Radiation Dose Considerations in CT Guided Interventional Procedures

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Disclosure

- Nothing to disclose

Outline

- CT dosimetry and metrics
- Dose levels in CT guided interventional procedures
- Dose monitoring
  - Real time monitoring
  - Dose notification and dose alert
- Dose reduction techniques
- Dose to operator and staff

CT Guided Interventional Procedures

- Scan mode: CT Fluoro, Biopsy (intermittent), Helical
- Scan coverage: short for CTF and Biopsy
- Number of scans: many more than diagnostic CT
- Dose perspective:
  - Usually higher dose than diagnostic CT
  - High variation among different procedures, and cases of the same procedure

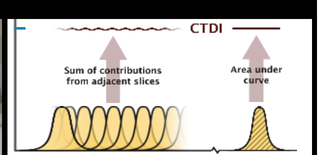
CT Dosimetry

- CTDI, CTDIw, CTDIvol
- Dose length product (DLP)
- Size specific dose estimate (SSDE)
- Organ dose (e.g. skin dose)
- Effective dose

CT Dose Index (CTDI)

- Acrylic CTDI phantoms
  - 32 cm diameter (body)
  - 16 cm diameter (head)
- 100 mm ion chamber
- Multi scan average dose
  - Single measurement

CTDI ion chamber (100 mm long)



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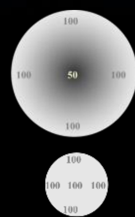
$CTDI_w$ and $CTDI_{vol}$

- $CTDI_w$
  - Weighted average of center and periphery doses

$$CTDIw = \frac{2}{3} CTDI_{100}(edge) + \frac{1}{3} CTDI_{100}\ (center)$$

- $CTDI_{vol}$
  - Takes into account scan overlap or gaps

CTDIvol = CTDIw / Pitch



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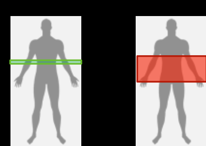
Dose length product (DLP)

- $CTDI_{vol}$ doesn't count for scan length
  - E.g. partial abdominal scan and a abdomen and pelvis scan may have the same CTDIvol
- DLP = $CTDI_{vol}$ x Scan Length
- DLP in interventional procedures
  - Biopsy mode: Short scan length, low DLP
  - Helical scan: Long scan length, high DLP



CTDIvol = 10 mGy
Scan length = 5 cm
DLP = 50 mGy*cm

CTDIvol = 10 mGy
Scan length = 30 cm
DLP = 300 mGy*cm

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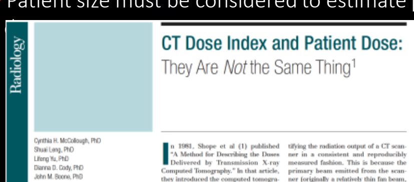
$CTDI_{vol}$ is NOT patient dose

- CTDI quantifies scanner radiation output
- Patient size must be considered to estimate patient d...

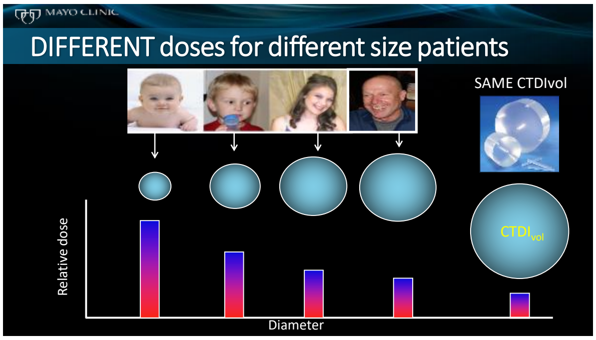


Radiology

CT Dose Index and Patient Dose:
They Are *Not* the Same Thing[1]

Cynthia H. McCollough, PhD
Shuai Leng, PhD
Lifeng Yu, PhD
Dianna D. Cody, PhD
John M. Boone, PhD
Michael F. McNitt-Gray, PhD

In 1981, Shope et al (1) published "A Method for Describing the Doses Delivered by Transmission X-ray Computed Tomography." In that article, they introduced the computed tomography (CT) dose index (CTDI) as a metric ... tifying the radiation output of a CT scanner in a consistent and reproducibly measured fashion. This is because the primary beam emitted from the scanner (originally a relatively thin fan beam, which with current technology has ex-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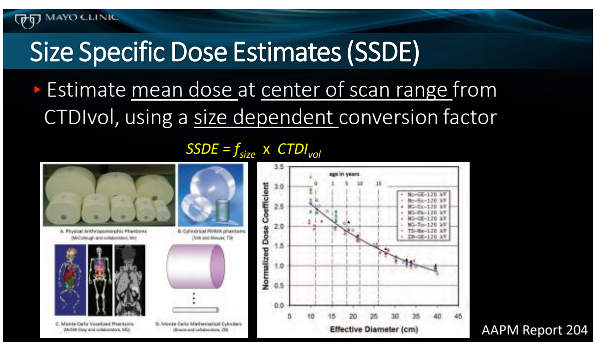
DIFFERENT doses for different size patients
SAME CTDIvol
CTDI vol
Relative dose
Diameter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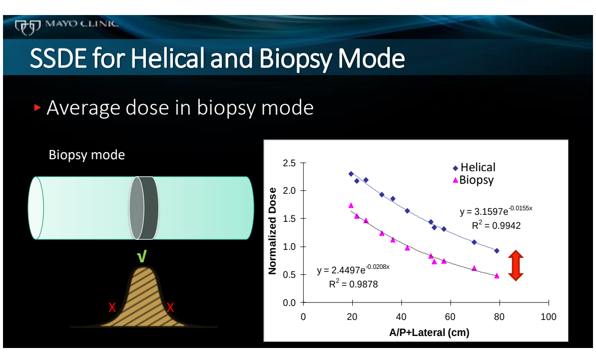
Size Specific Dose Estimates (SSDE)
Estimate mean dose at center of scan range from CTDIvol, using a size dependent conversion factor
SSDE = f size x CTDI vol
Normalized Dose Coefficient
Effective Diameter (cm)
AAPM Report 204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SSDE for Helical and Biopsy Mode
Average dose in biopsy mode
Biopsy mode
Helical
Biopsy
y = 3.1597e-0.0155x
R2 = 0.9942
y = 2.4497e-0.0208x
R2 = 0.9878
Normalized Dose
A/P+Lateral (cm)

Skin Dose Estimation

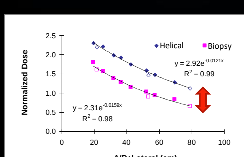
- Skin dose can be respectively estimated from CTDIvol for helical mode and biopsy

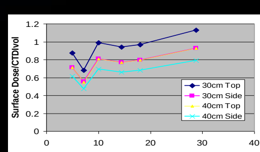
$$\text{skin dose} = \begin{cases} 1.2 \times CTDI_{vol} & \text{helical mode} \\ 0.6 \times CTDI_{vol} & \text{biopsy mode} \end{cases}$$

Bauhs et al, CT dosimetry: Comparison of measurement techniques and devices. Radiographics, 2008
Leng *et al,* Radiation Dose Levels for Interventional CT Procedures. AJR. 2011

Skin Dose Estimation

- Dependence on patient size and beam collimation

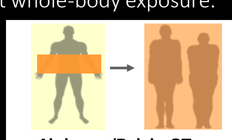




Leng *et al,* A direct skin dose calculation method in CT scans without table motion: influence of patient size and beam collimation. *Med Phys* 2010; 37:3110

Effective Dose

- A calculated quantity that reflects the radiation detriment of a non-uniform exposure in terms of an equivalent whole-body exposure.



* ICRP Report 102 (A14), 2007; ICRP Report 60, 1991

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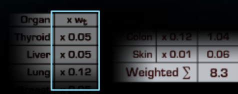
Effective Dose

- Method 1
  - Based on organ dose estimates (e.g. MC) and tissue weighting factors
- Method 2
  - Convenient "shortcut" based on DLP: E = *k* x DLP
  - 5 generic k values, based on body region



Anatomical Region	*k* value mSv/ (mGy-cm)
Head & Neck	0.0031
Head	0.0021
Neck	0.0059
Chest	0.014
Abdomen & Pelvis	0.015

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Dose Levels in CTGI

1. Yang K, Ganguli S, Delorenzo MC, Zheng H, Li X, Liu B. Procedure-specific CT Dose and Utilization Factors for CT-guided Interventional Procedures. Radiological Society of North America; 2018;289(1):150–157
2. Tam AL, Ensor JE, Zvavanjanja RC, et al. JOURNAL CLUB: Standardizing CT-Guided Biopsy Procedures: Patient Dose and Image Noise. Am J Roentgenol. American Roentgen Ray Society ; 2015;205(4):W390–W399
3. Stewart JK, Looney CB, Anderson-Evans CD, et al. Percutaneous cryoablation of renal masses under CT fluoroscopy: radiation doses to the patient and interventionalist. Abdom Imaging. Springer US; 2015;40(7):2606–2612
4. Rathmann N, Haeusler U, Diezler P, et al. Evaluation of Radiation Exposure of Medical Staff During CT-Guided Interventions. J Am Coll Radiol. Elsevier; 2015;12(1):82–89
5. McCarthy CJ, Kilcoyne A, Li X, et al. Radiation Dose and Risk Estimates of CT-Guided Percutaneous Liver Ablations and Factors Associated with Dose Reduction. Cardiovasc Intervent Radiol. Springer US; 2018;1–8
6. Nawfel RD, Judy PF, Silverman SG, Hooton S, Tuncali K, Adams DF. Patient and Personnel Exposure during CT Fluoroscopy-guided Interventional Procedures. Radiology. Radiological Society of North America ; 2000;216(1):180–184
7. Leng S, Christner JA, Carlson SK, et al. Radiation Dose Levels for Interventional CT Procedures. Am J Roentgenol. American Roentgen Ray Society ; 2011;197(1):W97–W103
8. Kloeckner R, Santos DP dos, Schneider J, Kara L, Dueber C, Pitton MB. Radiation exposure in CT-guided interventions. Eur J Radiol. Elsevier; 2013;82(12):2253–2257
9. Tsalafoutas IA, Tsapaki V, Triantopoulou C, Gorantonaki A, Papailiou J. CT-Guided Interventional Procedures without CT Fluoroscopy Assistance: Patient Effective Dose and Absorbed Dose Considerations. Am J Roentgenol. American Roentgen Ray Society; 2007;188(6):1479–1484

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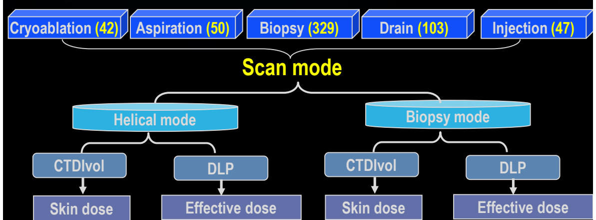
Dose Survey

- Different scopes and number of patients
- Imaging mode varies from practice to practice
- Dose metrics varies: CTDIvol, DLP, Skin dose, Effective dose etc.
- Common threads among disparate surveys:
  - Radiation dose widely varies: ~1-120 mSv effective dose &~100-2000 mGy peak skin dose
  - Helical scans are the primary contributor to effective dose
- These data can serve as benchmarks within the institution or for other radiology practices

Dose Survey

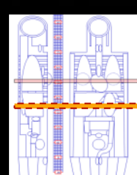
- 561 patients in total



Leng *et al,* Radiation Dose Levels for Interventional CT Procedures. AJR. 2011

Effective Dose Estimation

- E = k*DLP.
- For helical mode, published k factor of 0.015 for the torso was used
- For Biopsy mode: k factor was determined using ImPACT: k=E/DLP, average k in typical body regions



http://www.impactscan.org/

1 Jessen et al., 1999; 50: 165-172.
3 Shrimpton P., et al., *European Guidelines for Multislice CT*; 2004.
4 Shrimpton, et al., *Br J Radiol.* Dec 2006;

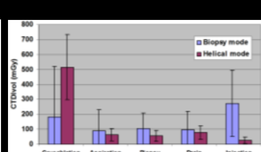
Average CTDIvol

- Generally higher CTDIvol than diagnostic exams
- Significant difference among procedures
- Large variation among the same procedure

TABLE 1: Volumetric CT Dose Index ($CTDI_{vol}$) for Each Scan Mode and Procedure Type

Procedure	$CTDI_{vol}$ (mGy)	
	Intermittent Mode	Helical Mode
Cryoablation (*n* = 42)	183 ± 338	515 ± 217
Aspiration (*n* = 50)	89 ± 141	65 ± 41
Biopsy (*n* = 329)	102 ± 105	56 ± 36
Drain (*n* = 103)	95 ± 124	79 ± 45
Injection (*n* = 47)	273 ± 222	26 ± 23

Note—Data are mean ± SD.



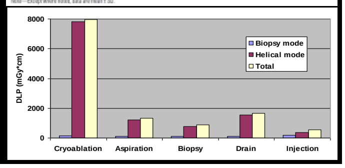
Dose Length Product (DLP)

- Most DLP comes from helical mode
- Biopsy mode contributes little to DLP due to the short scan range

TABLE 2: Dose-Length Product (DLP) for Each Procedure

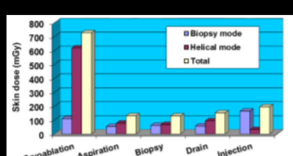
Mode	DLP (mGy × cm)				
	Cryoablation	Aspiration	Biopsy	Drain	Injection
Intermittent mode	132 ± 244	97 ± 135	110 ± 111	108 ± 125	198 ± 158
Helical mode	7814 ± 3360	1221 ± 696	792 ± 582	1554 ± 984	367 ± 283
Total	7946 ± 3351	1318 ± 724	902 ± 606	1662 ± 1019	565 ± 348
Intermittent/total (%)	2	7	12	7	35
Helical/total (%)	98	93	88	93	65

Note—Except where noted, data are mean ± SD.



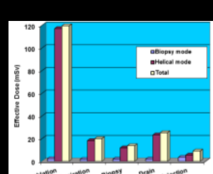
Skin dose

- The max skin dose observed was 1950 mGy
- 553 (out of 561) patients with skin dose < 1000 mGy (96%)
- Both biopsy mode and helical mode contribute substantially to skin dose.



Effective dose

- Mean effective doses were 119.7 ± 50.3, 20.1 ± 11.0, 13.8 ± 9.2, 25.3 ± 15.4, and 9.1 ± 5.5 mSv for the 5 types of procedures.
- Mean effective dose across all procedures was 24.1, with 2.3 mSv (9%) from intermittent mode and 21.8 mSv (91%) from helical mode.



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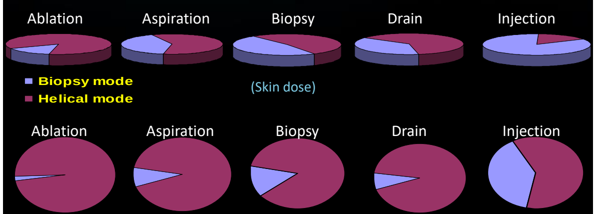
Dose Fraction: Biopsy Mode and Helical Mode



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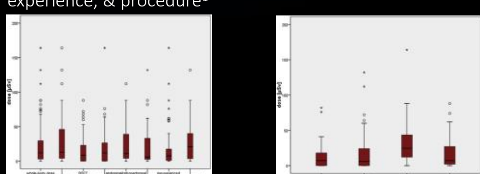
Personnel dose surveys

- Personnel dose is relatively low and varies with complexity, experience, & procedure[1]



[1]Rathmann N, Haeusler U, Diezler P, et al. Evaluation of Radiation Exposure of Medical Staff During CT-Guided Interventions. J Am Coll Radiol. Elsevier; 2015;12(1):82–89

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Dose Monitoring

- Live tracking on the scanner
- Displays both a countdown of scan time remaining and the accumulation of CTDIvol during such procedures

Jones et al, Best Practices Guidelines for CT-Guided Interventional Procedures. JVIR. 2017

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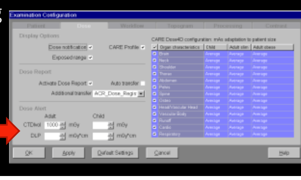
Dose Notification and Dose Alert

- XR-25 defined the *dose notification* and *dose alert*
- Dose Notification: protocol level
- Dose Alert: global setting



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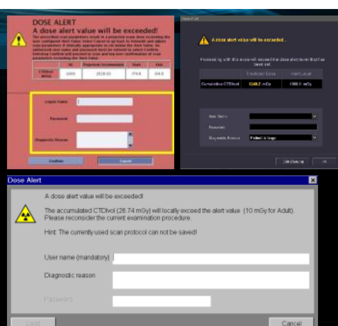
Dose Alert

- Pop-up window once threshold reached.
- Username, diagnostic reason and password may be needed before continuing the procedure.



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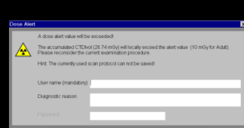
Potential Problems with Dose Alert in CTGI

- Common to exceed dose alert, even at 2000 mGy
- Interrupt workflow, may substantial delay urgent procedures
  - Occur the first time threshold is reached
  - Some sw may occur frequently
- Password may be needed
- Potential solutions:
  - Disable password
  - Disable dose alert (Caution: global setting, this will disable dose alert for all protocols)



McCollough and Favazza, Potential Clinical Ramifications of Dose Alert on CT-Guided Interventional Procedures. JACR. 2016

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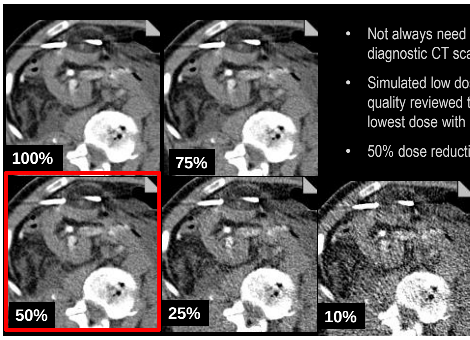
Dose Reduction

- Limit scan range
- Set the right image quality
- Limit number of scans
- Use automatic exposure control
- Select appropriate KV
- Use iterative reconstruction



- Not always need same quality as diagnostic CT scans.
- Simulated low dose scans, image quality reviewed to determine the lowest dose with sufficient IQ
- 50% dose reduction

Leng *et al*, Radiation Dose Reduction for CT-Guided Renal Tumor Cryoablation. AJR, 2011

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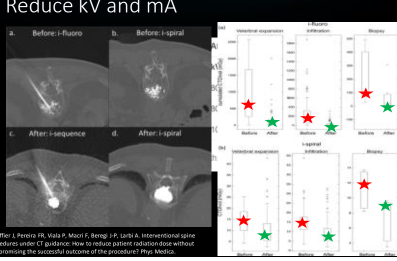
Radiation dose reduction techniques

- Reduce kV and mA



[2]Greffier J, Pereira FR, Viala P, Macri F, Beregi J-P, Larbi A. Interventional spine procedures under CT guidance: How to reduce patient radiation dose without compromising the successful outcome of the procedure? Phys Medica.

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Radiation dose reduction techniques

- Reduce number of monitoring scans[1]

Reduced number of monitoring scans from every 3 mins to physicians discretion and lower technique

Procedure phase	Median standard protocol DLP	Median dose reduction protocol DLP	P
Total	4833.5 mGy*cm	2648 mGy*cm	<0.01
Targeting	2087 mGy*cm	1092 mGy*cm	<0.01
Monitoring	1733 mGy*cm	866 mGy*cm	<0.01

[1]Levesque VM, Shyn PB, Tuncali K, et al. Radiation dose during CT-guided percutaneous cryoablation of renal tumors: Effect of a dose reduction protocol. Eur J Radiol. Elsevier; 2015;84(11):2218–222

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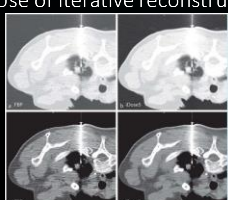
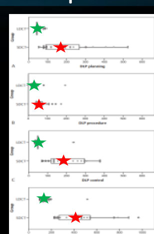
Radiation dose reduction techniques

- Use of iterative reconstruction





★ Pre-change
★ Post-change

Chang D, Hiss S, Mueller D, et al. Radiation Dose Reduction in Computed Tomography-Guided Lung Interventions using an Iterative Reconstruction Technique. © Georg Thieme Verlag KG; 2015;187(10):906–914

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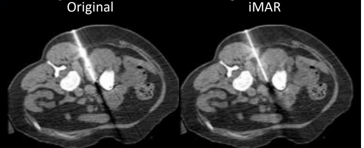
Metal Artifact Reduction

- Metal artifacts are commonly seen in CTGI
- Techniques used to overcome metal artifacts, e.g. high kV, high mA, may increase radiation dose
- Metal artifact reduction (MAR) can help improve image quality and reduce radiation dose.

Original iMAR



[1]Sheedy, EN et al. Can Metal Artifact Reduction Improve the Conspicuity of Interventional Needle Placement? RSNA 2018 VI147-ED-X:

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Radiation dose reduction techniques

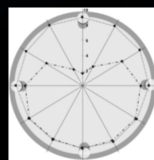
- Use of angular beam modulation

Significant reduction in patient dose:

	Effective dose	Breast dose	12 o'clock skin dose
Reduction	35%	47%	75%

Significant reduction in personnel dose:

	In beam	10 cm from beam
Reduction	72%	27%



Study	Test Design	Hand Dose Rate: Without Needle Holder*	Hand Dose Rate: With Needle Holder†	Tube Voltage (kVp)	Tube Current (mA)	Collimation (mm)
Present study, without ABM	Phantom	4.69 mSv/sec	0.11 mSv/sec	120	60	14.4
Present study, with ABM	Phantom	1.32 mSv/sec	0.08 mSv/sec	120	60	14.4

Hohl C, Suess C, Wildberger JE, et al. Dose Reduction during CT Fluoroscopy: Phantom Study of Angular Beam Modulation 1 Conclusion: ABM leads to significant dose reductions for both patients and personnel during CT fluoroscopy-guided thoracic interventions, without impairing image quality. Radiology. 2008;246(2)

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Radiation protection for the operator and staff

- In most scenarios, reduction of patient dose also results in reduction of operator dose
- Select low dose imaging mode, if possible
- Time, distance, and shielding
  - Outside scan room if possible
  - Stay at low dose areas: use gantry as a shield
  - Shielding devices: lead apron, thyroid, hand, eye
- Monitoring occupational dose

Jones et al, Best Practices Guidelines for CT-Guided Interventional Procedures. JVIR. 2017

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Summary

- CT scans performed during interventional procedures are different than those in diagnosis:
  - More scans are commonly performed
  - Scan mode different
- Dose in CT-guided interventional procedures:
  - Higher than routine diagnostic scans
  - Significant dose variation for different procedures, for the same procedures, among different institute
  - Helical scans contribute majority of the effective dose
- Various dose reduction techniques can be used to reduce radiation dose without sacrificing outcome of CT guided interventional procedures

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Acknowledgement

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Thank You!