2)	<.001
Total procedural contrast volume (mL/kg)	3.8 (2.9–5.3)	4 (2.5–5.2)	.494
Number of cine-angiograms	7 (4–12)	11 (7–15)	<.001
Total fluoroscopy time (min)	30.8 (17–55)	42.3 (30–60)	.023
Length of procedure (min)	140 (110–207)	161 (135–217)	.106

Protocols to Decrease Radiation During 3DRA



Conversion factor for DAP to mSv for 3DRA for various age group and Life time attributable cancer risk from 3DRA

Table 4. Conversion Factors Determined Using Patient-Specific Monte-Carlo Calculations to Enable Approximation of the Effective Dose (ED) From 3DRA by Using the DAP Provided by the System

Age Categories (yrs)	Average Weight (kg)	Number of Patients	Slope ($mSv/cGy/cm^2$)	Intercept (mSv)	R^2	Average DAP (cGy/cm^2)	Average ED* (mSv)	Attributable Life-Time Cancer Mortality Risk[22]† (% per Sv)
<1	12.2	10	0.0124	0.22	0.96	111	0.60	16
1–5	16.5	28	0.0141	−0.15	0.96	128	0.65	16
5–10	44.0	21	0.0035	0.73	0.88	384	1.08	13
10–15	67.3	30	0.0025	0.74	0.75	650	1.38	10
>15	77.7	11	0.0017	2.11	0.45	1094	2.36	4

*$mSv/cGy/cm^2$ conversion factors (ED = DAP × slope + intercept).

†National Research Council. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2.* Washington, DC: The National Academies Press, 2006

- Chest X-Ray – 0.02 mSv
- Roundtrip flight NY-LA – 0.03 mSv
- Annual US background radiation – 3 mSv
- CT angio – 2-12 mSv
- Annual limit for radiation workers (*10 CFR 20.1201*) – 50 mSv

OBJECTIVES

Kevin Hill, MD MSCI

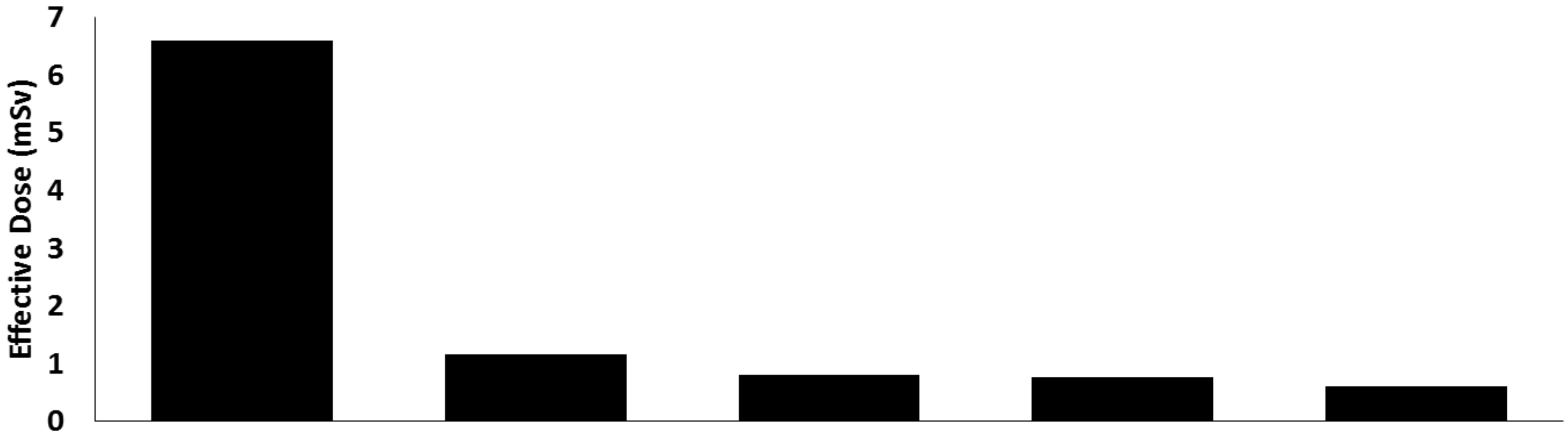
- Evaluate variability in image quality and radiation dose parameters across:
  - **Generations of fluoroscopy equipment**
  - Fluoroscopy equipment vendors

APPROACH: *Vendor assessments*

Institution	Fluoroscopy vendor	Model	Installation date
A	Philips	Allura Xper FD 10/10	2004
A	Phillips	Allura Clarity	2014
B	Siemens	Artis Q	2014
C	Toshiba	Ultimax	2012
D	GE	Innova	2013

Simulated neonatal cardiac catheterization

(20min fluoroscopy time, 4 biplane acquisitions)



	Phillips Xper (Release: 2004)	Phillips Clarity	Siemens Artis Q	Toshiba Ultimax	GE Innova
Fluoro IQ	**10.3**	**9.8**	**8.0**	**10.4**	**9.5**
Cine IQ	**11.1**	**11.0**	**10.1**	**10.4**	**10.6**

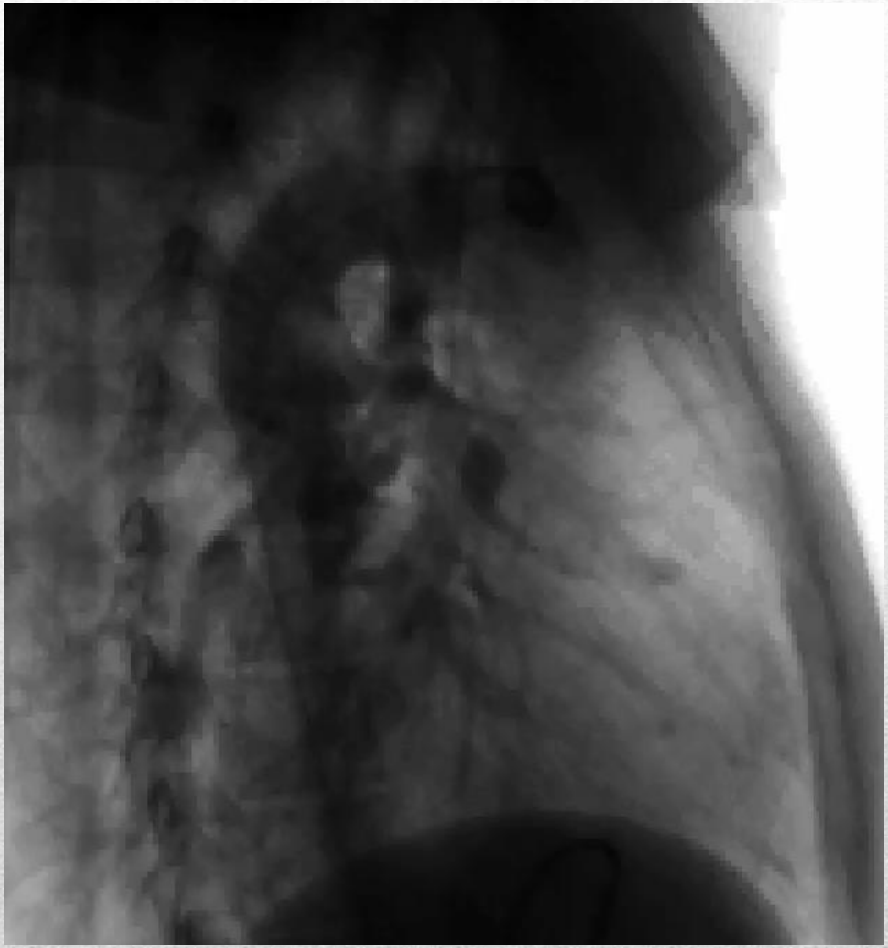
Institutional imaging parameters used to calculate doses: 5 / 7.5 fps for fluoroscopy/cineangiography except for the older generation Phillips Xper system (only allows 15 fps). The institution using the Toshiba system uses fluoro-save for acquisitions.

Conclusions

- **New generation equipment vastly superior**
- **Vendor differences in dose and image quality**
- **Institutional variability in "set-up"**
  - ***These data can help guide standardized institutional approaches to limit dose while maintaining safe Image Quality***

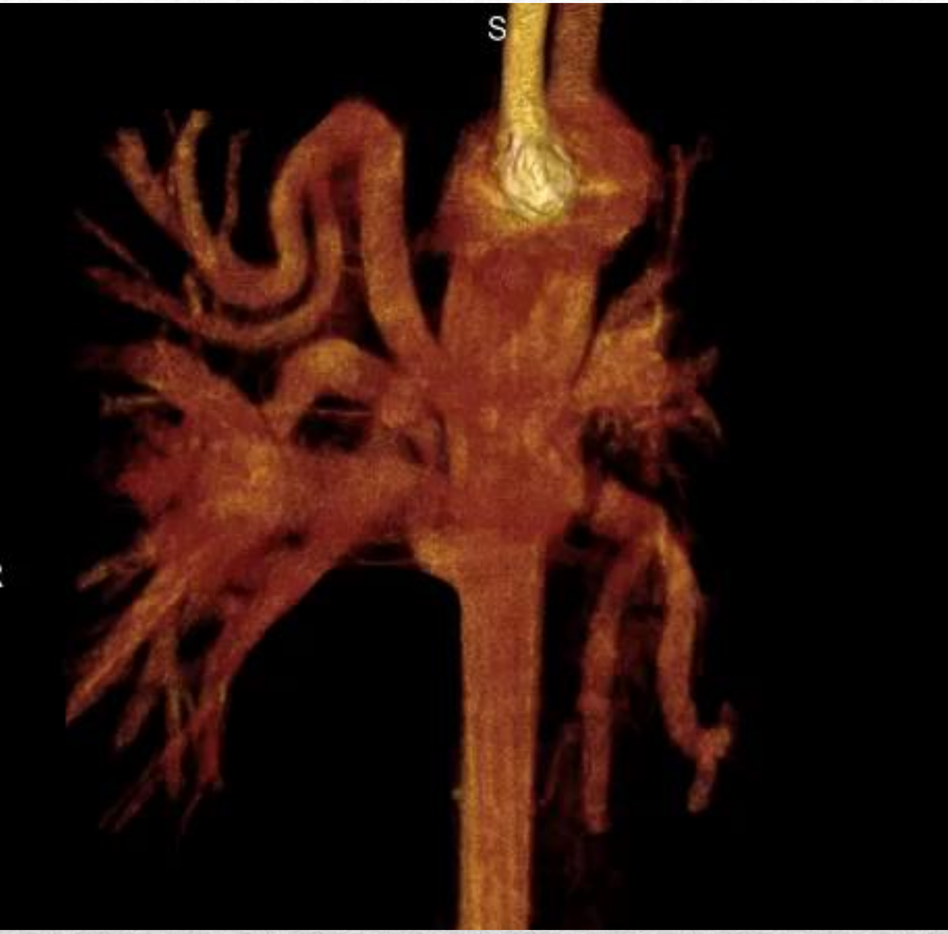
3D-DSA

3D-DA

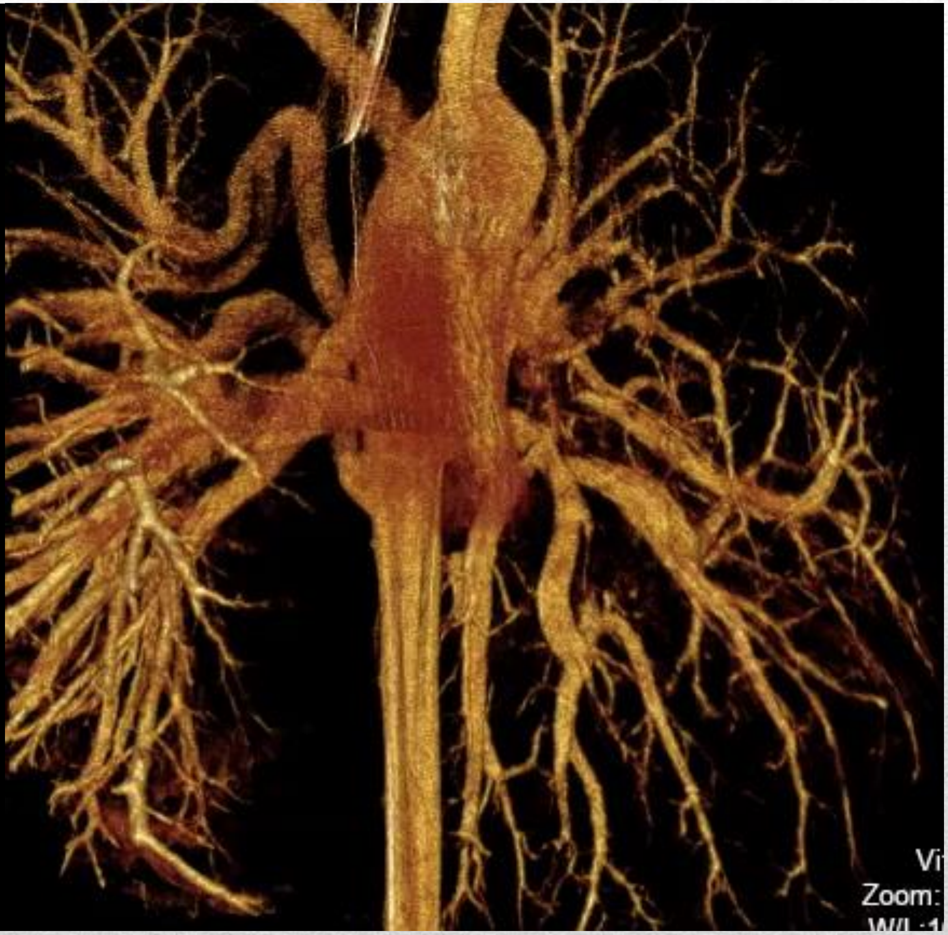


3D-DSA

3D-DA



3D-DSA



3D-DA

3D-DSA

Protocols to Decrease Radiation During 3D-DSA

Protocol	≤ 30 kg	> 30kg
Frame Rate (frames/sec)	15/15	15/15
C-Arm rotation	206^{o}	206^{o}
Tube Voltage (kV)	60/73	60/73
Tube Current (mA)	564	564
Pulse Width (ms)	3.7	3.7
Field of View (inches)	8	12
Source to image distance (cm)	110	120
Delay time (sec)	1	2
Rotation Time (sec)	4.1	4.1
AEC dose (μR)	150 dose rate ≈ 0.033 mGy/sec	250 dose rate ≈ 0.055 mGy/sec

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3D-DSA vs. 3D-DA

In Patients < 2 years of age

Variable	3D-DSA (n=15)	3D-DA (n=15)	P-Value
Mean Age (months)	14 ± 5	15 ± 6	0.239
Weight (Kg)	14.4 ± 2.5	12.2 ± 2.4	0.114
BSA (m^2)	0.42 ± 0.22	0.44 ± 0.08	0.103

3D-DSA vs. 3D-DA

Comparison of Radiation and Contrast Dose in Children < 2 Years

Variable	3D-DSA (n = 15)	3D-DA (n = 15)	P-Value
Mean Dose-Area product (cGy.cm^2)	188 ± 51	128 ± 141	0.143
Mean Air Kerma (mGy)	21.7 ±17.7	11.4 ± 2.8	0.104
Mean Contrast Dose (mL/Kg)	1.02 ± 0.1	1.81 ± 0.2	**<0.001***

3D-DSA vs. 3D-DA

Comparison of Total procedure Radiation and Contrast Dose in Children < 2 Years

Variable	3D-DSA (n=15)	3D-DA (n=15)	P-Value
Procedure length (min)	140 ± 30	144 ± 29	0.722
Duration of radiation (min)	39.7 ± 12.4	38 ± 11.6	0.365
Total procedural DAP ($cGy.cm^2$)	543 ± 299	442 ± 162	0.173
Total procedural Air Kerma (mGy)	144 ± 56	95 ± 38	0.1
Procedural contrast volume (mL/Kg)	2.85 ± 0.76	5 ± 2	**<0.001***

3D-DSA vs. 3D-DA

Diagnostic Quality and Utility Scores

	3D-DSA (%)	3D-DA (%)	P-Value
Rotational Angiography	86	84	0.32
Multi-planar Reformation	84	88	0.12
3D Reconstruction	79	86	0.14
3D Road Mapping	88	89	0.36

3DRA Fusion

Multi-Modality Fusion (MMF)
Radiation reduction

Multi-Modality Fusion (MMF)

Patient Demographics

Comparison of 3DRA, MR and CT Fusion

Variable	3DRA-Fusion (n=25)	MR-Fusion (n=25)	CT-Fusion (n=25)	P-Value
Age (years)	9.8 ± 5.5	10.2 ± 6.3	11.1 ± 7.2	0.39
Weight (Kg)	26.6 ± 11.4	28.4 ± 12.3	30.3 ± 14.5	0.46
BSA (m^2)	1.02	1.08	1.2	0.11

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Multi-Modality Fusion (MMF)
Radiation reduction

Multi-Modality Fusion (MMF)
Procedure Times, Radiation and Contrast Dose

Variable	3DRA-Fusion (n=25)	MR-Fusion (n=25)	CT-Fusion (n=25)	P-Value
Radiation (min)	21.8 ± 12.2	18 ± 9.7	19.4 ± 10.4	**0.04**
# of angiography	7.2 ± 3.8	5.4 ± 4.7	6.8 ± 3.6	0.52
Dose-Area ($cGy.cm^2$)	4101 ± 1382	2454 ± 1113	5607 ± 2465	**0.01**
Air Kerma (mGy)	654 ± 224	499 ± 189	806 ± 328	**0.01**
Contrast (mL/Kg)	4.9 ± 3.1	2.7 ± 2.4	5.9 ± 3.8	**<0.001**
Procedure (min)	214 ± 93	163 ± 38	167 ± 42	**0.03**
Anesthesia time (min)	258 ± 112	384 ± 174	213 ± 98	**<0.001**

Multi-Modality Fusion (MMF)
Radiation reduction

Multi-Modality Fusion (MMF)

Satisfaction Scores Among Operators and Independent Observers

Overall Satisfaction Scores (%)	3DRA-Fusion (n=15)	MR-Fusion (n=15)	CT-Fusion (n=10)	ANOVA P-Value
Operators	90 ± 6	82 ± 12	84 ± 10	0.33
Independent Observers	91 ± 5	96 ± 2	92 ± 4	0.74
Paired T-Test	0.75	**0.029***	0.637	
ICC-Correlation	0.962	0.401	0.766	
P-Value	**<0.001***	0.26	0.11	

Summary

- 3DRA can be performed with low dose radiation.
- Tomographic imaging acquired from rotational angiography can help decrease the overall procedural radiation and contrast dose.
- 3D-DSA can limit contrast volume required for imaging.
- 3DRA-Fusion is more reliable than MR or CT fusion and can therefore limit the number of angiograms required during complex interventions, thereby limiting total procedural radiation.

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TOSHIBA Leading Innovation

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Kevin Hill, MD MSCI