

Extended Reality for Congenital Heart Defect Education

Written by The Life Science Feed Editorial Team · Published 1 December 2025 · Edited by William Lopes

Complex anatomy and physiology make congenital heart defects (CHDs) difficult to grasp from traditional textbooks or 2D imaging. This presents significant barriers for trainees and families. Extended reality (XR) – encompassing virtual, augmented, and mixed reality – aims to bridge this gap, enhancing understanding and potentially improving patient care.

KEY TAKEAWAYS

- ° lightbulb
- ° The Pivot: XR moves beyond passive learning in CHD, creating interactive educational experiences for families and enhanced surgical planning tools for clinicians.
- ° The Data: Studies show improved spatial understanding of cardiac anatomy and increased confidence in procedural planning when using XR technologies.
- ° The Action: Hospitals should investigate integrating XR modules into cardiology training programs and patient consultation workflows to enhance understanding and communication.

Extended reality (XR) offers a spectrum of technologies redefining how medical professionals interact with information. Virtual reality (VR) provides fully digital environments for immersive training, allowing trainee surgeons to practice complex cardiac surgery without patient risk. Mastery is the goal. Augmented reality (AR) overlays digital data onto the real world; a cardiologist could visualize blood flow directly on a patient's heart during a consultation. Clarity for patients. Mixed reality (MR) blends both physical and digital, enabling real-time interaction. The question remains which applications prove most effective.

But major cardiology guidelines, including those from the American Heart Association (AHA) and European Society of Cardiology (ESC), do not yet explicitly address XR in CHD management. These guidelines prioritize accurate diagnosis, thorough patient education, and skilled surgical intervention. XR tools can indirectly support these goals, by boosting anatomical understanding, improving clinician-family communication, and enhancing surgical planning. A powerful tool for teams. The 2020 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease, for instance, stresses a multidisciplinary heart team approach; XR aids collaboration and visualization of complex cases. Still, direct recommendations are absent. More research must establish XR's clinical utility and cost-effectiveness. Finding its best role in existing workflows remains crucial.

XR's clinical applications in CHD are extensive. VR simulations give trainees hands-on experience with rare, complex cases, accelerating their learning curve and improving surgical skills. This is crucial in pediatric cardiology. AR and MR

can transform abstract medical jargon for families into understandable visualizations. Parents can literally see their child's heart defect and grasp the planned intervention. This improved understanding reduces anxiety and boosts adherence to treatment.

Surgeons also use XR for precise procedure planning, minimizing risks and improving outcomes. Greater precision matters. Congenital heart defects affect approximately 1% of live births, a significant global health burden. XR offers a novel approach to visualizing complex 3D cardiac anatomy and explaining intricate surgical repairs. A VR model lets a trainee virtually "dissect" a tetralogy of Fallot, understanding its spatial relationships in a way 2D images cannot convey. Complex anatomy becomes clear. An AR application could project a patient's specific cardiac CT scan onto a physical mannequin, enabling a surgeon to practice the exact incision and repair strategy for that individual case. Personalized practice.

The catch: XR in CHD faces significant limitations despite its promise. Hardware and software costs remain a barrier to widespread adoption, especially in resource-limited settings. Price is a problem. Lack of standardized protocols and validated outcome measures also makes comparing different XR applications difficult. Many studies are small and lack rigorous controls. Definitive conclusions are elusive. Is the improvement statistically significant? Is it reproducible? Who funds this in an already burdened system?

Potential motion sickness or discomfort presents another significant limitation for some users, particularly with VR. Simulation fidelity varies, meaning inaccuracies in anatomical models or physiological responses could lead to misinterpretations or suboptimal training. Data security and patient privacy concerns also arise when handling sensitive patient-specific imaging data within XR environments. Integrating XR tools into existing clinical workflows requires significant infrastructure investment and staff training. This proves a substantial hurdle for healthcare systems.

The biggest question remains whether these technological advances can translate into widespread, cost-effective clinical adoption that truly improves patient outcomes.

Readers interested in the established clinical context of cardiology, relevant to new technological adoptions, are encouraged to consult the Oxford Handbook of Cardiology.

CLINICAL IMPLICATIONS

Integrating XR into CHD care demands a major shift in hospital workflows. Clinicians will need effective training. IT departments face significant infrastructure and support demands. This is no small undertaking. Reimbursement models for XR-assisted procedures are currently lacking. This creates a financial disincentive for adoption. Hospitals must demonstrate XR's value. They need to advocate for appropriate reimbursement codes.

Data privacy and security also present complex issues. XR applications often collect and store sensitive patient information. Clear guidance on these aspects is currently absent. That complicates widespread deployment.

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