X-ray Physics and Imaging

X-ray production

High energy electrons hit metal target

Attenuation principles

Absorption varies with tissue density

Digital detectors

CR and DR systems replace film

Dose considerations

ALARA principle (As Low As Reasonably Achievable)

Image quality metrics

Contrast, resolution, noise tradeoffs

1. X-ray Production

Process Overview

X-rays are produced when high-energy electrons are rapidly decelerated by collision with a metal target (typically tungsten). The X-ray tube operates under high voltage (typically 40-150 kVp).

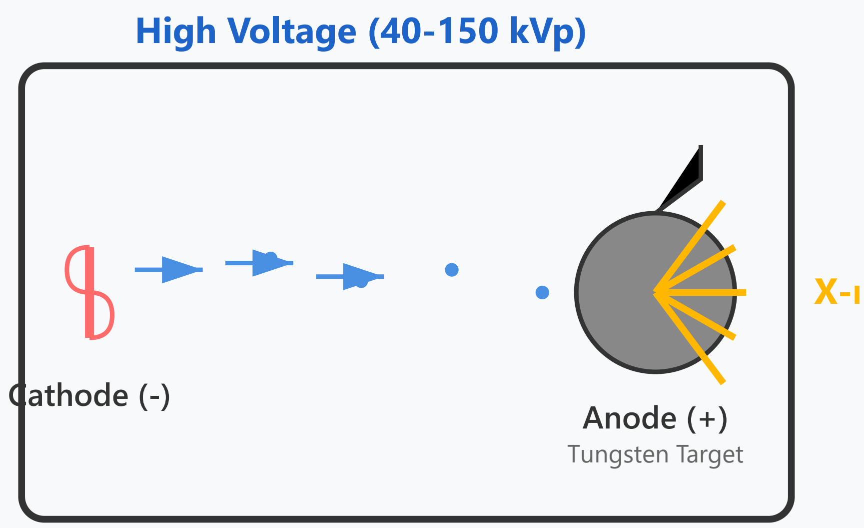
Key Components

- **Cathode:** Heated filament that emits electrons through thermionic emission
- **Anode:** Rotating tungsten target that electrons strike
- **Tube voltage (kVp):** Determines electron acceleration and X-ray energy
- **Tube current (mA):** Controls the number of electrons and X-ray quantity

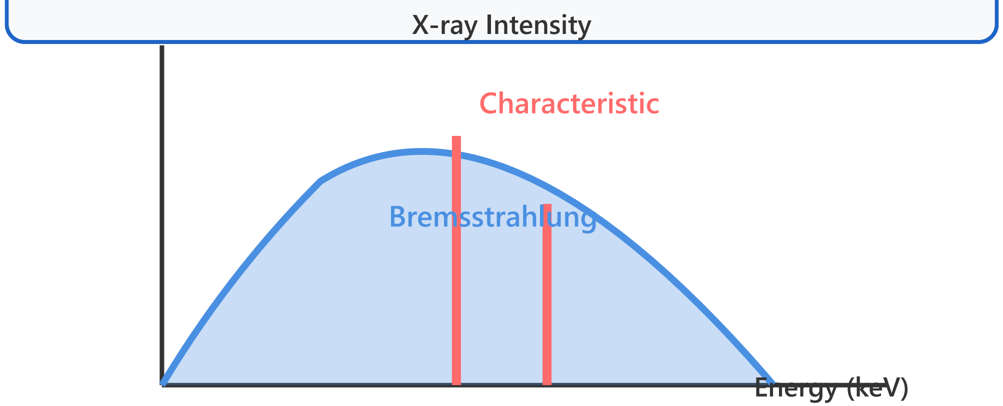
Two Types of X-ray Production:

Bremsstrahlung (Braking radiation): ~80% of X-rays, continuous spectrum
Characteristic radiation: ~20% of X-rays, discrete energy peaks

X-ray Tube Schematic



X-ray Energy Spectrum


X-ray Intensity
Characteristic
Bremsstrahlung
Energy (keV)

2. Attenuation Principles

Fundamental Concept

Attenuation is the reduction in X-ray intensity as it passes through matter. Different tissues attenuate X-rays differently based on their density and atomic number, creating image contrast.

Beer-Lambert Law

$I = I_0 \times e^{(-\mu x)}$

Where: I = transmitted intensity, I_0 = incident intensity, μ = linear attenuation coefficient, x = thickness

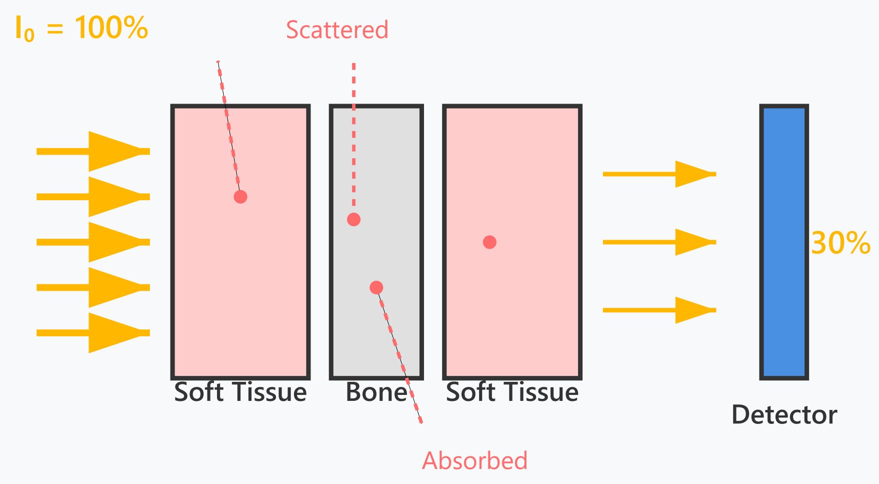
Interaction Mechanisms

- **Photoelectric absorption:** Dominant at low energies, highly dependent on atomic number (Z^3)
- **Compton scattering:** Dominant at diagnostic energies, depends on electron density
- **Coherent scattering:** Minimal contribution in diagnostic imaging

Tissue Attenuation Ranking:

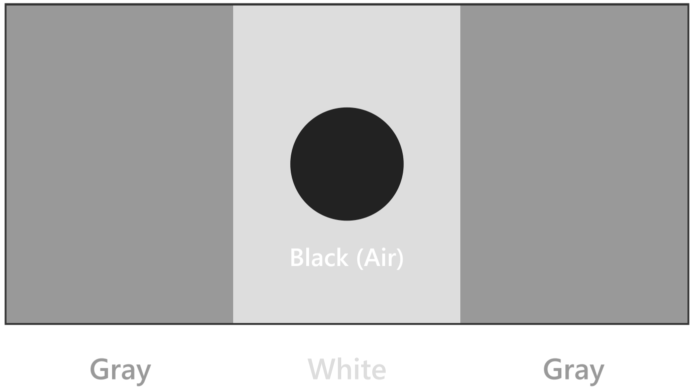
Metal > Bone > Soft tissue > Fat > Air
High attenuation appears WHITE, low attenuation appears

X-ray Attenuation Through Tissue



Resulting X-ray Image

BLACK



3. Digital Detectors

Evolution from Film to Digital

Digital radiography has replaced traditional film-based imaging, offering immediate image availability, wider dynamic range, and post-processing capabilities.

Computed Radiography (CR)

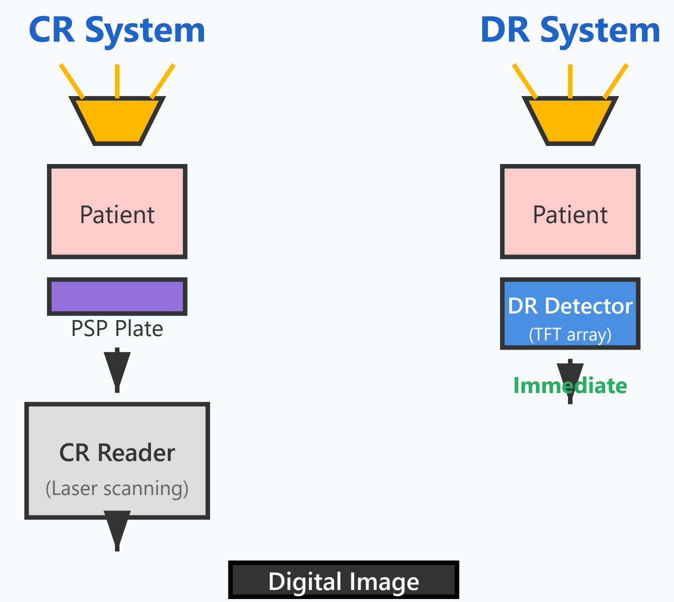
- Uses photostimulable phosphor plates (PSP)
- Requires separate reader unit to extract image
- More affordable, slower workflow
- Spatial resolution: ~2.5-5 line pairs/mm

Direct Radiography (DR)

- **Indirect DR:** Scintillator (CsI) + photodiode array
- **Direct DR:** Amorphous selenium converts X-rays directly to electrical signal
- Immediate image display (3-5 seconds)
- Better spatial resolution: ~3-7 line pairs/mm
- Higher detective quantum efficiency (DQE)

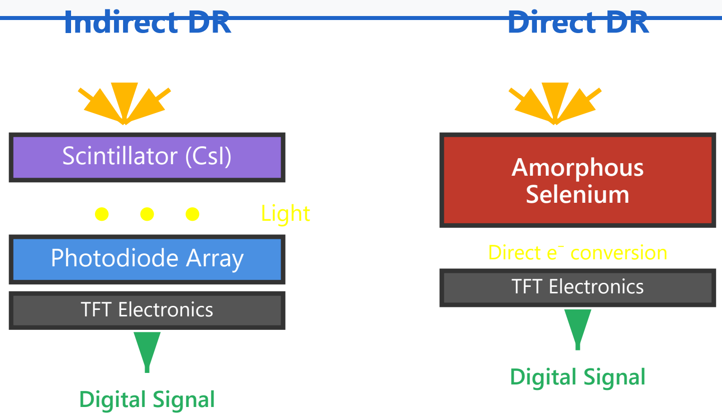
Digital Advantages:

CR vs DR System Comparison



Detector Technology Layers

• Wide dynamic range (10,000:1 vs 50:1 for film)
• Post-processing capabilities
• PACS integration and teleradiology
• Reduced repeat examinations



4. Dose Considerations

ALARA Principle

"As Low As Reasonably Achievable" - the fundamental principle guiding radiation protection. All imaging should balance diagnostic benefit against radiation risk.

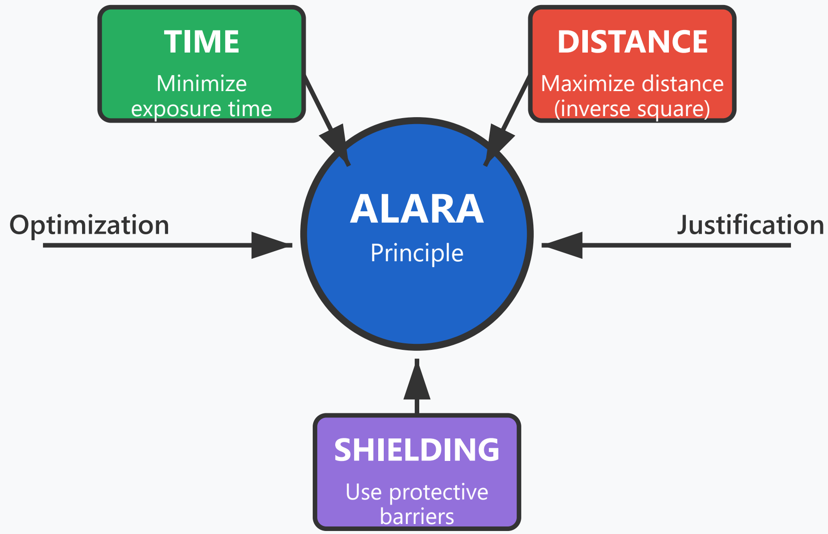
Radiation Units

- **Absorbed dose (Gray, Gy):** Energy deposited per unit mass
- **Equivalent dose (Sievert, Sv):** Accounts for biological effectiveness
- **Effective dose (mSv):** Considers organ sensitivity; used for risk comparison

Dose Reduction Strategies

- **Justification:** Is the exam necessary?
- **Optimization:** Use proper technique (kVp, mAs, collimation, filtration)
- **Shielding:** Protect radiosensitive organs (gonads, thyroid, breasts)
- **Digital imaging:** Better dose efficiency with DR systems
- **Automatic exposure control (AEC):** Prevents overexposure

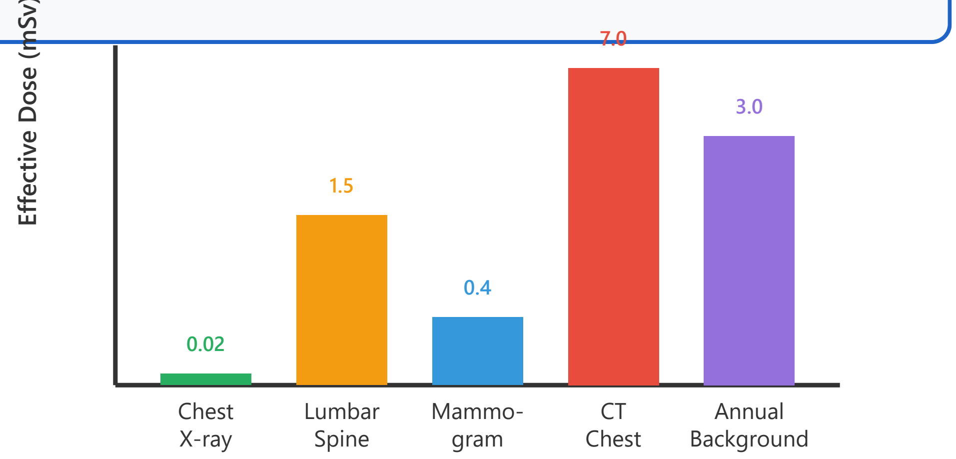
ALARA Implementation



Radiation Dose Comparison

Typical Effective Doses:

Chest X-ray: 0.02 mSv
Lumbar spine: 1.5 mSv
CT chest: 7 mSv
Background radiation: ~3 mSv/year



5. Image Quality Metrics

Key Quality Parameters

Image quality in radiography represents a balance between multiple competing factors. Understanding these tradeoffs is essential for optimal imaging.

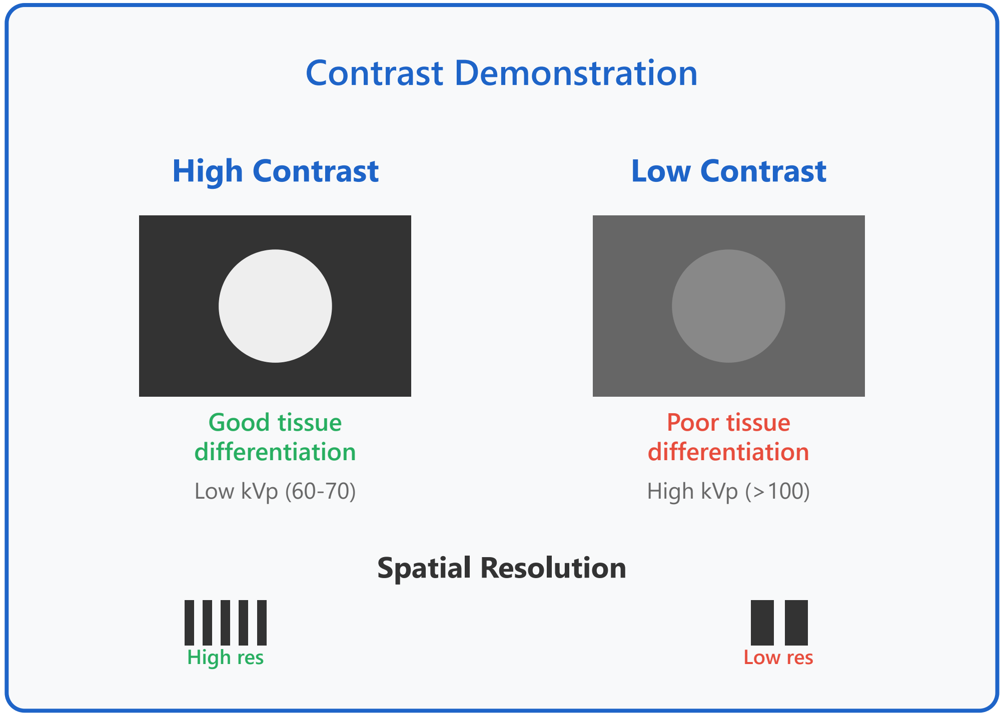
Contrast

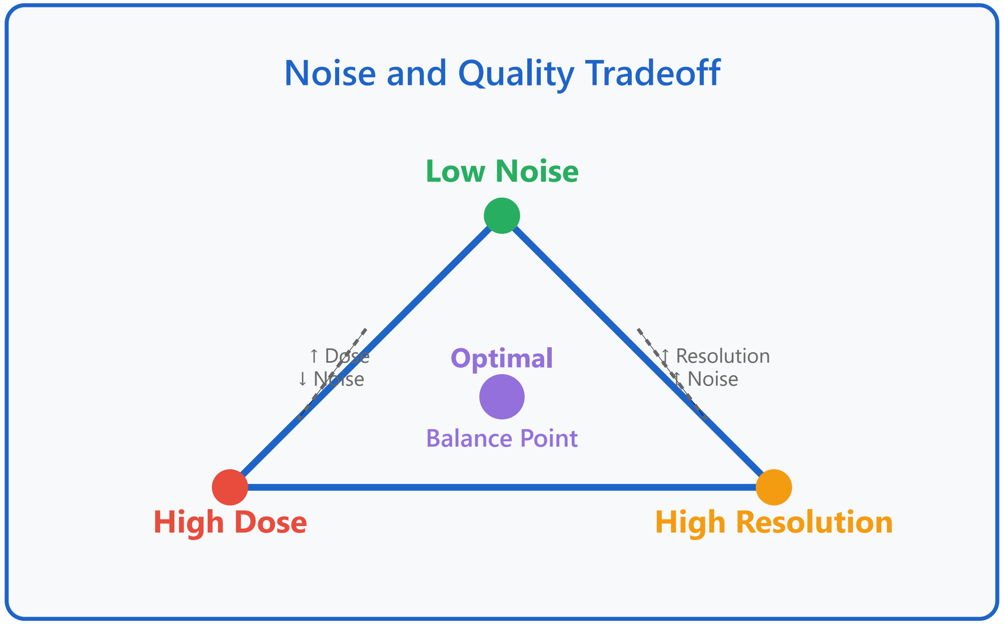
- Difference in brightness between adjacent structures
- Controlled by: kVp (lower = higher contrast), tissue differences
- Subject contrast vs. detector contrast
- Window/level adjustment in digital imaging

Spatial Resolution

- Ability to distinguish small, closely spaced objects
- Measured in line pairs per millimeter (lp/mm)
- Limited by: focal spot size, detector element size, motion blur, geometric factors
- Typical DR resolution: 3-7 lp/mm

Noise





- Random variation in image pixel values
- Types: quantum noise (dominant), electronic noise, structural noise
- Reduced by: higher dose (more photons), larger pixels, image smoothing
- Measured by signal-to-noise ratio (SNR)

Fundamental Tradeoff:

Resolution ↑ → Noise ↑ → Dose must ↑
Noise ↓ → Smoothing → Resolution ↓
Optimal imaging balances these factors for diagnostic task