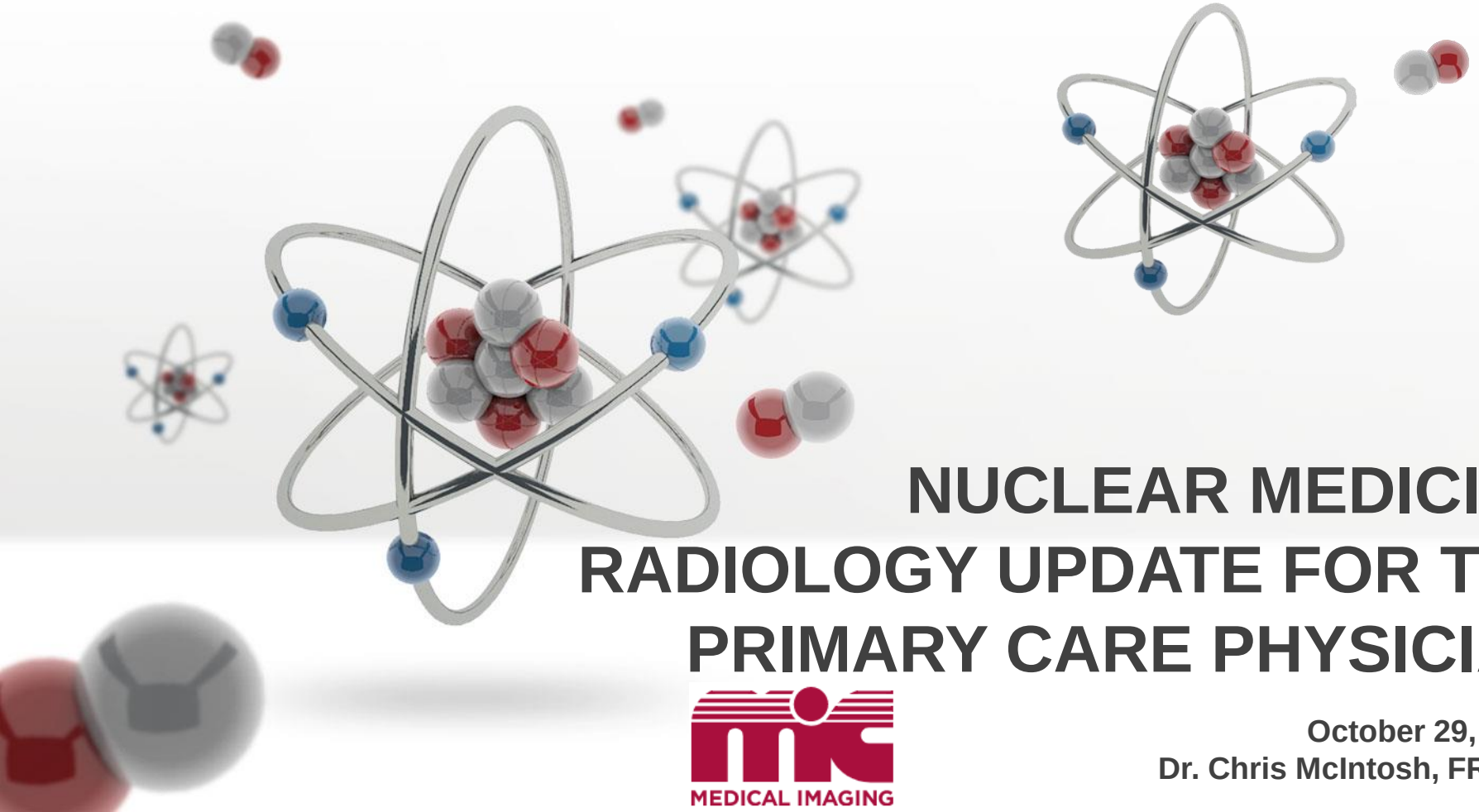

NUCLEAR MEDICINE RADIOLOGY UPDATE FOR THE PRIMARY CARE PHYSICIAN

MEDICAL IMAGING

October 29, 2022

Dr. Chris McIntosh, FRCPC

Disclosures

Presenter Disclosure

Chris McIntosh

Partner with MIC Medical Imaging

Disclosure of Financial Support

This presentation has received no financial support from any organization.

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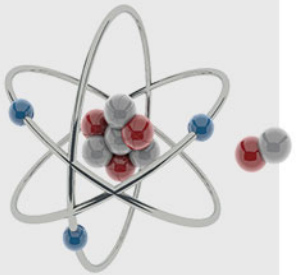
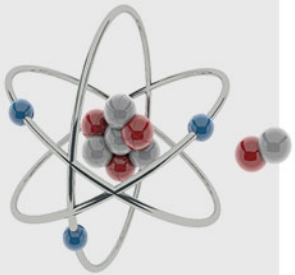
Objectives

1. Recognize the limitations of basic nuclear medicine tests
2. List different indications for assessing bone mineral density
3. Describe the radiation risks for patients undergoing nuclear medicine tests



Outline

- Principles of nuclear medicine
- Bone Mineral Densitometry
- Radiation safety

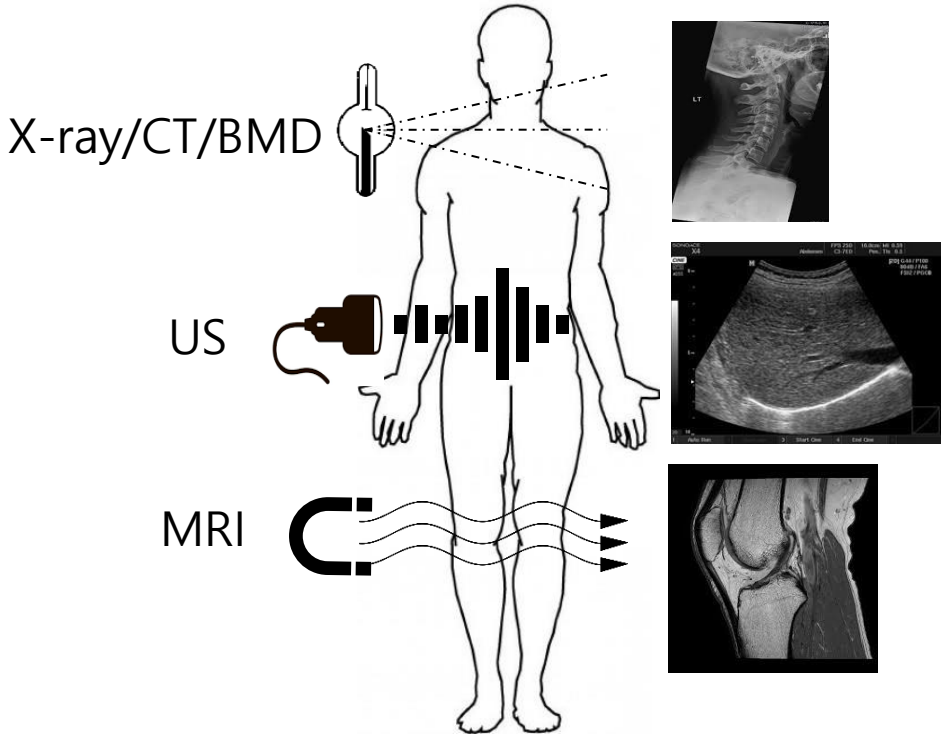


Principles of Nuclear Medicine

Radiology

External source

Images anatomy



Principles of Nuclear Medicine

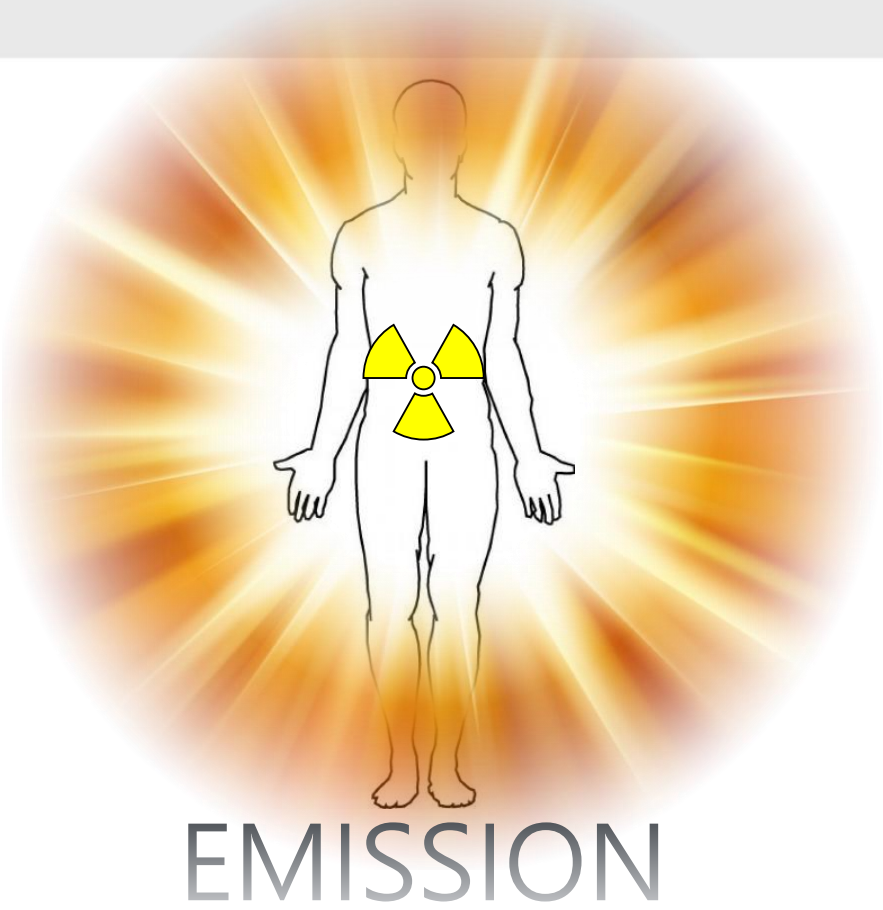
Nuc Med

Radiopharmaceutical:

Internal source

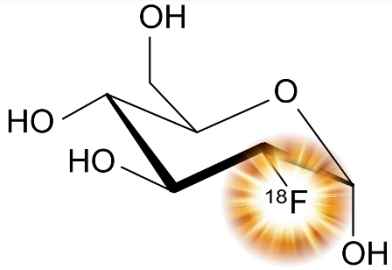
- Injected
- Swallowed
- Inhaled

Images physiology

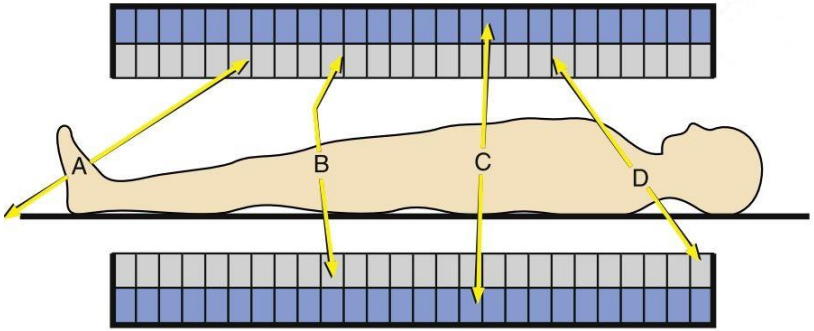


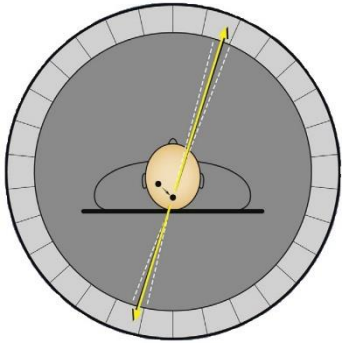
Principles of Nuclear Medicine

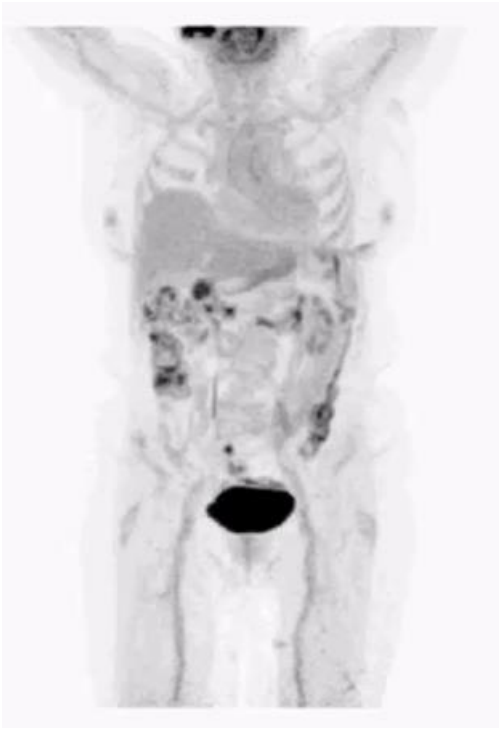
Nuc Med



2-deoxy-2-^{18}F-fluoroglucose
(^{18}F-FDG)

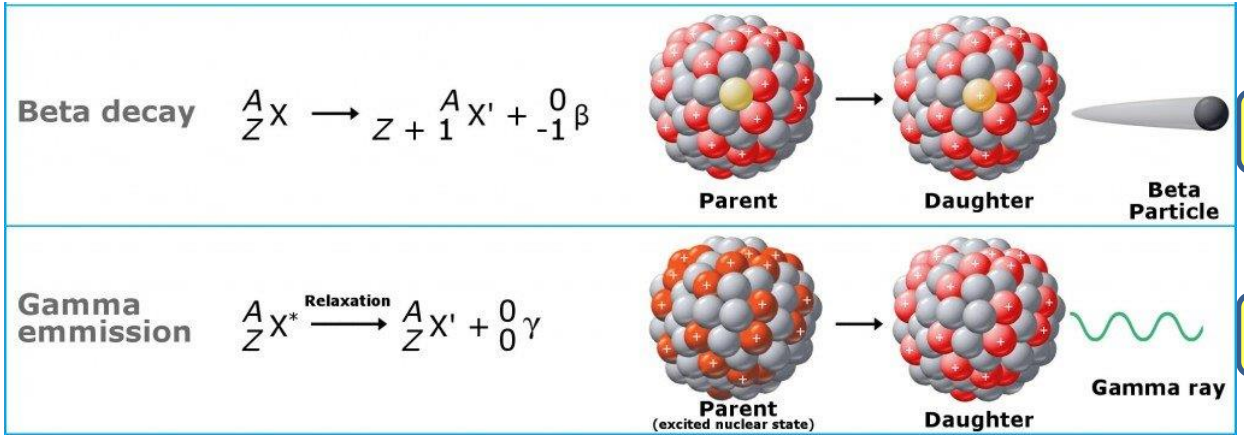






Principles of Nuclear Medicine

Two types of radioactive decay that are imaged in different ways

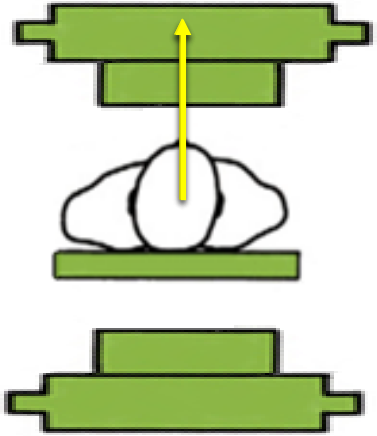


β^{+}(positron)= PET

γ (photon)= gamma camera

Principles of Nuclear Medicine

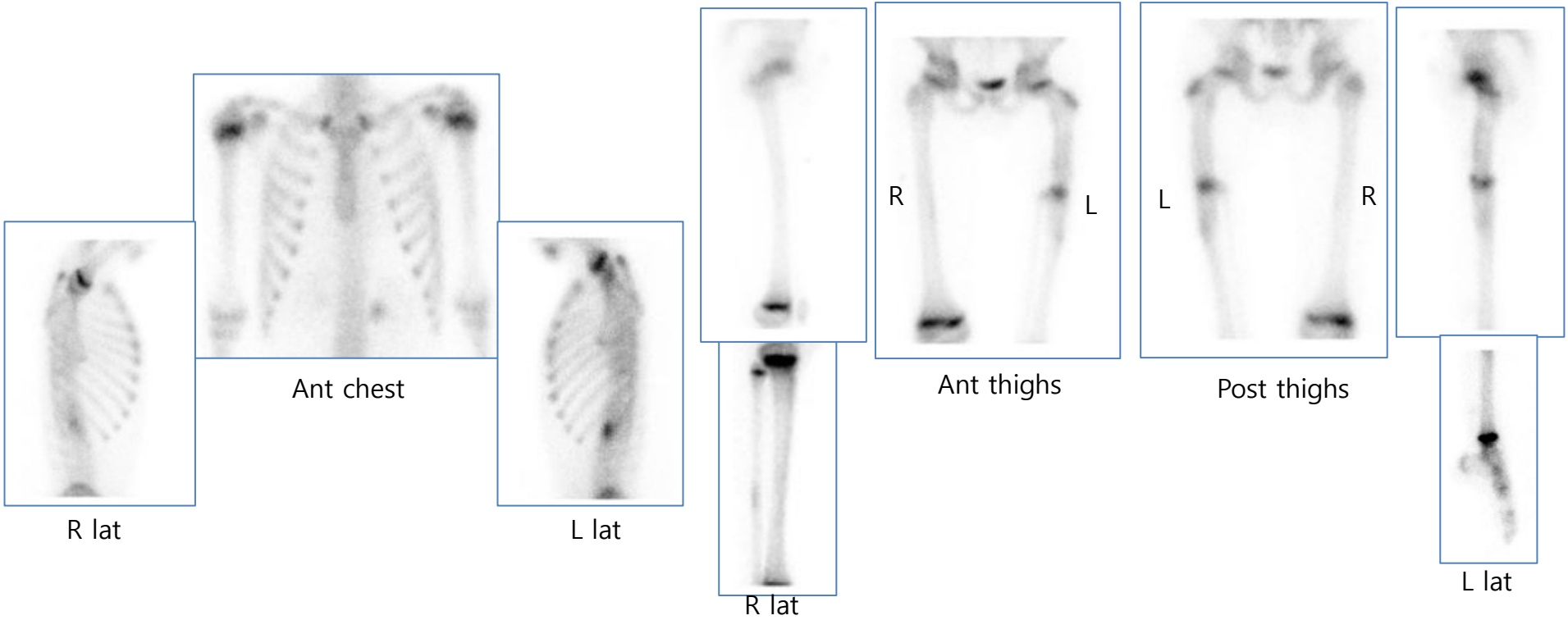
Gamma camera



- Single photon
  - Planar imaging
  - Dynamic
  - SPECT

Principles of Nuclear Medicine

Gamma camera: Planar images of a bone scan



Principles of Nuclear Medicine

Gamma camera:

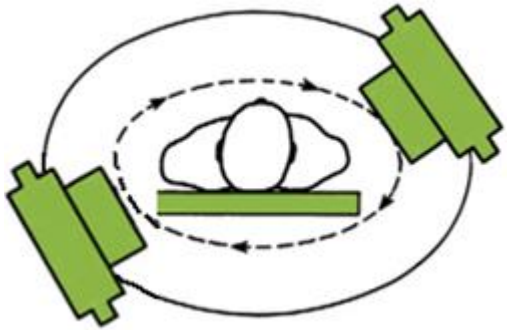
Whole-body bone scan

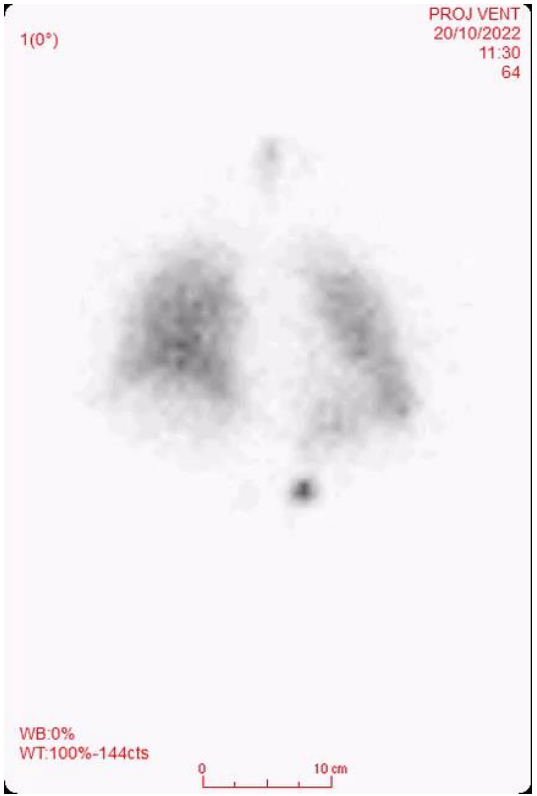
Principles of Nuclear Medicine

Gamma camera:

SPECT

Single photon emission commuted tomography

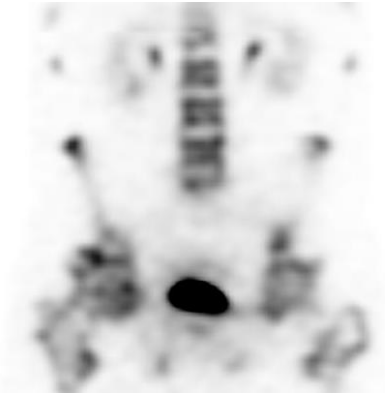




Principles of Nuclear Medicine

Gamma camera: SPECT

Axial



Coronal

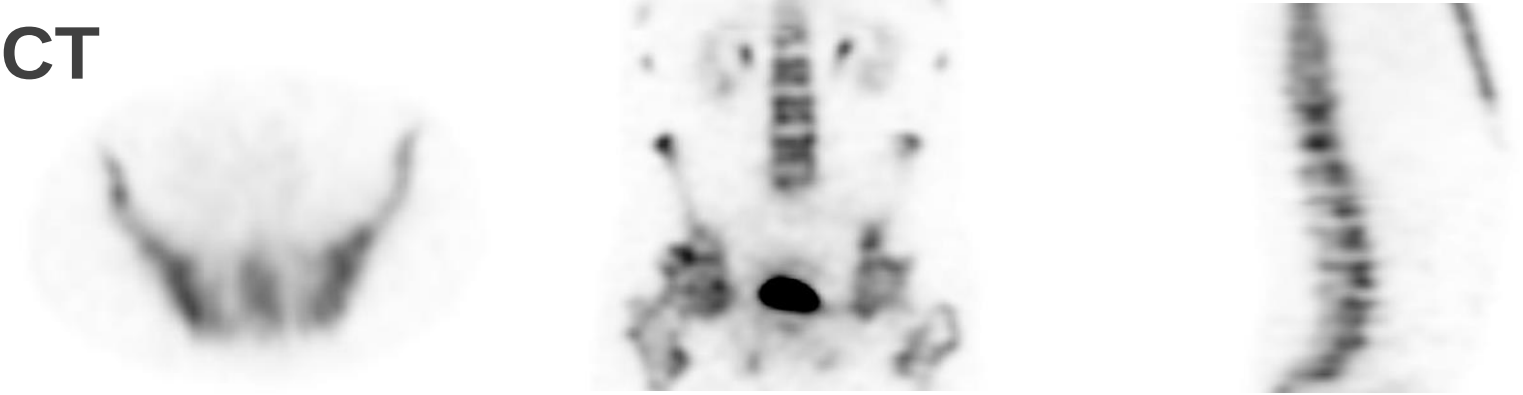
Sagittal

Principles of Nuclear Medicine

Gamma camera: SPECT/CT

Principles of Nuclear Medicine

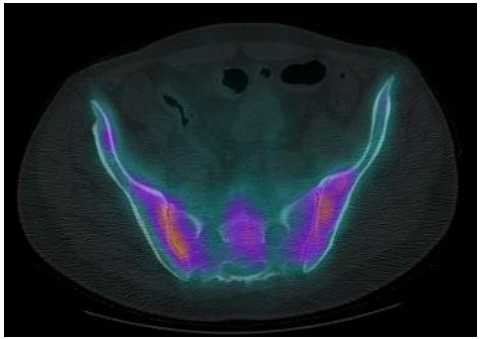
SPECT



CT

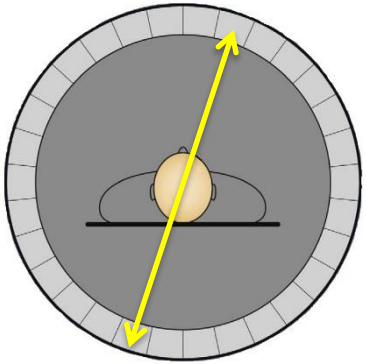
Principles of Nuclear Medicine

Fused SPECT/CT

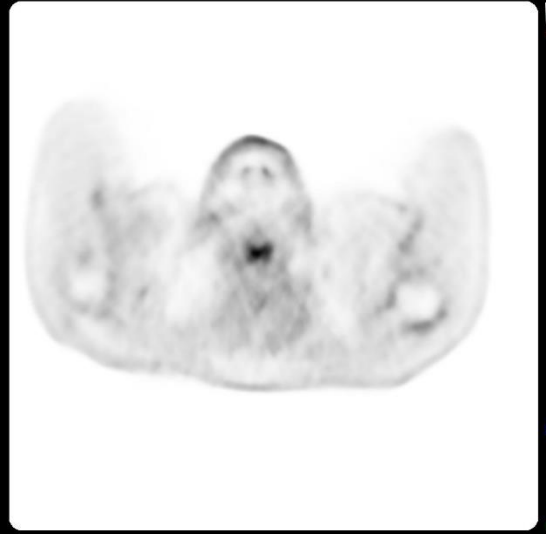


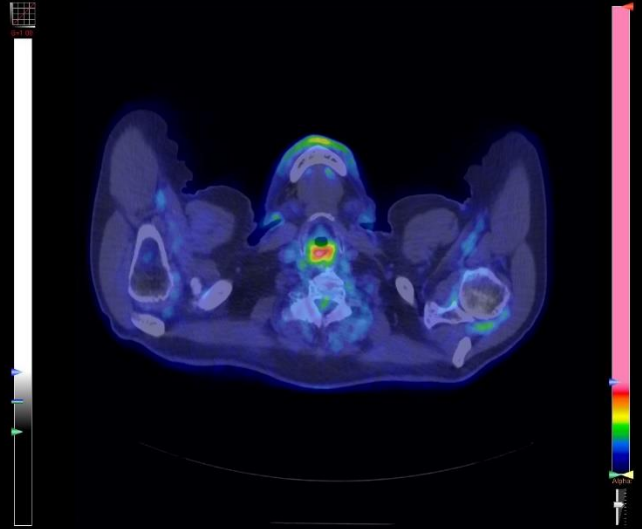
Principles of Nuclear Medicine

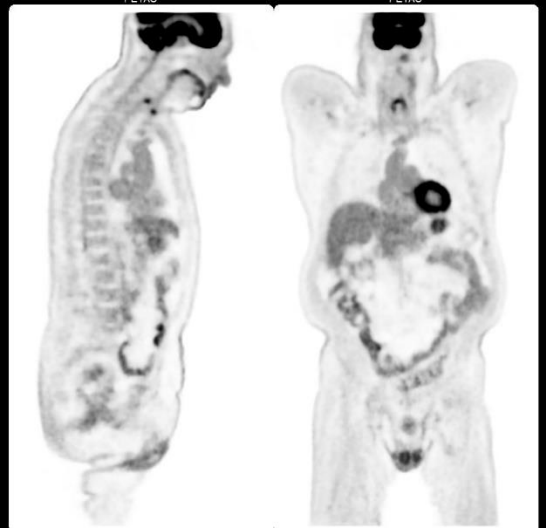
PET camera



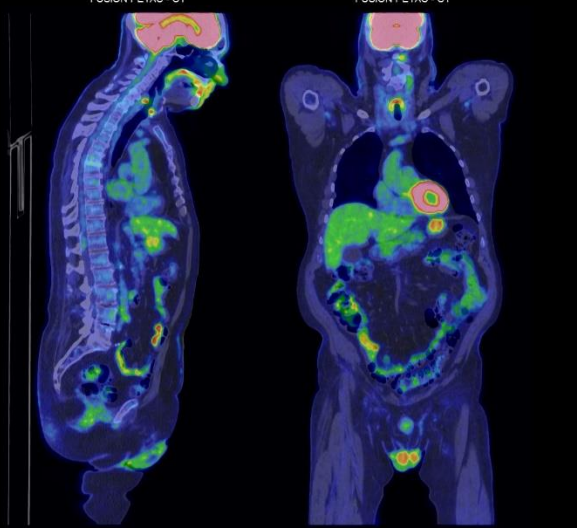
- Two simultaneous photons
- Coincident detection (180°)
- Better Sn and Sp
- Full ring of detectors ($$$)






PETAC
PETAC


CT
CT

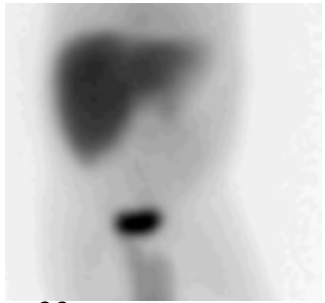

FUSION PETAC - CT
FUSION PETAC - CT

Principles of Nuclear Medicine

Change the radioisotope, change the scan

^{99m}Tc-MAG3

^{99m}Tc-ECD



^{99m}Tc-HIDA

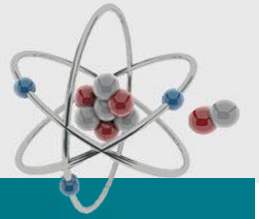
^{99m}Tc-MIBI

^{99m}Tc-MDP

^{123}I-MIBG

^{99m}Tc-Sulfur Colloid

Types of NM studies (commonly performed in Edmonton)



Endo: thyroid pertechnetate, I-123, I-131, parathyroid MIBI, neuroendocrine tumor

Neuro: brain perf, dementia, seizure, CSF flow/VP shunts

Pulm: V/Q scan, quantitative perfusion

Cardio: MIBI, Rb-82, viability, MUGA, R→L shunts

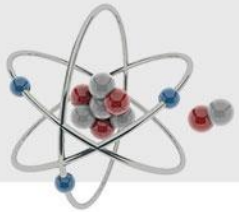
Onco: FDG, F-DOPA, DOTATATE, PSMA

Renal: MAG3, renal cortical, GFR

GI: RBC bleed, HIDA, Meckel's, gastric emptying, Therasphere

MSK: bone scan, WBC scan, Ga-67, NM arthrogram, BMD

Principles of Nuclear Medicine

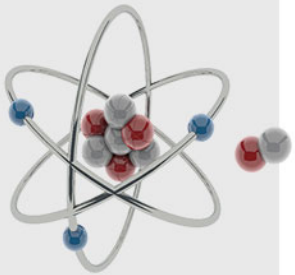


Limitations

- Not a first line investigation
- Less available for emergencies (banker's hours)
- Certain tests/tracers have limited availability
- Targeted: better for specific questions
- Slow acquisitions. May need multiple time points or different days
- Radiation dose (?) – more on this later

Outline

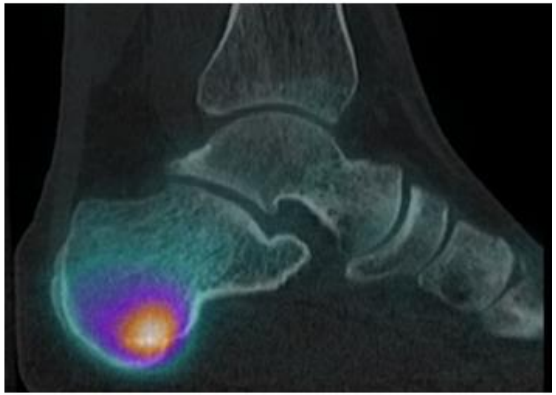
- Principles of nuclear medicine
  - Brief discussion on bone scans
- Bone Mineral Densitometry
- Radiation safety



Bone scan (^{99m}Tc-MDP)

Common indications

1) Occult fracture/stress fracture
2) Pain generator
3) Osteomyelitis
4) Loose prosthesis
5) Neoplastic disease
6) Arthritis
7) Avascular necrosis
8) Complex regional pain syndrome



Tibial stress fracture

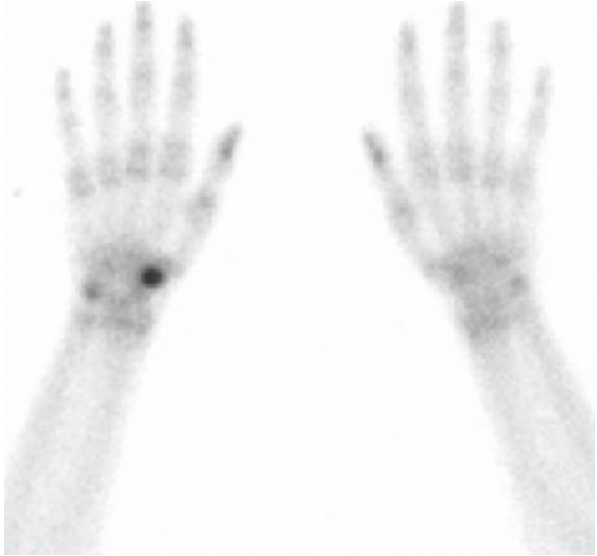
Sacral insufficiency fracture

Metastasis

CRPS

Bone scan (^{99m}Tc-MDP)

Fracture assessment



X-ray occult scaphoid fracture

TABLE 8-1 Time after Fracture at which Bone Scan Becomes Abnormal

TIME AFTER FRACTURE	PERCENTAGE ABNORMAL	
	Patients <65 yr	All Patients
1 day	95	80
3 day	100	95
1 wk	100	98

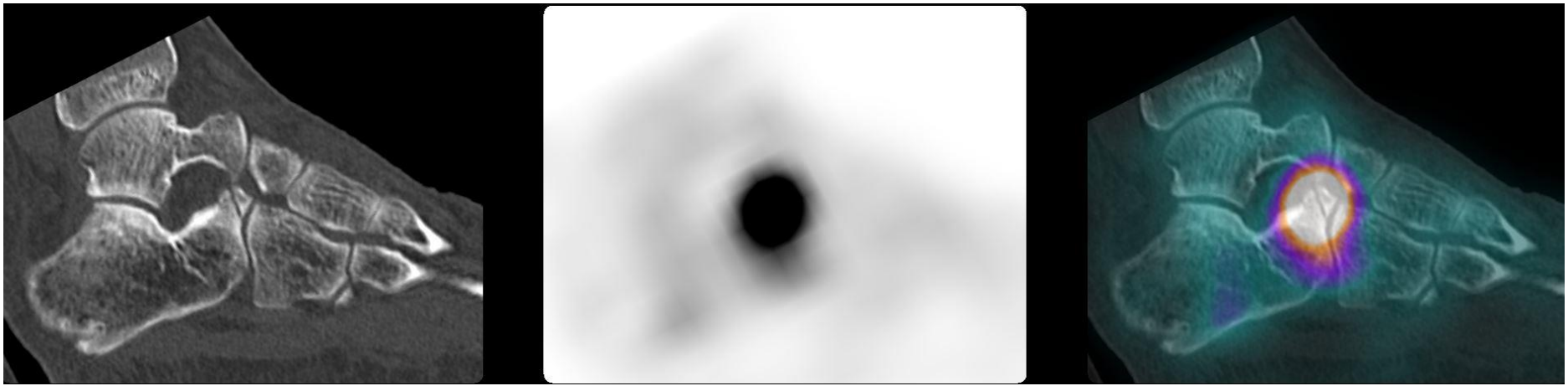
Mettler; Essentials of Nuclear Medicine Imaging 6th Ed.

Bone scan (^{99m}Tc-MDP)

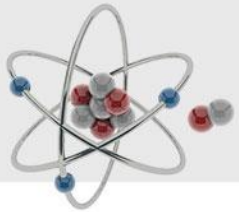
Example: L foot pain, query occult fracture

Bone scan (^{99m}Tc-MDP)

Example: L foot pain, query occult fracture



Bone scan (^{99m}Tc-MDP)

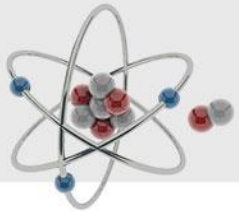


Bone scan VS CT

- In hospital/ER, CT can be performed immediately, while bone scan may be 1-2 day delay. CT has shorter acquisition time
- Outpt setting, bone scan typically has a shorter waiting list (a few days). Longer acquisition time
- Bone scan will routinely do whole-body images for patients >50yo, as an additional screen for bone abnormality

- Most bone scans will be done as SPECT/CT, so higher Sn and Sp than bone scan or CT alone.

Bone scan (^{99m}Tc-MDP)



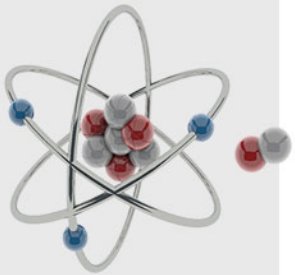
Bone scan VS MRI

- Bone scan shorter wait list
- Whole-body assessment
- No concern about MRI contraindications (metal, pacemaker, etc)

- Bone scan only has uptake in BONE
- Poor assessment of ligaments/tendons, menisci, soft tissues, and radiculopathy
- Limited ability to characterize bone tumors

Outline

- Principles of nuclear medicine
- **Bone Mineral Densitometry**
- Radiation safety



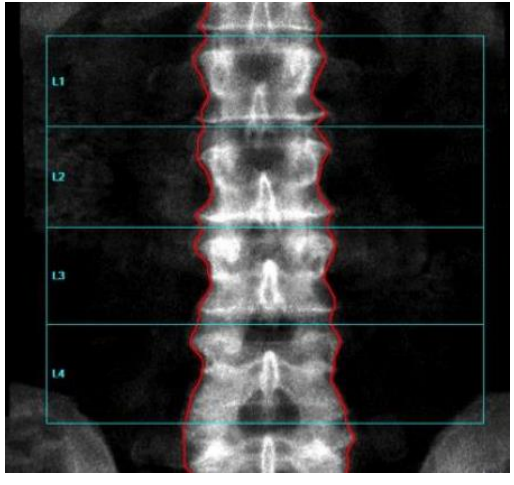
Bone Mineral Densiometry (BMD)

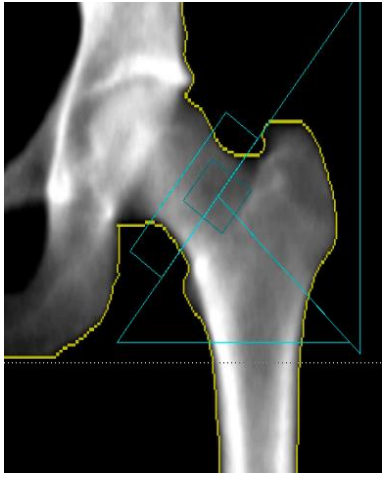
(dual energy x-ray absorptiometry DEXA)

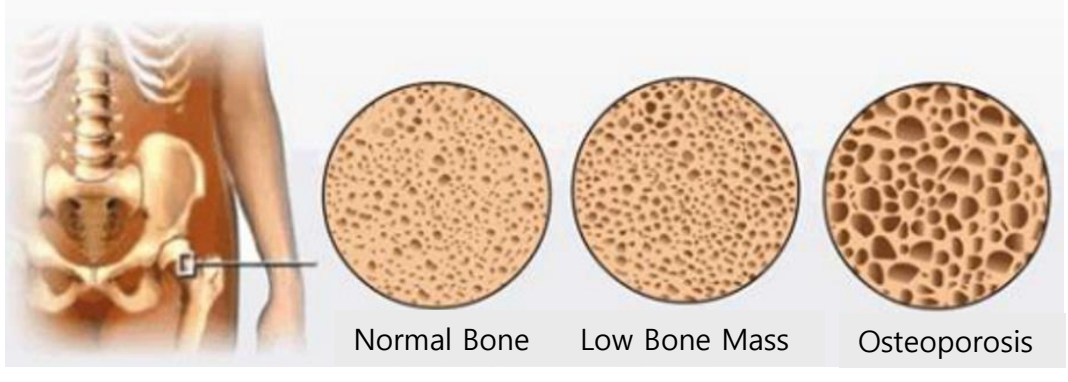
Osteoporosis Canada
Ostéoporose Canada

osteoporosis.ca

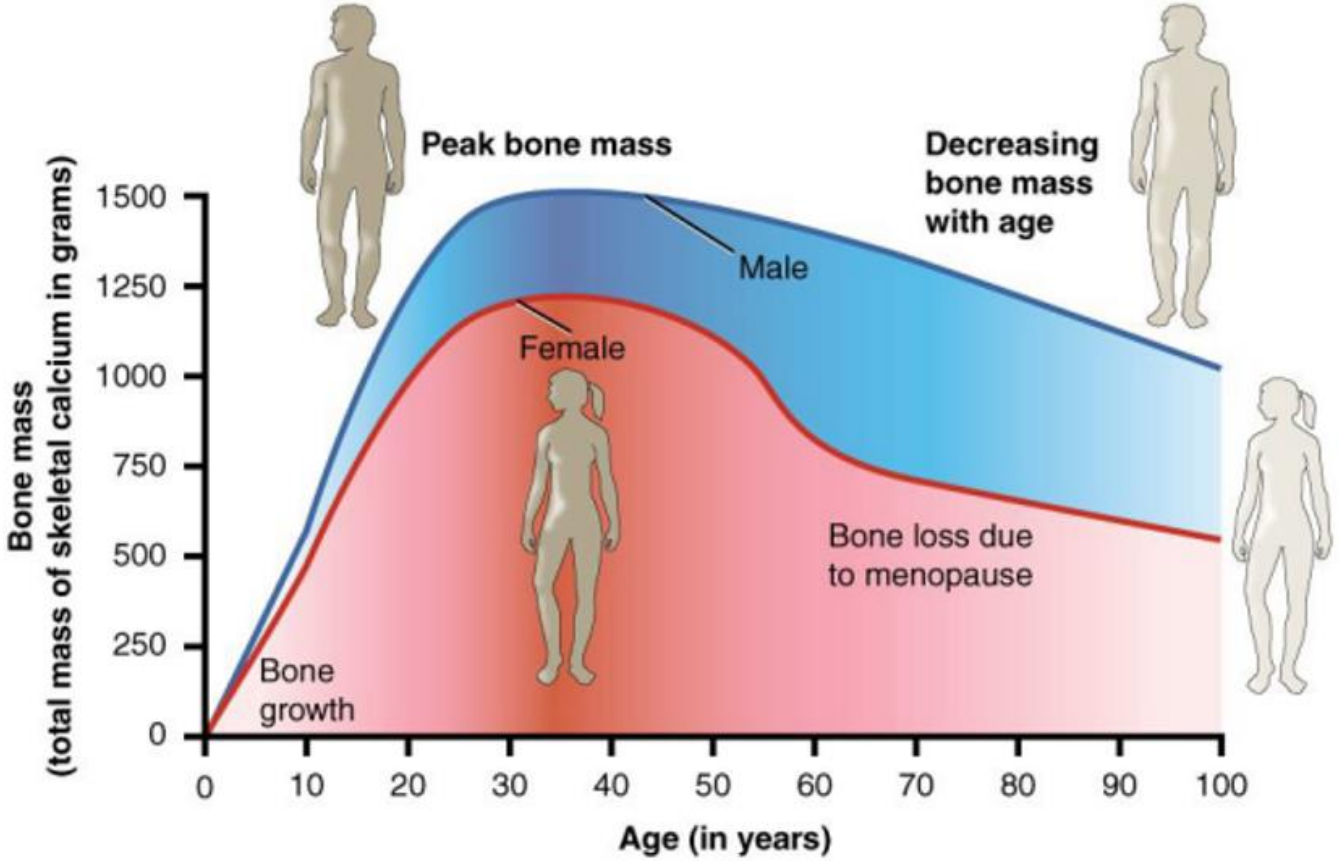
BMD: Principles





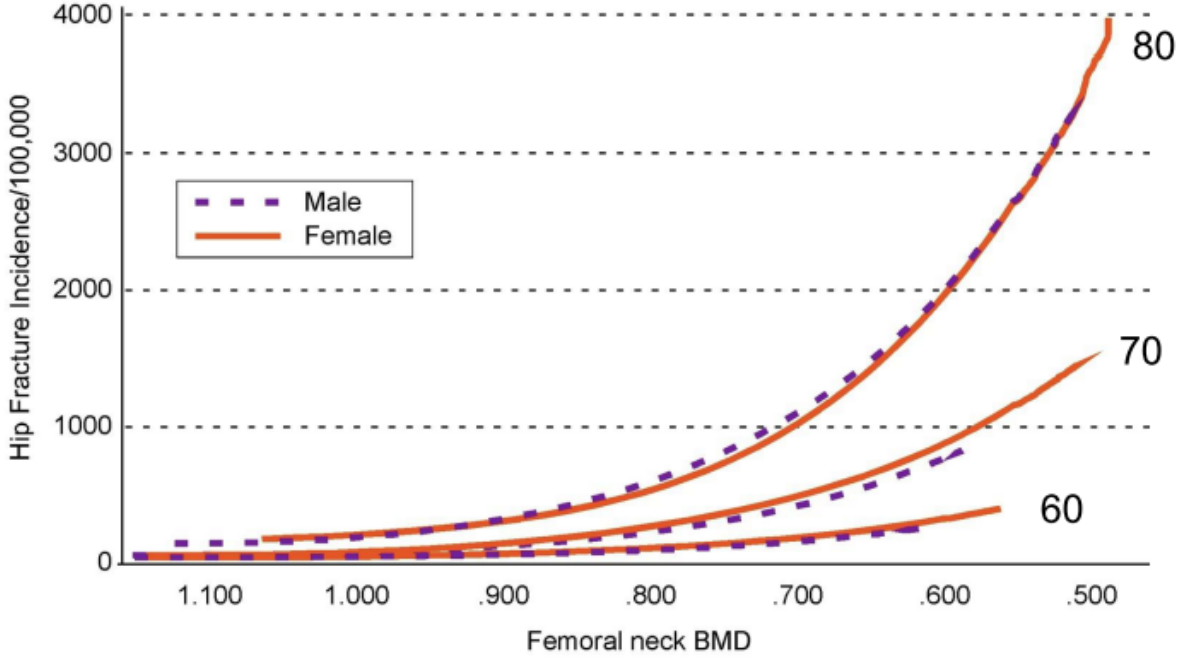


BMD: Principles



BMD: Principles

In the Rotterdam study; the hip fracture risk at a given BMD is the same for men and women



BMD: Indications for testing

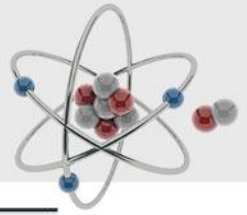


Table 1: Indications for measuring bone mineral density

Older adults (age ≥ 50 yr)	Younger adults (age < 50 yr)
Age ≥ 65 yr (both women and men)	Fragility fracture
Clinical risk factors for fracture (menopausal women, men age 50–64 yr)	Prolonged use of glucocorticoids*
Fragility fracture after age 40 yr	Use of other high-risk medications†
Prolonged use of glucocorticoids*	Hypogonadism or premature menopause (age < 45 yr)
Use of other high-risk medications†	Malabsorption syndrome
Parental hip fracture	Primary hyperparathyroidism
Vertebral fracture or osteopenia identified on radiography	Other disorders strongly associated with rapid bone loss and/or fracture
Current smoking	
High alcohol intake	
Low body weight (< 60 kg) or major weight loss (> 10% of body weight at age 25 yr)	
Rheumatoid arthritis	
Other disorders strongly associated with osteoporosis	

*At least three months cumulative therapy in the previous year at a prednisone-equivalent dose ≥ 7.5 mg daily.
†For example, aromatase inhibitors or androgen deprivation therapy.

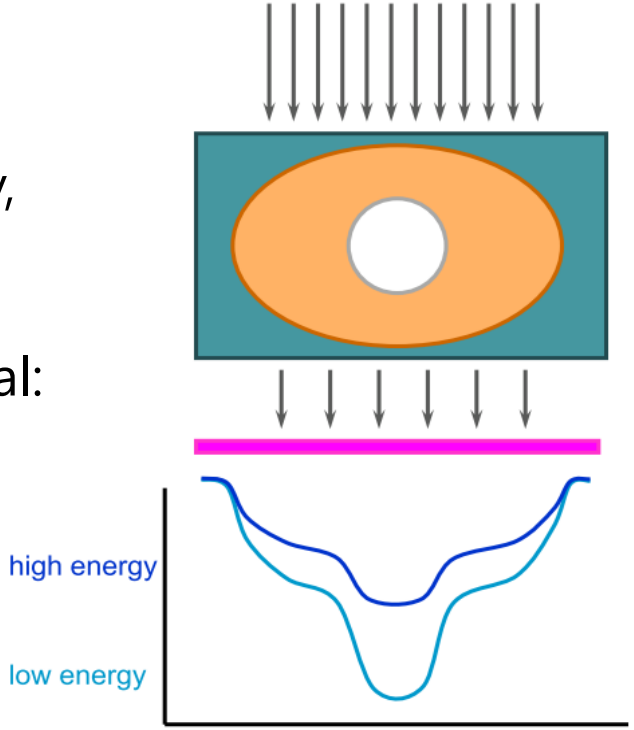
2010 Canadian Osteoporosis Clinical Practice Guidelines, CMAJ 2010; 182 (17) 1864-1873

BMD: Technique

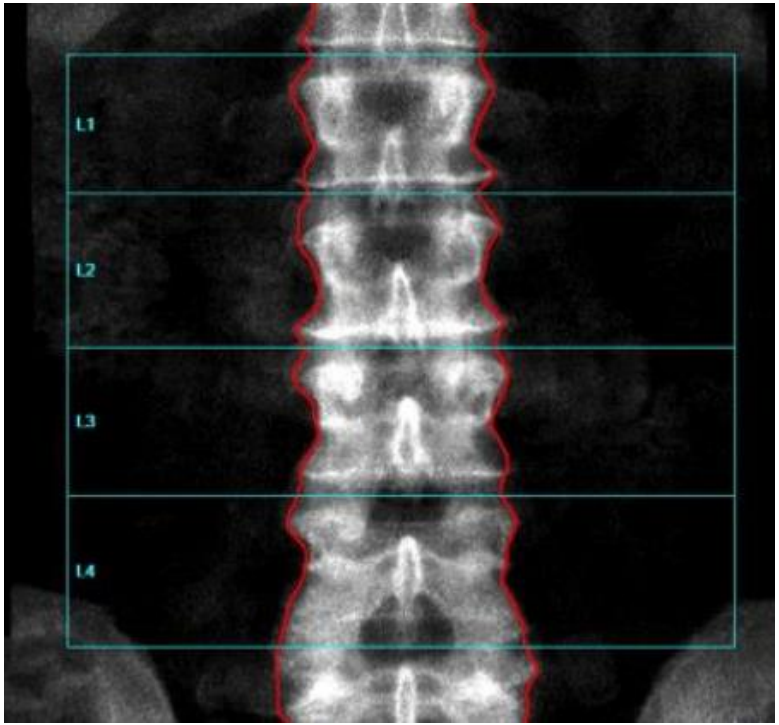
In densitometry, X-rays need to pass through 2 types of material:

- Bone
- Not bone

Calculate BMD



$$I = I_o e^{-\mu_m m}$$



MIC Terra Losa

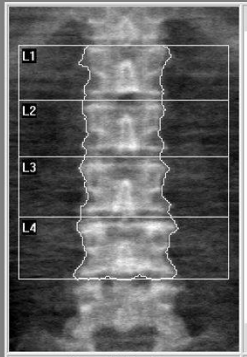
9566 - 170 Street
Edmonton, Alberta T5T 5R5

Patient Information:

Name:	
Patient ID:	
Identifier 2:	
Postal Code:	
Sex:	Female
Ethnicity:	White
Height:	157.6 cm
Weight:	66.2 kg
DOB:	
Age:	71
Menopause Age:	56
Referring Physician:	

Scan Information:

Scan Date:	January 22, 2021 - B01222103
Scan Type:	a Lumbar Spine
Analysis Date:	01/22/2021 08:53
Analysis Protocol:	Spine
Report Date:	01/22/2021 09:03
Institution:	MIC Terra Losa
Operator:	sj/tw
Model:	Discovery W (S/N85812)
Comment:	
Software version:	13.6.0.2



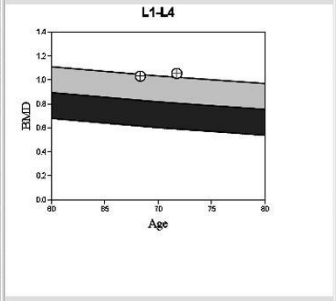


Image not for diagnostic use

116 x 129

T-score vs. White Female. Source:2012 BMDCS/Hologic
Z-score vs. White Female. Source:2012 BMDCS/Hologic

k = 1.130, d0 = 44.9

Results Summary:

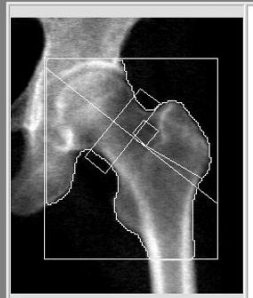
Region	Area[cm²]	BMC[(g)]	BMD[g/cm²]	T-score	PR (Peak Reference)	Z-score	AM (Age Matched)
L1	13.34	13.21	0.990	0.0	100	2.0	128
L2	13.47	13.42	0.996	-0.3	97	1.9	126
L3	15.23	16.01	1.051	-0.3	97	2.0	126
L4	17.61	20.32	1.154	0.8	109	3.2	144
Total	**59.66**	**62.96**	**1.055**	**0.1**	**101**	**2.3**	**131**

Total BMD CV 1.0%, ACF = 1.034, BCF = 0.998, TH = 7.629

Results History: L1-L4

Scan Date	Age	BMD	T-score	BMD Change vs Baseline	BMD Change vs Previous
01/22/2021	71	1.055	0.1	2.4%*	2.4%*
08/22/2017	68	1.031	-0.1		

* Significant at 95% confidence. LSC is 0.022 g/cm² or 0.022 g/cm² for different scan types.



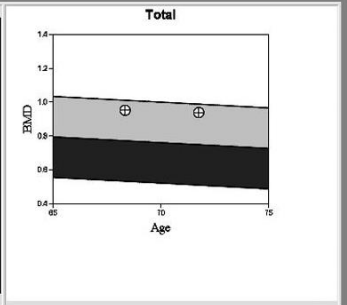


Image not for diagnostic use

95 x 110

T-score vs. White Female. Source:2012 BMDCS/NHANES White Female.
Z-score vs. White Female. Source:2012 BMDCS/NHANES White Female.

NECK: 49 x 15

k = 1.137, d0 = 48.6

Results Summary:

Region	Area[cm²]	BMC[(g)]	BMD[g/cm²]	T-score	PR (Peak Reference)	Z-score	AM (Age Matched)
Neck	5.47	3.93	0.718	-1.2	85	0.7	112
Troch	10.43	7.82	0.750	0.5	107	1.9	133
Inter	22.27	24.09	1.082	-0.1	98	1.2	122
Total	**38.17**	**35.84**	**0.939**	**0.0**	**100**	**1.6**	**126**
Ward's	1.17	0.51	0.437	-2.5	60	0.1	103

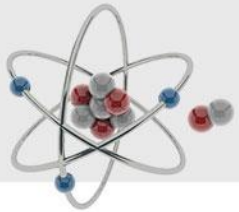
Total BMD CV 1.0%, ACF = 1.034, BCF = 0.998, TH = 5.702

Results History:

Scan Date	Age	BMD	T-score	BMD Change vs Baseline	BMD Change vs Previous
01/22/2021	71	0.939	0.0	-1.3%	-1.3%
08/22/2017	68	0.952	0.1		

* Significant at 95% confidence. LSC is 0.027 g/cm² or 0.027 g/cm² for different scan types.

BMD: Scoring



T-score is derived from comparing an individuals BMD with the mean value for young normals, expressed as the difference in standard deviation

	T-score
Normal	Equal to -1.0 or higher
Low Bone Mass (Osteopenia)	Between -1.0 and -2.5
Osteoporosis	Equal to -2.5 or lower
Severe Osteoporosis	Equal to -2.5 or lower with fracture

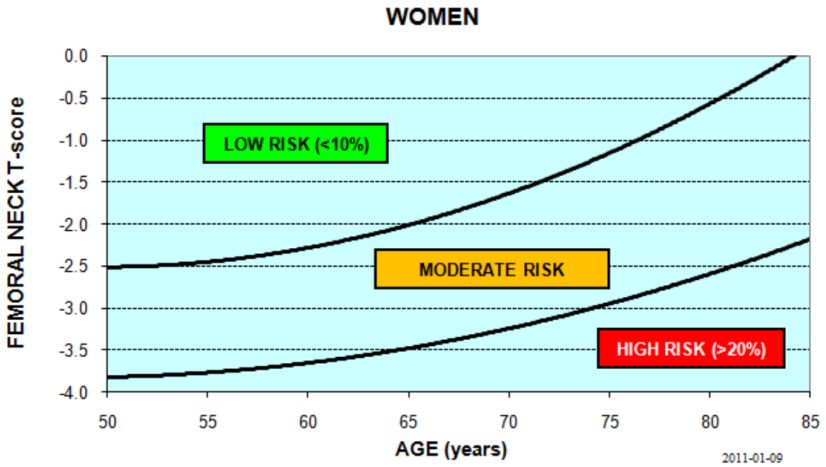
BMD: Risk calculation

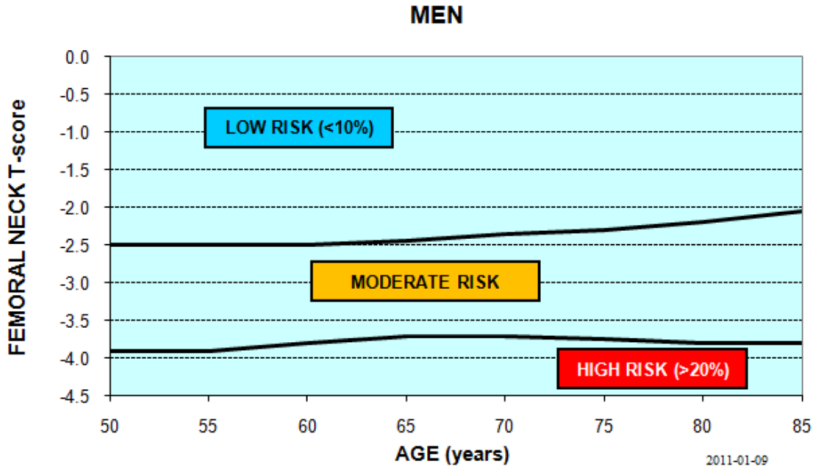
CAROC (**C**anadian **A**ssociation of **R**adiologists – **O**steoporosis **C**anada)

- Gender
- Age
- Femoral neck T-score

Modifiers

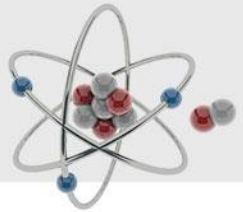
- Fragility fracture risk
- Prolonged steroid use





osteoporosis.ca

BMD: Risk calculation



FRAX® Fracture Risk Assessment Tool

Home | Calculation Tool | Paper Charts | FAQ | References | English

Calculation Tool

Please answer the questions below to calculate the ten year probability of fracture with BMD.

Country: Canada Name/ID: About the risk factors

Questionnaire:

1. Age (between 40 and 90 years) or Date of Birth
   Age: Date of Birth: Y: M: D:
2. Sex — Male / Female
3. Weight (kg)
4. Height (cm)
5. Previous Fracture — No / Yes
6. Parent Fractured Hip — No / Yes
7. Current Smoking — No / Yes
8. Glucocorticoids — No / Yes
9. Rheumatoid arthritis — No / Yes
10. Secondary osteoporosis — No / Yes
11. Alcohol 3 or more units/day — No / Yes
12. Femoral neck BMD (g/cm^2)

Select BMD

Clear | Calculate

Weight Conversion

Pounds → kg

Convert

Height Conversion

Inches → cm

Convert

00870161

Individuals with fracture risk assessed since 1st June 2011

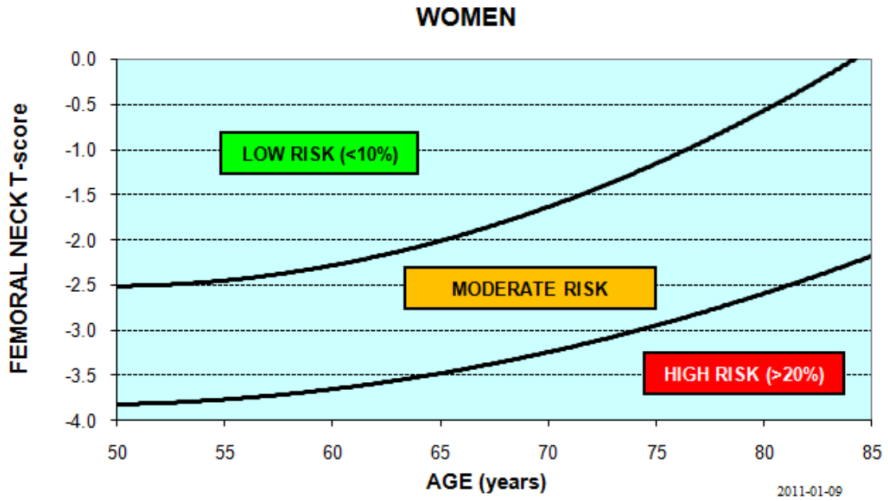
FRAX is an alternative validated risk calculation tool

BMD: Treatment concepts

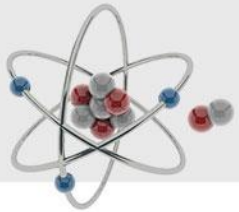
LOW RISK
- <10% 10-year absolute fracture risk
- **Lifestyle, nutrition**

MODERATE
- 10-20%
- **Lifestyle, nutrition**, +/- drug therapy

HIGH
- >20%
- **Lifestyle, nutrition**, drug therapy



BMD: Monitoring



Follow-up interval is guided by:

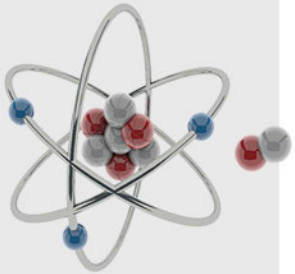
- Expected rate of change
- Precision of the DEXA machine *(f/u on the same machine)*
- Provincial imposed minimum follow-up times

A stable or increasing BMD is an acceptable response to drugs or lifestyle/nutrition

Change in density does not change risk category

Outline

- Principles of nuclear medicine
- Bone Mineral Densitometry
- Radiation safety



Typical Dose Estimates

Every day activity	Radiation dose (mSv)
Eating 1 banana	0.0001
Smoking 20 cigarettes	0.001
Sleeping next to someone for 1 year	0.02
Flight from Washington DC to LA	0.05
Simply existing for 1 year (radiation in your own body)	0.39
Annual exposure from radon gas	1.3
Annual exposure (natural) Edmonton	2.4
Annual dose limit nuclear energy worker	50 (100/5yr)

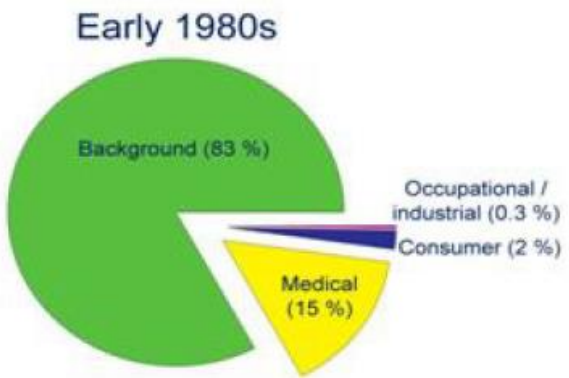
www.discovermi.org
http://hps.org/documents/background_radiation_fact_sheet.pdf
https://nuclearsafety.gc.ca/eng/resources/fact-sheets/natural-background-radiation.cfm?pedisable=true

Typical Dose Estimates

Annual Medical Dose (National Council on Radiation Protection)

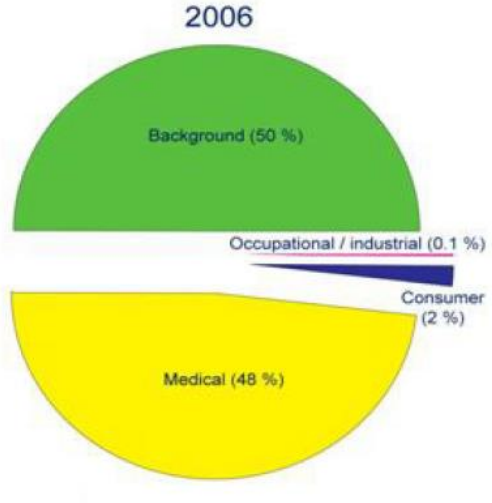
NCRP Report 93 (1987)

- US annual effective dose 3.6 mSv/yr
- 0.54 mSv (~15%) from medical procedures

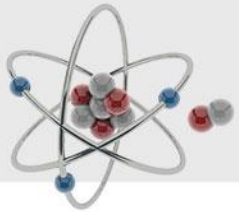


NCRP Report 160 (2009)

- US annual effective dose 6.2 mSv/yr
- 3.0 mSv (~48%) from medical procedures
- Largest increases from CT and nuclear medicine



Typical Dose Estimates



Radiology exam	Radiation dose (mSv)
Chest X-ray (AP)	0.02
Chest X-ray (LAT)	0.04
Lumbar spine X-ray (AP)	0.7
Mammogram (4 views)	0.7
CT Head	2.0
CT Abdomen	10.0
Coronary angioplasty	7.5-57.0

NM exam	Radiation dose (mSv)
DEXA	0.0004
Bone scan: ^{99m}Tc-MDP	4.2
Renal scan: ^{99m}Tc-MAG3	5.2
Brain perf: ^{99m}Tc-HMPAO	6.9
Cardiac MIBI: stress+rest	12.5
Gallium scan: ^{67}Ga	18.5
PET/CT scan: ^{18}F-FDG	14-32

*these are only estimates, with limitations based on biological data and the mathematical models used

www.discovermi.org, fact sheets
http://hps.org/documents/meddiagimaging.pdf

Lifetime attributable risk (BEIR VII Report 2006)

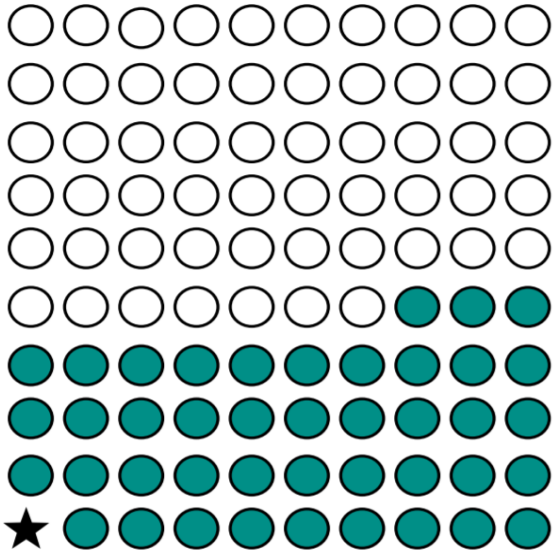


Figure 2. In a lifetime, approximately 42 (solid circles) of 100 people will be diagnosed with cancer[2] from causes unrelated to radiation. The calculations in this report suggest approximately one cancer (star) in 100 people could result from a single exposure 100 mSv of low-LET radiation.

http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/beir_vii_final.pdf

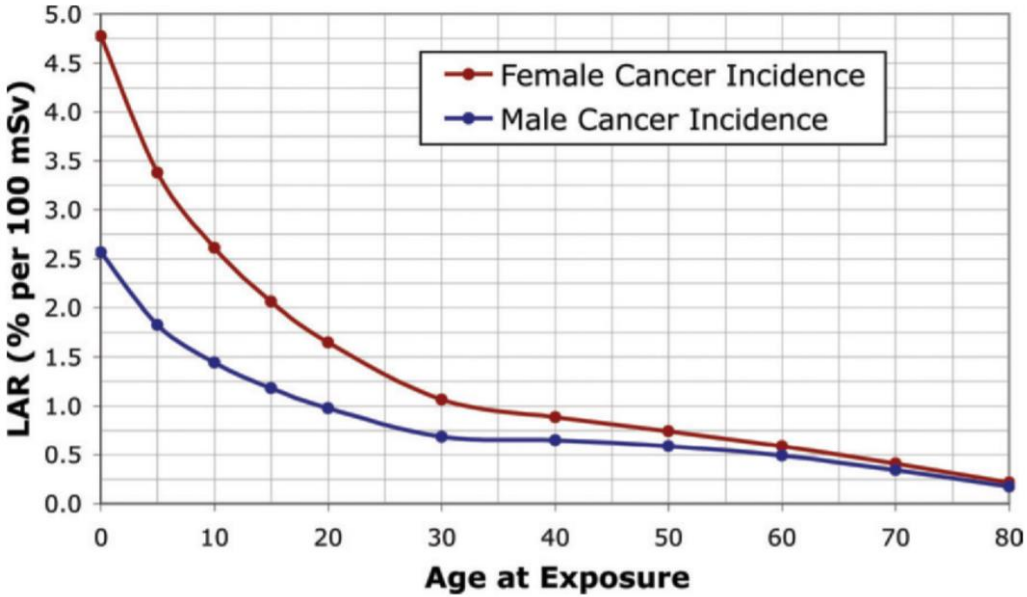


Figure 1. BEIR VII linear no-threshold risk model demonstrating lifetime attributable risk (LAR) of cancer incidence, an additive risk higher than the baseline rate of 42%. Graph shows that for patients who receive CT exposure of 10 mSv, which is common at abdominal CT, excess risk is predicted to be 1/1000 (where the y-axis equals 1) for a 32-year-old woman or a 19-year-old man. Data for this graph were extracted from table 12D of BEIR VII.

RadioGraphics 2015; 35:1706–1721

Lifetime attributable risk
AAPM Position statement 2018

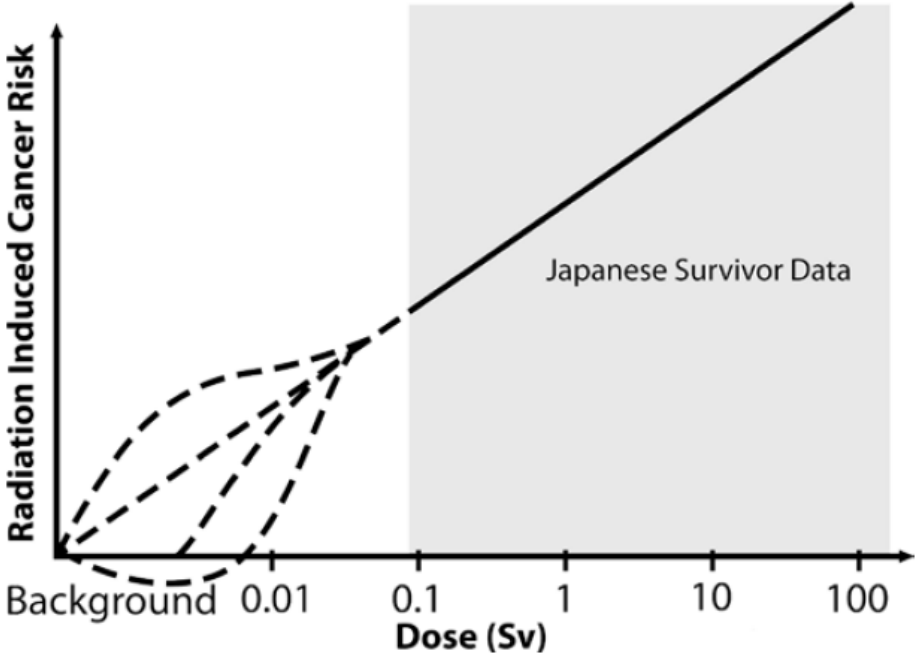


Figure 4: Graph shows models for extrapolating radiation-induced cancer risk to low doses (dashed line and curves). Linear no-threshold (LNT) model = dashed straight line.

Radiology 2012; 264:312–321

American Association of Physicists in Medicine Position Statement:

At the present time, epidemiological evidence supporting increased cancer incidence or mortality from radiation doses below 100 mSv is inconclusive. As diagnostic imaging doses are typically much lower than 100 mSv, when such exposures are medically appropriate, the anticipated benefits to the patient are highly likely to outweigh any small potential risks.

Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged. These predictions are harmful because they lead to sensationalistic articles in the public media that cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures.

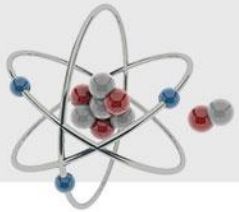
https://www.aapm.org/org/policies/details.asp?id=439&type=PP

SAFETY: Radiation Exposure

ALARA: as low as reasonably achievable

Use the minimum radiation dose that still allows for an accurate test

ICRP 103 (International Commission on Radiological Protection)



Questions to ask for each procedure

Is the medical exam justified?

- Will this exam provide an appropriate answer?
- Does the information already exist?

What are the risks?

- What is the benefit of having the exam vs the harm of the dose received?

Can the risks be minimized

- Can the protocol be optimized to reduce the dose?

More information

Image Wisely

https://www.imagewisely.org/Imaging-Modalities/Computed-Tomography/How-to-Understand-and-Communicate-Radiation-Risk

~20-30 min read about radiation principles, radiobiology, risks and risk perception, and discussing radiation risk with patients.

image gently (pediatrics)

Choosing Wisely Canada

https://choosingwiselycanada.org/radiology/

https://choosingwiselycanada.org/nuclear-medicine/