

Advanced Medical Imaging Technologies

Advanced Medical Imaging Technologies – Study Notes

1. Overview

- **Purpose:** Visualize anatomy, physiology, and pathology with high resolution and functional information.
- **Trend:** Integration of hardware, software, and AI to improve image quality, speed, and diagnostic value while reducing patient risk.

2. Core Modalities & Recent Advances

Modality	Principle	Key Recent Developments	Clinical Impact
Magnetic Resonance Imaging (MRI)	Nuclear magnetic resonance of hydrogen protons in a magnetic field.	• 7T scanners – ultra-high field for sub-millimeter detail.	
		• Compressed sensing & parallel imaging – faster scans, less motion artifact.	• Early detection of micro-lesions (e.g., neuro-degeneration).
		• Magnetic Resonance Fingerprinting (MRF) – simultaneous multi-parameter mapping (T1, T2, PD).	• Quantitative biomarkers for treatment monitoring.
		• Hyperpolarized ¹³C MRI – real-time metabolic imaging.	

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Computed Tomography (CT)	X-ray attenuation measured from multiple angles, reconstructed into cross-sections.	• Photon-counting detectors (PCD-CT) – energy-resolved imaging, higher contrast, lower dose. • Iterative reconstruction (IR) & AI-enhanced reconstruction – noise reduction, dose reduction. • Dual-energy & spectral CT – material decomposition (e.g., iodine vs calcium). • Total-body PET (2m axial FOV) – whole-body imaging in a single scan, ultra-low dose.	• Precise vascular plaque characterization. • Low-dose lung cancer screening.
		• Novel tracers – ^{68}Ga PSMA (prostate), ^{18}F flortaucipir (tau), ^{18}F FDG analogs for inflammation. • Hybrid PET/MRI – combined functional and high-soft-tissue contrast. • Ultra-fast (plane-wave) imaging – $>10,000$ fps, enables shear-wave elastography & functional Doppler.	• Early systemic disease staging. • Theranostics (diagnostic + targeted radionuclide therapy).
Positron Emission Tomography (PET)	Detection of 511-keV photons from positron-electron annihilation; maps radiotracer distribution.	• 3D/4D volumetric probes – real-time volumetric rendering. • Contrast-enhanced ultrasound (CEUS) – microbubble agents for perfusion assessment.	• Point-of-care cardiac and abdominal evaluation. • Non-invasive liver fibrosis staging.
Ultrasound (US)	High-frequency sound waves reflected from tissue interfaces.		

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Optical Imaging	Light-based techniques (e.g., OCT, fluorescence, photoacoustic).	• Optical Coherence Tomography Angiography (OCTA) – microvascular mapping of retina.	• Early detection of retinal disease, skin cancer. • Real-time guidance during surgery.
		• Photoacoustic tomography – combines optical contrast with ultrasound resolution for deep tissue imaging. • Multiphoton microscopy – in-vivo cellular imaging in research settings.	
Hybrid & Emerging Systems	Combine complementary physics for synergistic data.	• PET/CT & PET/MRI –	