THE FORMULA SHEET

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X-ray Production & Interaction

k-shell binding energies (keV)

Mo	Rh	Ag	W	Iodine	Barium
20	23	25	70	33	37

*k-edge ≈ k-shell binding energy

characteristic energies (keV)

Mo	Rh
18 & just below 20	20 and just below 23

· PE absorption $\propto Z^3/E^3$
· Compton Scatter $\propto 1/E$
· Prob(PE) = Prob(Compton) @ 25 keV soft tissue
@ 40 keV bone
· HVL = thickness needed for transmitted x-ray beam intensity to be 50% of initial beam intensity
ex.) 3 HVL attenuation = (1/2) x (1/2) x (1/2) = (1/8) => 1/8th of incident beam is transmitted. Caution: don't confuse absorbed vs. transmitted.

Projection Radiography

· 15% ↑in kVp increases efficiency of x-ray production, requiring only half the initial mA·s to keep the same total number of photons.

Film-Screen	Indirect Digital	Direct Digital	CR
screen + film	CsI scintillator	amorphous selenium	PSP

· assume AEC in effect when in doubt
· geometric magnification = SID/SOD

3 Determinants of Resolution
(1) Detector (pitch), (2) Motion (exposure time, compression paddles), (3) Effective Focal Spot Size (filament size, geometric blurring, anode angle)

Fluoroscopy

deterministic risk: AK in [Gy]
stochastic risk: KAP = AK x area in [Gy·cm^2]
JC Sentinel Event if >15 Gy fluoro to single field
@1m, operator gets 1/1000th of dose to patient
safety: time, distance, shielding
collimation decreases KAP
magnification increases AK (II > FPD) and improves spatial resolution for II, and improves spatial resolution for FPD only when binning turned off.

Mammography

· Target/Filter Combinations
→→→increasing breast density
Mo/Mo, Mo/Rh, Rh/Rh, W/Ag
· focal spot: 0.1mm mag, 0.3mm reg
· PNL within 1 cm between CC & MLO
ACR Phantom: 4.2cm, 50% glandular
· (fiber, spec groups, masses)
Old: (6,5,5), passing (4,3,3)
· New: 😈(6,6,6), passing (2,3,2)
· Breast MR: 0.1 mmol/kg gad, perform during days 7-13 of menstrual cycle, first delayed phase image within 2 minutes of contrast injection

Computed Tomography (CT)

beam pitch = $\frac{\text{distance table traveled in one rotation}}{\text{beam thickness}}$
beam pitch > 1: ↓ dose, worse resolution
beam pitch < 1: ↑ dose, better resolution
keep pitch < 2; "pitch" = "beam pitch"
Cardiac CT: prospective gating target 50-60 bpm.
retrospective gating ↑ dose, but allows diast+syst imaging separately, hence EF can be calculated.
CNR $\propto \sqrt{voxel\ volume}$
· 16cm head phantoms, 32cm body phantoms; these phantoms underestimate dose to peds, and overestimate dose to obese (fat protects organs)
· CTDIvol = (2/3 periph + 1/3 central)/pitch, in [Gy]
· DLP = CTDIvol x scan length, in [Gy·cm], approximates cancer risk using conversion factor

Ultrasound

$c_{soft\ tissue}$ =1540 m/s; $c_{bone} > c_{soft\ tissue} > c_{fat}$
c = TF x λ , where TF = transducer freq. (in Hz),
λ wavelength (in meters)
· axial res = SPL/2, where SPL≈2λ
· "axial res" here is smallest distance resolvable between two features. "Better" is smaller number.
· FOV_{axial} = c x PRP / 2
· PRF = 1/PRP
· Don't confuse TF with PRP. ↑TF → better ax/lat/elev res + worse attenuation. ↑PRP → deeper axial FOV and slower screen refresh rate.
· lat/elev res best in focal zone, ·also ↑scan line density → better lateral res
· attenuation of sound in soft tissue (dB) = 0.5 dB/cm/MHz, where MHz is TF, cm is total distance traveled. Total distance (roundtrip) traveled by an ultrasound pulse is 4 cm for lesion of depth 2 cm.
· depth-resolution tradeoff: use the highest frequency that penetrates deep enough for you to see the structure you're interested in. ↑TF → better ax/lat/elev resolution but greater attenuation per cm of tissue depth
·Thermal Index (TI) - heating
·Mech. Index (MI) - cavitation risk

Nuclear Medicine

Activity in Becquerel (Bq) is decays per second
1 mCi = 37 MBq
1/(effective $t_{1/2}$) = 1/(physical $t_{1/2}$) + 1/(biological $t_{1/2}$)

Radioisotope Physical Half-Lives					
Tc99m	I-123	I-131	Ind, Thal, Ga	Xe-133	F-18
6 hrs	13 hr	8 d	3 d	5 d	110 min

Gamma Energies (keV)					
Tc99m	I-123	I-131	Ga-67	Xe-133	F-18
140	159	365	~100, 200, 300, 400	81	511

Activity Exponential Decay: $A(t) = A_0 \exp(-\lambda t)$
λ is decay constant, A_0 is initial activity at t=0
Half-life ($t_{1/2}$) can be calculated using $t_{1/2} = 0.693/\lambda$
Activity remaining at N half-lives is $A_0(1/2)^N$
Milk the Mo-Tc generator q24 hrs x 5 days
Mo breakthrough - 700 keV photons
Aluminum breakthrough - color strip

Gamma Camera QC
daily: extrinsic uniformity, photopeak
weekly: intrinsic uniformity, bar phantom (linearity, spatial resolution)
monthly: center of rotation (COR)
quarterly: Jascszak phantom

Dose Calibrator QC
Constancy (daily)
Linearity (quarterly)
Accuracy (annually)
Geometry (on repair)

MRI

Larmor Freq = (42 MHz/T) x B
Longitudinal (T1) relaxation - spin-lattice
Transverse (T2) relaxation - spin-spin

Weighting	TR	TE
T1	short	short
T2	long	long
Proton Density	long	short

spin-echo TR: short (<500ms), long (>1500ms)
spin-echo TE: short (<30ms), long (>150ms)

Scan Time = $\frac{\text{(NEX) x (\# slices) x TR x } N_y}{\text{turbo factor}}$
NEX = number of repetitions (a.k.a. NSA)
N_y = # phase encoding steps
turbo factor = 1 for regular spin-echo

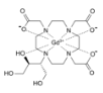
$$\text{SNR} \propto \text{voxel volume} \times \sqrt{\frac{\#\text{measurements}}{\text{receiver bandwidth}}}$$

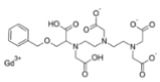
N_x : # freq encoding steps, N_y : # phase encoding steps
measurements = N_x x N_y x NEX

$$\text{voxel volume} = \left(\frac{FOV_x}{N_x} \cdot \frac{FOV_y}{N_y} \cdot \Delta \right)$$

Δ : z-axis slice thickness
·↑ voxel volume → worse resolution, ↑SNR
·↑ N_y → ↑pixels in phase encoding axis, ↑ scan time
· ↑receiver bandwidth→↓chem shift Type 1, ↓SNR, ↓scan time (from shorter echo)
· Change TE to remove chemical shift Type 2
· FDA limit whole-body SAR: 4 W/kg for 15 min

Macrocyclic vs Linear





macrocyclic better for chelation, decreased NSF risk
NSF risk by ACR Group: 2 (low, GFR screening optional), 1 (high, avoid for GFR<30, dialysis, AKI), 3 (insufficient info – treat like 2).

Radiation Dose Units & Nucs Safety

See *Radiology Simplified*