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Meta-CathLab: A Paradigm Shift in Interventional Cardiology Within the Metaverse

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Meta-CathLab is an innovative concept merging interventional cardiology with the metaverse, offering transformative possibilities in the field. By leveraging virtual reality technology, it provides unique training experiences for interventionalists, improves procedural efficiency, and enables real-time collaboration among experts globally. Challenges include upgrading catheterisation laboratories, securing patient data, and addressing ethical considerations. In the face of rapidly advancing medical technologies, Meta-CathLab has immense potential to redefine interventional cardiology, revolutionise procedures, and enhance cardiovascular care standards.

The landscape of interventional cardiology has made remarkable strides over the years, fuelled by rapid technologic progress and innovative breakthroughs. As the quest for improved health care, enhanced procedural precision, and advanced medical training continues, emerging technologies offer new avenues for exploration.[1] The horizon of possibilities extends even further with the advent of the metaverse, characterised by its multidimensional nature and seamless digital interactions, that has found applications in diverse domains, including medicine. In this realm of possibilities, the concept of Meta-CathLab emerges as a visionary integration, uniting interventional cardiology with the virtual world to create the future catheterisation laboratory based on augmented and virtual reality (AR/VR). In this article, we delve into the definition of Meta-CathLab and explore its key components, highlighting the advantages and underlining the challenges ahead.

Meta-CathLab Concept and Its Components

The futuristic Meta-CathLab concept refers to the integration of interventional cardiology with the metaverse, creating an immersive catheterisation laboratory where health professionals can conduct procedures and collaborate remotely via the use of AR/VR.[2] Meta-CathLab envisions a virtual catheterisation laboratory within the metaverse, where medical professionals can immerse themselves in an interactive and dynamic VR space. This concept transcends traditional catheterisation laboratories, providing a platform for enhanced training, procedural planning, global collaboration, and improved access to cardiovascular care. In addition to the core technology of angiographic imaging, wires, catheters, and balloon interventions, the Meta-CathLab should include several new technologies (Fig. 1).

Voice assistance control and voice-powered virtual assistants are key components that enable interventionalists to interact with the virtual catheterisation laboratory with voice commands. This feature reduces the need for manual input, streamlines workflow, and enhances the efficiency of procedures. Moreover, high-speed 5G cellular internet is essential for Meta-CathLab, as seamless and high-speed internet connectivity is required for real-time collaboration and data exchange between remote locations. The ability to access and share information instantaneously facilitates global collaboration and enhances patient care.

In addition, haptic feedback devices represent a significant advancement in virtual reality technology. These devices aim

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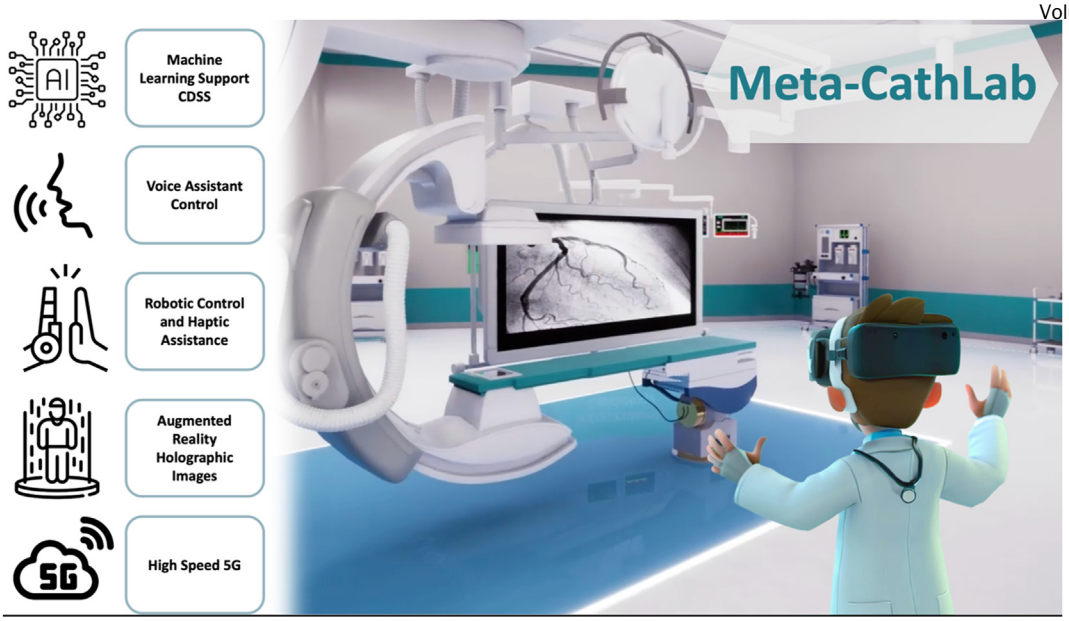

Figure 1. The Meta-CathLab and its key components. CDSS, clinical decision support system.

to replicate tactile sensations, allowing interventionalists to experience the sensation of handling instruments in a virtual environment. This tactile feedback is crucial in interventional cardiology, where the sense of touch plays a vital role in making precise and delicate manoeuvres during procedures.

Real-time imaging and AR-supporting systems with free-floating 3-dimensional holographic images can offer interventionalists a more dynamic and interactive approach to procedural planning and execution. Real-time imaging allows for instant visualisation and assessment of patient anatomy, and AR overlays provide additional information and guidance during procedures.

Remote robotic control and telemedicine integration enable remote assistance and training capabilities in Meta-CathLab. Interventionalists can perform procedures without being physically all the time inside the catheterisation room as well as seek guidance and support from experts in more advanced medical centres, improving access to high-quality care in remote or underserved areas.

In an era in which artificial intelligence and large language models thrive, machine-learning support and clinical decision support systems can provide personalised recommendations and real-time insights during procedures.[3] By leveraging machine-learning algorithms, Meta-CathLab can assist interventionalists in making informed decisions, optimising procedural precision, and improving patient care.

Meta-CathLab Benefits

Meta-CathLab offers numerous advantages that have the potential to transform interventional cardiology (Fig. 2). One of its major benefits is pre-procedural planning. Through virtual exploration of patient anatomy, interventionalists can optimise procedural efficiency and precision. This goes beyond what traditional cardiac computed tomographic angiography (CTA) can offer, because Meta-CathLab allows for real-time collaboration among interventionalists from around the world. This facilitates comprehensive treatment strategies, drawing on a wealth of collective expertise. The ability to access remote assistance and training capabilities further improves access to high-quality care and expands educational opportunities for medical professionals worldwide.

Global collaboration is a hallmark of Meta-CathLab. Medical professionals can connect virtually and consult on complex cases, sharing insights, experiences, and knowledge. This enables a more informed and multidisciplinary approach to patient care, regardless of geographic locations.[4] Furthermore, the integration of cutting-edge technologies such as voice assistance control and haptic feedback devices streamlines workflow enhances procedural efficiency and reduces the learning curve for trainees.

Training in the Meta-CathLab as an Immersive Simulation Environment

One of Meta-CathLab's key benefits is providing interventionalists with a unique and immersive training experience. VR training allows trainees to immerse themselves in realistic simulations, enabling them to practice complex procedures repeatedly while ensuring patient safety. This training environment enhances technical skills, decision-making abilities, and overall competence, ultimately leading to improved patient outcomes. Efficient training has always been the cornerstone of interventional cardiology, and exploring new ways to enhance and ameliorate the way interventionalists train is a priority (Fig. 2).

One of the key weaknesses to address is the tactile feedback that interventionalists learn in the traditional catheterisation laboratory. Interventional cardiology relies not only on what is seen but also on what is felt at the fingertips. Newer VR technologies and haptic feedback devices are starting to implement variable haptic and vibration feedback to create tactile feel, but it may take some time to reproduce the exact sensation of handling a coronary wire.

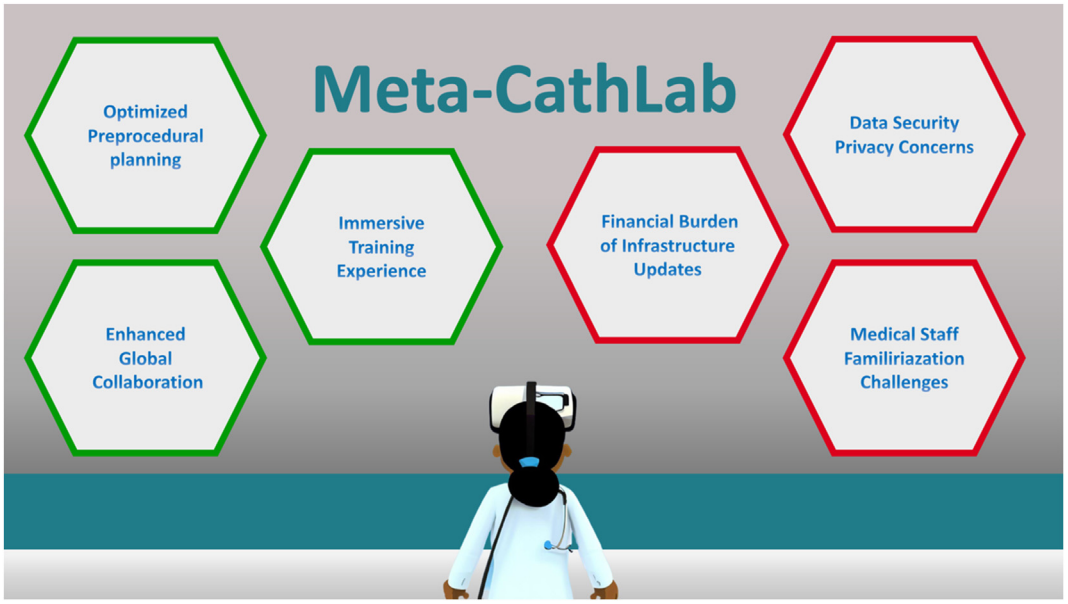

Figure 2. Benefits and challenges of the implementation of Meta-CathLab.

The Meta-CathLab must incorporate various tactile and haptic technologies to overcome this limitation. These technologies should aim to simulate real technical troubleshooting scenarios, such as difficult stent delivery, difficult wire crossing, balloon expansion, and managing complications. By incorporating such challenges into the virtual training environment, fellows, students, and interventionists can enhance their skills and confidence in handling complex cases.

Addressing the Challenges

Despite its potential, the implementation of Meta-CathLab comes with several challenges and limitations. One significant hurdle is the need to upgrade existing catheterisation laboratories with state-of-the-art AR displays and advanced simulations to seamlessly integrate the new technology. This process demands substantial funding and the establishment of cutting-edge technologic infrastructure, with continuous updates and maintenance necessary to ensure the successful implementation and long-term sustainability of Meta-CathLab. A first and crucial step, however, would be to progressively implement AR/VR supporting devices instead of completely upgrading and changing the existing infrastructure (Fig. 2).

Data security emerges as a critical concern within this interconnected environment. Patient information must be protected, secured, and anonymised to maintain confidentiality and comply with health care regulations. Robust data security measures are imperative to safeguard patient privacy and prevent unauthorized access. Ethical considerations, such as obtaining patient consent and addressing liability concerns, require thorough examination to ensure the responsible implementation and practice of Meta-CathLab.

In addition, the transition to this heavily technology-based catheterisation laboratory poses a challenge for medical staff. They need to undergo comprehensive training and familiarisation with the new tools and interfaces to use them effectively. Adequate support and training programs must be in place to ensure a smooth and successful integration of Meta-CathLab into the medical practice. Overcoming these challenges will be crucial to unlocking the full potential of Meta-CathLab and reaping its benefits in advancing interventional cardiology and patient care.[5]

Conclusion

Meta-CathLab represents a futuristic concept that leverages AR/VR technology and the metaverse to transform interventional cardiology and the conventional catheterisation laboratory. With its unique advantages in training, procedural planning, global collaboration, accessibility, and technologic advancements, Meta-CathLab has the potential to revolutionise the field of interventional cardiology. However, as with any emerging technology, there are challenges to address, including upgrading catheterisation laboratories, ensuring data security, and addressing ethical considerations. Despite these challenges, the future integration of the metaverse in interventional cardiology holds immense promise for enhancing patient care and redefining the standard of cardiovascular interventions. As technology continues to evolve, Meta-CathLab is poised to play a pivotal role in shaping the future of interventional cardiology and advancing the frontiers of medical practice and training.

Ethics Statement

This report complies with ethical standards and de-identifies personal information to maintain confidentiality.

Patient Consent

The authors confirm that patient consent is not applicable to this article.

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Disclosures

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