
بسم الله الرحمن الرحیم

The role of digital twins in Anesthesiology & Critical Care

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SBMU

COI: None

The Economist

THE WORLD AHEAD 2027

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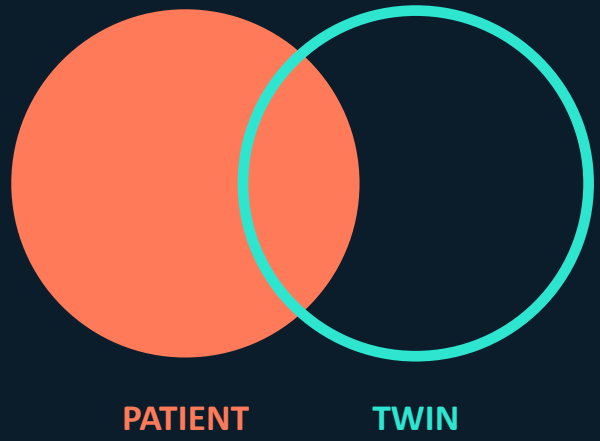
What if your patient had a twin who already had the surgery?



What is the PROBLEM?

We fly the patient through surgery with partial instruments

Blind

Deep physiology hides behind a handful of numbers on the monitor.

Fast

Hemodynamics shift in seconds; good decisions need minutes of foresight.

Once

No rehearsal: we cannot test a plan on the patient before acting.

Digital twins promise one thing: a rehearsal space.

What Is a Digital Twin?

A digital twin is

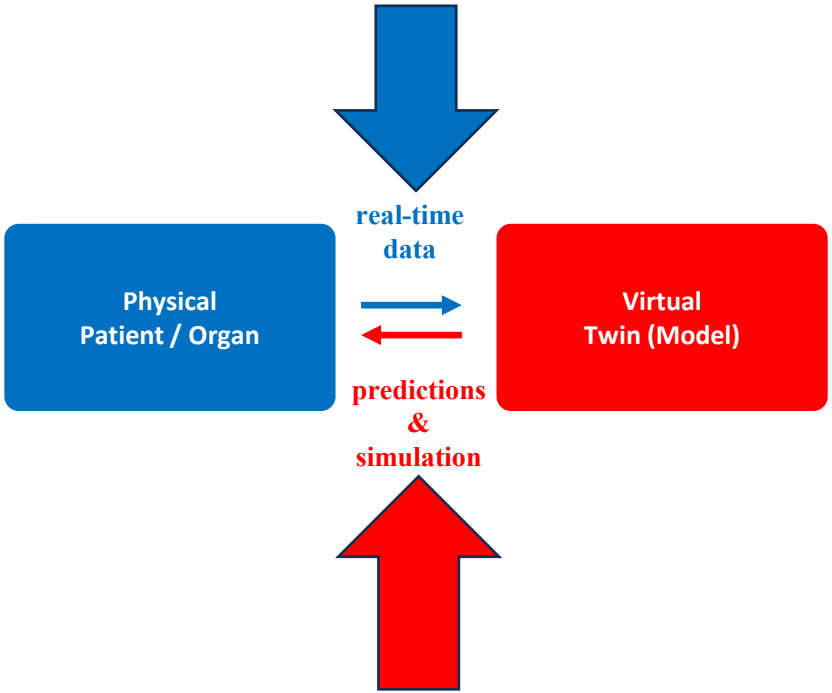
- a set of **virtual information constructs** that mimics the structure, context, and behavior of a natural, engineered, or social system (or system-of-systems)
- is **dynamically updated** with data from its physical twin
- has a **predictive** capability
- and **informs decisions** that realize value.
- The **bidirectional interaction** between the virtual and the physical is central to the digital twin.

What Is a Digital Twin?

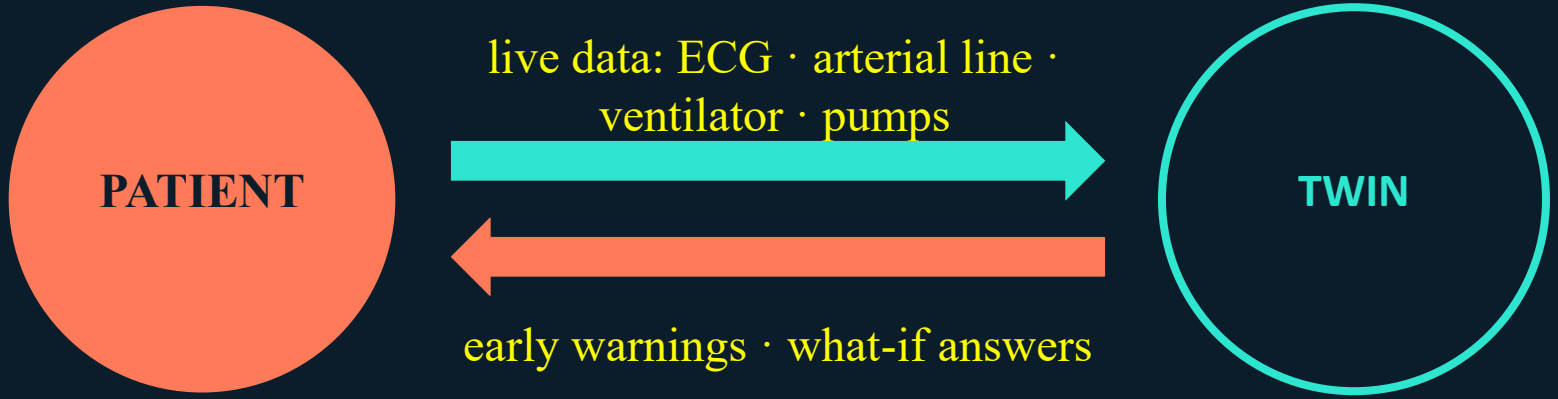
Summary:

A living, continuously updated virtual replica of a physical object, process, or system linked to its real counterpart by a constant, two-way flow of data.

The concept was born decades ago in aerospace and manufacturing; NASA's paired spacecraft models, later formalized by GE and Siemens as part of Industry 4.0; long before it reached the bedside.



Anesthesiology View
A digital twin is a living model of one specific patient



Not a dashboard | **Not a static risk score** | **Not a black-box chatbot**

Patient-specific · continuously updated · able to simulate the future

From Factory Floors to the Human Body

1960s–70s

NASA pairs physical spacecraft with a ground-based replica during the Apollo program: the **conceptual** root of the digital twin

2000s

"Digital twin" formalized in manufacturing and aerospace (GE, Siemens) as part of Industry 4.0

2014

The Living Heart Project launches: the first multi-scale virtual twin of the human heart

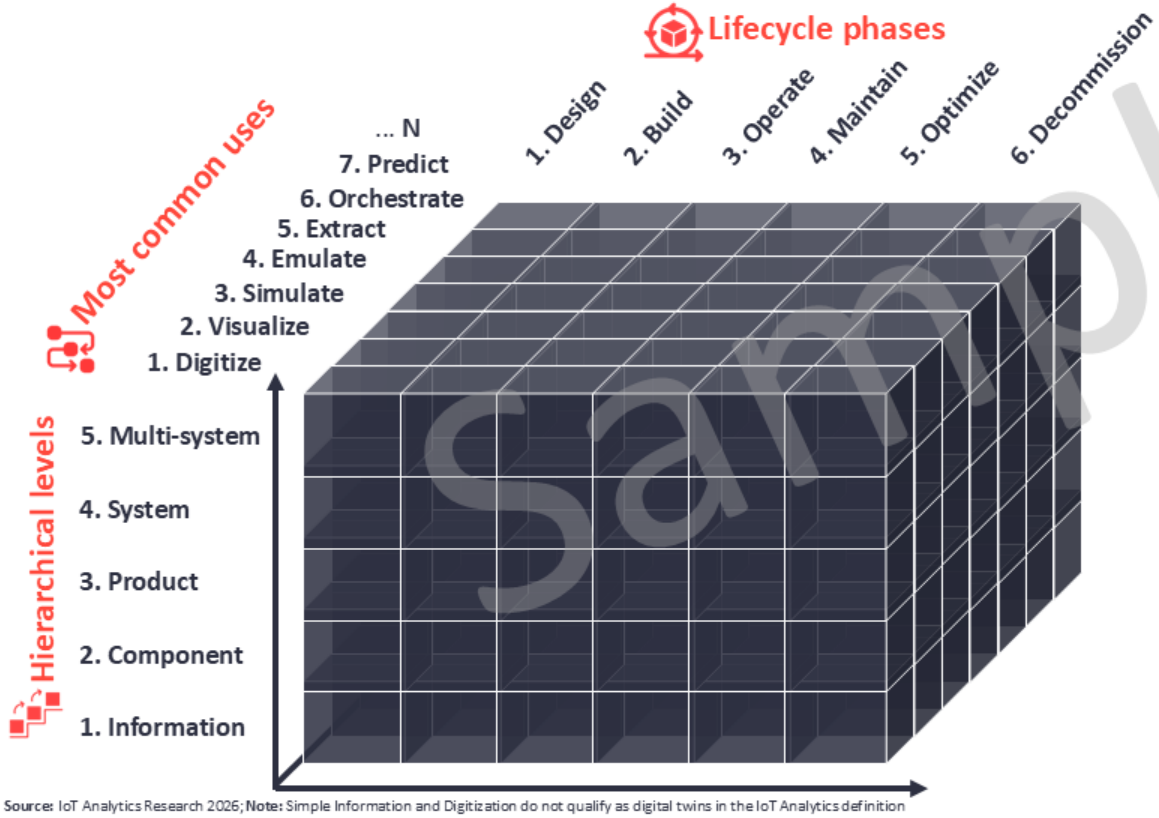
2020s

Digital twins reach cardiology, critical care, anesthesiology, oncology, mental health, and hospital operations

Source: https://iot-analytics.com

Digital twin classification (1/5)

IoT Analytics classifies digital twins based on 3 key dimensions: 1) lifecycle phases, 2) hierarchical levels, and 3) usage.



Sample

Explanation

- There are **3 main dimensions** describing the concept of digital twins
- **Each axis** of the cuboid represents **one dimension** of the digital twin:
  - The **X-axis** represents the 6 **lifecycle phases** from design to decommissioning.
  - The **Y-axis** represents the 5 **hierarchical levels** from information to multi-system.
  - The **Z-axis** represents the 7 **most common uses**.
- Each combination of these 3 dimensions results in a **different digital twin classification**—210 different combinations are possible in total.

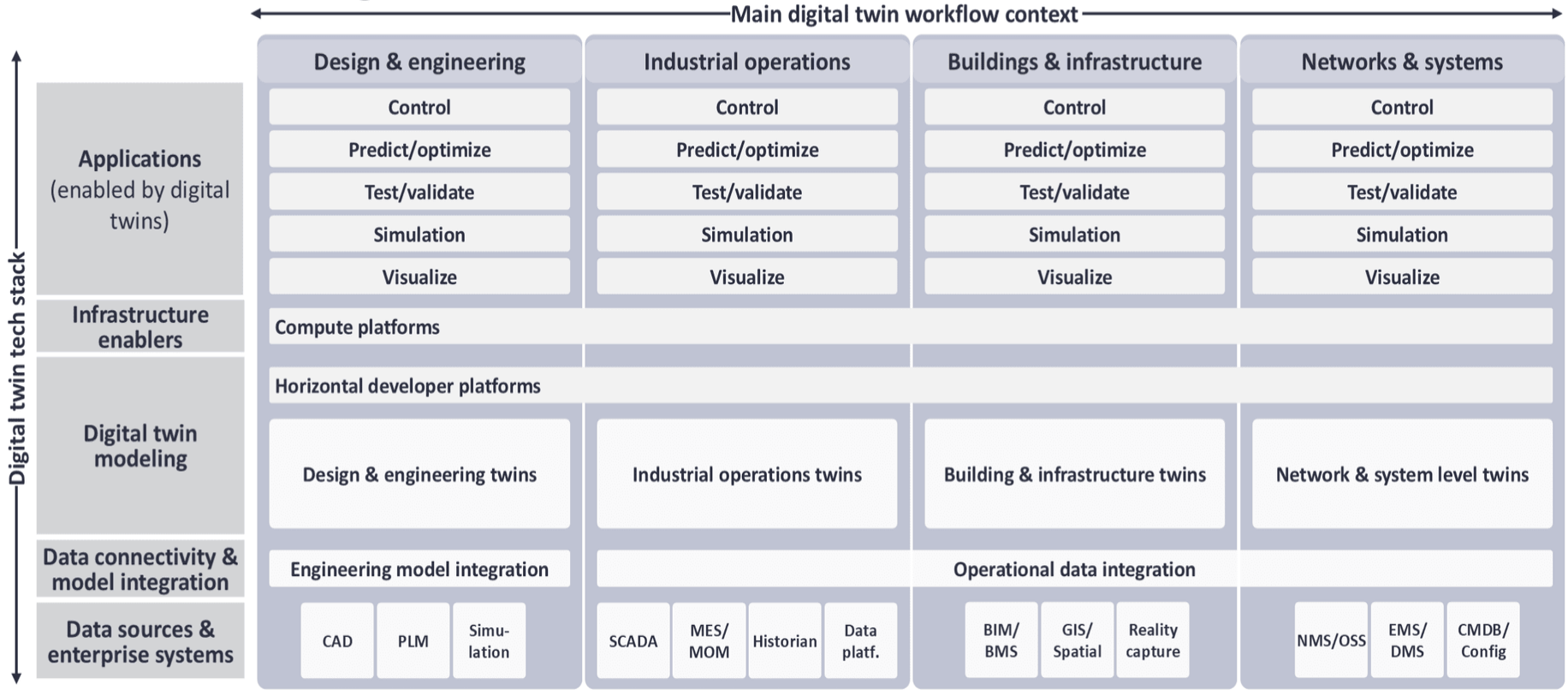
Note: For simplicity, the cuboid model does not consider different input data types

Source: IoT Analytics Research 2026; **Note:** Simple Information and Digitization do not qualify as digital twins in the IoT Analytics definition

IOT ANALYTICS

Source: https://iot-analytics.com

The end-to-end digital twin stack

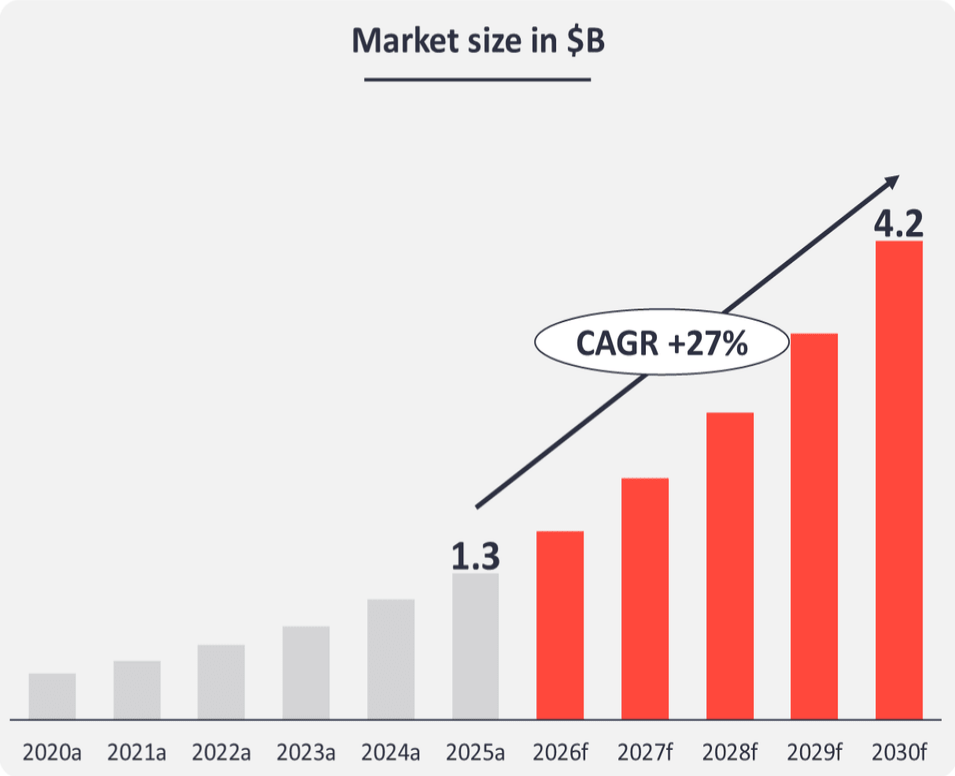


Note: *A large share of well-known "digital twin" suppliers are excluded from the narrow digital twin market because their offer is fundamentally simulation software, CAD/PLM, IIoT, or a broad portfolio layer rather than a standalone digital twin product sold on its own.
Source: IoT Analytics Research 2026–Digital Twin & Simulation Software Market Report 2026–2030. We welcome republishing but ask for citation with link to original post and company website.

IOT ANALYTICS

Source: https://iot-analytics.com

Global standalone digital twin software market 2025–2030

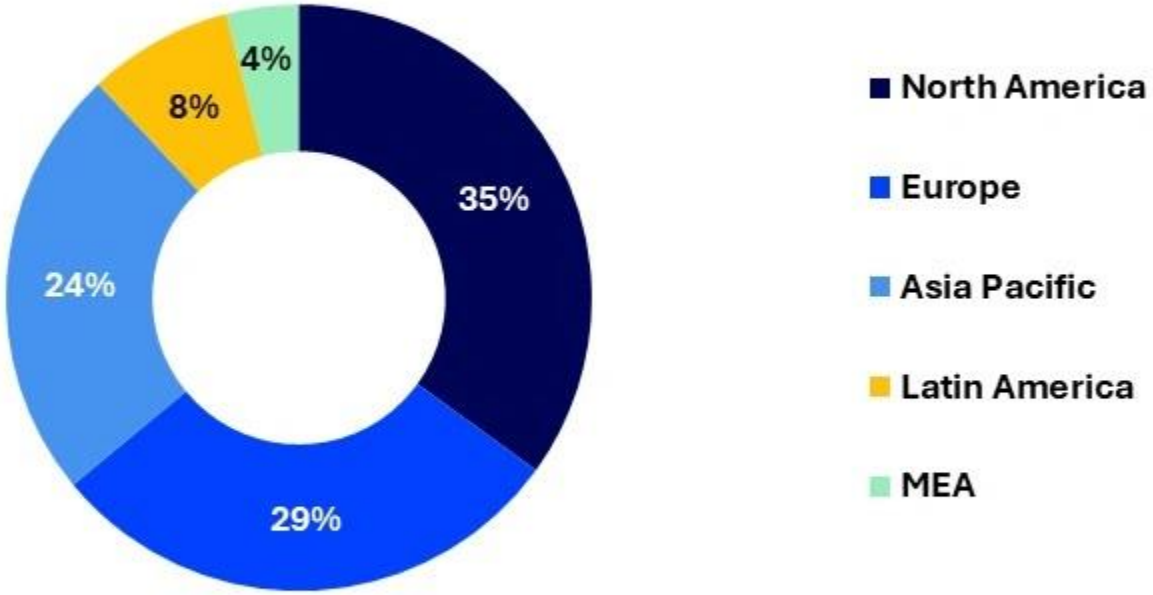


Key market players

Microsoft, aws, NVIDIA, ALTAIR, DASSAULT SYSTEMES, cadence, Honeywell, EMERSON, Ansys, aspentech, Bentley, SIEMENS, GE VERNOVA, ScaleOut Software, DataMesh, NEMETSCHEK GROUP, AKSELOS, neara, IP FABRIC, FORWARD, DNV, KBC, AUTODESK, Falkor, etap, EATON

Source: IoT Analytics Research 2026–Digital Twin & Simulation Software Market Report 2026–2030. We welcome republishing but ask for citation with link to original post and company website.

Digital Twin As-a-Service Market Share, By Region, 2024 (%)



The North America region is leading digital twin as-a-service market, accounting for a significant share of 35% in 2024. Asia Pacific region is projected to grow at the significant CAGR during the forecast period.

Source: https://www.precedenceresearch.com/digital-twins-as-a-service-market

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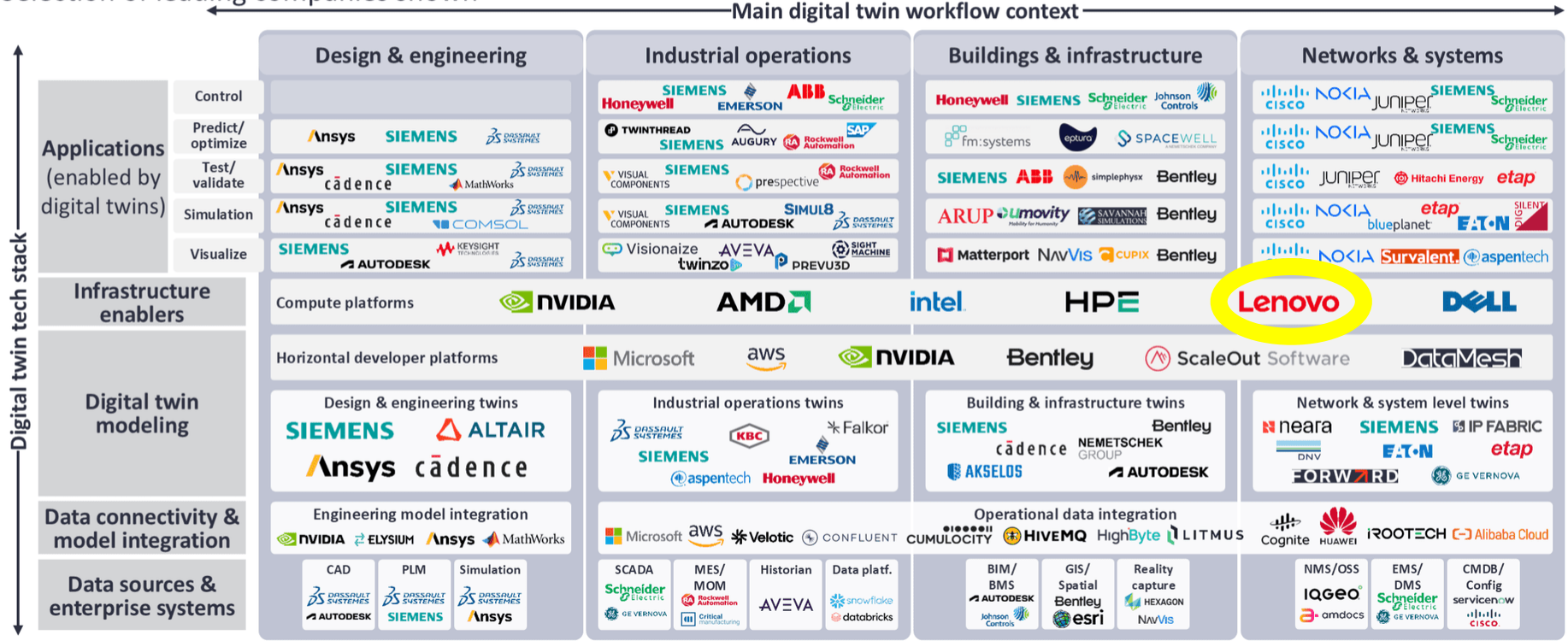
Source: https://iot-analytics.com

Competitive digital twin landscape 2026

Selection of leading companies shown



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Forbes

INNOVATION > AI

FIFA Turned Every World Cup Player Into A Digital Twin

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FIFA Turned Every World Cup Player Into A Digital Twin

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Digital twins create the highest value when decisions are costly, interdependent, and simulation can move risk earlier

	Aspects that increase the value of digital twins	Description	Example
Urgency to employ a DT	**High cost of error**	Mistakes are expensive, unsafe, or slow to reverse.	**Rolls-Royce** uses digital twins to predict engine failures, optimizing maintenance to prevent **costly operational disruptions** and testing delays.
	High pressure to shorten timelines	Market, customers or technology shifts force faster design, build, or ramp-up.	**BMW** uses digital twins to **shorten production setup from weeks to days**, meeting intense pressure to launch forty new vehicles.
Digital twin fit	**High simulation leverage**	Virtual testing can reduce physical prototypes, trials, commissioning risk, or late-stage rework.	**Wipro** PARI uses digital twins for virtual commissioning of assembly lines, simulating automation software to **slash on-site physical trials and cut rework by 40% to 50%.**
	High system interdependence	Mechanical, electrical, thermal, software, spatial, and operational systems interact.	**The Shard** uses BIM digital twins to coordinate complex structural, spatial, and MEP (mechanical, electrical, plumbing) systems, enabling real-time clash detection to resolve cross-system conflicts.
	High data availability	Relevant domain data (CAD, BIM, PLM, EDA, IoT, scans, test, sensors) is accessible.	**Thames Water** combines smart meters, acoustic loggers, and GIS data into a digital twin, **ensuring high data availability** to pinpoint leaks and save one million liters daily.
	High repeatability	The same or a similar twin workflow can be reused across products, projects, or sites.	**BMW** reuses its dip-tank validation workflow to **repeat vehicle feasibility checks** across new models and global plants.

Source: IoT Analytics Research 2026–Digital Twin & Simulation Software Market Report 2026–2030. We welcome republishing but ask for citation with link to original post and company website.

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- Per Executive Order 14434, federal agencies are now using "Super Intelligence" (SI) in place of "Artificial Intelligence" (AI). You may see both terms across NIH content during this transition.

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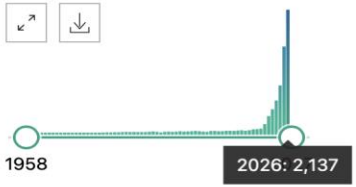

PUBLICATION DATE

1 year

6,330 results

Page 1 of 633

1 Cite

Advancing the Alzheimer's disease research and care pipeline with agentic artificial intelligence: Opportunities, challenges, and priorities from the international clinical trials on Alzheimer's disease (CTAD) task force.

Rouch L, Middleton L, Aisen P, Weiner M, Kourtzi Z, Pinheiro-Chagas P, Nosheny R, Possin K, Vellas B, Bose N, Andrieu S; CTAD Task Force members.

J Prev Alzheimers Dis. 2026 Nov 16:100678. doi: 10.1016/j.tjpad.2026.100678. Online ahead of print.

PMID: 43039790 Free article.

Complementary initiatives are creating **digital** wet labs for in silico experimentation. At the same time, agentic AI is increasingly being used to address pre-discovery bottlenecks by automating data harmonization and inferring missing information through **digital** ...

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- Get the Latest Updates and FAQs on the transition
- Per Executive Order 14434, federal agencies are now using "Super Intelligence" (SI) in place of "Artificial Intelligence" (AI). You may see both terms across NIH content during this transition.

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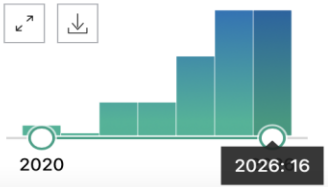

PUBLICATION DATE

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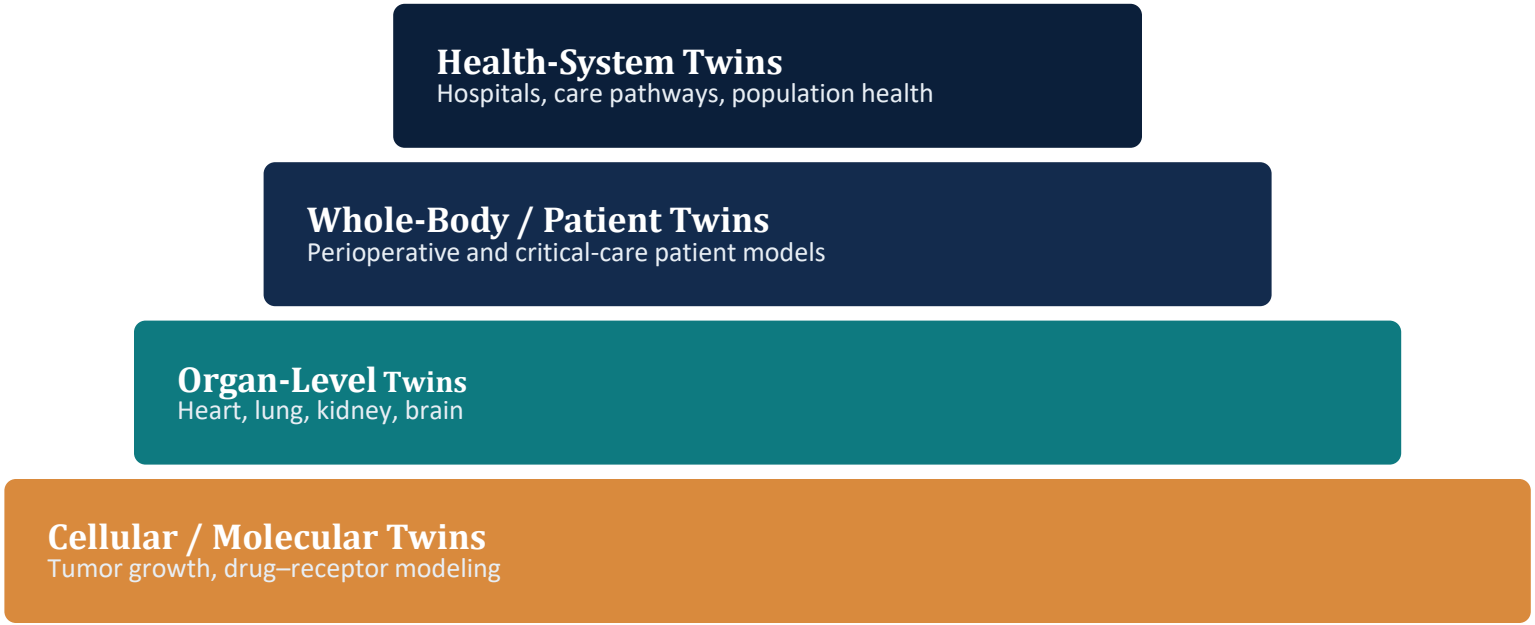
Single-cell-level digital twins for preterm birth prevention strategies.

Einhaus J, Neidlinger P, Fondeur O, Sato M, Anronikov S, Miyazaki K, Maechler A, Amar JN, Ando K, Badea V, Gaudilliere DK, Sabayev M, Feyaerts D, Diop M, Tsai AS, Cambriel A, Ganio EA, Lagarde R, O'Kelly E, Stelzer IA, Hedou J, Wong RJ, Blumenfeld YJ, Lyell DJ, Shaw GM, Oskotsky TT, Sirota M, Giudice LC, Stevenson DK, Aghaeepour N, Gaudilliere B.

Sci Adv. 2026 Oct 23;12(43):eaed2741. doi: 10.1126/sciadv.aed2741. Epub 2026 Oct 21.
PMID: 42905824 Free PMC article.

Digital twin models can accelerate therapeutic development by enabling low-risk testing of candidate interventions. ...We present Simulated Immunome Modeling of Clinical Outcomes (SIMCO), a single-cell-level **digital twin** framework that models immunomed

Digital Twins Across Scales of Medicine



A single patient can be represented at several of these scales simultaneously;

and the models can talk to one another!!!!!!!!!!!!

medicine.stanford.edu

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The future begins now

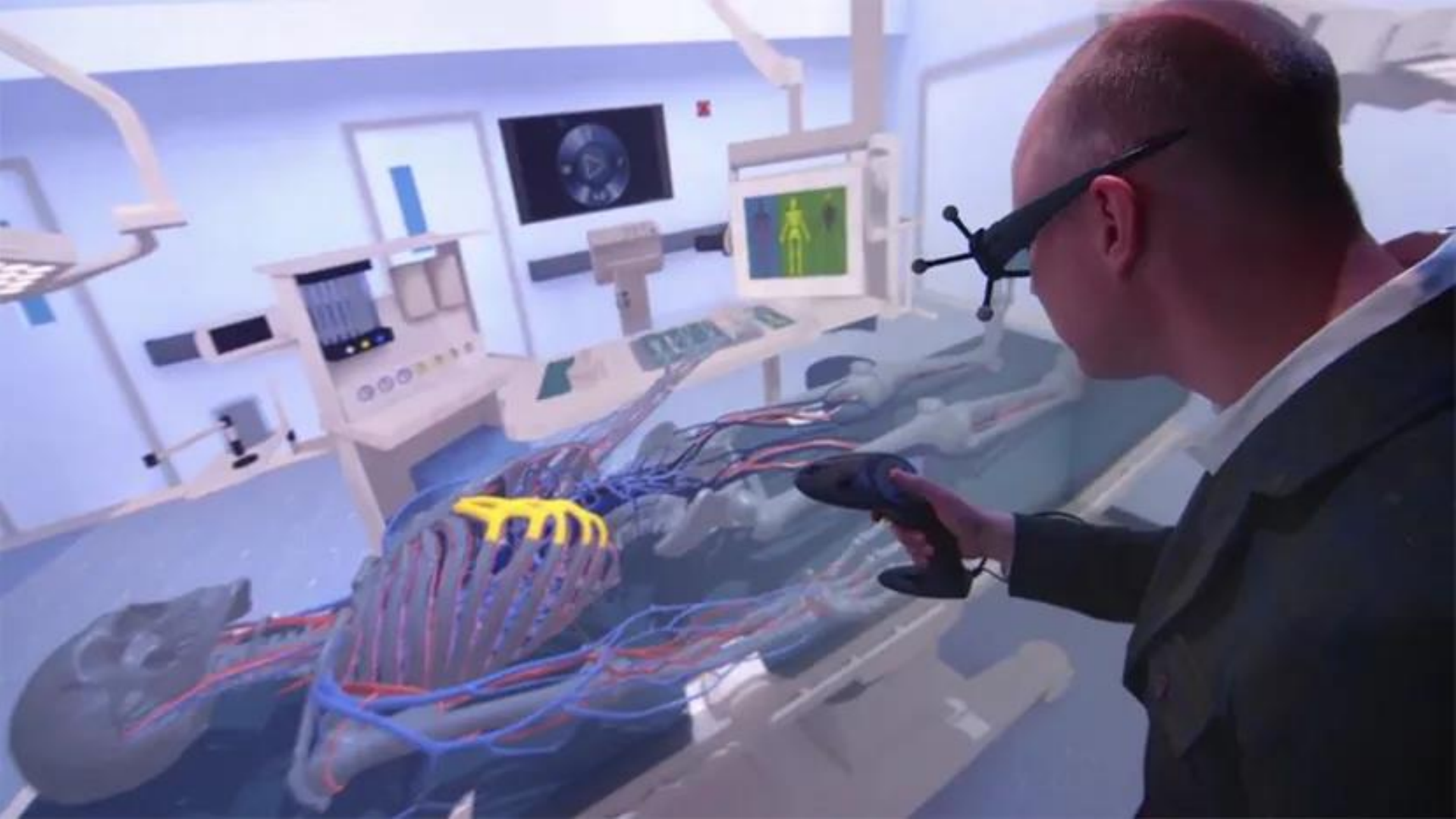
The Virtual You: How Medical Digital Twins are Revolutionizing Healthcare



By Rebecca Handler

Explore how medical digital twins - AI-powered virtual patient models - are transforming healthcare with personalized care, prediction, and prevention.


THE VIRTUAL YOU
How Medical Digital Twins
Are Revolutionizing Healthcare



The Living Heart Project

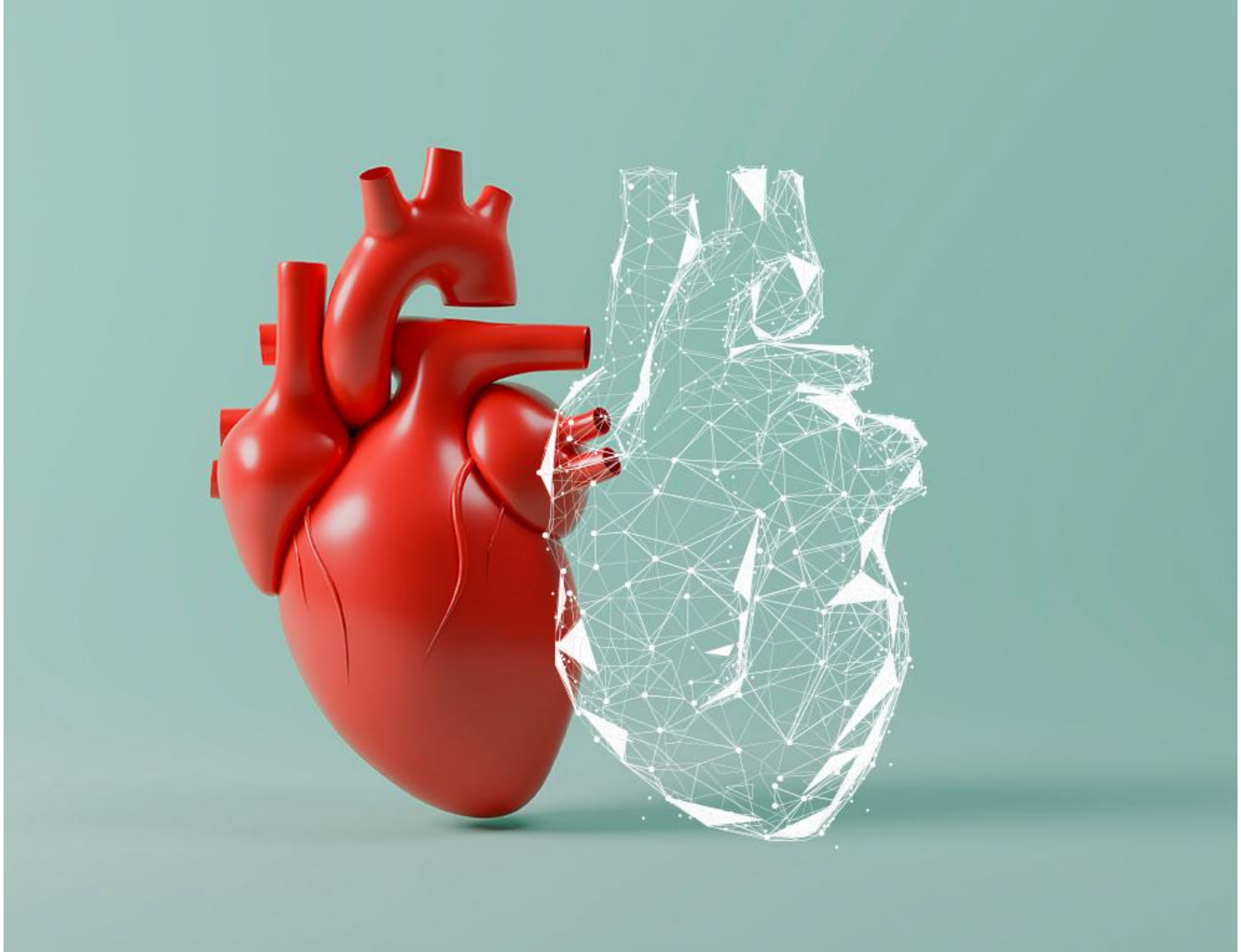
Launched in 2014 by Dassault Systèmes, the Living Heart Project built the first multi-scale virtual twin of the human heart; modeling electrical, structural, and fluid dynamics together, and customizable to an individual patient's own anatomy.

In one Boston hospital's congenital heart program, nearly 2,000 procedures have now been planned and rehearsed using patient-specific virtual hearts before the real operation begins.

150+ member organizations

28 countries

~2,000 procedures guided





ZYGOTE

Solid Heart Gen 2

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Anatomical model of the human heart

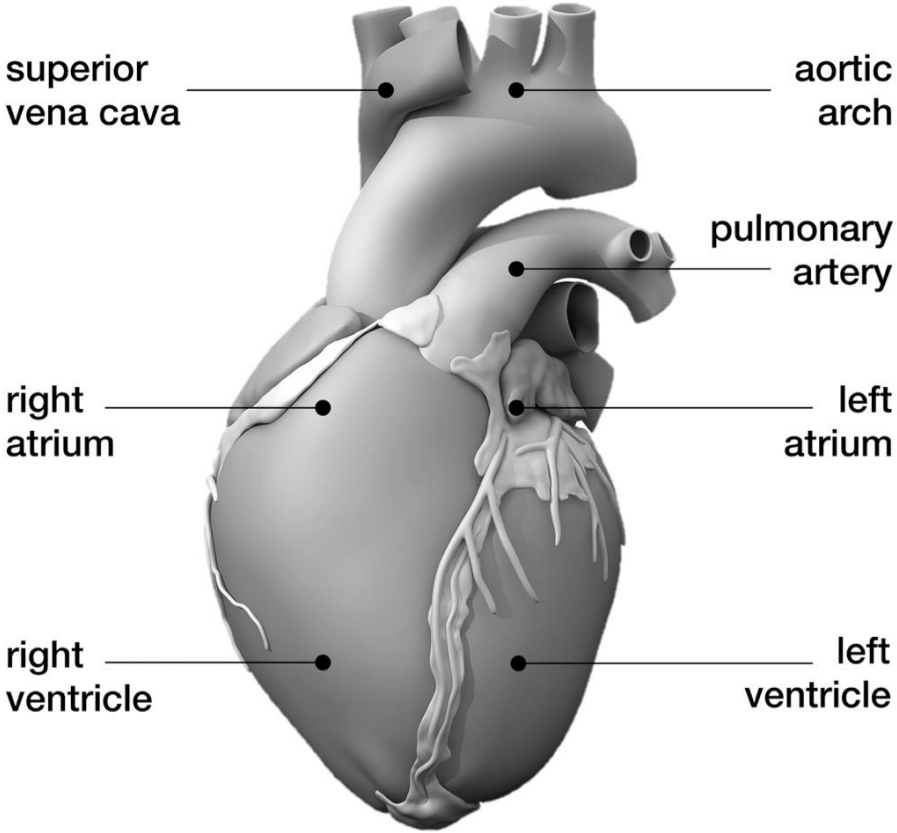

Figure 1.
Anatomic model of the human heart created from computer tomography and magnetic resonance images. The model displays the characteristic anatomic features: The aortic arch, the pulmonary artery, and the superior vena cava; the two upper chambers, the left and right atria; and the two lower chambers, the left and right ventricles; adopted with permission from [50].

Circulatory model of the human heart

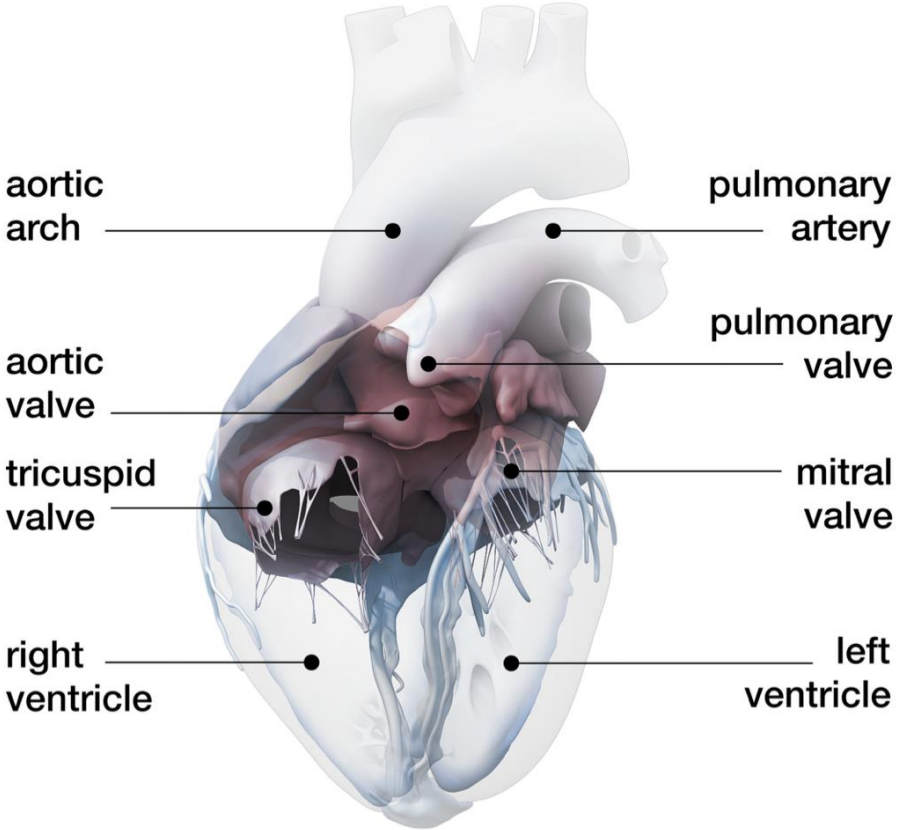

Figure 2.
Circulatory model of the human heart created from computer tomography and magnetic resonance images. The model displays the characteristic circulatory features: The tricuspid and mitral valves, which connect the right and left atria to the right and left ventricles; and the pulmonary and aortic valves, which connect the right and left ventricles to the pulmonary and systemic circulation; adopted with permission from [50].

Solid model of the human heart

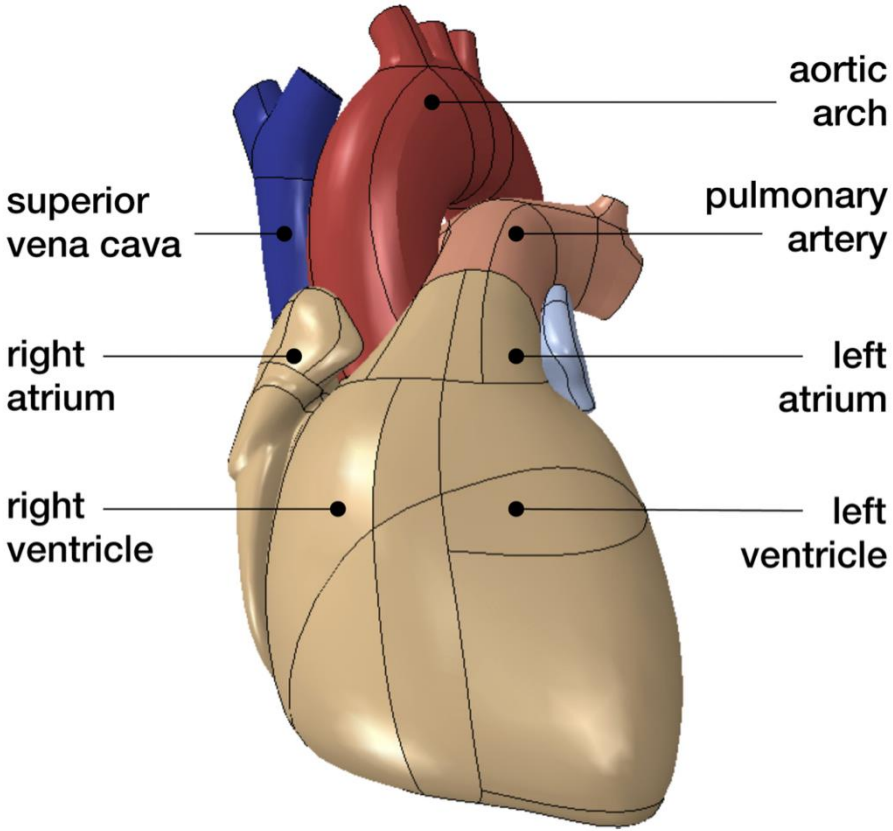

Figure 3.
Solid model of the human heart with anatomic details including the aortic arch, pulmonary artery and superior vena cava, left and right atria, and left and right ventricles.

Finite element model of the human heart

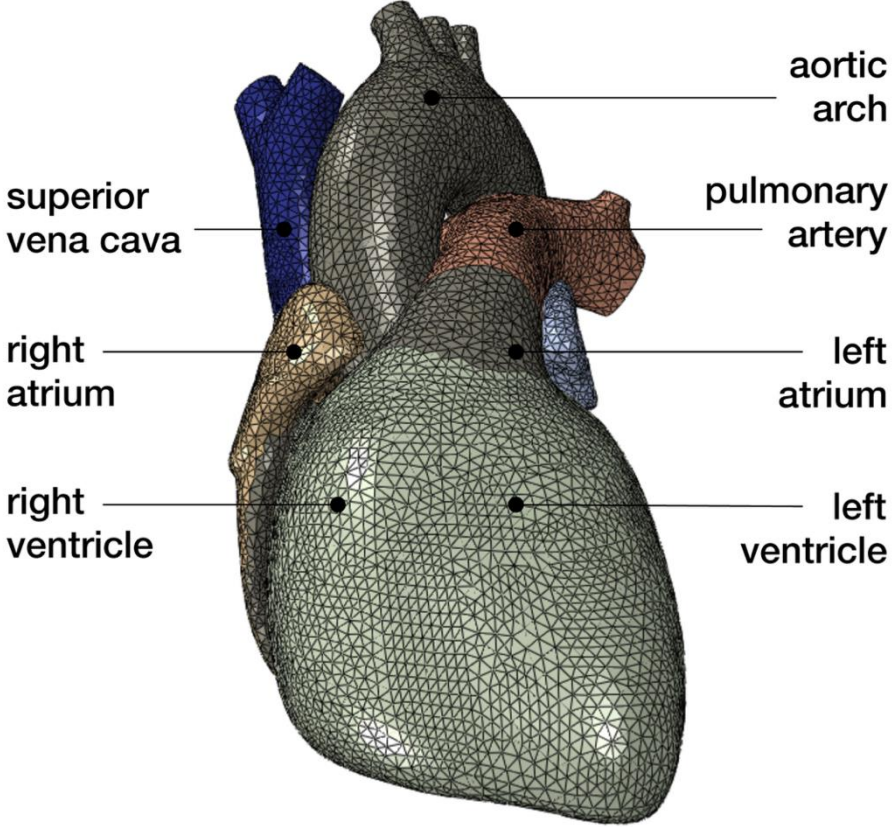

Figure 4.
Finite element model of the human heart discretized with 208,561 linear tetrahedral elements, 47,323 nodes, and 189,292 degrees of freedom, of which 47,323 are electrical and 141,969 are mechanical.

Muscle fiber model of the human heart

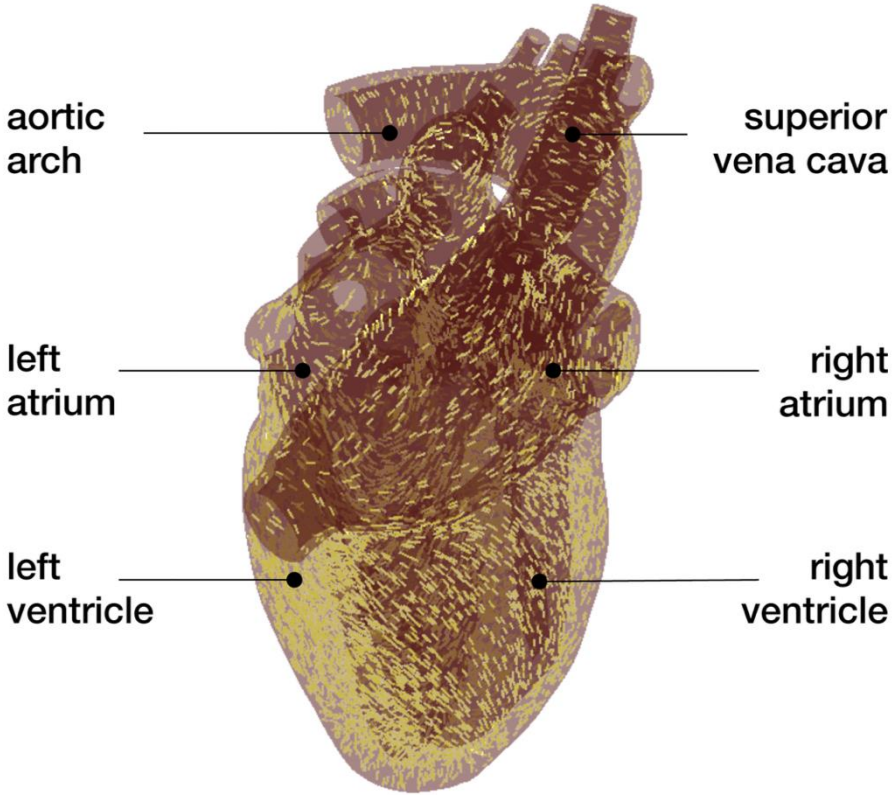

Figure 5.
Muscle fiber model of the human heart with 208,561 discrete fiber and sheet directions interpolated and assigned to each integration point.

Blood flow model of the human heart

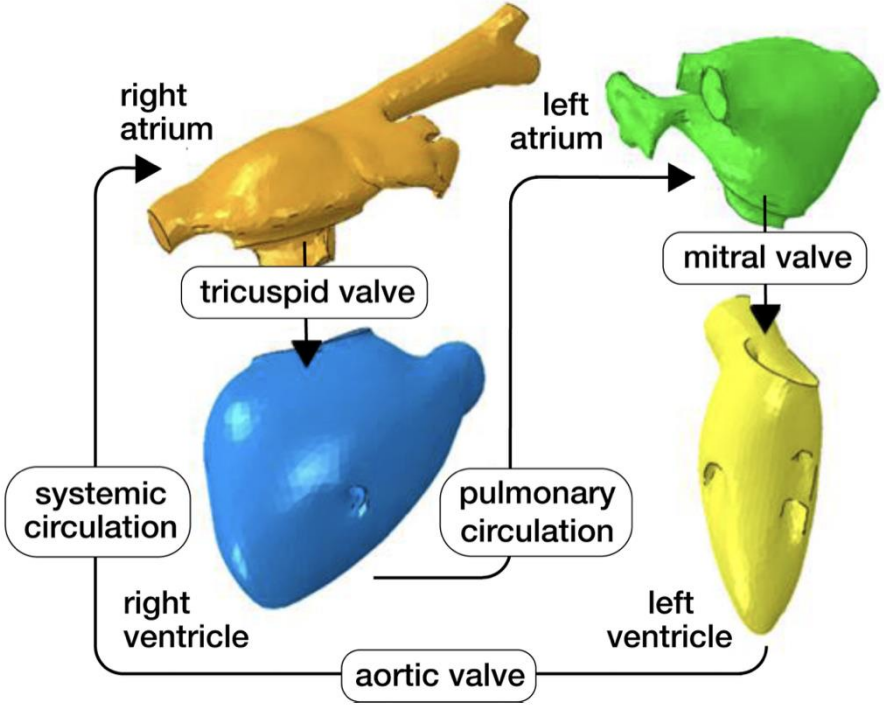

Figure 6.
Blood flow model of the human heart with surface-based fluid cavity representation of the right atrium, right ventricle, left atrium, and left ventricle connected through viscous resistance models of Windkessel type for the tricuspid valve, pulmonary circulation, mitral valve, aortic valve, and systemic circulation.

Spatio-temporal evolution of electrical potential, mechanical deformation, and muscle fiber strain across the human heart.

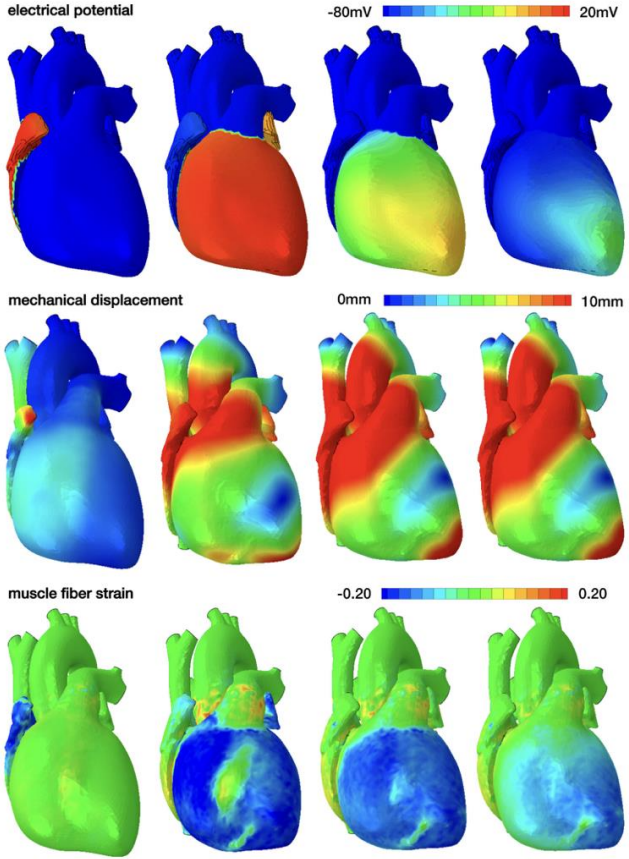

Figure 7.
Spatio-temporal evolution of electrical potential, mechanical deformation, and muscle fiber strain across the human heart. During systole, the heart depolarizes rapidly from −80mV to +20mV, the muscle fibers contract and shorten up to 20% to induce ventricular ejection. During diastole, the heart repolarizes gradually from +20mV to −80mV, the muscle fibers relax and relengthen to their initial length to induce ventricular filling.

Cardiac & Cardiovascular Applications



Structural Intervention Planning

Virtually test device sizing and positioning before procedures such as TAVR



Congenital Heart Disease

Patient-specific models let surgical teams rehearse rare anatomy before entering the OR



Arrhythmia & Electrophysiology

Simulating electrical activation patterns to guide ablation strategy



Personalized Device Selection

Matching pacemakers and devices to unusual or pediatric anatomy

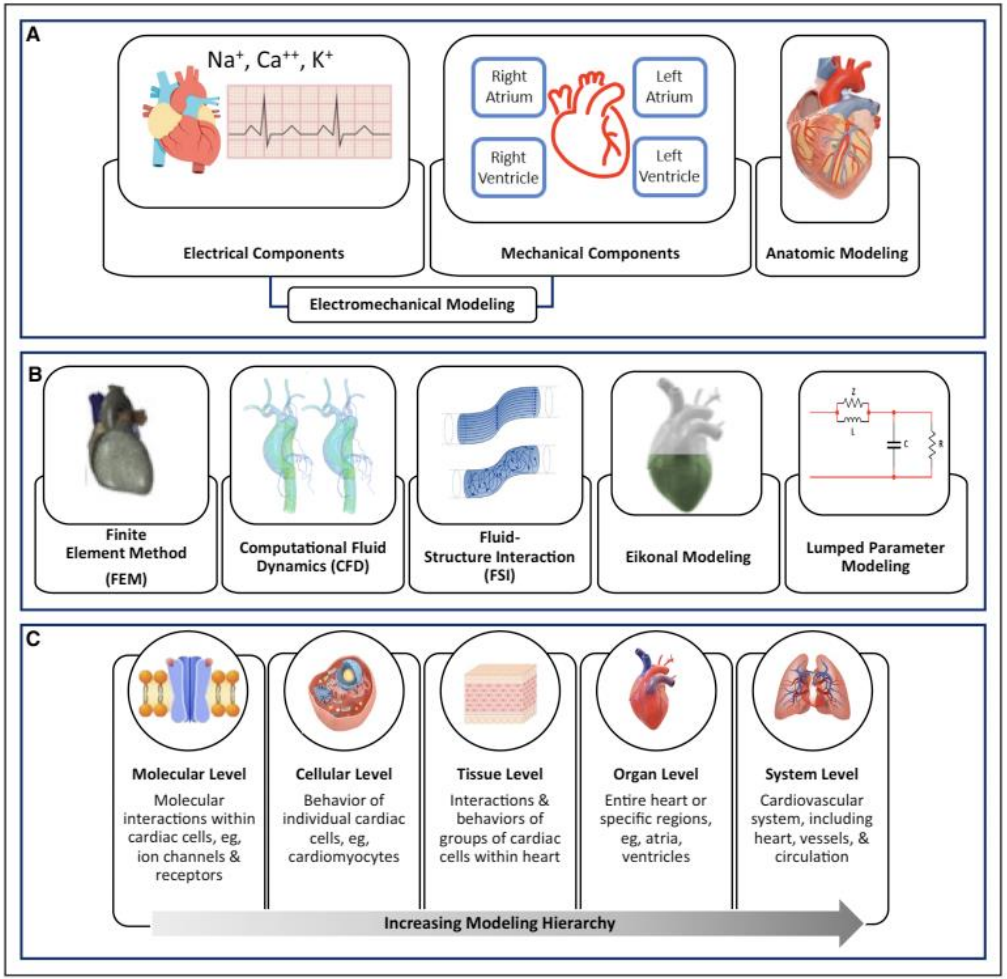

Figure 3. Illustration of technique categories used to create cardiovascular system models.
A, Physiological aspects of modeling. **B**, Modeling methods. **C**, Increasing modeling hierarchy.

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The Perioperative Human Digital Twin

Hannah Lonsdale, Geoffrey M. Gray, Luis M. Ahumada, Hannah M. Yates, Anna Varughese, Mohamed A. Rehman

All Children's Hospital, School of Medicine

Research output: Contribution to journal › Article › peer-review

Overview

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Pages (from-to)	885-892
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The Perioperative Human Digital Twin

Hannah Lonsdale, MBChB,* Geoffrey M. Gray, PhD,† L
Hannah M. Yates, BS,‡ Anna Varughese, MD,‡ and M

GLOSSARY

BRCA = BReast CAncer gene; **ECG** = electrocardiog
electronic medical record; **GPS** = Global Positioning
human epidermal growth factor receptor 2; **HIPAA** = I
Act; **IoMT** = Internet of Medical Things; **IoT** = Interne
data; **PWC** = physiologic data warehouse; **RPM** = ren
acute respiratory syndrome coronavirus 2

The 20th-century approach to medicine has led to one-size-fits-all consensus guidelines applied over an entire patient population. This is highly

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From monitor to twin: four levels of intelligence

Monitor

Shows what is happening now

Alarm

Tells you when it is already late

Predictor

Forecasts what is likely next

Twin

Simulates what happens if you act

Anatomy of an anesthesia twin



1

Sense

ECG, arterial line, SpO_2, ventilator, pumps

2

Assimilate

Bayesian / Kalman updating keeps the model in sync

3

Model

Mechanistic physiology plus machine learning

4

Simulate

Run virtual fluids, drugs and ventilation

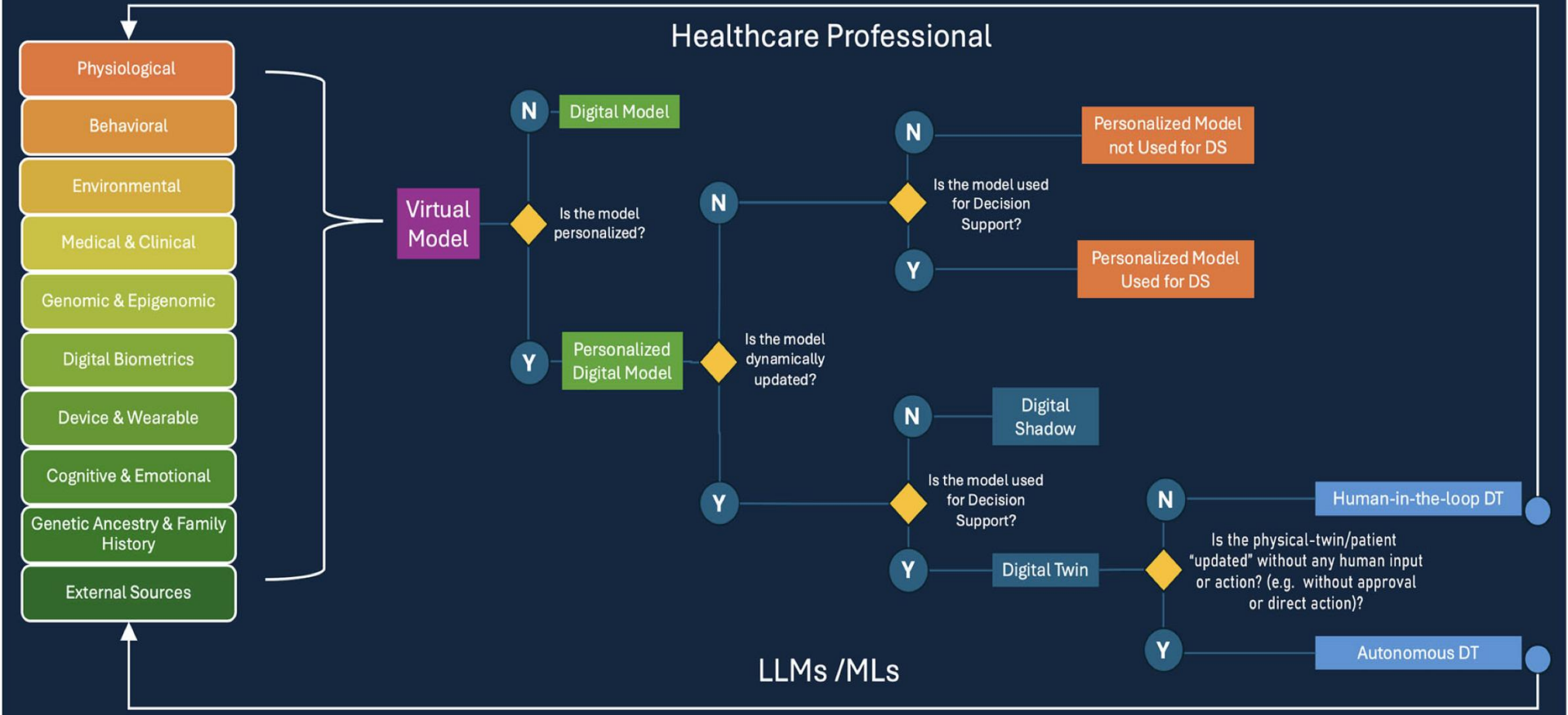
5

Decide

The clinician chooses; the twin advises

Hybrid design: mechanistic physiology explains why; machine learning finds patterns the equations miss

Virtual System Possible Choices



Promise

Where twins can serve the anesthesiologist



Hemodynamics

Predict hypotension before it happens

Drug dosing

Patient-specific PK/PD and target-controlled delivery

Depth of anesthesia

Model response to hypnotics and opioids

Ventilation & ICU

Lung mechanics, weaning and ARDS strategies

Airway & regional

Imaging-based planning of difficult airways and blocks

Pain medicine

Bidirectional assistant for physician and patient

Applications in the ICU

Hemodynamic management

Predict response to fluids, vasopressors and inotropes.

Mechanical ventilation

Tune settings and anticipate weaning readiness.

Early deterioration

Flag sepsis, shock or arrhythmia risk before overt change.

Drug dosing

Individualise sedation, antibiotics and anticoagulation.

We already use a twin: TCI pump & HPI

TCI: the oldest twin in the OR

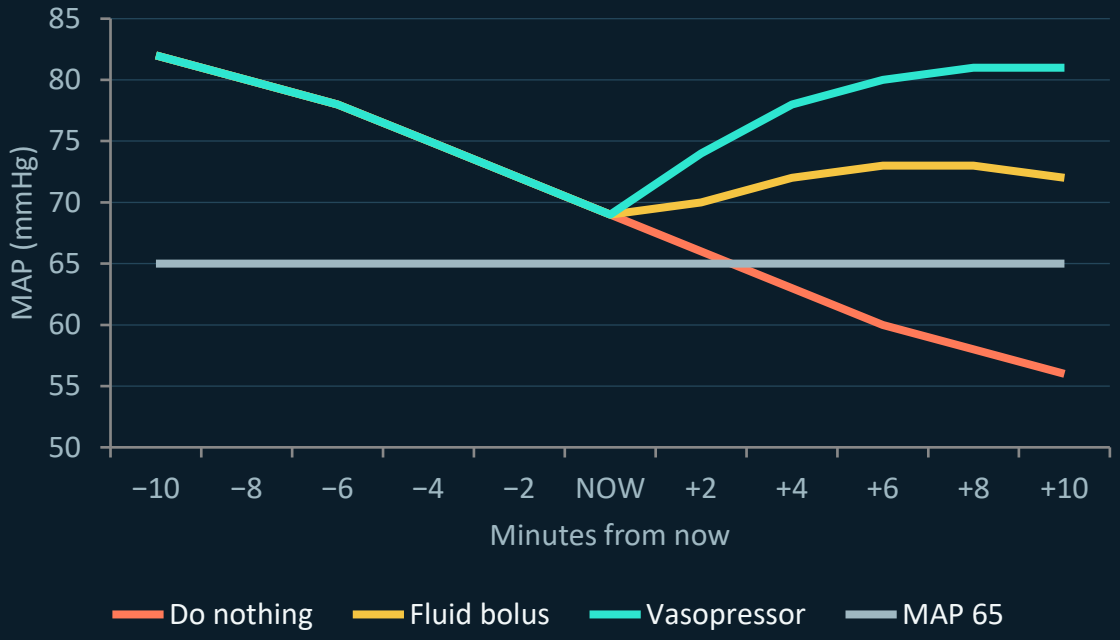
- Marsh, Schnider and Eleveld models simulate drug concentration in this patient, in real time
- The pump does not measure plasma levels. It computes them

Hypotension Prediction Index

- Machine-learning predictor trained on the arterial waveform
- The HYPE randomized trial (JAMA 2020) reported less intraoperative hypotension

Next step: from one drug or one number to the whole patient.

The what-if engine: three futures, one decision

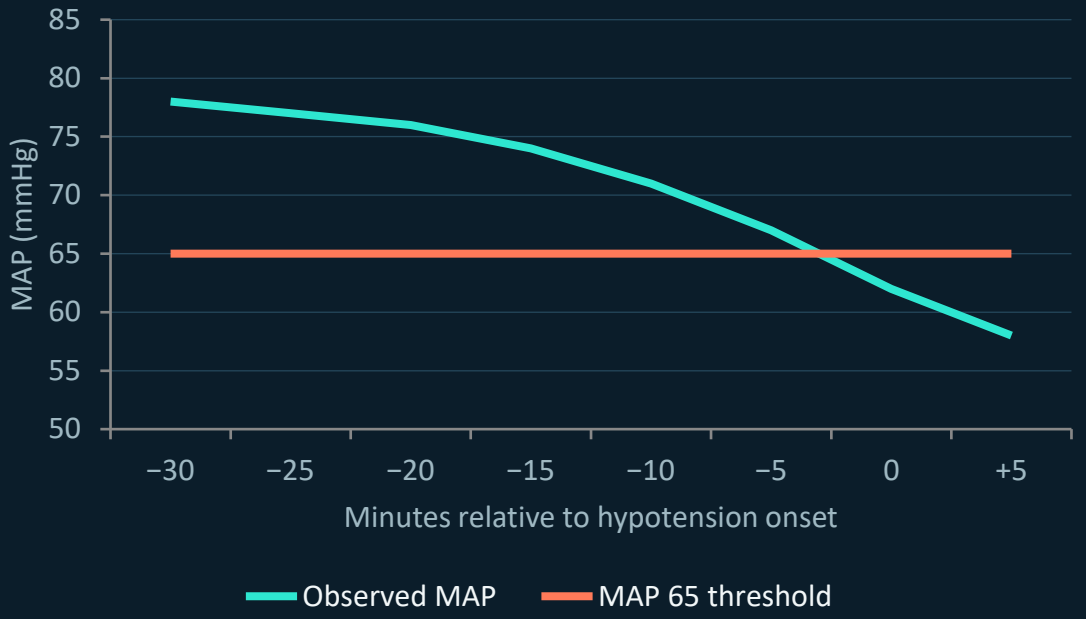


NOW: MAP 70, falling

The twin simulates each option on this patient's own physiology. The clinician picks the future that clears the threshold.

Schematic illustration, not patient data

Seeing the drop 15 minutes before it happens



TWIN ALERT · −15 min

"MAP < 65 likely within about 10 minutes."

Time to adjust vasopressor, volume or anesthetic depth, before the drop.

Schematic illustration, not patient data

The virtual test drive: rehearse before you treat

A

Fluid bolus

Raises preload; benefit depends on fluid responsiveness and ventricular function.

B

Vasopressor

Restores perfusion pressure quickly; watch afterload and cardiac output.

C

Watch and wait

Trajectory continues; shows time to threshold if nothing changes.

Three futures simulated in seconds → one chosen for the real patient

Plan



Shahid Beheshti University of Medical Sciences

- Pain
- Adult Cardiac ICU
- Pediatric Cardiac ICU

Our roadmap at SBMU: from registry to bedside

15 min

target warning horizon before hemodynamic instability after cardiac surgery

1. Retrospective data preparation from the cardiac anesthesia registry
2. Hybrid twin: physiology models plus machine learning
3. Temporal and external validation
4. Prospective real-time feasibility at the bedside

Hard truths we must face

Data

- Missing and noisy signals
- Bias from single-center cohorts
- Interoperability across monitors

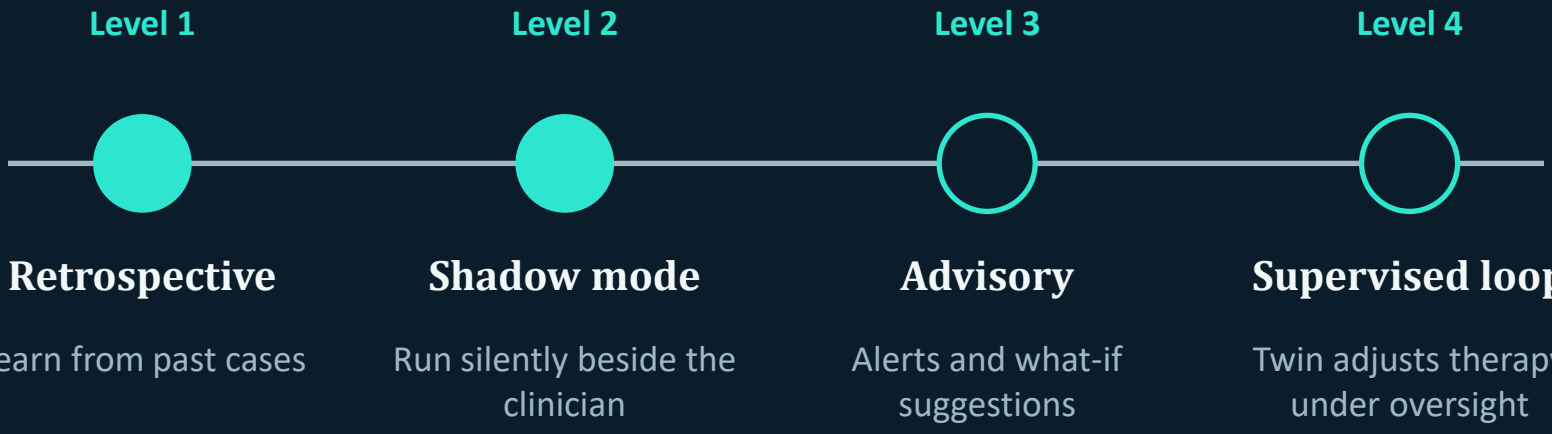
Trust

- Prospective validation, not only retrospective AUC
- Bedside explainability
- Alarm fatigue

Governance

- Privacy and data ownership
- Who is accountable for a twin-guided decision?
- Regulation as medical-device software

A maturity ladder for clinical adoption



The opportunity: take twins to the bedside, responsibly and step by step.

The anesthesiologist does not become obsolete: becomes the pilot of the simulator.

1. A twin is a living, patient-specific model, not a dashboard.
2. Its power is the what-if: rehearse before you treat.
3. Success needs validation, trust and governance, not only algorithms.

چهارشنبه،
۱۱ آذر
۱۴۰۵

بیمارستان
شهدای
تجریش

رایگان



جمهوری اسلامی ایران
مجلس شورای اسلامی
رئیس

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رئیس محترم جمهوری اسلامی ایران

سلام‌علیکم

مطابق اصل یکصد و بیست و سوم (۱۲۳) قانون اساسی جمهوری اسلامی ایران، «**قانون ملی توسعه هوش مصنوعی**» مصوب ۱۴۰۵/۵/۲۸ مجلس شورای اسلامی به شرح پیوست ابلاغ می‌شود.

محمدباقر قالیباف

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Either we will make our own digital twin and manage it

OR ~~others will make~~ our digital twin

NO other option

سالها دل طلب جام جم از ما می کرد — وآنچه خود داشت ز بیگانه تمنا می کرد

گوهری کز صدف کون و مکان بیرون است — طلب از گمشدگان لب دریا می کرد

مشکل خویش بر پیر مغان بردم دوش — گاو به تا ید نظر حل معما می کرد

دیدمش خرم و خندان قدح باده به دست — و اندر آن آینه صد گونه تماشا می کرد

گفتم این جام جهان بین به تو کی داد حکیم — گفت آن روز که این گنبد مینا می کرد

بیدلی در همه احوال خدا با او بود — او نمی دیدش و از دور خدا را می کرد

این همه شعبده خویش که می کرد اینجا — سامری پیش عصا و ید بیضا می کرد

گفت آن یار کزو گشت سر دار بلند — جرمش این بود که اسرار هویدا می کرد

فیض روح القدس ار باز مدد فرماید — دیگران هم بکنند آنچه مسیحا می کرد

گفتمش سلسله زلف بتان از پی چیست

گفت حافظ گله ای از دل شیدا می کرد