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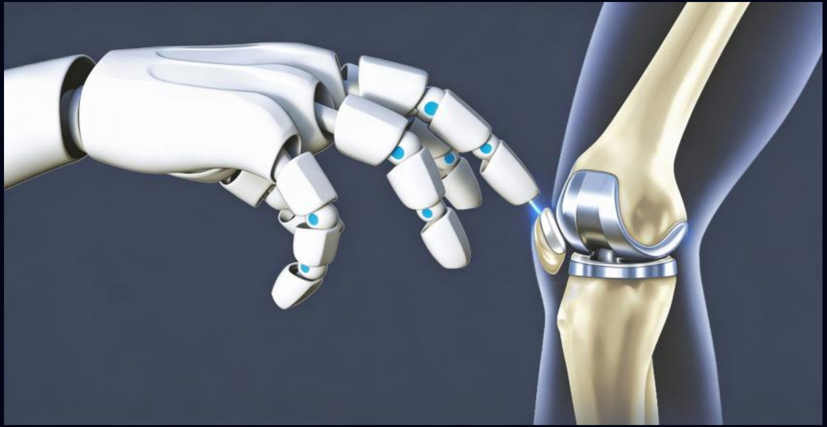

Current trends in Knee replacement surgery/Orthopedics

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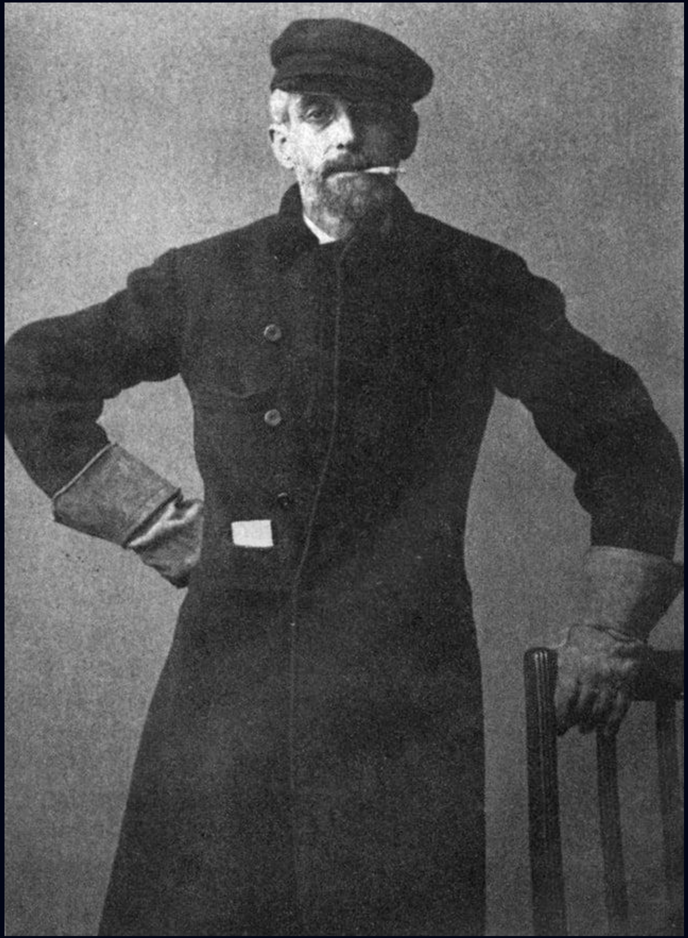
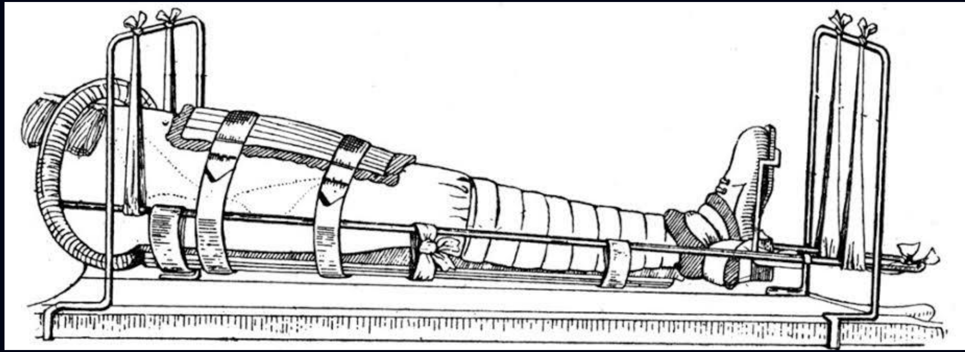


HUGH OWEN THOMAS
FATHER OF ORTHOPAEDICS



How it evolved

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Evolution of Surgical Robotics

- **1985:** First robotic surgery (PUMA 560) — neurosurgical biopsies
- **1991:** Transurethral prostate resection with improved accuracy
- **1990s–2000s:** Zeus and Da Vinci platforms for general/cardiac surgery
- **2000s onwards:** Dedicated joint replacement robotic systems (ROBODOC, MAKO, ROSA, NAVIO, MISSO)

Why Robotics in TKA?

Despite high implant survivorship (>90% at 10 years), patient satisfaction remains suboptimal

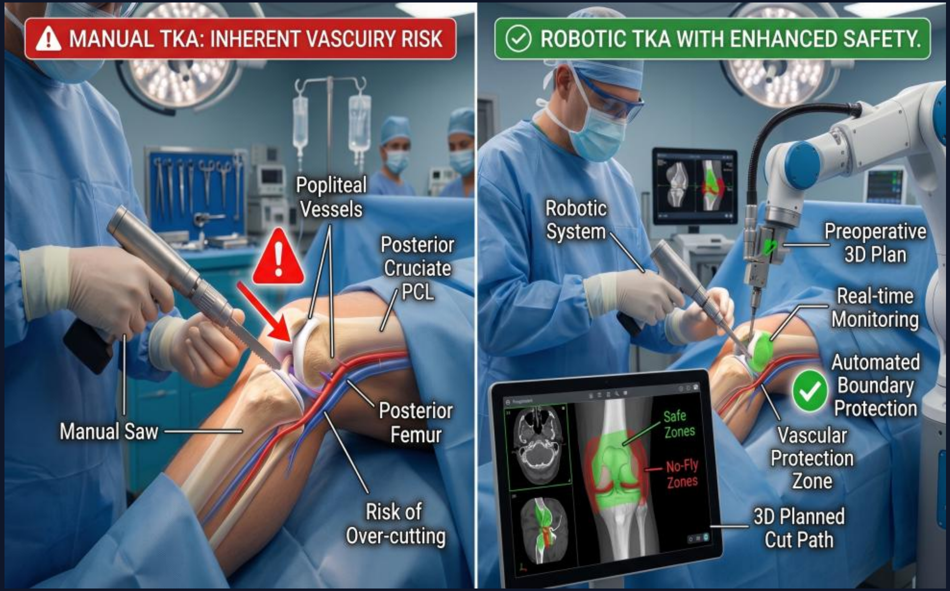
- Despite technical success, patient dissatisfaction persists in 15–20% of coventional TKR
- Implant malalignment and soft-tissue imbalance
- Suboptimal kinematics and inconsistent results
- Robotics improves precision, reproducibility, and personalization

Why Robotics in TKA?

1. Not Because Conventional TKA Is Inadequate But Because Consistency Compounds Over Time
2. Not Because You Lack Skill But Because Precision Becomes Reproducible
3. Not Because Your Outcomes Are Poor But Because Risk Management Matters

Limitations of Manual TKA

- Poor reproducibility of alignment guides
- Risk of soft-tissue and vascular injury
- Limited intraoperative data on gap measurements
- Suboptimal positioning leads to instability and reduced survival
- Surgeons rely on visual approximation of mechanical and anatomical axes
- Intramedullary Referencing
- Surgeon Fatigue
- Assumption of Standard Anatomy

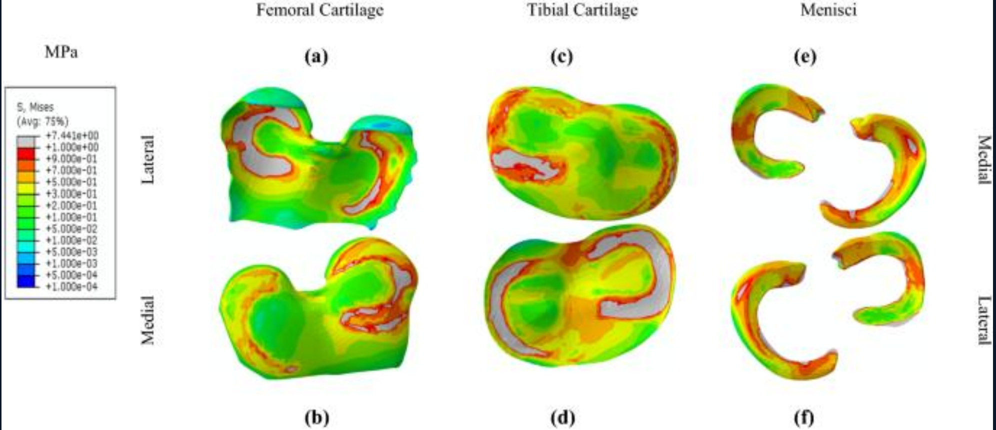


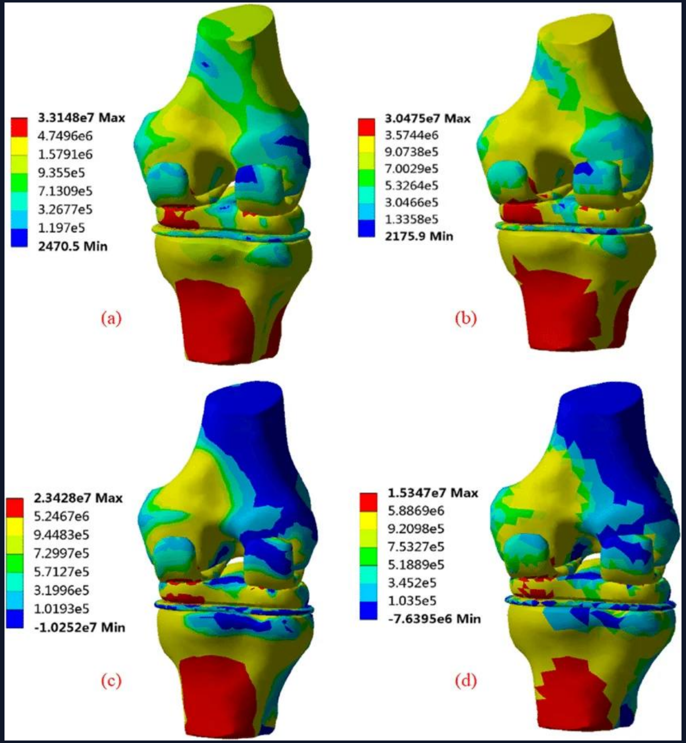
Clinical Advantages

- Improved accuracy and reproducibility of bone cuts and implant positioning
- Better soft-tissue balancing and reduced gap imbalance
- Fewer outliers in mechanical axis restoration
- Potential for less tissue trauma and faster rehabilitation

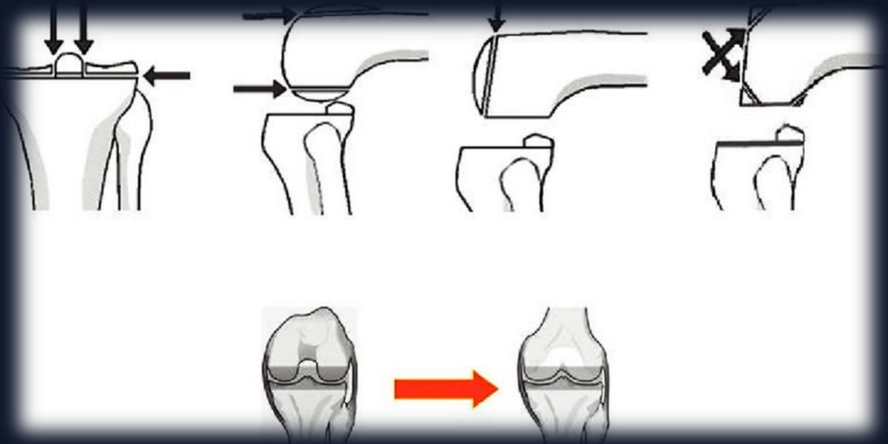
The Persistence of Data deficit

Human visual approximation cannot reliably compute the multivariable equations required for real-time, 3D soft-tissue balancing





Evidence Summary



Radiographic Outcomes: Consistently superior alignment accuracy with reduced outliers

Patient-Reported Outcomes: Mixed results; some improvement in early recovery and pain scores

Complication Rates: Newer systems (MAKO, ROSA) show low rates comparable to manual TKA

An Analogy: Manual Driving, GPS, and Lane Assist

1. Manual Jigs = Freehand Driving
2. Navigation = GPS
3. Robotics = GPS + Lane Assist+ADAS

The Distinction Between "Good" and "Consistent"

A surgeon can be highly skilled and still experience variability. **Good does not equal consistent every single time.**

Milestones to Proficiency

1

Cases 1–6: Foundation Phase

Workflow and ergonomic mastery dominate this initial phase. Teams learn equipment setup, patient positioning, and basic navigation. Focus is on developing comfortable, repeatable processes.

2

Cases 7–16: Acceleration Phase

Significant reduction in operative time occurs as teams become fluent with the technology. Registration becomes faster, and intraoperative decision-making improves dramatically.

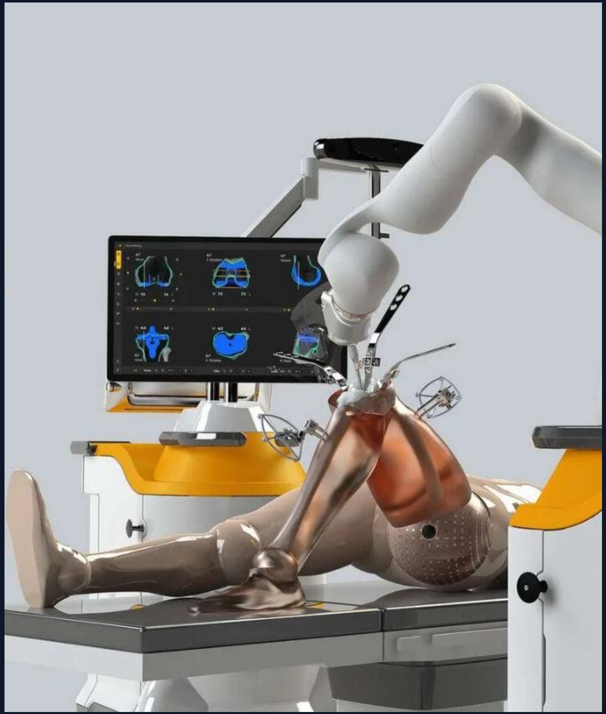
3

Cases 20+: Mastery Phase

Operative efficiency becomes comparable to manual techniques. Teams achieve optimal workflows, and the technology becomes seamlessly integrated into surgical practice.

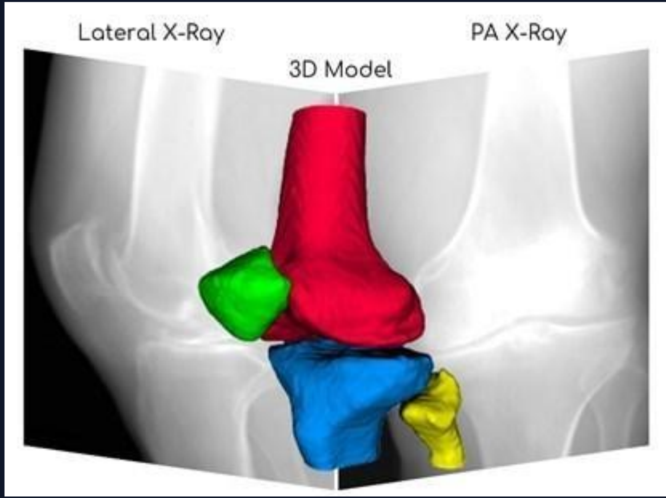
Learning Curve & Training

- Proficiency achieved within 10–30 cases for most systems
- Operating time: 90 min → 60 min after ~20 cases
- Time stabilizes around 30–32 cases
- Simulation, proctoring, and team training essential for success



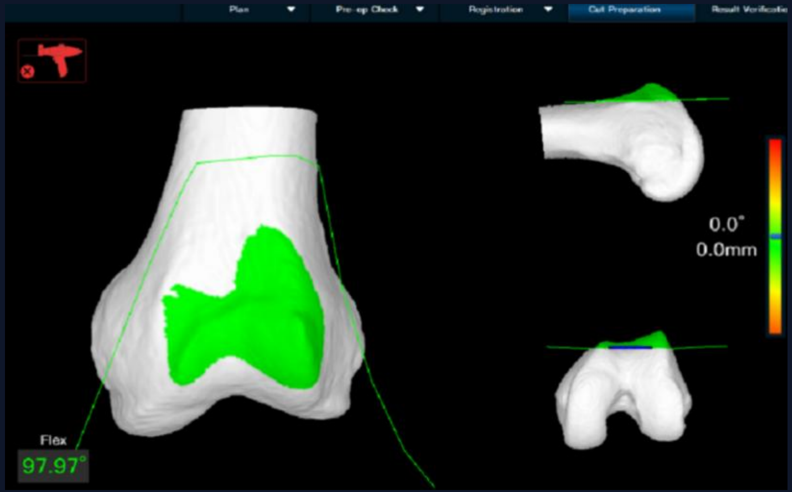
Deep learning for 3D anatomical reconstruction

- From 2D to Digital Twin: Augmented reality and Artificial Intelligence, specifically Deep Learning algorithms, can now translate standard 2D radiographs into highly predictive 3D 'Digital Twins' of the patient's anatomy.
- This allows for virtual surgical rehearsal, precise biomechanical modeling, and component sizing with >98% accuracy before the first incision.



AI - driven predictive kinematics

- Finite Element Models (FEM) combined with neural networks can now simulate the mechanical response and risk of ligament tear under various loading conditions, allowing us to predict the optimal alignment angle to prevent aseptic loosening.

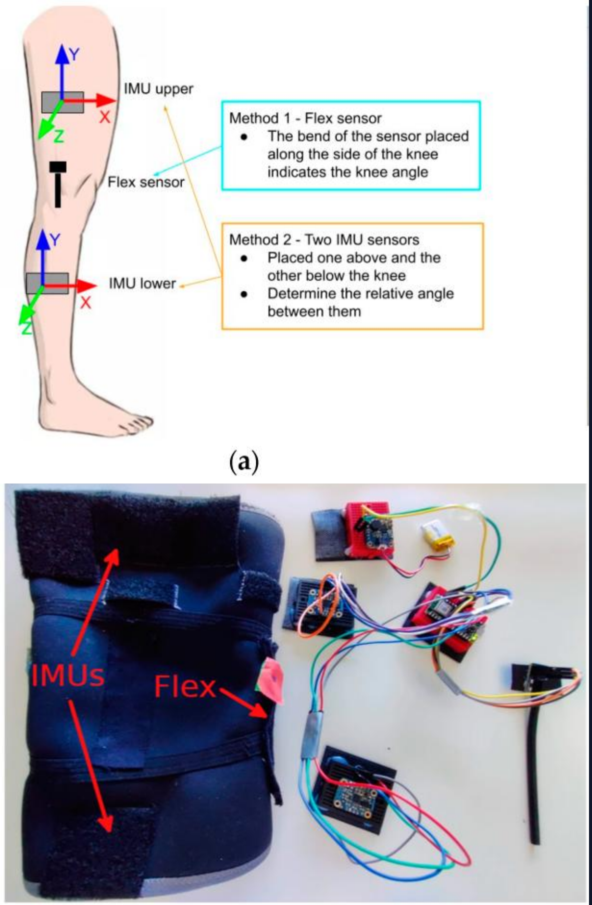


The Robotic Advantage: Continuous Intraoperative Bio-feedback

- The robotic system acts as an intraoperative data node.
- It captures real-time soft-tissue tension and gap measurements, creating a continuous feedback loop.
- It dynamically adjusts with the digital twin, translating biological variability into executable algorithms

Wearable Sensors & Post-Operative Machine Learning

- <u>The Bio-economy of Recovery</u>: The flow of bio-information continues post-operatively.
- Wearable inertial measurement units (IMUs) continuously track gait kinematics (spatiotemporal parameters, sample entropy).
- Machine learning models—such as Random Forest and Support Vector Machines—process this data to predict functional recovery trajectories, allowing clinicians to set data-backed expectations and reduce readmission/complication rates.



The Post-PMMA Era: Biomimetic Adhesives and Micro-Gap Tolerances

- Beyond PMMA: AI-decoded biomimetic adhesives (e.g., oyster-inspired) offer instant, high-strength bonding (~10 MPa) in wet, physiological environments.

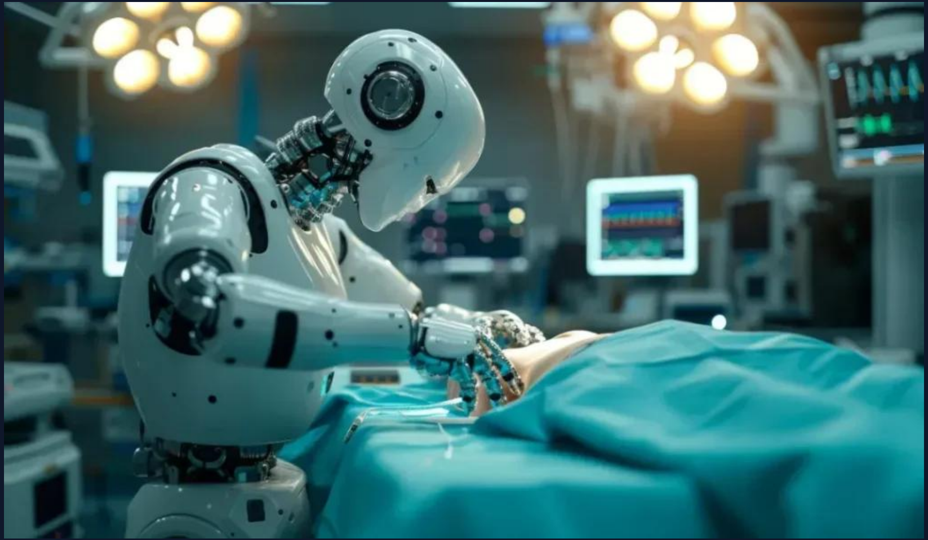
- The Robotic Prerequisite: Advanced bioadhesives require micro-capillary gap tolerances. Sub-millimeter robotic precision is mandatory to prevent the micro-fractures and irregular surfaces that cause these glues to fail.

Limitations & Challenges

- High capital and per-case costs
- Limited availability in low-resource settings
- Implant/system compatibility issues
- Initial longer OR time during learning phase
- Long-term cost-effectiveness data still evolving

Future Directions

- Increased autonomy with surgeon oversight
- Smaller, portable robots for broader accessibility
- Cost reduction and value-based implementation strategies
- *The future of joint replacement is not just about better cutting tools; it's about gleaning bio-information. By embracing AI and bioinformatics, we transition from reactive mechanical surgery to predictive, personalized biological restoration*



Thank You