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EDITORIAL

Personalized Medicine and Future of Surgical Planning: Metaverse, Virtual Surgeries & Surgical Planning with the Use of Digital Twinning

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Surgical planning is one of the most promising areas where Digital Twins (DTs), the metaverse, virtual surgeries, and personalized medicine and surgery intersect to revolutionize patient care. These technologies enable more precise, efficient, and safer surgical procedures while also allowing for personalized treatment tailored to each patient's specific needs. These concepts are applied in surgical planning and the execution as follows:

Digital Twinning in Surgical Planning

A Digital Twin is a virtual representation of a patient's anatomy, created using data from various sources such as medical imaging (CT scans, MRIs), genetic information, and real-time monitoring through sensors or wearables. This digital model allows surgeons to simulate and plan surgeries with incredible precision before making any incision. Key aspects include:

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- *Personalized Anatomy Models:* By creating a detailed, patient-specific Digital Twin, surgeons can have an accurate 3D model of the patient's organs, tissues, and bone structure. This allows them to study the specific anatomical features of the patient in detail, identifying potential challenges or abnormalities that may not be visible on standard imaging.
- *Pre-Surgical Simulation:* Surgeons can virtually rehearse the procedure in a simulated environment, testing various approaches and strategies. This reduces the likelihood of unexpected complications during actual surgery and increases the overall success rate.
- *Predictive Analytics:* The Digital Twin can be used to predict the outcomes of various surgical approaches, helping to select the most effective treatment strategy. For example, it can simulate how tissues will respond to different surgical techniques or post-operative care, optimizing the recovery process.

The Metaverse in Surgical Planning and Training

The metaverse—a shared, immersive, virtual environment where people can interact with digital twins and other virtual representations—can significantly enhance surgical planning and training.

- *Immersive Surgical Simulations*: Surgeons can use the metaverse to enter an immersive environment where they interact with the Digital Twin of a patient. This allows them to visualize the anatomy from different angles, practice the surgery multiple times, and experiment with different techniques in a risk-free virtual setting. For complex surgeries, like brain or heart surgery, this has becomes invaluable for honing skills and understanding the nuances of individual cases.
- *Collaborative Surgery Planning:* The metaverse can connect surgeons from around the world in a collaborative, virtual space. Surgeons can discuss surgical approaches, share insights, and participate in joint decision-making, all while interacting with the Digital Twin of the patient. This enhances the exchange of expertise, especially for rare or complex conditions.
- *Patient Education and Involvement:* Patients can also enter the metaverse to interact with their own Digital Twin. By visualizing their surgery and recovery process in 3D, they can better understand the procedure, ask questions, and feel more involved in their care decisions. This enhances patient satisfaction and engagement in the treatment process.

Virtual Surgeries & informed decision-making during surgery

Virtual surgeries are becoming a powerful tool for both pre-surgical planning and real-time surgical support.

- *Virtual Reality (VR) Surgery Practice:* Surgeons can practice and refine their skills using VR platforms that replicate real-world surgical environments. These virtual surgeries allow surgeons to rehearse techniques, familiarize themselves with the anatomy, and optimize their approach before performing the actual surgery.
- *Real-Time Guidance during Surgery:* During actual surgery, the surgeon can access real-time data from the patient's Digital Twin. For example, augmented reality (AR) overlays can be used during the procedure, showing critical information such as the location of blood vessels or tumors that may not be immediately visible. This provides enhanced precision and supports more informed decision-making during the surgery.
- *Robotic-Assisted Surgery:* Virtual surgery technology is closely tied to robotic surgery systems. Surgeons can control robotic instruments through virtual interfaces, allowing for highly precise and minimally invasive procedures. Robotic systems can integrate data from Digital Twins to adjust the operation based on real-time feedback, ensuring optimal outcomes.

Personalized Medicine and Surgery

Personalized medicine relies on genetic, molecular, and clinical data to create more effective treatments with fewer side effects. This refers to tailoring medical treatments to the individual characteristics

of each patient. In surgery, this concept extends to personalized surgical planning:

- *Tailored Surgical Approaches:* Each patient's unique anatomy, medical history, and genetic predispositions can affect how they respond to surgery. Surgeons can customize the surgical approach using a Digital Twin based on the patient's specific needs, such as considering potential complications, surgical risks, or recovery trajectories. For example, a surgeon might select a less invasive technique for a patient with a specific genetic marker that indicates a higher risk for scarring or tissue damage.
- *Optimized Recovery Plans:* Digital Twins can continue tracking a patient's recovery after surgery, providing personalized post-operative care recommendations. By simulating how a patient's body is healing and adjusting based on real-time data, healthcare providers can optimize recovery plans to prevent complications such as infections, blood clots, or improper healing.
- *Genomic Data Integration:* Personalized medicine in surgery can also extend to the use of genomic data. For example, specific gene mutations can influence how a patient responds to anesthesia, heals after surgery, or recovers from certain treatments. This data can be integrated into the Digital Twin to create a comprehensive, predictive model that informs surgical strategies.

Future Outlook: Advanced Applications and Integration

While these technologies are still developing, the future of surgical planning holds immense potential:

- *Predictive Surgery:* With further advancements in AI and data analytics, Digital Twins will be able to not only simulate surgeries but predict outcomes in real-time, adjusting for changes in the patient's condition, treatment response, and recovery progress.
- *Integrating Multi-Disciplinary Expertise:* Digital Twins and the metaverse could integrate input from various specialties—such as cardiology, neurology, and oncology—into a unified surgical plan, ensuring comprehensive and highly specialized care for complex conditions.
- *Personalized Implants and Devices:* For some surgeries, especially orthopedic or reconstructive procedures, Digital Twins can help design custom implants or devices tailored to a patient's anatomy specifications. This ensures a better fit and faster recovery.

Thus, the integration of Digital Twins, the metaverse, virtual surgeries, and personalized medicine is transforming the landscape of surgical planning and execution. By providing surgeons with detailed, patient-specific models, enhancing surgical training, and enabling real-time decision support during procedures, these technologies are setting the stage for more precise, effective, and personalized surgical interventions. As these innovations continue to evolve, the future of surgery holds the promise of even more refined, data-driven, and patient-centered care.