Advancing Medical Education and Planning Through Extended Reality: A Mini Review of XR Applications in Medicine

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Outline

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- XR use cases in medical education
- XR use cases in surgical and clinical planning
- AI methods in XR development
- Clinical example 1: Placenta accreta
- Clinical example 2: Neurovascular simulation
- XR + AI integration pipeline
- Current challenges and conclusion

Introduction to XR in medicine

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What is extended reality?

XR is a collective term for Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR)

Virtual reality:

- fully immersive, blocks out the real world

Augmented reality:

- overlays digital content onto the real-world view

Mixed reality:

- blends virtual content into the real world with interaction

Key benefits in medicine

Immersive 3D learning improves anatomy understanding and skill acquisition

- Hands-free interaction supports sterile environments like operating rooms
- Increased engagement and retention in medical education
- Enhanced surgical planning through personalized 3D visualizations

XR use cases in medical education

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- **Anatomy learning**
  - interactive 3D models improve spatial understanding
- **Procedural training**
  - VR simulators for endoscopy and suturing
- **Clinical scenario simulations**
  - safe rehearsal of emergencies and rare cases
- **Remote learning**
  - Portable headsets enable decentralized, asynchronous training
- **Collaborative learning**
  - MR platforms support group-based tasks in shared virtual spaces

XR in surgical and clinical planning

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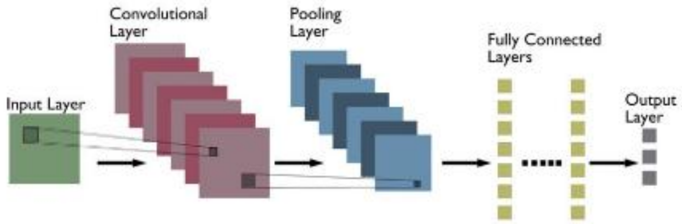
- **Preoperative rehearsal**
  - VR enables exploration of patient-specific 3D scans
- **Intraoperative guidance**
  - AR/MR overlays assist real-time navigation
- **Precision and safety**
  - Better targeting, reduced operative time, improved outcomes
- **Real-time data integration**
  - AR displays imaging and instrument positions in the field of view
- **Interdisciplinary collaboration**
  - Shared 3D models enhance surgical team communication

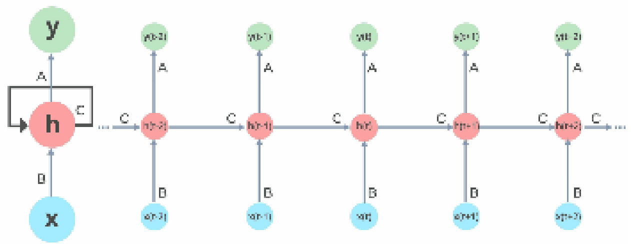
AI methods in XR development

- Convolutional Neural Networks (CNNs)
- Recurrent Neural Networks (RNNs)
- Generative Adversarial Networks (GANs)
- Reinforcement Learning (RL)
- Vision Transformers (ViTs)
- Diffusion Models

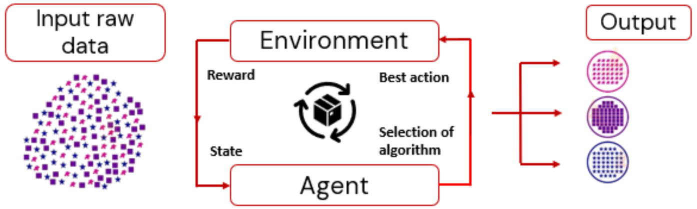
CNNs



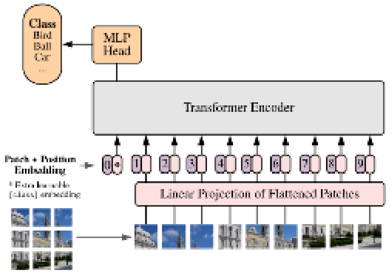
RNNs



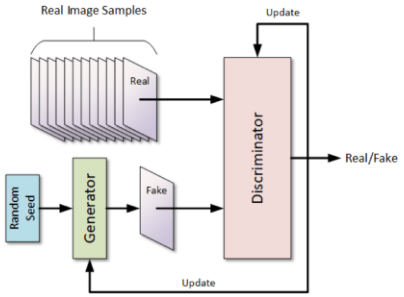
RL



DMs



ViTs



GANs

Clinical example 1: Placenta accreta

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High-risk condition where the placenta abnormally invades the uterine wall

- Ultrasound used for initial diagnosis; MRI adds soft-tissue detail
- AI segments placenta and invasion zones on MRI scans
- AR headsets overlay 3D MRI data onto live ultrasound during examination

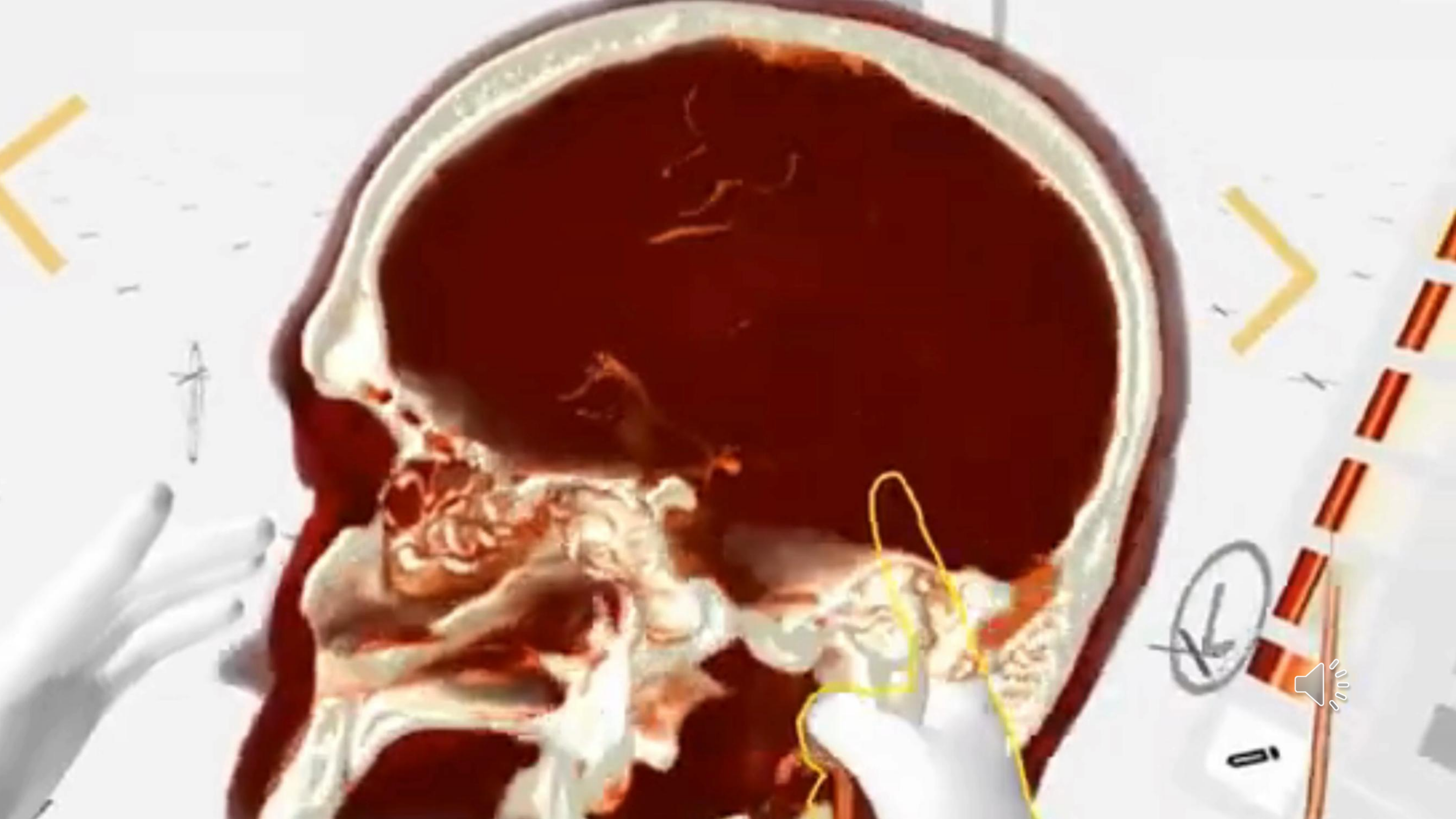
Supports surgical planning by visualizing anatomy and risk zones in real time improves clinician confidence and reduces intraoperative surprises


ADULT
71
97
19
36.0
36.3

Clinical example 2: Neurovascular simulation

High-risk procedures like aneurysm coiling and AVM embolization require precise planning

- VR simulations allow safe rehearsal of catheter navigation and device placement
- AI (CNNs) segments vessels from CT/MR angiography to build patient-specific 3D models
- AR overlays provide real-time guidance and track instrument positions intraoperatively
- Haptics + AI enable realistic force feedback, improving manual skill development



XR + AI integration pipeline

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Pipeline flow:

- Imaging data → AI processing → XR visualization
- AI models segment anatomy, track instruments, and denoise images in real-time
- Fused outputs from CT/MRI and live video are aligned and displayed in XR
- Hybrid rendering combines traditional graphics with AI-based enhancements

Current challenges

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- **Data variability and bias**
  - limited AI generalization across devices and populations
- **Black-box AI models**
  - reduced interpretability and clinician trust
- **High computational demands**
  - hinder real-time performance in XR environments
- **Regulatory validation**
  - complex due to evolving standards and AI opacity
- **Ethical concerns**
  - over-reliance on automation and patient data privacy

Conclusion

- AI-enhanced XR offers immersive, personalized medical training and planning
- Use cases like placenta accreta and neurovascular simulation show real clinical impact
- Emerging methods (e.g., diffusion models, ViTs) will boost realism and adaptability
- Future XR systems will be more intelligent, explainable, and clinically integrated

Safer, more effective care through human-AI collaboration in immersive environments.

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