

Radiation Safety in Medical Imaging

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IU Health - Morgan Hospital

Outline

- ❖ Types and measurement of ionizing radiation
- ❖ Sources of radiation exposure in today's world
- ❖ Radiation exposure in medical imaging
- ❖ Methods of radiation dose reduction

Handouts and questions

❖ **<http://www.stanford.edu/~hallett>**

.pdf file available: Choose folder “IU Morgan”

❖ Questions? xraydoc97@yahoo.com

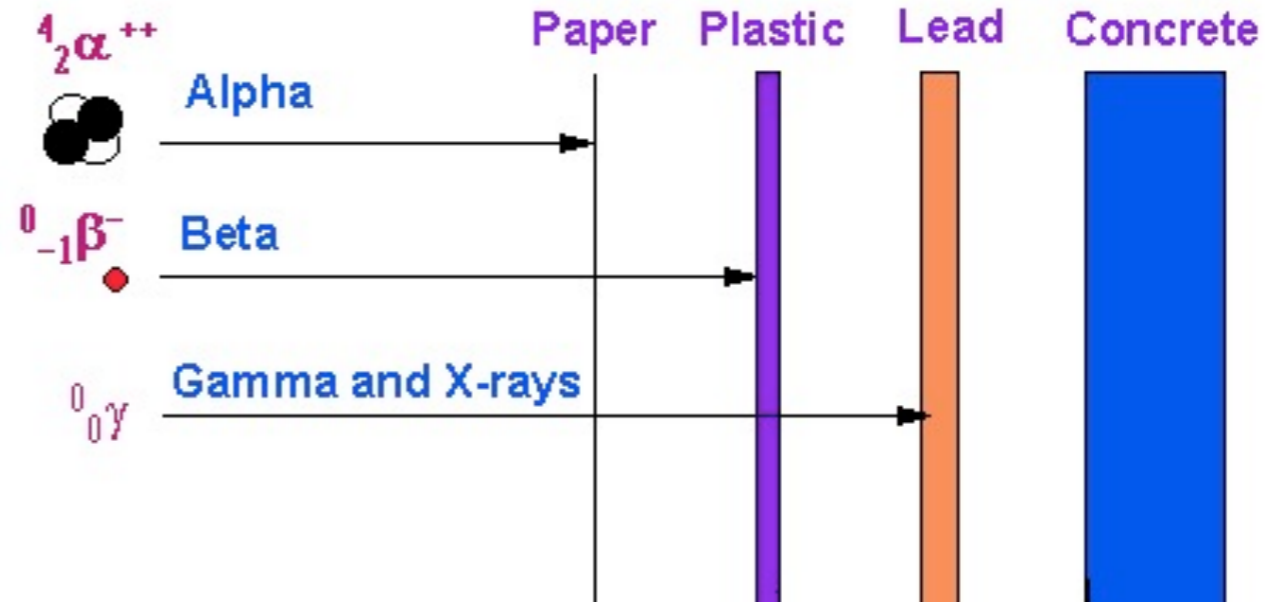
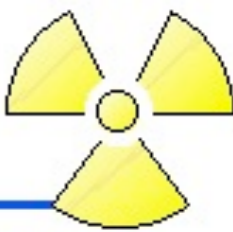
Types of Ionizing Radiation

- ❖ Alpha Emission: ${}^4\text{He}$ emitted, limited tissue penetration
- ❖ Beta Emission: electrons (e^-) emitted - example: ${}^{131}\text{I}$
- ❖ Positron Emission: $2 \times 511 \text{ keV}$ annihilation photons at 180° angle (${}^{18}\text{F}$ FDG PET)
- ❖ Neutrons:
- ❖ Gamma Rays: Excited nuclei give off photons of energy, return to non-excited state
- ❖ X-Rays: Photons like gamma rays but have different origin

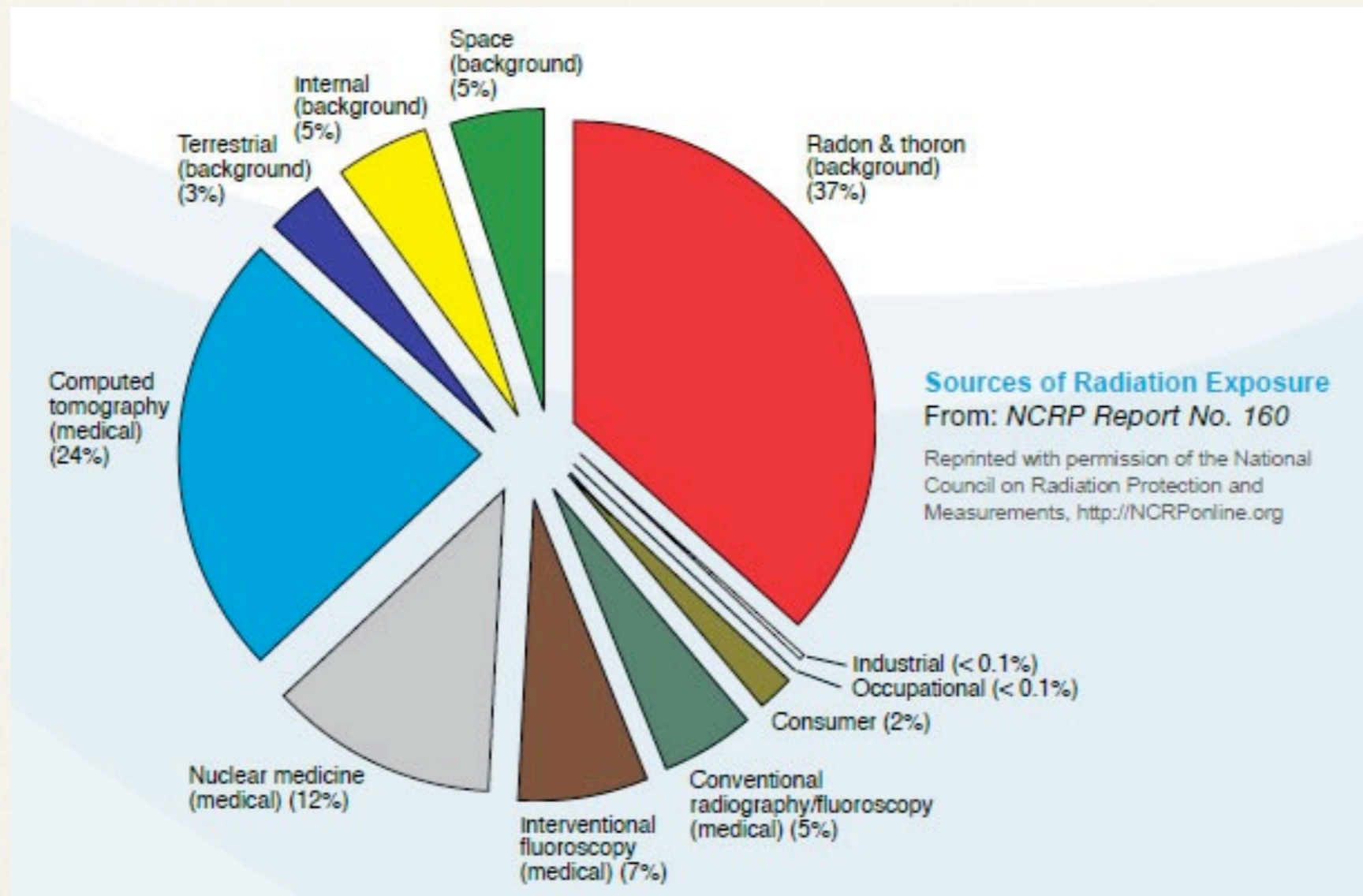
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Penetrating Distances

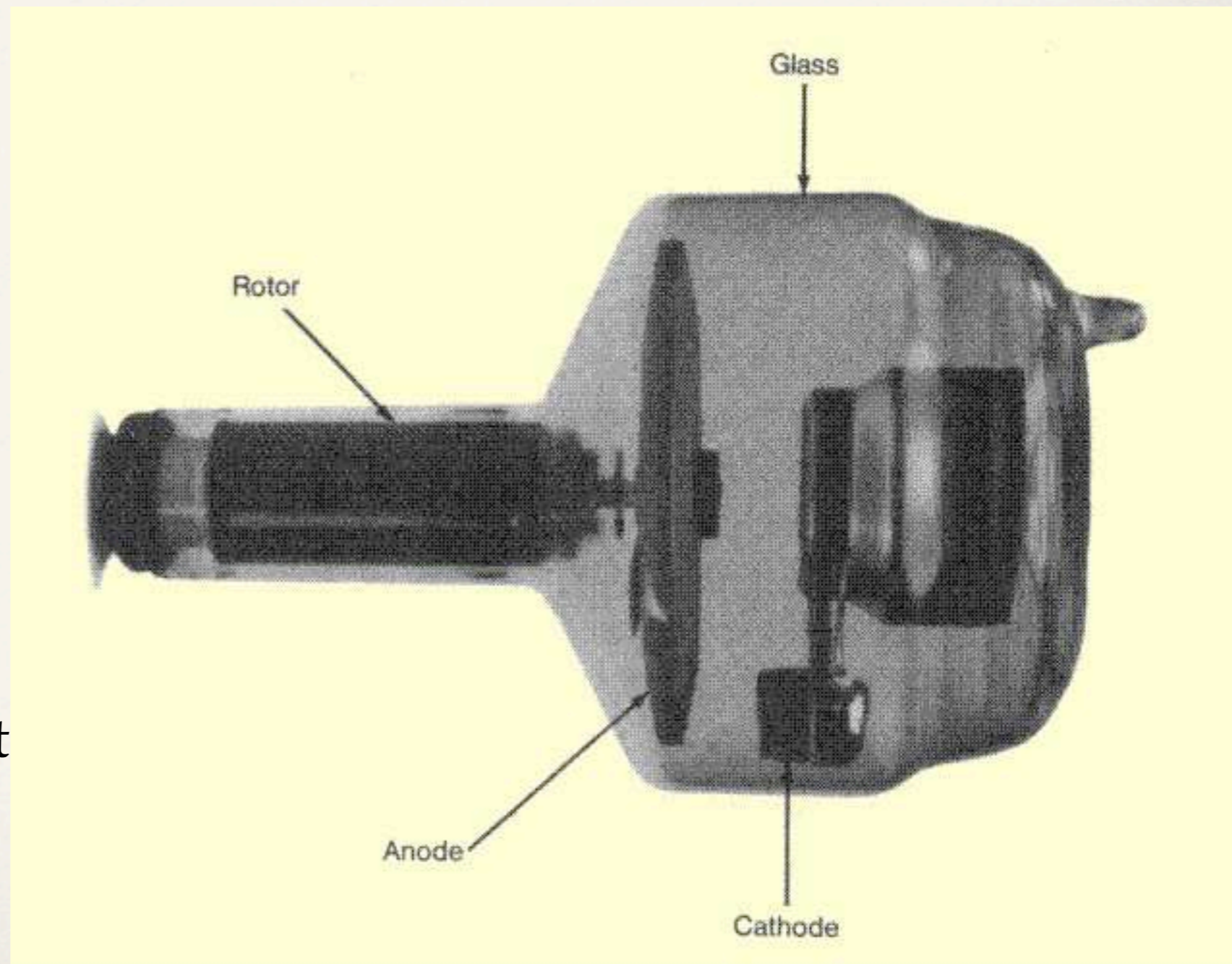


Sources of Radiation Exposure



How are X-rays generated?

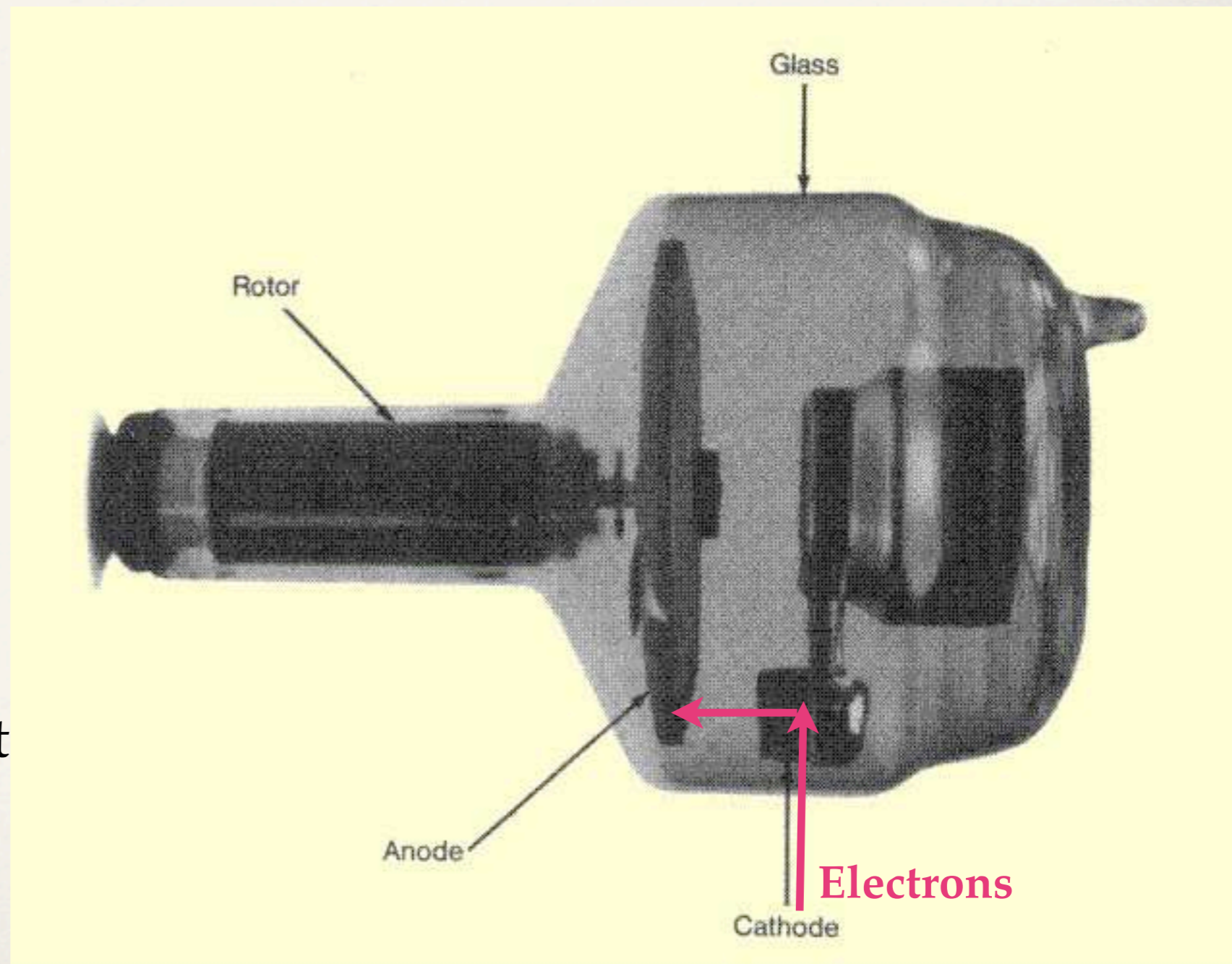
- ❖ High energy electrons flow to cathode, across vacuum to strike anode
- ❖ electrons interact with individual atoms of the anode material -> produce x-rays and heat



Sprawls, P. The Physical Principles of Medical Imaging, 2ed.

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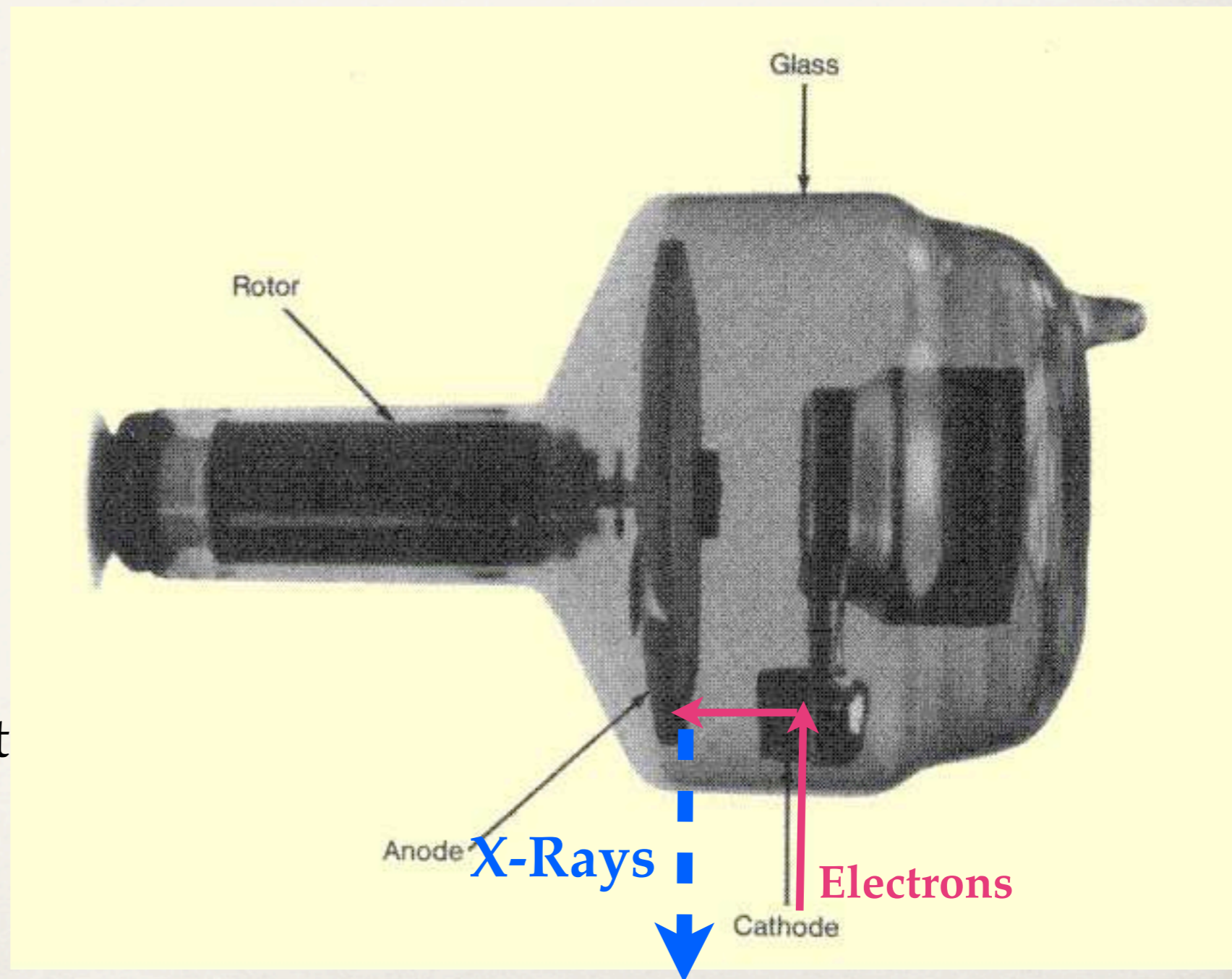
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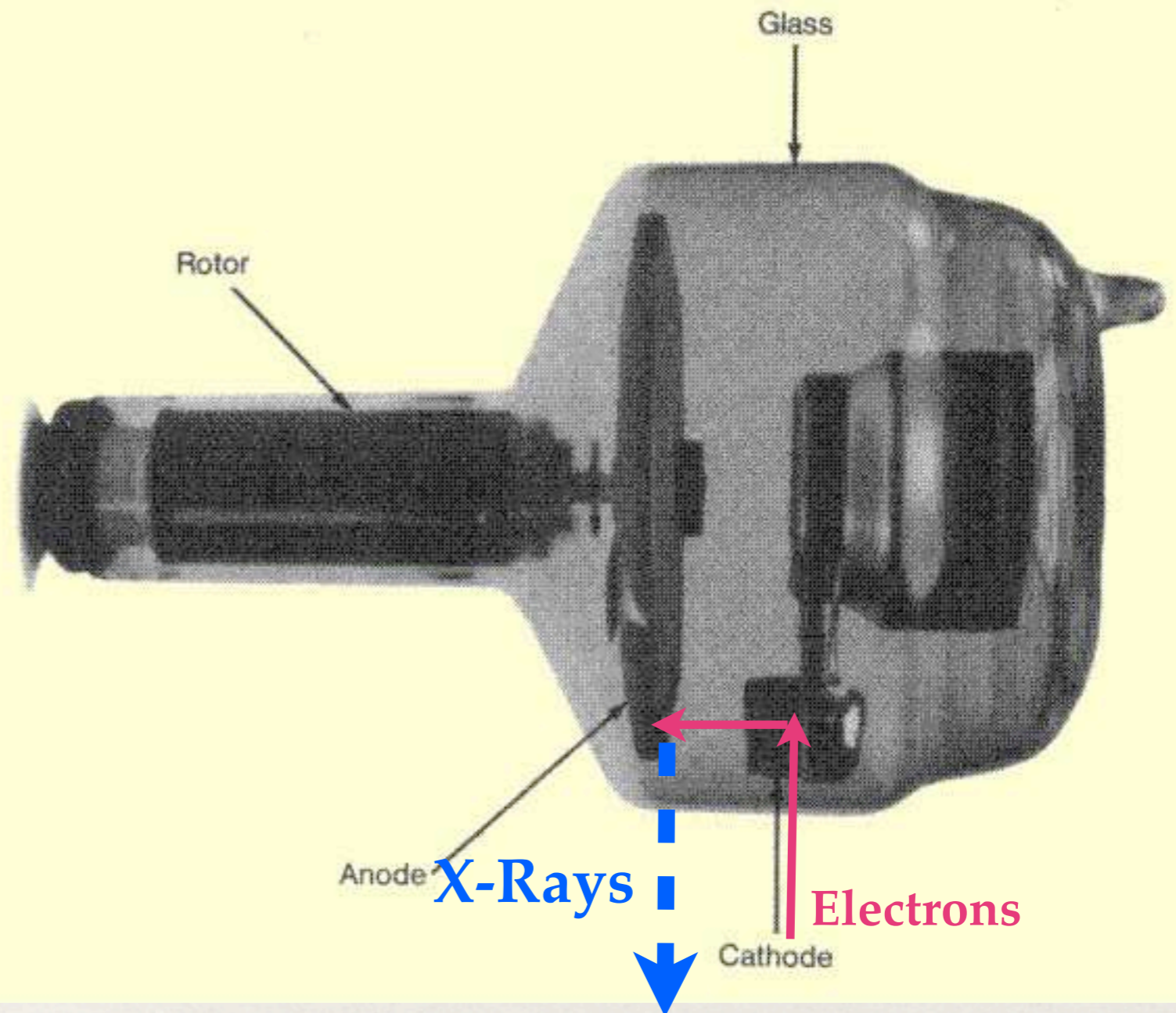
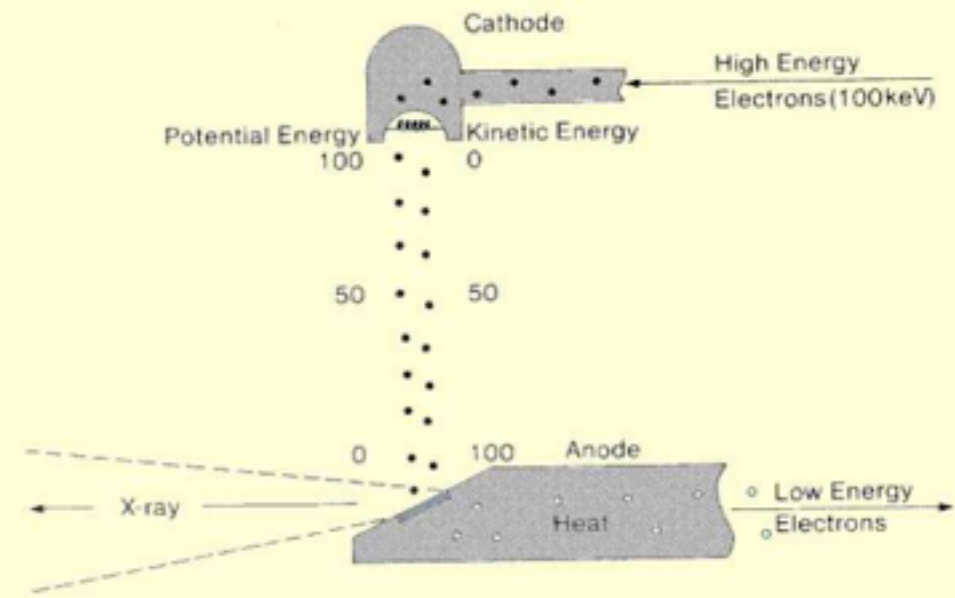
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Measurements of Dose

- ❖ Absorbed Dose: energy imparted to tissue, per unit mass
 - ❖ Unit = Gray = 1 joule per kg (mGy = 0.001 Gy)
- ❖ Dose Equivalent: Absorbed dose X factor for type of radiation
 - ❖ Unit = **Sievert** or **millisievert (mSv)**
 - ❖ for x-rays & gamma rays, factor = 1; so **1 mGy = 1 mSv**
- ❖ Exposure = energy transferred to unit mass of air
 - ❖ Units: Roentgen (R)

Determinants of Dose

- ❖ Peak X-ray Tube Voltage (kilovolt peak = kVp)
- ❖ Tube Current
- ❖ Length of Exposure
- ❖ DOSE proportional to current and time; and to (kVp)²
- ❖ Inverse Square Law: dose inversely proportional to square of distance to source

Other Factors

- ❖ Patient Size
 - ❖ Dose increases proportional to increase in thickness
- ❖ Filtration: all x-ray systems have filters (aluminum, etc) to remove low-level x-rays which do not contribute to diagnostic image quality but do contribute to dose
- ❖ Collimation: Excluding areas not needed to diagnosis will decrease dose
 - ❖ Also decreases scattered radiation reaching detector - improves image contrast

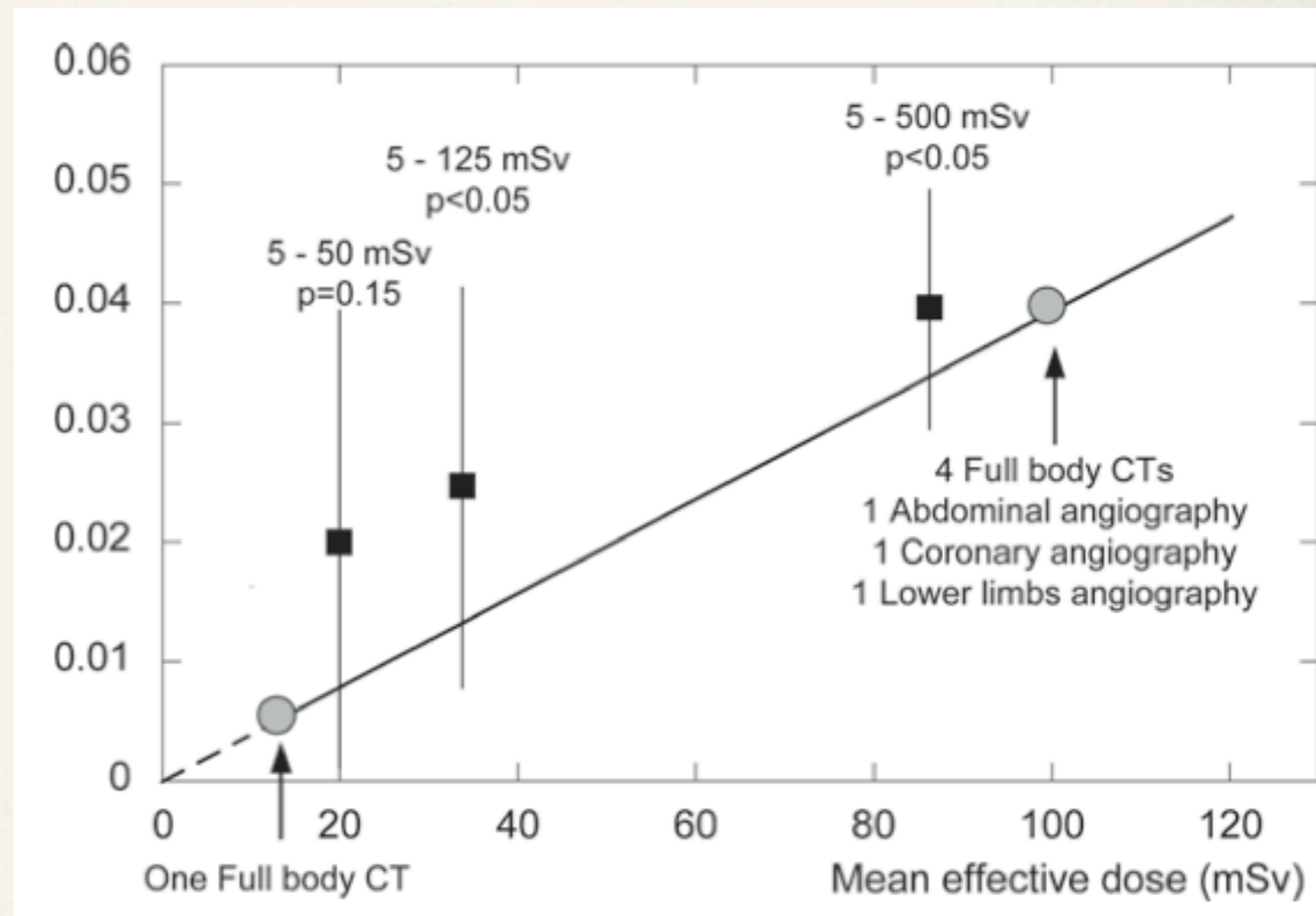
Effects of Radiation

- ❖ Dose $> 100\text{mSv}$: can cause deleterious effects
- ❖ Dose $< 100\text{ mSv}$: not as clear
 - ❖ Humans have high background cancer incidence (25-33%)
 - ❖ Would need large numbers of patients to accurately stratify risks
 - ❖ Use linear non-threshold approximation from higher doses

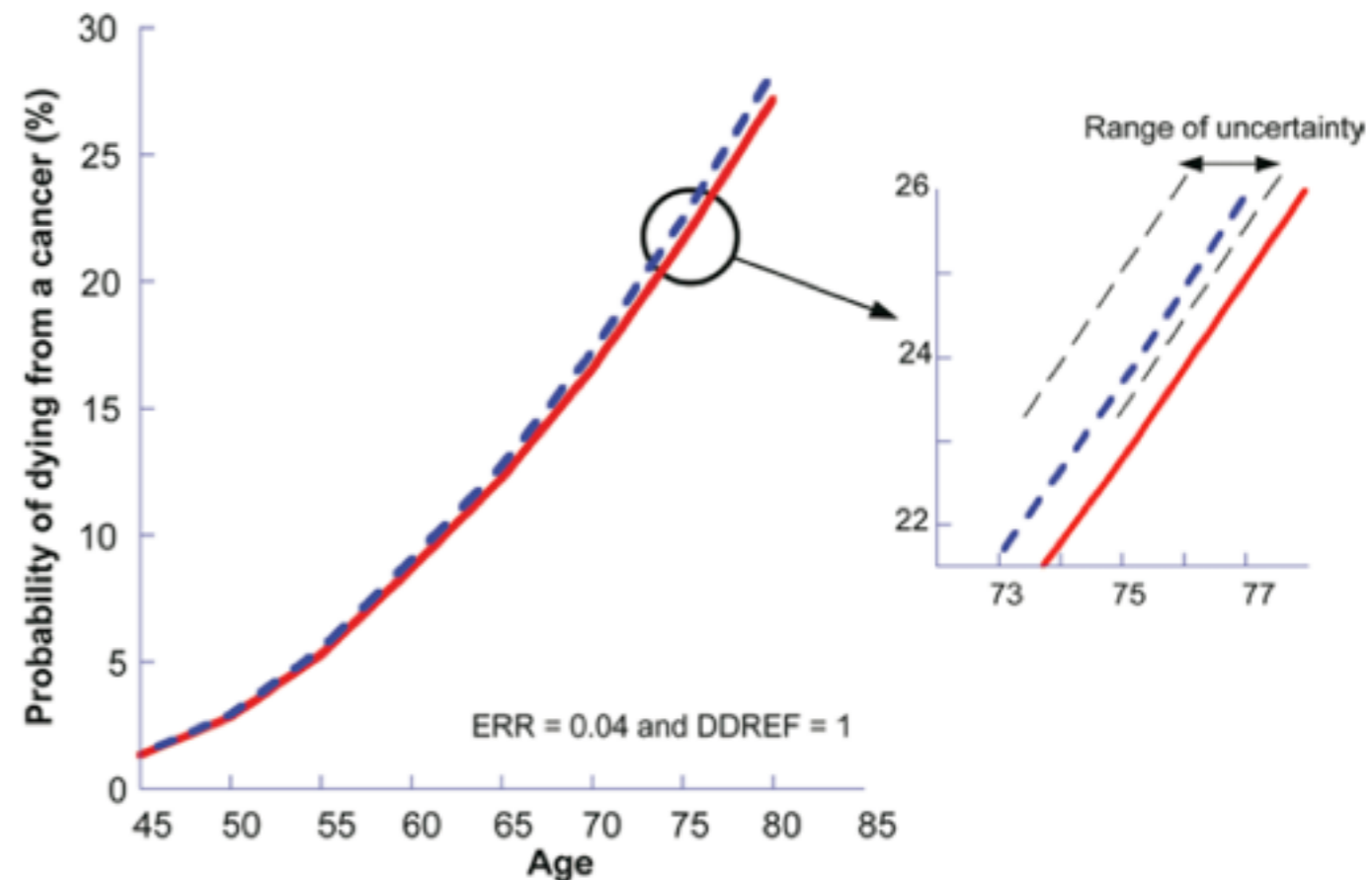
Japanese Atomic Bomb Survivors

- ❖ Excess Relative Risk (ERR) of mortality from solid tumors
- ❖ Low-dose patients (5-50 mSv) had ERR of 2%
- ❖ Diagnostic imaging falls into this range
- ❖ Data not reliable at very low dose (< 10 mSv)

ERR/100



Verdun FR, et al. Radiographics 2008; 28:1807-16



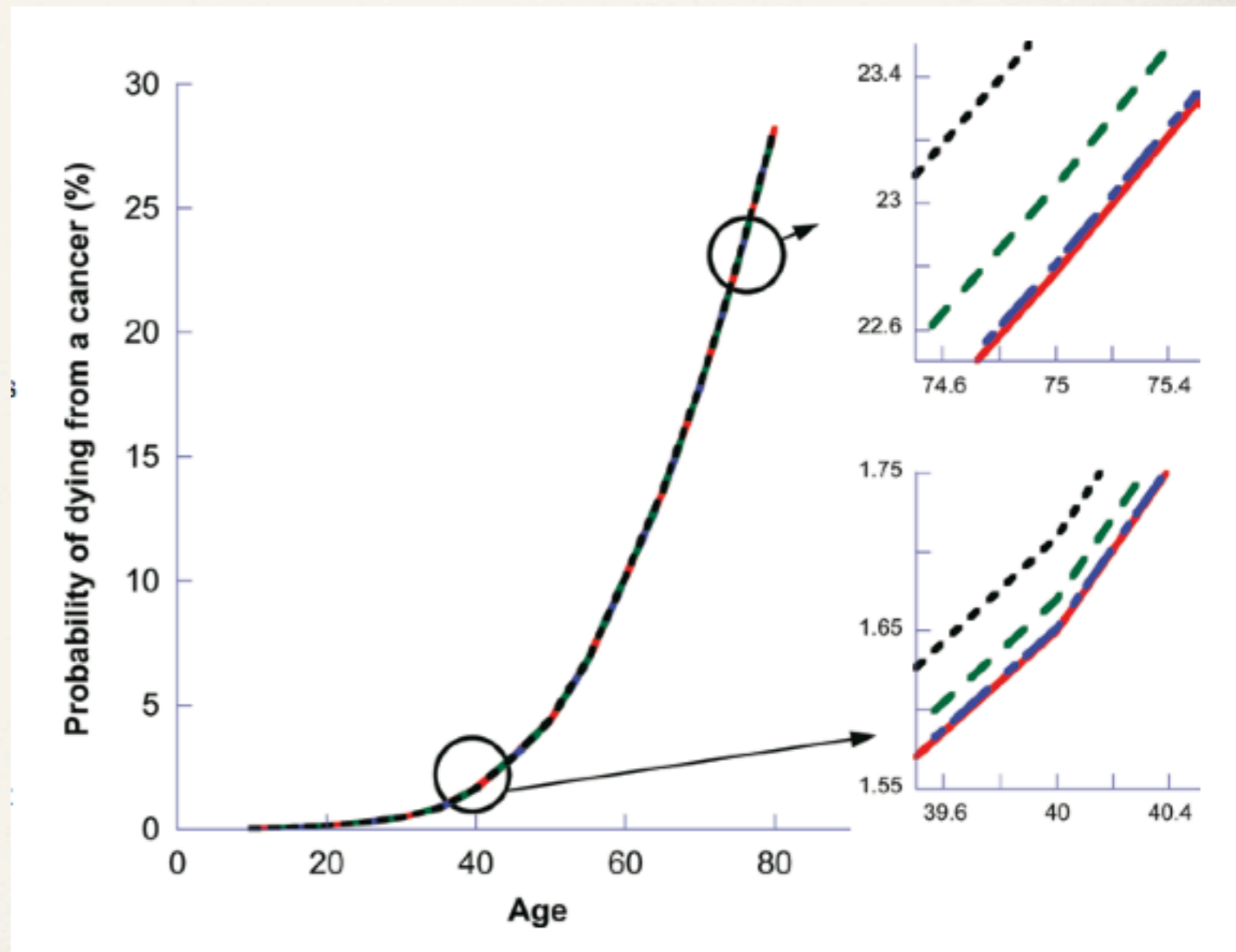
- ❖ Cancer risk estimates have inherent 2-fold to 5- fold level of uncertainty (less uncertainty at higher doses)
- ❖ Example: 40 yo Caucasian male receives 100 mSv
 - ❖ Excess absolute risk by age 75 = 1%

Rough Estimates.....

- ❖ Lifetime risk of dying from cancer = 25%
- ❖ Added (calculated) radiologic risk **increases by 1% per 100 mSv**
 - ❖ = 10% per Sv
- ❖ At low doses, **risk is reduced by 2 dose- and dose rate- effectiveness factors**, so **risk = 0.5% per 100 mSv**

Children

- ❖ 3-4 X more radiosensitive than adults
- ❖ Resultant small, but real, dose-dependent increase in long-term risk



What to tell patients?

Table 4
What to Tell Your Patients concerning Additional Risk of Death from Cancer

Effective Dose (mSv)	Risk	Quantification	Examination
<0.1	$<10^{-6}$	Negligible	Radiography of the chest (postero-anterior), extremities, or teeth
0.1–1.0	10^{-5}	Minimal or extremely low	Abdomen, lumbar spine
1.0–10	10^{-4}	Very low	CT of the brain, chest, or abdomen
10–100	10^{-3}	Low	Multiphase CT
>100	$>10^{-2}$	Moderate	Interventional procedures,* repeat CT

Sources.—References 10 and 22.

*Including the determinist effects of ionizing radiation (skin burns).

Real-world Correlation

For this procedure:	* Your approximate effective radiation dose is:	Comparable to natural background radiation for:	** Additional lifetime risk of fatal cancer from examination:
ABDOMINAL REGION:			
Computed Tomography (CT)-Abdomen and Pelvis	15 mSv	5 years	Low
Computed Tomography (CT)-Abdomen and Pelvis, repeated with and without contrast material	30 mSv	10 years	Moderate
Computed Tomography (CT)-Colonography	10 mSv	3 years	Low
Intravenous Pyelogram (IVP)	3 mSv	1 year	Low
Radiography (X-ray)-Lower GI Tract	8 mSv	3 years	Low
Radiography (X-ray)-Upper GI Tract	6 mSv	2 years	Low
BONE:			
Radiography (X-ray)-Spine	1.5 mSv	6 months	Very Low
Radiography (X-ray)-Extremity	0.001 mSv	3 hours	Negligible
CENTRAL NERVOUS SYSTEM:			
Computed Tomography (CT)-Head	2 mSv	8 months	Very Low
Computed Tomography (CT)-Head, repeated with and without contrast material	4 mSv	16 months	Low
Computed Tomography (CT)-Spine	6 mSv	2 years	Low
CHEST:			
Computed Tomography (CT)-Chest	7 mSv	2 years	Low
Computed Tomography (CT)-Chest Low Dose	1.5 mSv	6 months	Very Low
Radiography-Chest	0.1 mSv	10 days	Minimal
DENTAL:			
Intraoral X-ray	0.005 mSv	1 day	Negligible
HEART:			
Coronary Computed Tomography Angiography (CTA)	16 mSv	5 years	Low
Cardiac CT for Calcium Scoring	3 mSv	1 year	Low

Radiation Protection Strategies

Easy Rules of Radiation Protection

- ❖ First, the exam should be **Justified**
- ❖ Then, the exam should be **Optimized**

Justify the Exam

- ❖ Alternative imaging methods (without ionizing radiation) may exist
 - ❖ US
 - ❖ MRI
 - ❖ Physical Exam
- ❖ If CT is appropriate, one phase may be sufficient (e.g. not W/WO)

Optimize the Exam

- ❖ Radiologist plays role
 - ❖ Balance of image quality, diagnostic utility, and radiation dose
 - ❖ Pediatric patients
 - ❖ Large patients
 - ❖ Elderly

Dose-Reduction Strategies

- ❖ Use of 100 kV (or less)
- ❖ Automated tube current control
- ❖ Iterative Reconstruction
- ❖ Gating Strategies
 - ❖ Prospective (step and shoot) triggering
 - ❖ ECG Pulsing

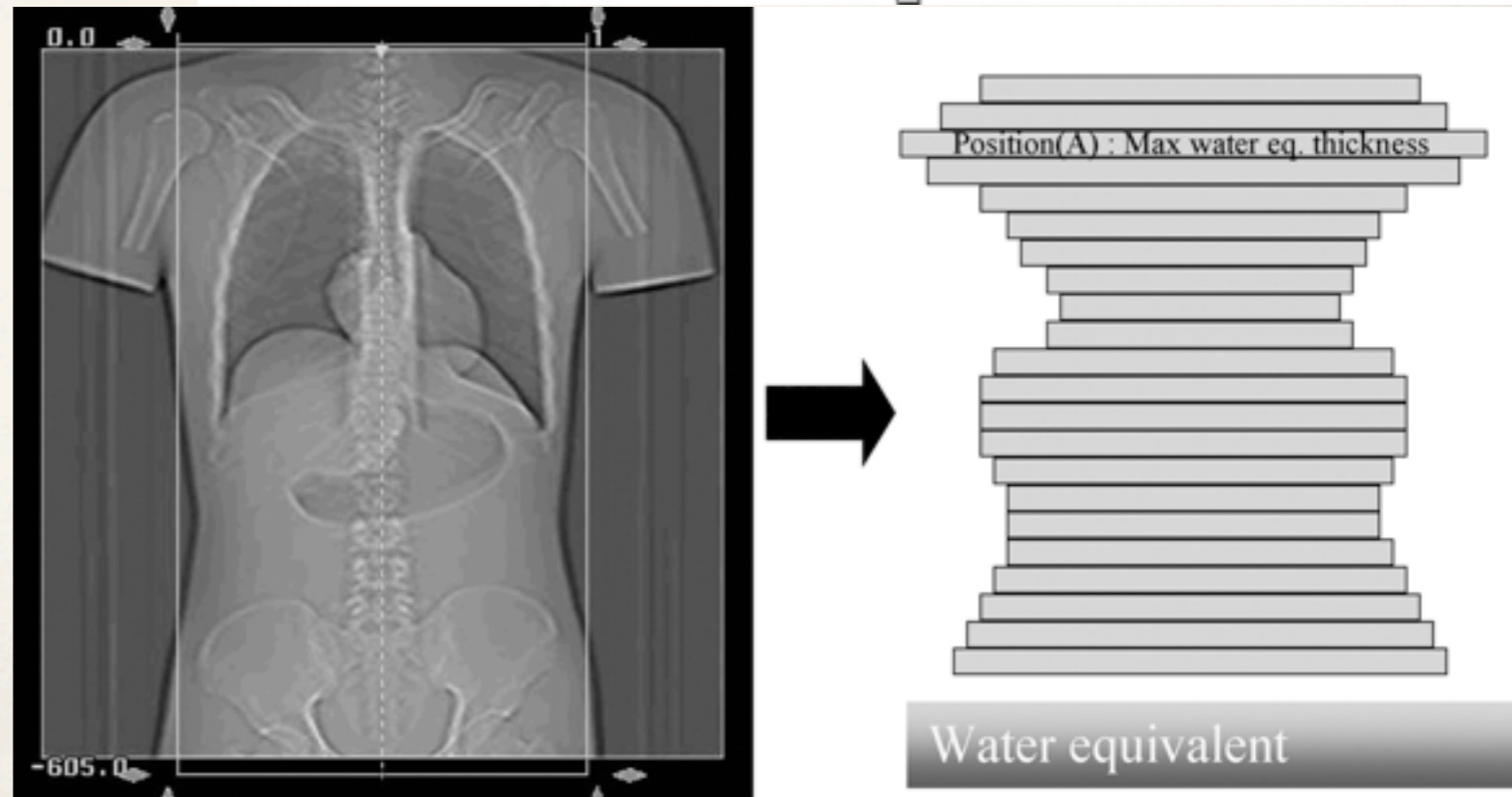
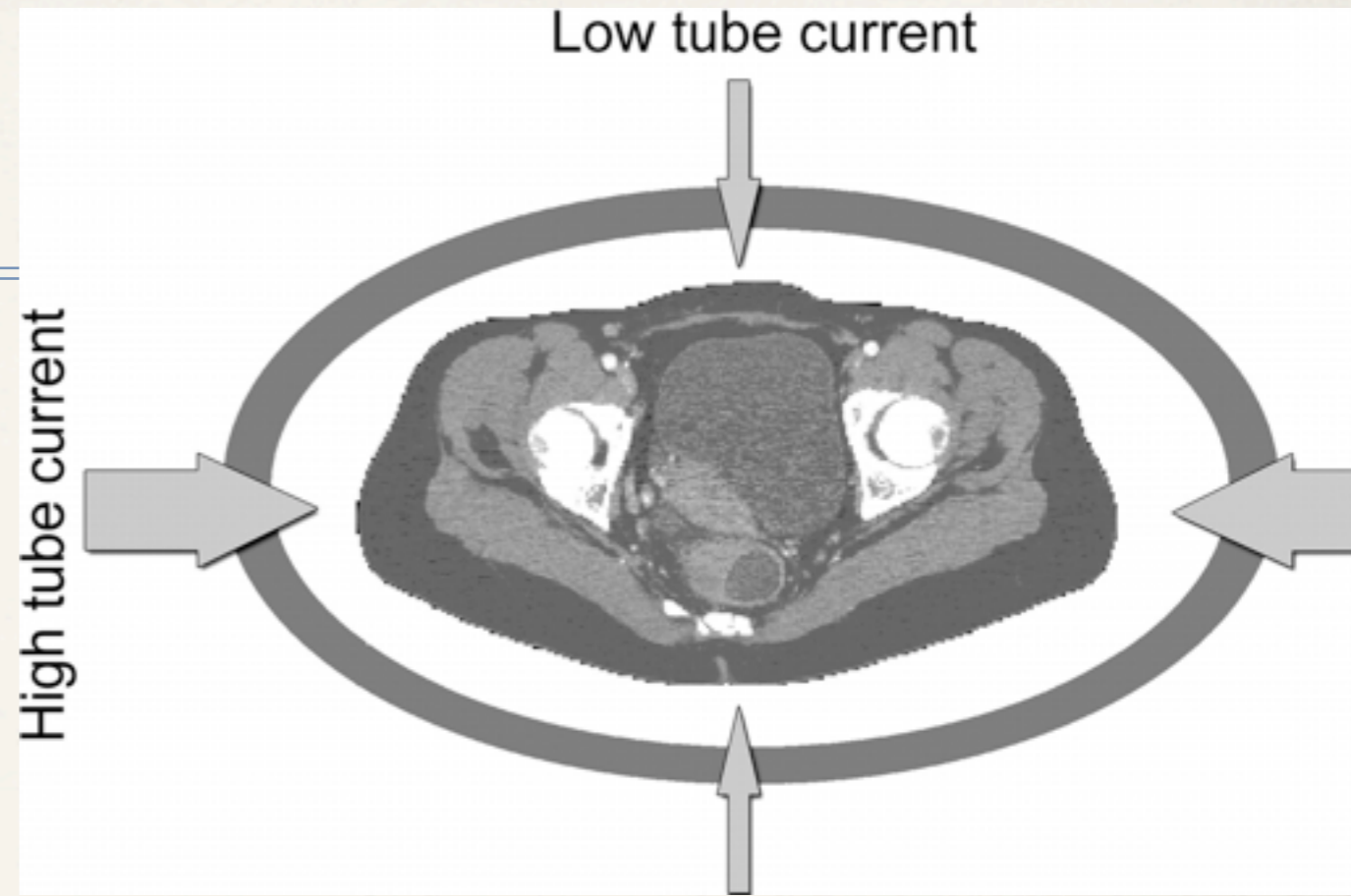
Reduced kV Imaging

- ❖ “Usual” CT voltage is 120 kV
- ❖ Dose proportional to (voltage)²
- ❖ Imaging at 100 kV (or 80 kV for peds) results in :
 - ❖ much lower dose
 - ❖ Better contrast enhancement (K-edge of Iodine)
 - ❖ More image noise at same mAs



Automated Tube Current Modulation

- ❖ Interactively changes tube current depending on thickness
- ❖ Angular and longitudinal modulation
- ❖ Can reduce dose by 45%



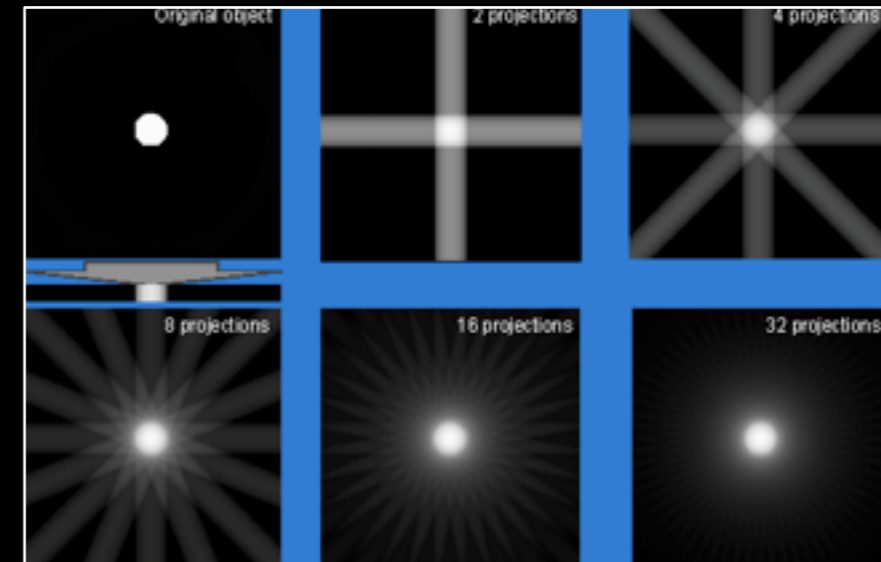
Kaldeep M, et al. Radiology 2004, vol. 233, 649-657

Lee S et al. Acta Radiol 2011 vol. 52; p.1101-1106

Iterative Reconstruction

TRADITIONAL CT Data Reconstruction

- Traditionally reconstructed using Filtered Back Projection (FBP)
- Necessary ASSUMPTIONS:
 - Focal spot infinitely small
 - Detector is single point in center of detector cell
 - Reconstructed voxel - no shape or size
 - Measured signal has no error from photon statistics or image noise



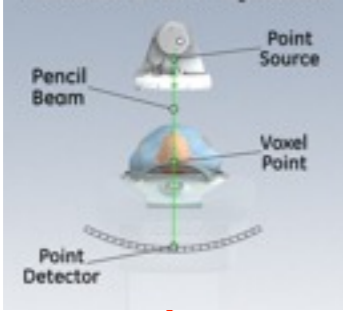
Conventional FBP

vs. Iterative Reconstruction

FBP Reconstruction

Raw Data

Assume "ideal" system



Perfect Sample

Image

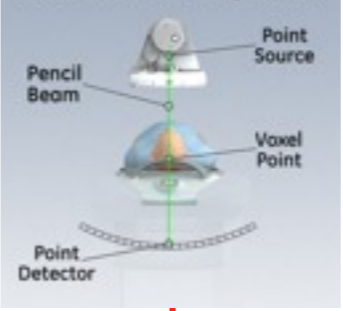


CPU required

Simple
Fast reconstruction
High Noise

ASiR Reconstruction

Raw Data



Powerful Statistical Model

Image



CPU required

Better Image Quality
Low Noise
Lower Dose

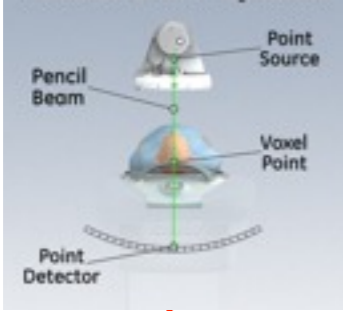
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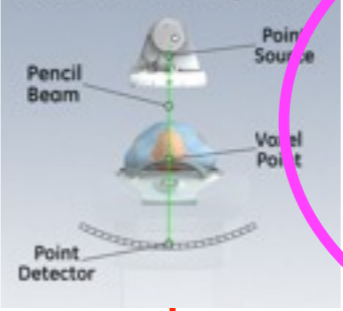


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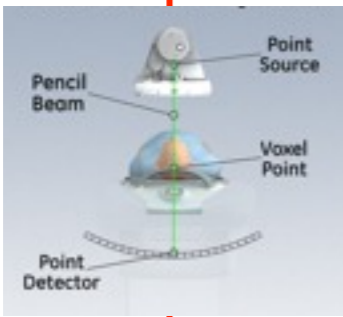
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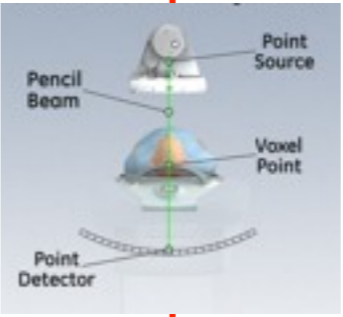


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Powerful Statistical Model



Image



CPU required

Better Image Quality
Low Noise
Lower Dose

Iterative Reconstruction

- Up to 50% dose reduction is possible at same image noise
- **OR:** Improved image quality at same dose
- 40% improvement in low contrast detectability



2007, Std.
Technique
CTDI=19



2008
ASiR
CTDI=9

Images courtesy of Mayo Clinic
Arizona

Cardiac Gating Techniques

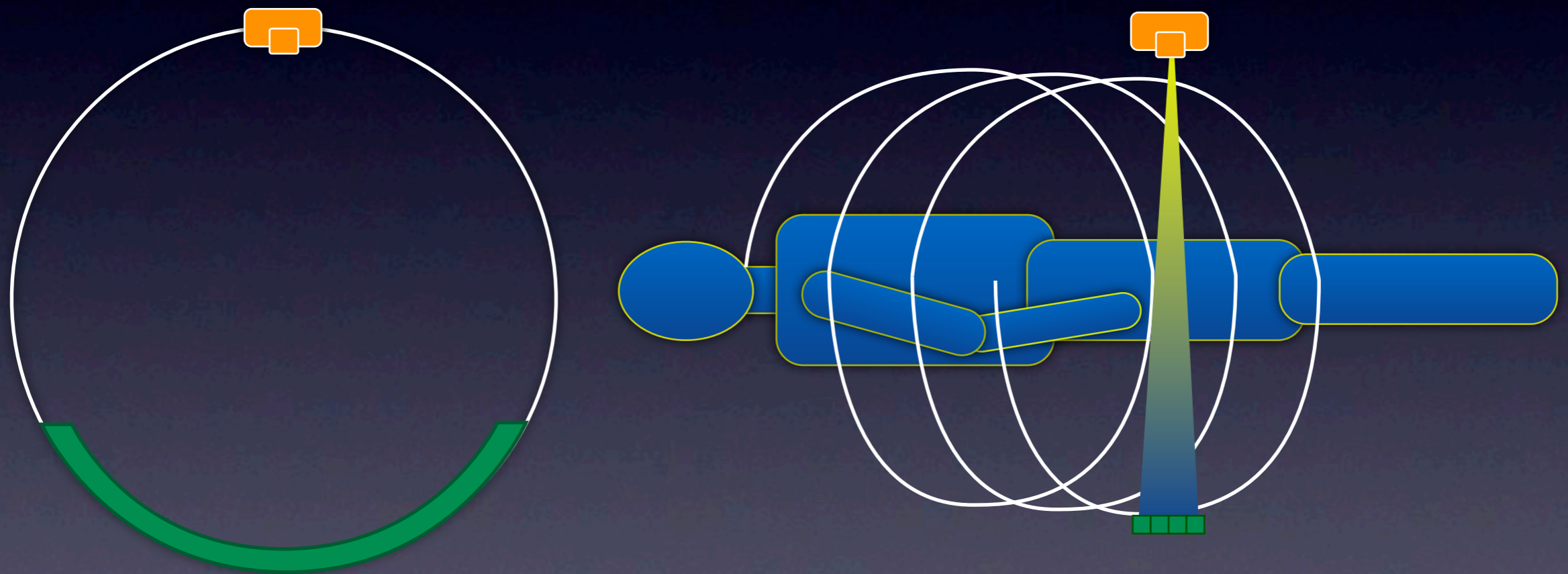
ECG-Gated CT

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Basic Principles of CT

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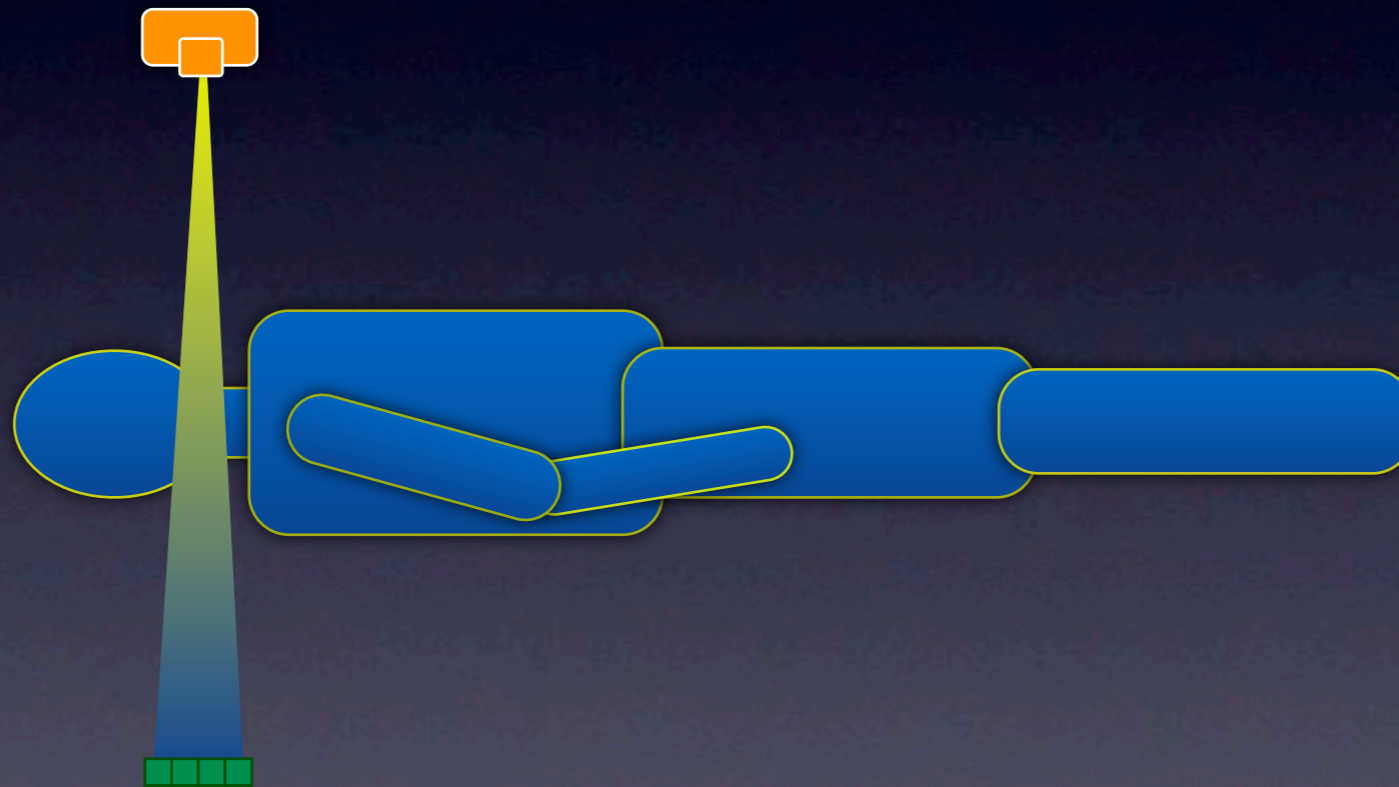


Principles of Gated CT

CT data acquired with EKG data

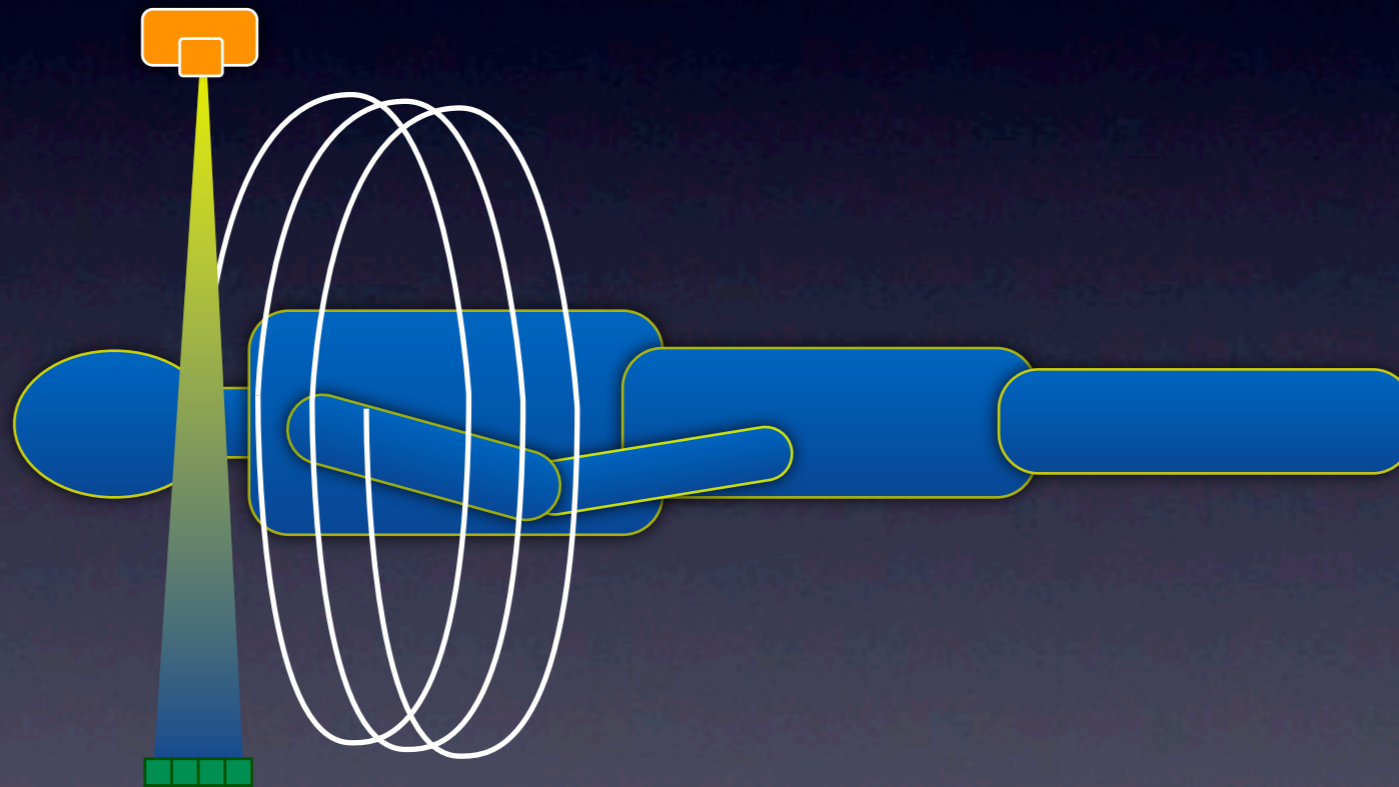
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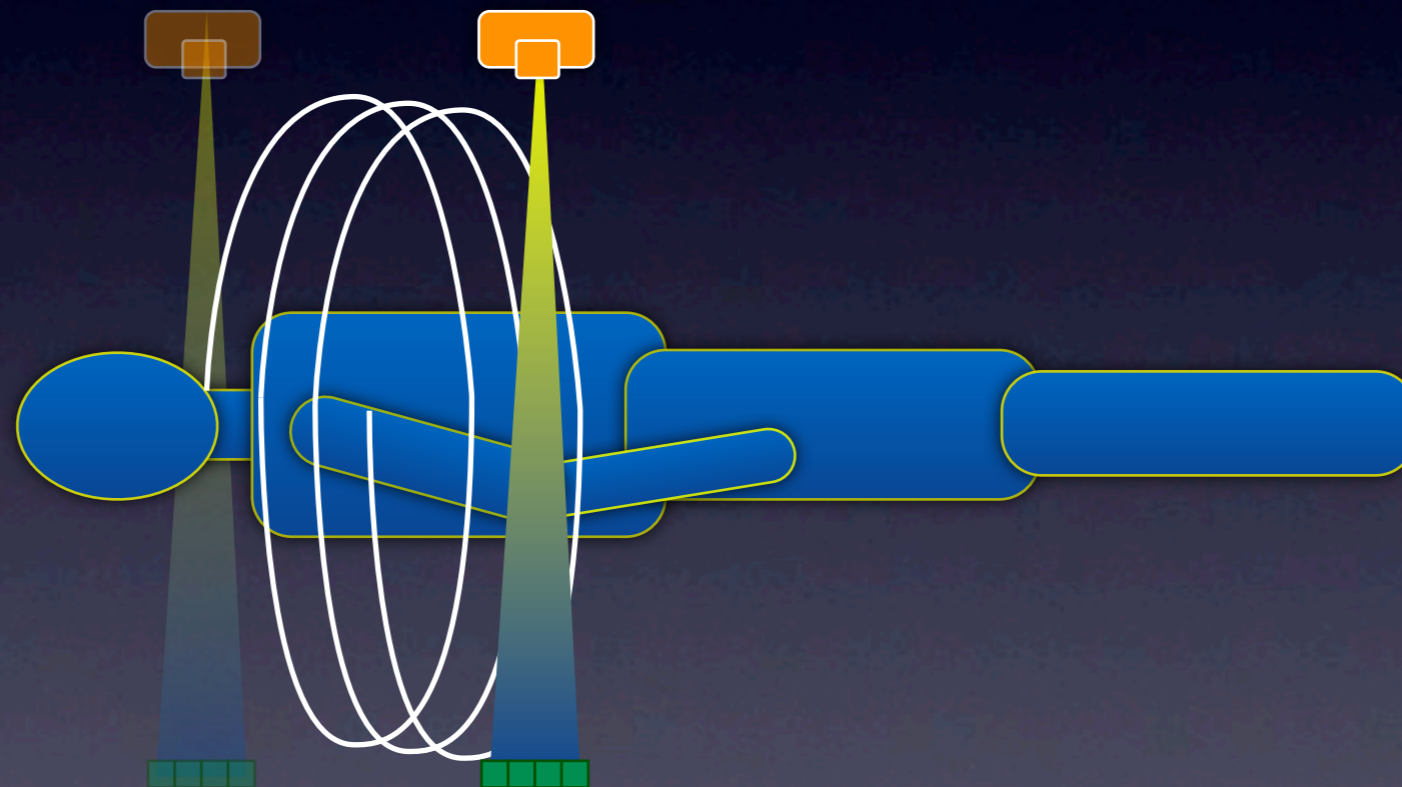
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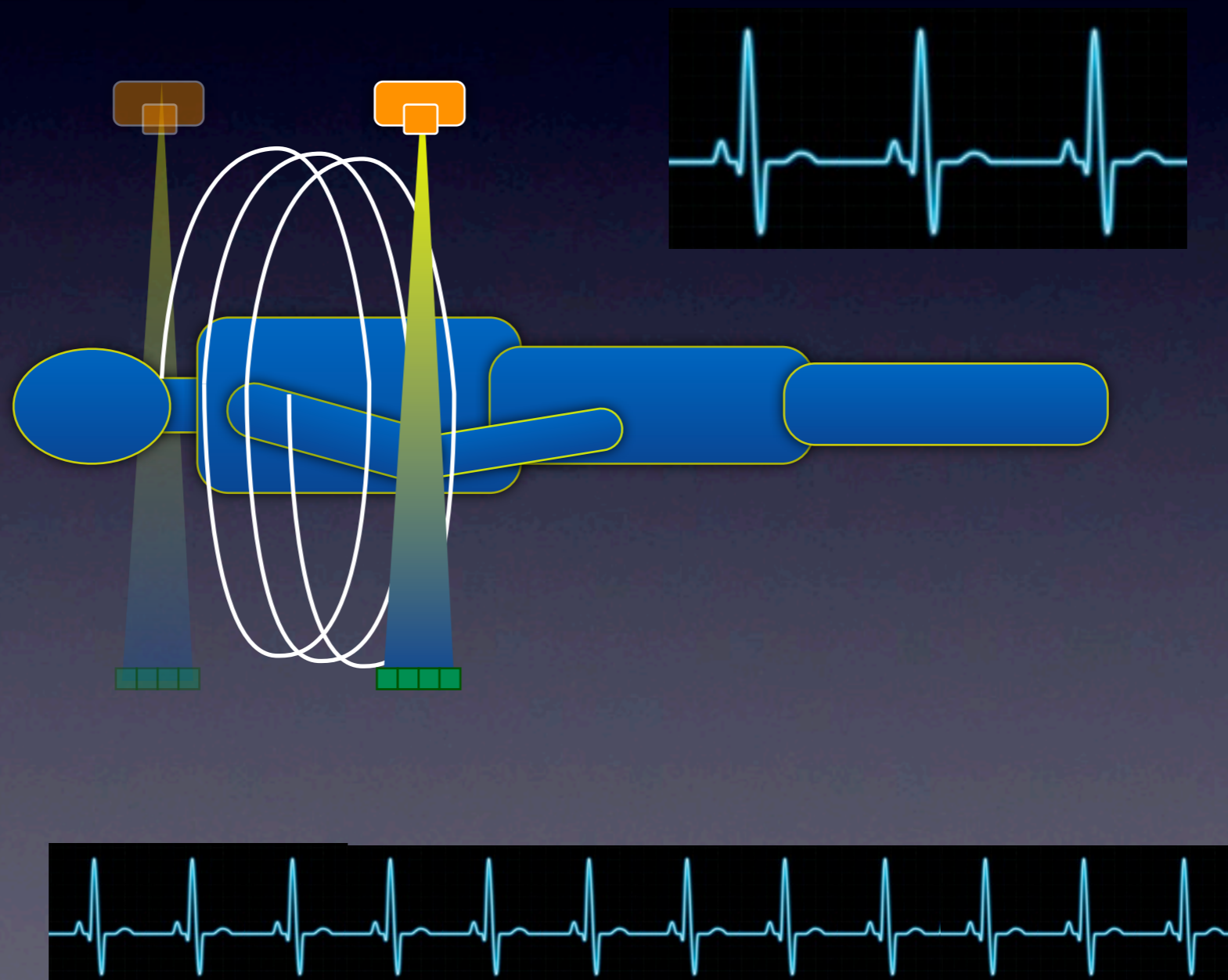
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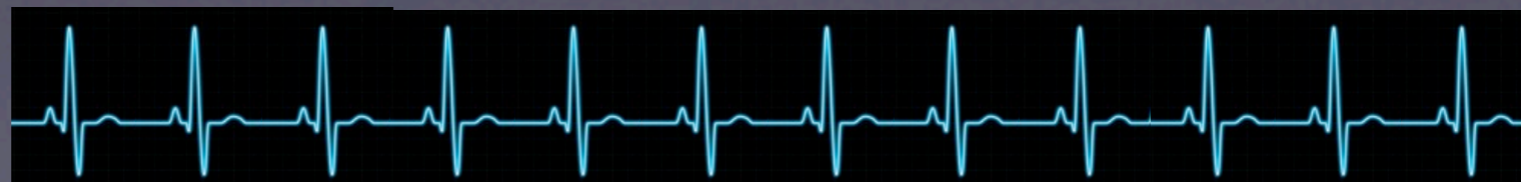
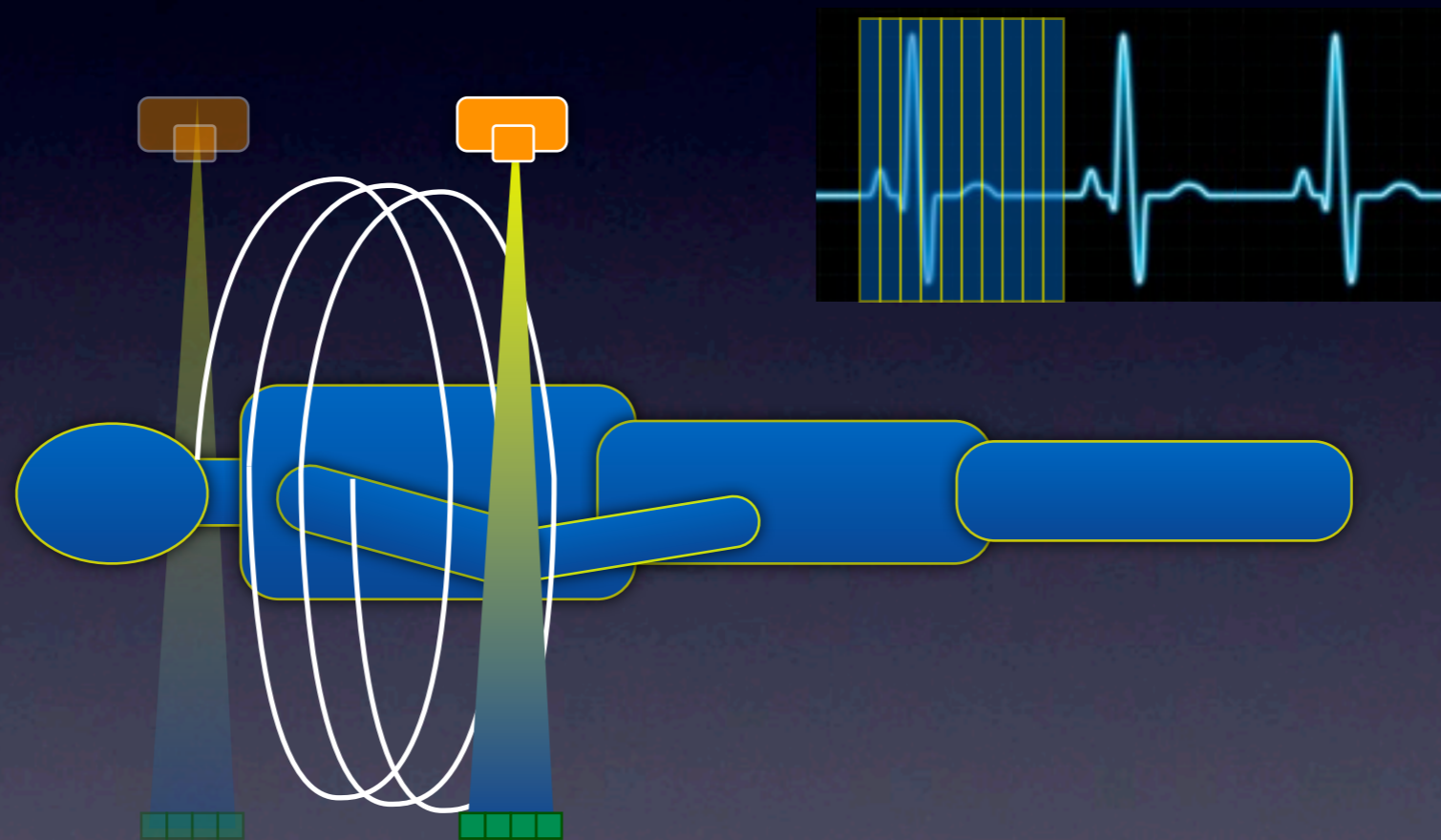
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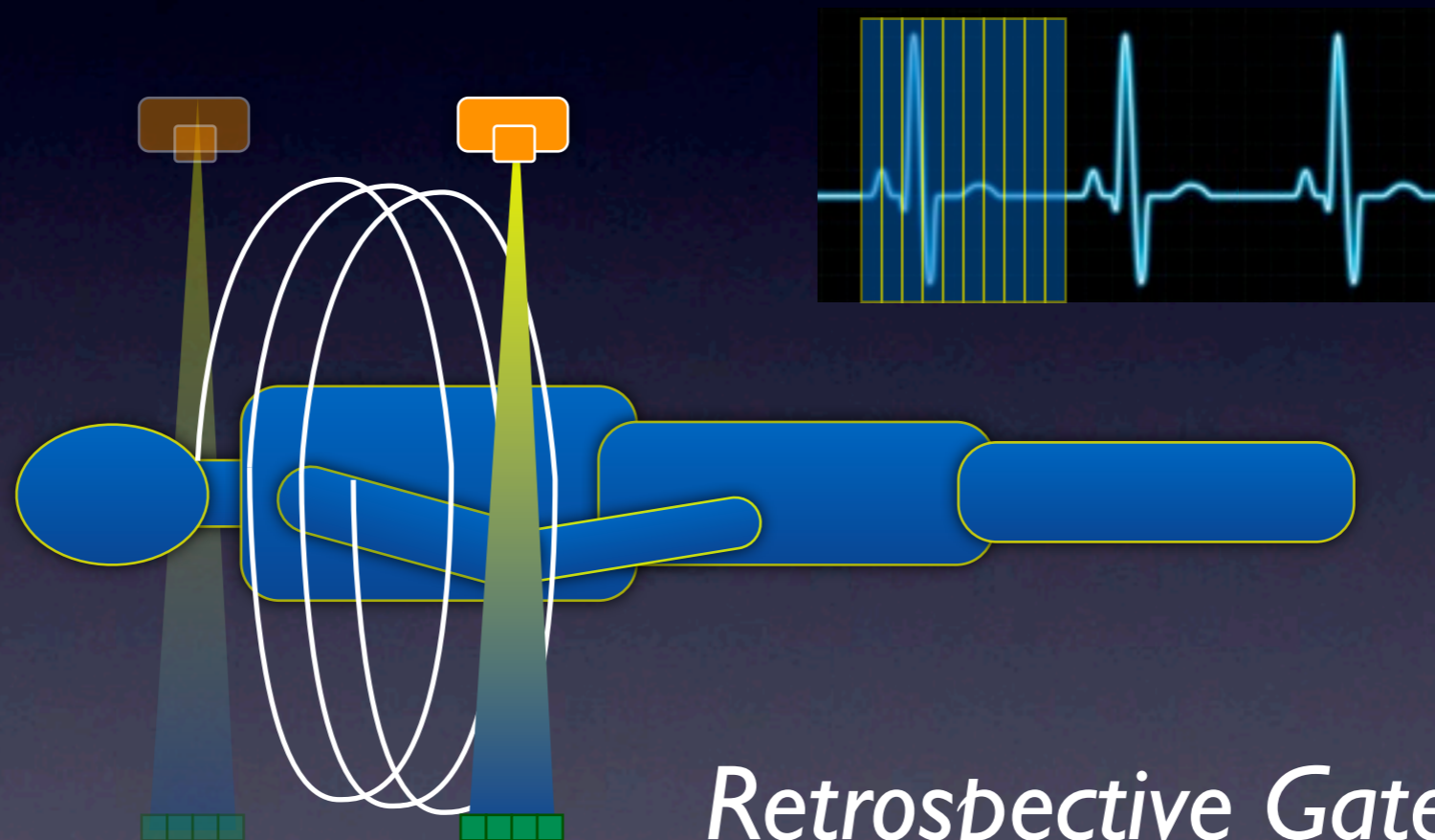
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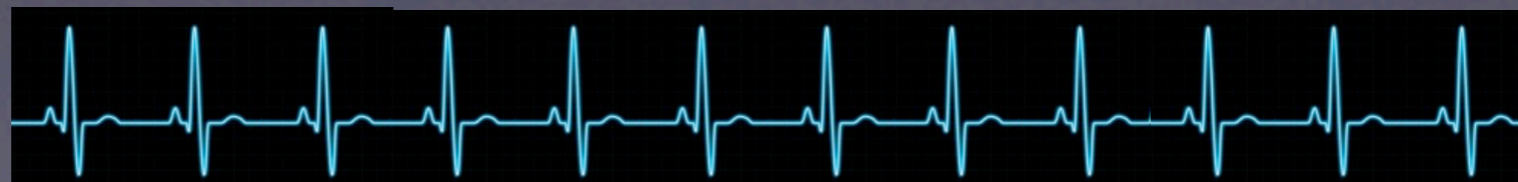


Principles of Gated CT

CT data acquired with EKG data

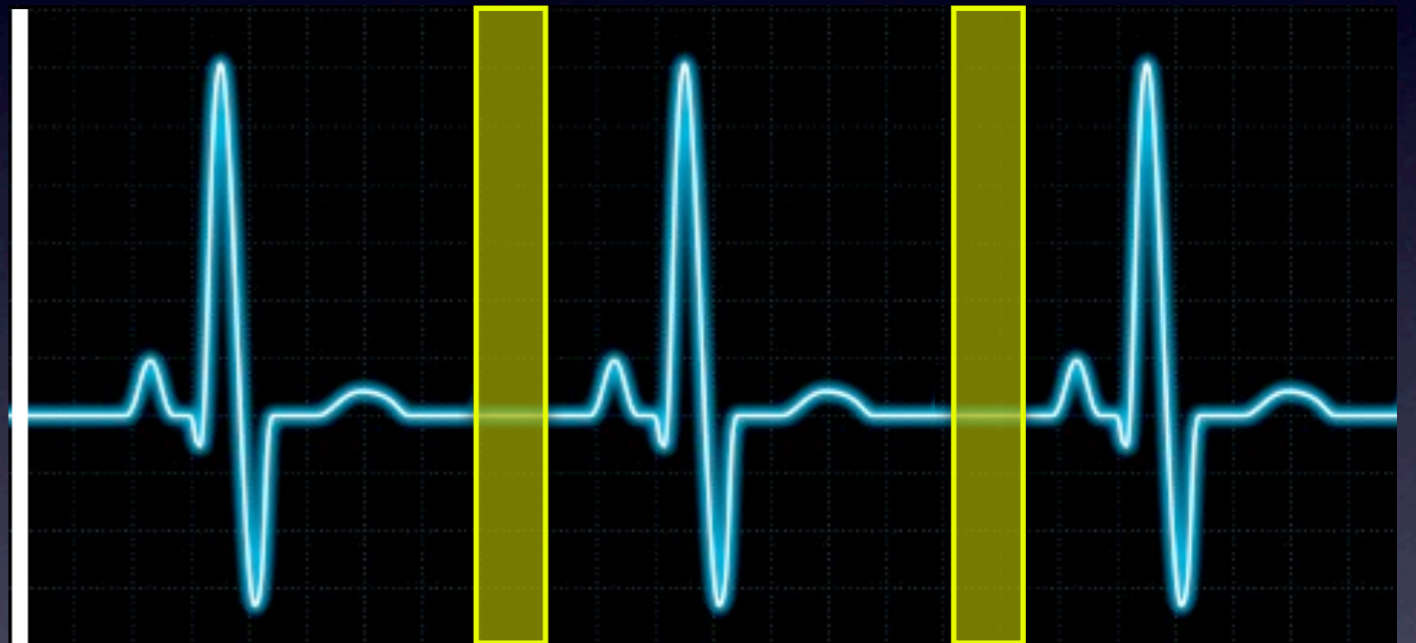
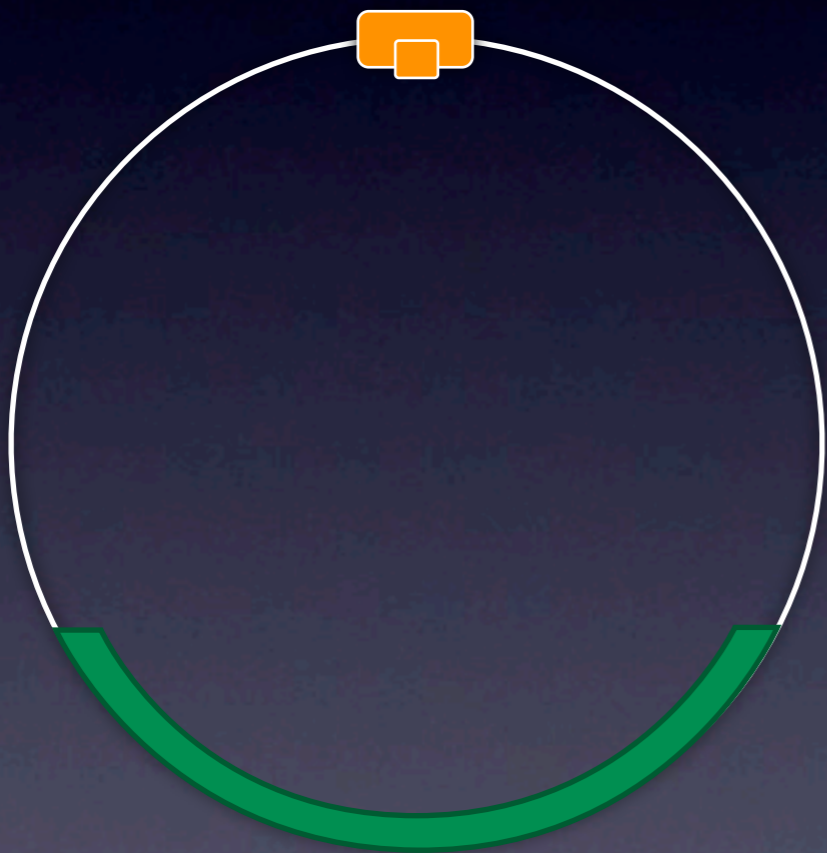


Retrospective Gated CT



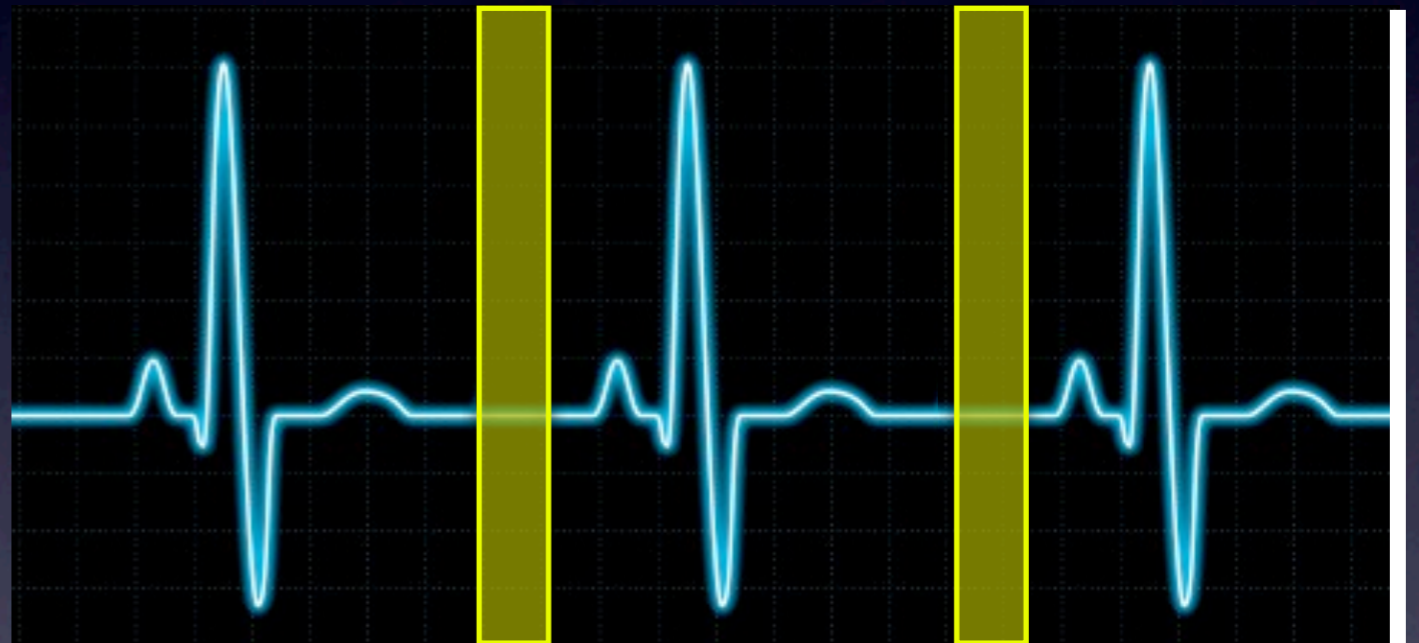
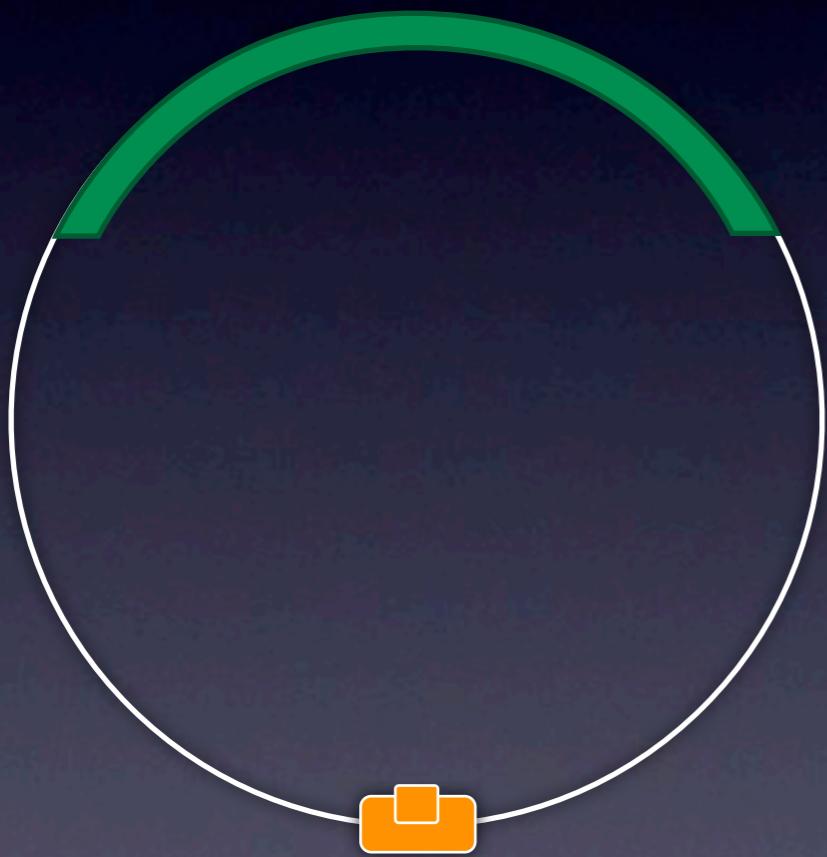
Coronary CTA Terms

Prospective Gating a.k.a. "step and shoot"



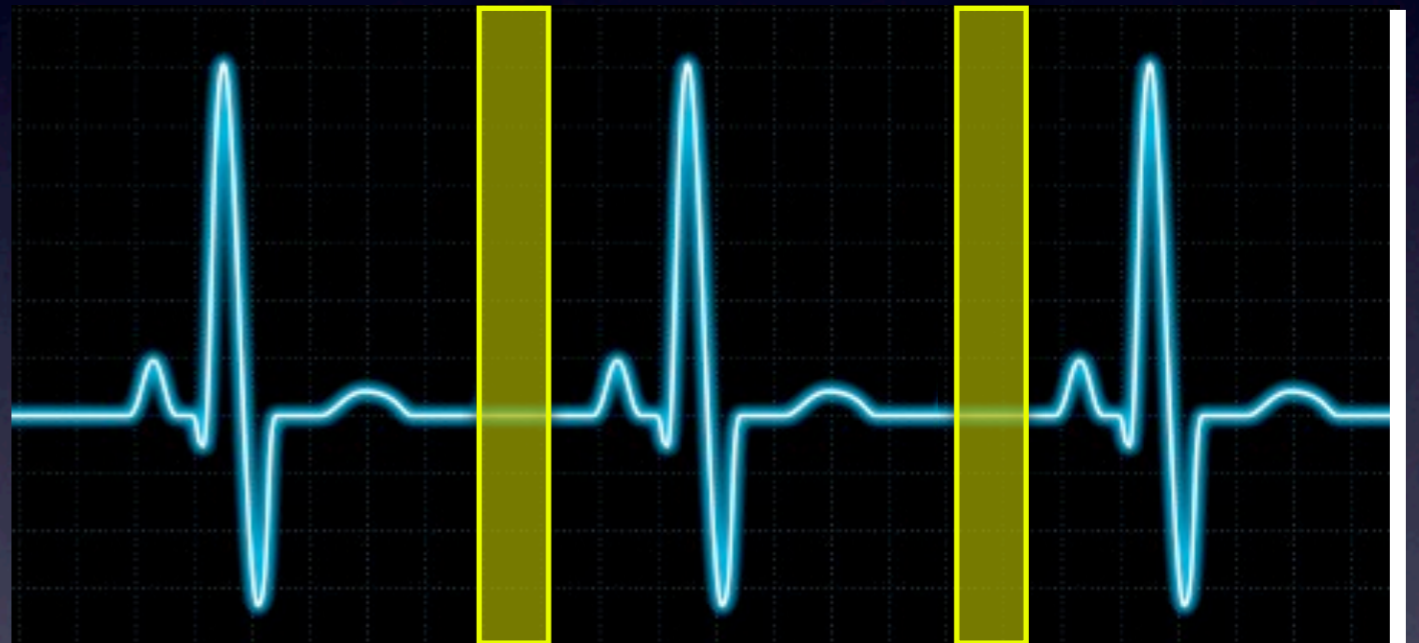
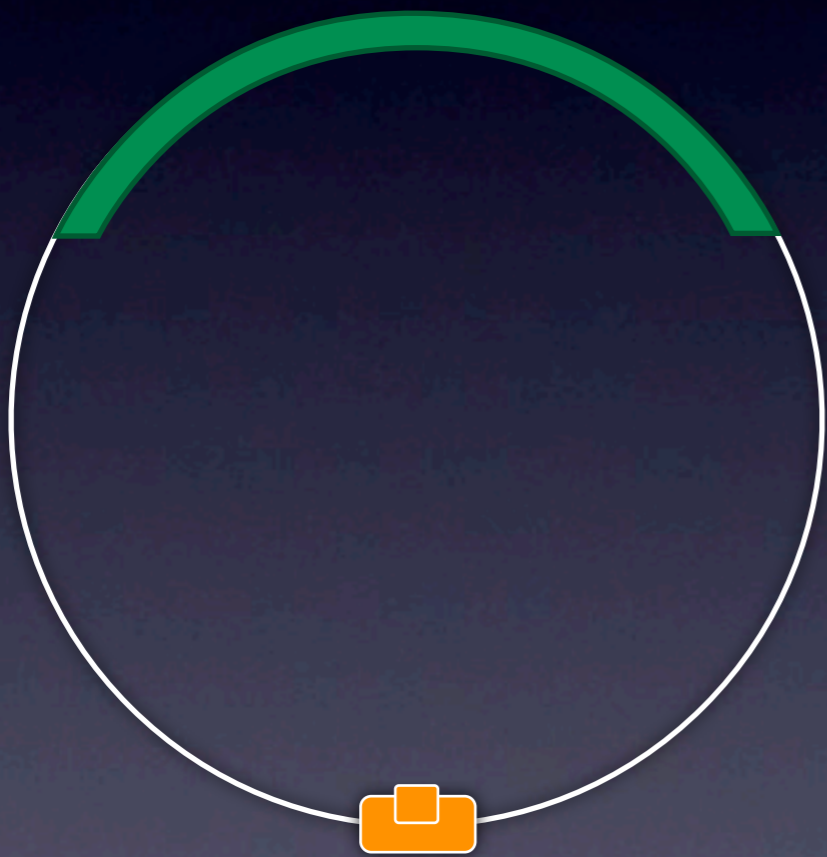
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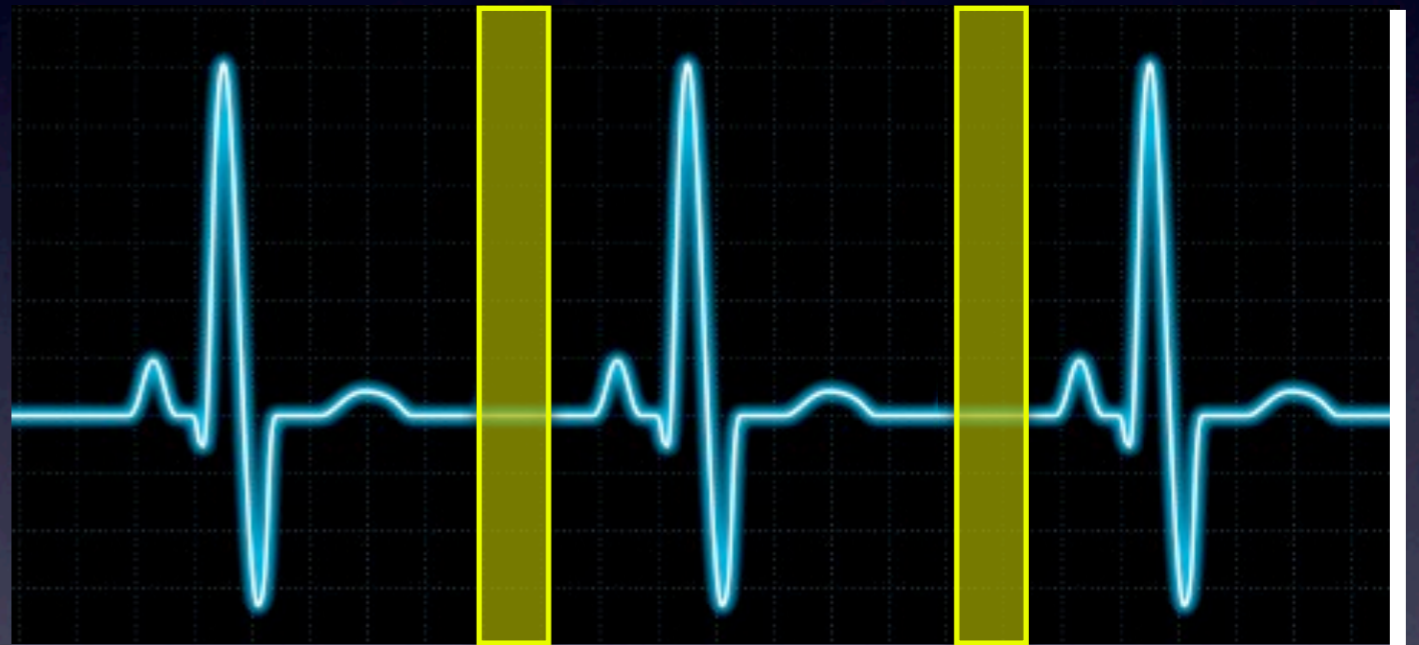
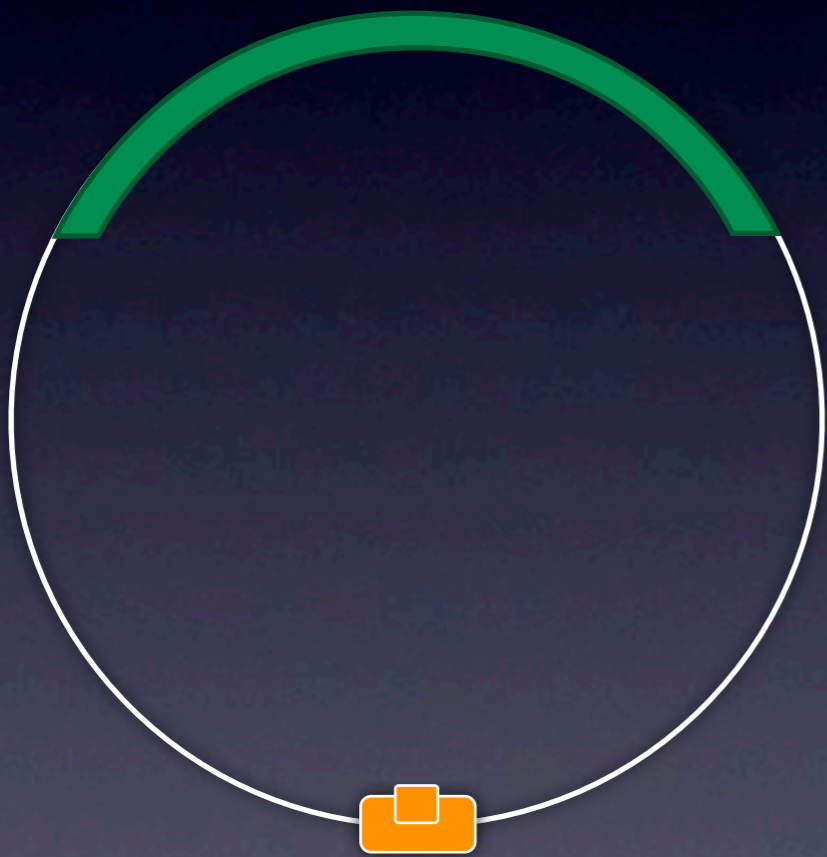
Prospective Gating a.k.a. “step and shoot”



Provides up to 80% dose reduction over conventional retrospective gating

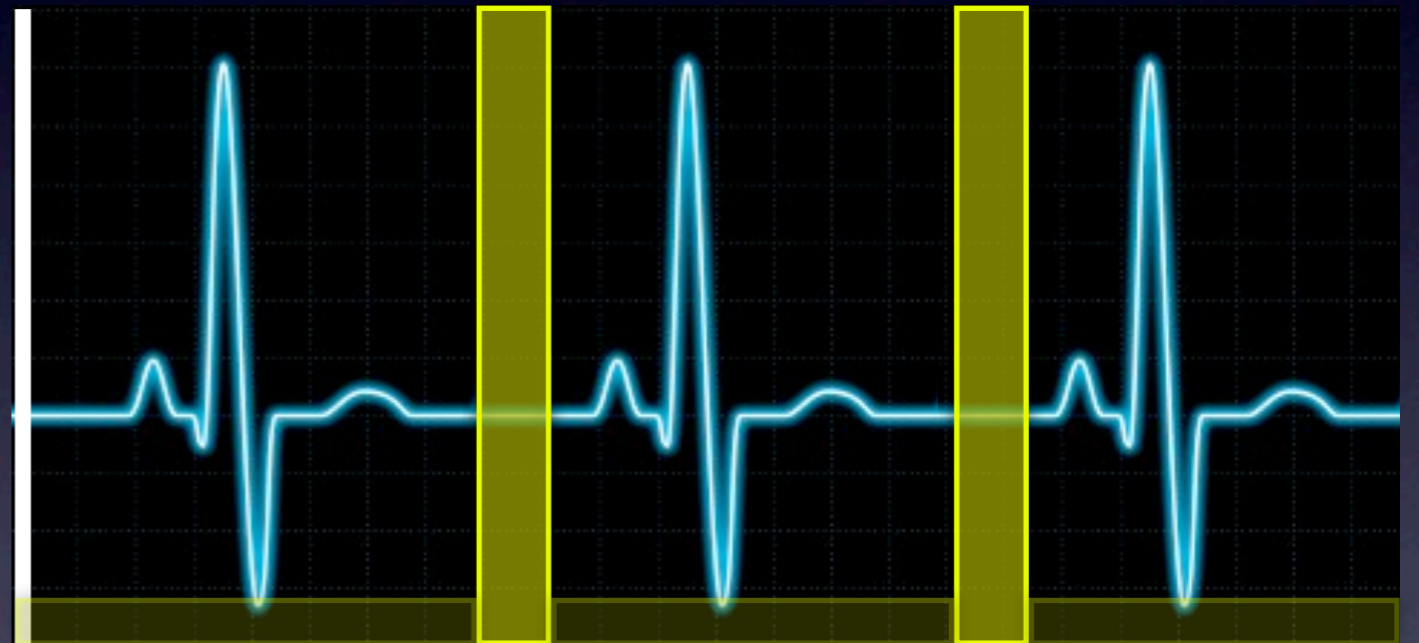
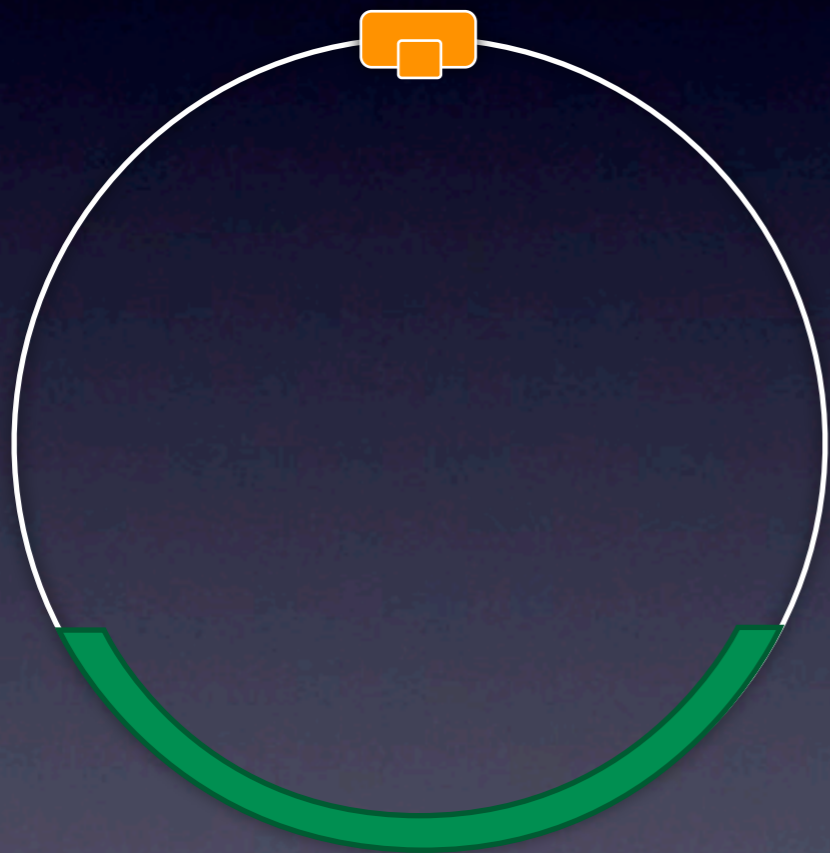
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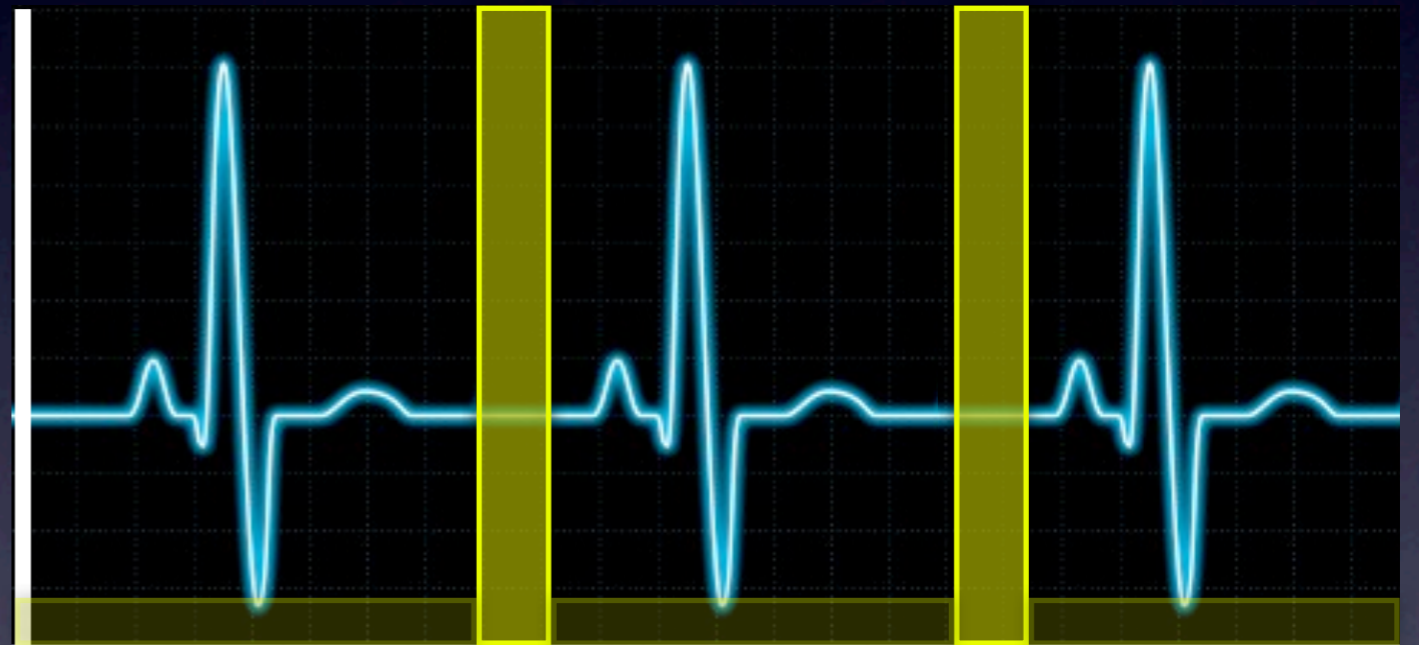
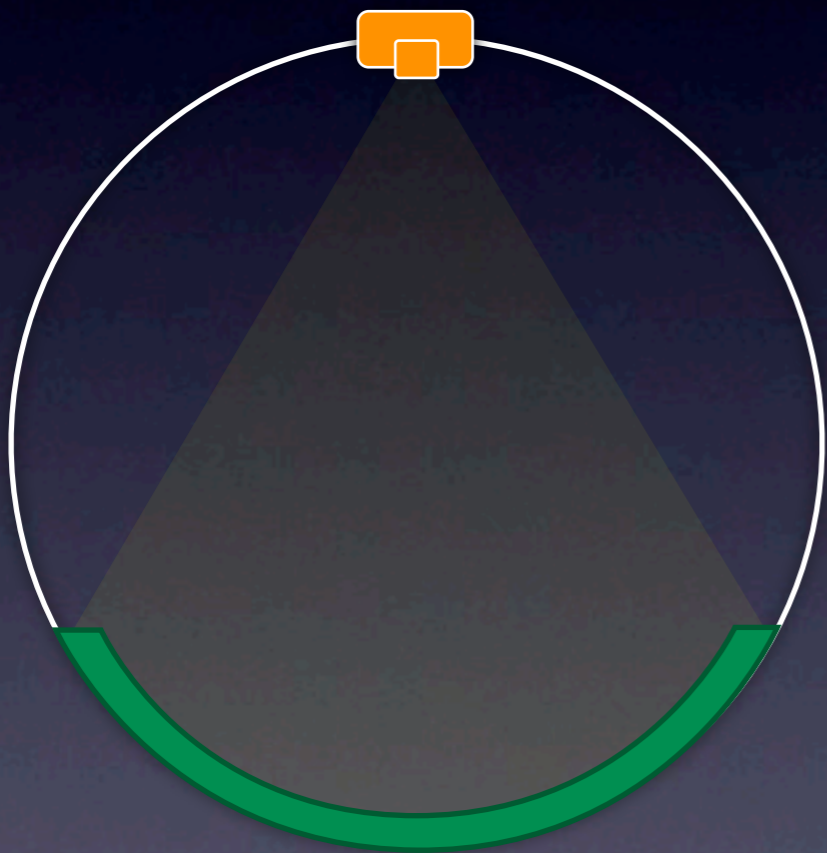


*Technique dependent on
stable heart rates*

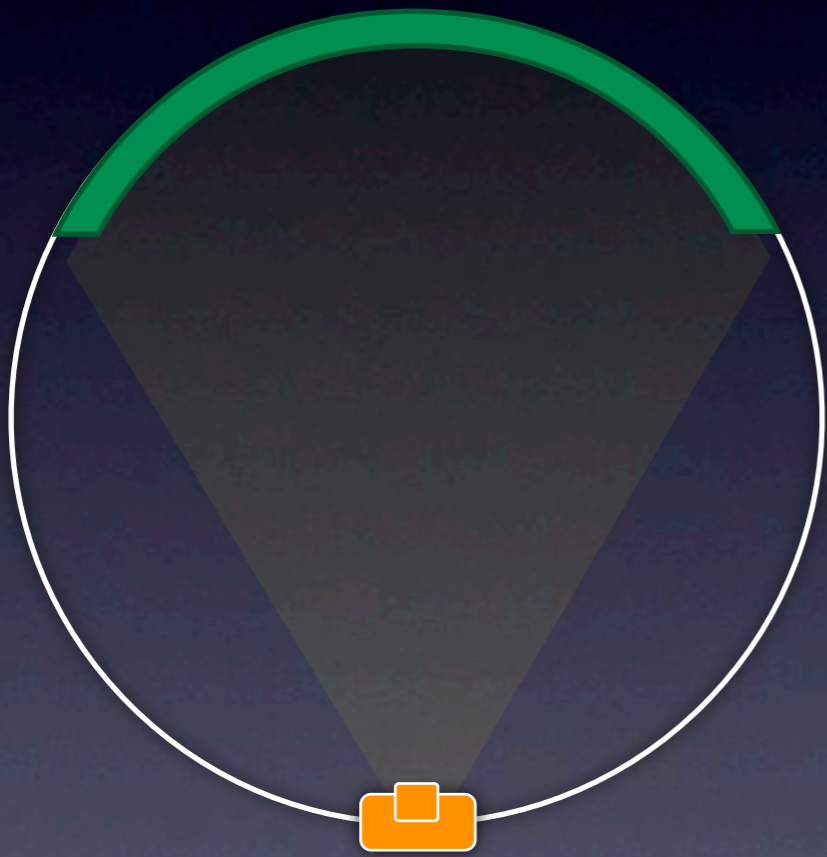
EKG Dose Modulation



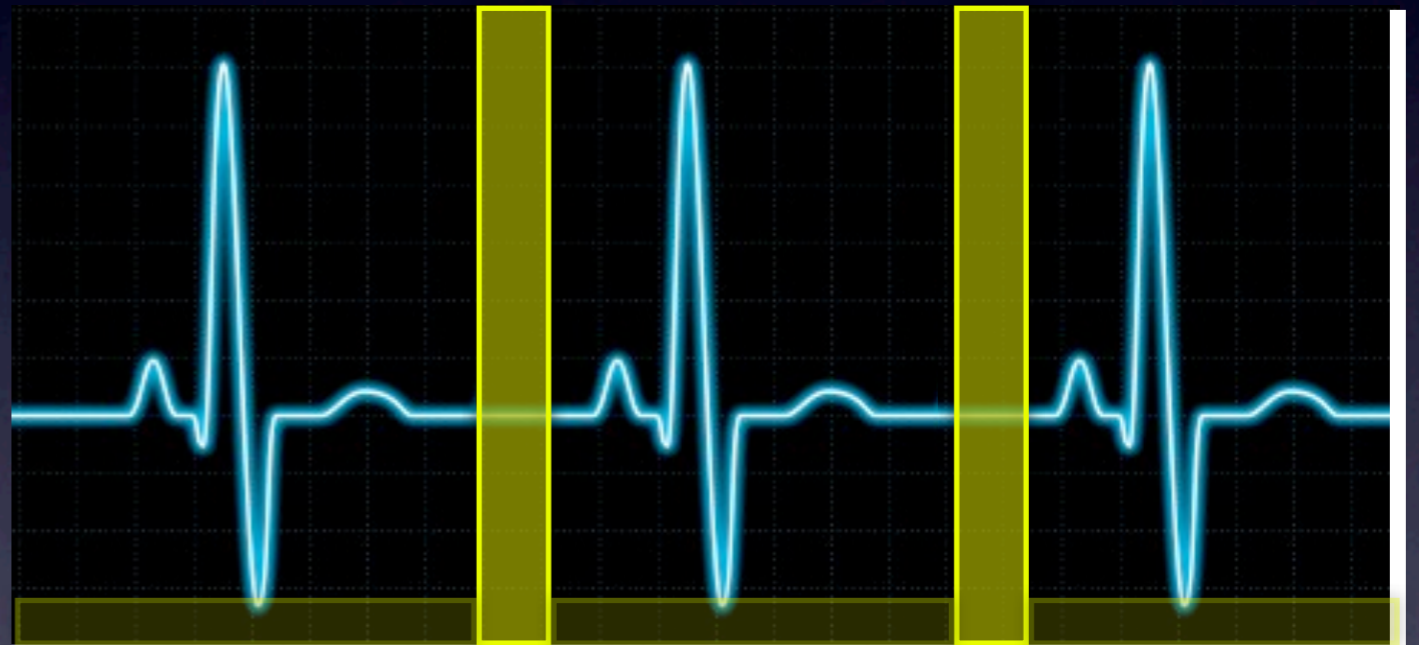
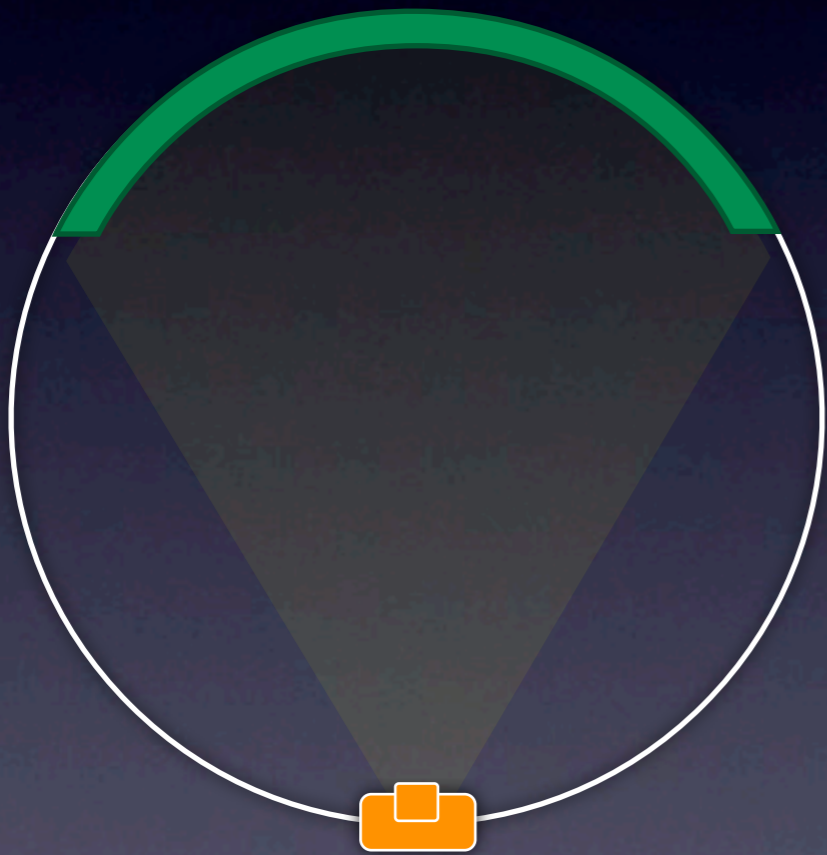
EKG Dose Modulation



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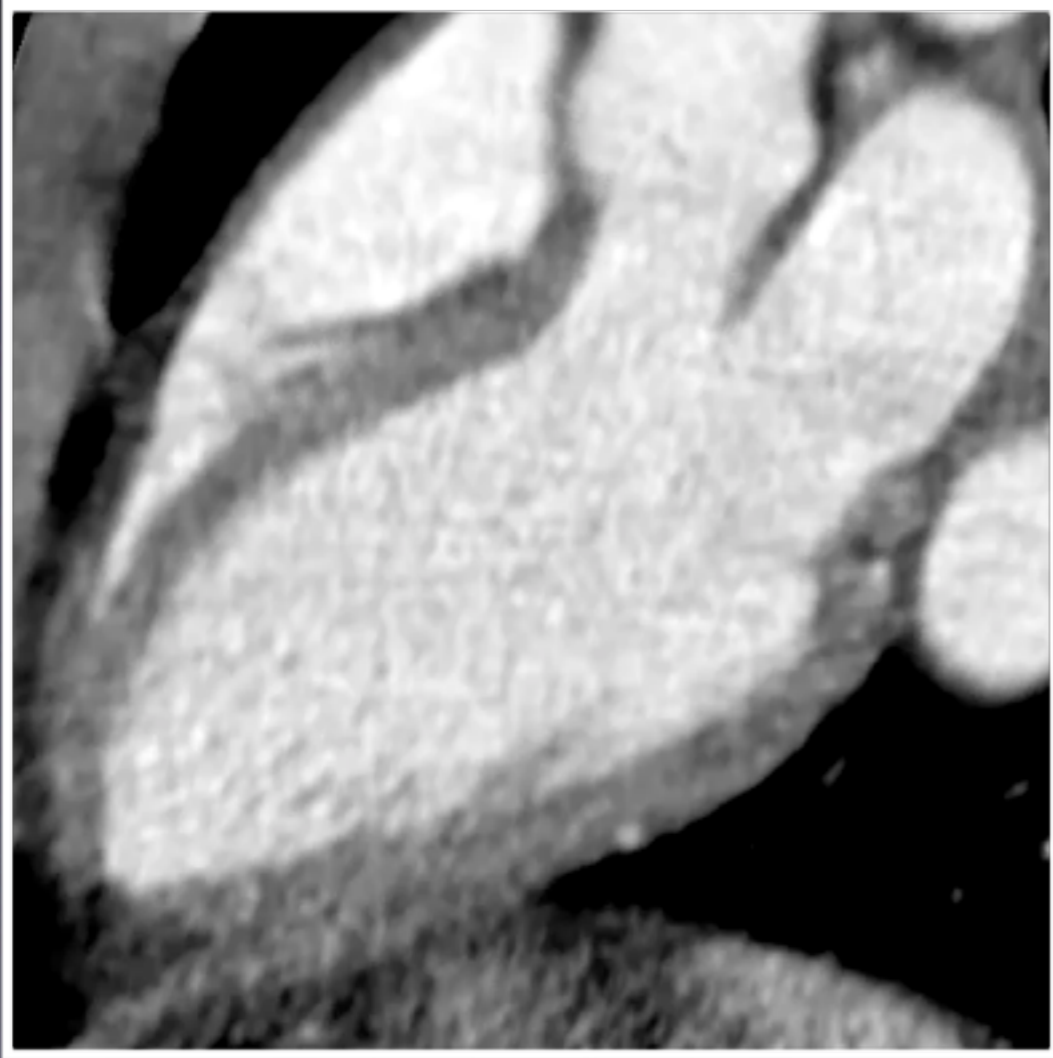


EKG Dose Modulation



Provides up to 55-75% dose reduction over conventional retrospective gating

EKG Dose Modulation



Patient-Specific Dose Reduction



Image Gently Campaign

image
gentlySM



- ❖ Initiative of the Alliance for Radiation Safety in Pediatric Imaging
 - ❖ launched in 2008, now multi-society and global
 - ❖ 14,000+ providers have signed pledge to decrease radiation dose
 - ❖ 26,000 downloads of CT dose-reduction protocols
 - ❖ Education for parents, patients, and providers

<http://www.pedrad.org/associations/5364/ig/>

Information for Parents

- ❖ Information on radiation exposure can and should be shared with patients and their families
- ❖ Does not decrease willingness to have exam performed¹
- ❖ Does improve parental understanding of risks, benefits

¹Larsen DB, et al. AJR August 2007 vol. 189; 271-275.

Information for Parents



What Parents Should Know About CT Scans for Children: Medical Radiation Safety

What is an X-ray?

X-rays are invisible beams of ionizing radiation that pass through the body and are altered by different tissues to create 2-dimensional images of many organs.

What is a CT scan?

CT scans use x-rays generated from a source that is rotated around the body to create 3-dimensional pictures of the body. CT studies can provide critical information for the care of your child, but obtaining the images results in more radiation exposure for the study than a single X-ray.

How much radiation is used in these exams?

We all are exposed to small amounts of radiation daily from soil, rocks, building materials, air, water, and cosmic radiation. This is called naturally occurring background radiation. The radiation used in X-rays and CT scans has been compared to background radiation we are exposed to daily. This comparison may be helpful in understanding relative radiation doses to the patient.

Radiation source

Days background radiation

Background.....	1 day
Chest X-ray (single).....	1 day
Head CT.....	up to 8 months
Abdominal CT.....	up to 20 months

image
gentlySM



www.imagegently.org

http://www.pedrad.org/associations/5364/files/Image_Gently_8.5x11_Brochure2pg.pdf

Dose Record for Parents



FOLD HERE

Date	Exam	Where Exam Performed

http://www.pedrad.org/associations/5364/files/Dose_Record_2x3.5_fold.pdf

Radiologists



- ❖ Sign pledge to Image Gently, PQI projects
- ❖ Be aware of need to decrease radiation dose to pediatric patients
- ❖ Work with physicist to down-size kVp and mAs to appropriate levels for kids
 - ❖ Protocols also available from ACR and www.pedrad.org
- ❖ Try to answer clinical question with single-phase exam
- ❖ Scan only the areas indicated

Pediatric CT Dose Calculator

CTwksht_1_25_08.xls

Sheets Charts SmartArt Graph

	A	B	C	D	E	F
1	Table I: mAs Reduction Factors for the Pediatric Abdomen and Thorax					
2						
3	Room #:		CT Unit:		Date:	
4						
5	Abdomen	kVp	mA	Time (sec)	Pitch Abdomen	Pitch Thorax
6	Baseline:	fill in	fill in	fill in	fill in	fill in
7	PA		Abdomen		Thorax	
8	Thickness (cm)	Approx Age	mAs Reduction Factor (RF)	Estimated mAs = BL x RF	mAs Reduction Factor (RF)	Estimated mAs = BL x RF
9	9	newborn	0.43	#VALUE!	0.42	#VALUE!
10	12	1 yr	0.51	#VALUE!	0.49	#VALUE!
11	14	5 yr	0.59	#VALUE!	0.57	#VALUE!
12	16	10 yr	0.66	#VALUE!	0.64	#VALUE!
13	19	15 yr	0.76	#VALUE!	0.73	#VALUE!
14	22	small adult	0.90	#VALUE!	0.82	#VALUE!
15	25	med adult	1.0	fill in	0.91	#VALUE!
16	31	large adult	1.27	#VALUE!	1.16	#VALUE!
17						
18	1. Type in baseline abdomen techniques and mAs in yellow cells					
19	2. Spreadsheet will calculate mAs estimated for pediatric patients of varying sizes					

Image Wisely Campaign

- ❖ Dose-saving pledge for imaging adults

- ❖ <http://www.imagewisely.org/>

- ❖ Q & A document for Referring MDs:

<http://www.imagewisely.org/Referring-Practitioners/Articles/Radiation-Safety-Information-and-Resources-for-Referring-Practitioners.aspx?CSRT=12316531177216267071>

- ❖ ABIM Foundation
- ❖ Promote discussion between doctors and their patients for:
 - ❖ Supported by evidence
 - ❖ Not duplicative of other tests or procedures already received
 - ❖ Free from harm
 - ❖ Truly necessary
- ❖ <http://www.choosingwisely.org>



Five Things Physicians and Patients Should Question

1

Don't do imaging for low back pain within the first six weeks, unless red flags are present.

Red flags include, but are not limited to, severe or progressive neurological deficits or when serious underlying conditions such as osteomyelitis are suspected. Imaging of the lower spine before six weeks does not improve outcomes, but does increase costs. Low back pain is the fifth most common reason for all physician visits.

2

Don't routinely prescribe antibiotics for acute mild-to-moderate sinusitis unless symptoms last for seven or more days, or symptoms worsen after initial clinical improvement.

Symptoms must include discolored nasal secretions and facial or dental tenderness when touched. Most sinusitis in the ambulatory setting is due to a viral infection that will resolve on its own. Despite consistent recommendations to the contrary, antibiotics are prescribed in more than 80 percent of outpatient visits for acute sinusitis. Sinusitis accounts for 16 million office visits and \$5.8 billion in annual health care costs.

3

Don't use dual-energy x-ray absorptiometry (DEXA) screening for osteoporosis in women younger than 65 or men younger than 70 with no risk factors.

DEXA is not cost effective in younger, low-risk patients, but is cost effective in older patients.

4

Don't order annual electrocardiograms (EKGs) or any other cardiac screening for low-risk patients without symptoms.

There is little evidence that detection of coronary artery stenosis in asymptomatic patients at low risk for coronary heart disease improves health outcomes. False-positive tests are likely to lead to harm through unnecessary invasive procedures, over-treatment and misdiagnosis. Potential harms of this routine annual screening exceed the potential benefit.

5

Don't perform Pap smears on women younger than 21 or who have had a hysterectomy for non-cancer disease.

Most observed abnormalities in adolescents regress spontaneously, therefore Pap smears for this age group can lead to unnecessary anxiety, additional testing and cost. Pap smears are not helpful in women after hysterectomy (for non-cancer disease) and there is little evidence for improved outcomes.

Other New Developments

- ❖ Quality Improvement Registry in CT Scans in Children (QuIRCC)
 - ❖ Group of 6 Children's Medical Centers
 - ❖ Work with FDA to define appropriate dose ranges for Peds CT
 - ❖ Based on SSDE (size specific dose estimate)
 - ❖ Acceptable range between 25% - 75% standard peds dose

The future: Radiation Cocktail?



- ❖ Recent investigations into DS DNA breaks after diagnostic CT
- ❖ Anti-oxidant and glutathione-elevating agent formula given 1 hour before CT:
 - ❖ vitamin C, vitamin E, natural mixed carotenoids (primarily beta-carotene), N-acetylcysteine, alpha-lipoic acid, and L-selenomethionine
- ❖ 58% fewer breaks in 60 min pre-treatment group
 - ❖ 23% in 15-min pretreatment group

Kuefner, MA, et al. Radiology April 16, 2012, Online before print:
doi: 10.1148/radiol.12111730

Antibodies to prevent damage?

- ❖ Ceramide accumulates on cell surfaces after radiation, transmits apoptotic signal for cell death
- ❖ Used monoclonal anti-ceramide Ab in mice exposed to 15 Gy radiation
- ❖ 90-day survival increased from 0 - 80% after moAb

Rotolo J, et al. *J Clin Invest.* 2012;122(5):1786–179

Summary

- ❖ Radiation is often necessary in today's healthcare environment
- ❖ Dose can and should be reduced as long as diagnostic quality preserved
 - ❖ Many options to decrease dose
 - ❖ Everyone needs to be involved
- ❖ Future developments may address cellular protection

Summary - 2: Referring Providers

- ❖ Become aware of radiation associated with diagnostic procedures
- ❖ Info for referring physicians at:

<http://www.imagewisely.org/Referring-Practitioners/Articles/Radiation-Safety-Information-and-Resources-for-Referring-Practitioners.aspx?CSRT=12316531177216267071>

<http://www.pedrad.org/associations/5364/ig/?page=595>

- ❖ Ask imaging providers about radiation dose strategies, ACR certification, Board-certification, Image Gently / Wisely pledges

Thanks for your attention!!

❖ **Handout available:**

<http://www.stanford.edu/~hallett>

Choose folder “IU Morgan”

❖ Questions? xraydoc97@yahoo.com

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