AI in Robotic Surgery: Evolution, Impact, and Global Advances

The da Vinci Surgical System – History and Adoption

Robotic surgery began as a futuristic concept but has become a mainstream reality in the last two decades. The seminal **da Vinci Surgical System** by Intuitive Surgical was launched in 2000 (Company History | Robotic Assisted Surgery | Intuitive), after the company's founding in 1995. This system gained the first FDA clearance for surgical robotics and paved the way for widespread adoption (4 robotic surgery trends to watch in 2025 | MedTech Dive). Since then, uptake has grown exponentially – as of 2023, Intuitive reports **over 12 million** robot-assisted procedures performed worldwide (Robotic Surgery Is Here to Stay—and So Are Surgeons | ACS). By 2024, annual procedure volume with da Vinci had reached about **2.68 million globally**, a 17% increase over the prior year (Intuitive Announces Preliminary Fourth Quarter and Full). In the United States alone, roughly **15% of all surgeries** are now performed with robotic assistance (Positioning The Industry For Growth In Robotic Surgery), translating to well over a million robot-assisted operations annually. This mainstream acceptance is drawing new competitors into the field, ending Intuitive's long-held monopoly and expanding robotic surgery's presence in more operating rooms (4 robotic surgery trends to watch in 2025 | MedTech Dive).

Common Robotic Procedures: Robotic systems are used across many specialties, but a few types of surgeries account for the majority of cases. Early adoption was led by **urologic surgeries** (especially prostate cancer prostatectomies), which quickly became a dominant use-case – about *three in four* U.S. prostate removals are now done robotically (Robotic Surgery Statistics and Facts (2025)). **Gynecologic procedures** (such as hysterectomies for cancer or fibroids) have also been a staple of robotic surgery (Robotic Surgery (August 2015). In recent years, **general surgeries** – e.g. hernia repairs, colorectal resections, and gallbladder removals – have seen dramatic growth in robotic assistance (Robotic Surgery (August 2015)). Robotic systems are even employed in complex

cardiothoracic surgeries (like mitral valve repair or lung lobectomy) and **head & neck surgeries**, though these constitute a smaller share of cases (4 robotic surgery trends to watch in 2025 | MedTech Dive) (Robotic Surgery Is Here to Stay—and So Are Surgeons | ACS). Today, it's routine to find robots assisting in **cardiac, urologic, gynecologic, and general laparoscopic procedures** in operating rooms around the world (4 robotic surgery trends to watch in 2025 | MedTech Dive). This broadening scope underscores how far the technology has come from its first urology-focused applications in 2000 (Company History | Robotic Assisted Surgery | Intuitive).

AI Across the Surgical Journey: Preoperative, Intraoperative, and Postoperative

Cutting-edge **artificial intelligence (AI)** technologies are accelerating improvements in robotic surgery at every stage of patient care. AI is being woven into the **pre-surgery planning**, the real-time **surgical execution**, and the **post-surgery recovery and analysis** phases to enhance outcomes and efficiency.

Preoperative Planning & Diagnostics

Before a robot ever touches the patient, AI is helping surgeons plan and make decisions. Machine learning algorithms can analyze **medical images** (CT, MRI, ultrasound) to identify tumors or anatomical structures and help map out the optimal surgical approach. For example, AI computer vision systems can automatically segment a tumor on a scan and suggest safe incision paths or instrument trajectories. AI can also review a patient's history and compare against thousands of prior cases to predict risks and recommend the best surgical strategy (AI Is Poised to "Revolutionize" Surgery | ACS). In essence, AI acts as a smart assistant during planning – integrating information from radiology, pathology, and the latest clinical guidelines to tailor a surgical game plan to the individual (AI Is Poised to "Revolutionize" Surgery | ACS). These tools improve preoperative **diagnostics** as well, by flagging abnormalities that a busy clinician might miss. (In fact, AI-driven image analysis has already shown it can reduce error rates in detecting cancerous lesions in fields like pathology and radiology (AI Is Poised to "Revolutionize" Surgery | ACS).) All of this upfront intelligence means by the time the surgical robot is deployed, the surgical team has a clearer roadmap for a safer, more effective procedure.

AI in the Operating Room: Automation and Decision Support

During robotic surgery, AI technologies are elevating the surgeon's capabilities and even taking on some tasks autonomously. **Computer vision** algorithms can monitor the live camera feed to recognize organs, blood vessels, and other anatomical landmarks in real time (AI Is Poised to "Revolutionize" Surgery | ACS). This situational awareness enables on-screen guidance – for instance, highlighting a delicate nerve to avoid, or providing an augmented reality overlay of a tumor's margins based on pre-op scans. In robotic systems, AI can also serve as a co-pilot: warning if instruments stray too close to critical structures, adjusting camera views automatically, or optimizing energy device settings for precise tissue cutting. Some platforms are experimenting with **voice-activated controls** (leveraging Natural Language Processing) so a surgeon can say "zoom in on the spleen" or "increase magnification" without taking their hands off the console.

Notably, researchers have demonstrated **partial automation of surgical tasks**. In 2022, a Johns Hopkins-led team showed that an AI-driven robot could perform a delicate laparoscopic suturing of intestinal tissue in a pig *without* human guidance – and with **better accuracy than human surgeons** (Robot performs first laparoscopic surgery without human help | Hub) (Robot performs first laparoscopic surgery without human help | Hub). This Smart Tissue Autonomous Robot (STAR) used advanced vision and control algorithms to place sutures and tie knots autonomously, adapting on the fly to subtle movements of soft tissue (Robot performs first laparoscopic surgery without human help | Hub) (Robot performs first laparoscopic surgery without human help | Hub). While fully autonomous surgery on humans remains a future goal, elements of autonomy are already emerging in today's OR. For example, orthopedic surgery robots can execute planned bone cuts with sub-millimeter precision once the surgeon approves the plan, and experimental laparoscopic AI systems can maintain a steady camera view centered on the instruments, acting like an automated camera operator. Meanwhile, AI-driven decision support tools can cross-reference live data (vital signs, instrument usage, etc.) against databases to suggest intraoperative adjustments. All these AI enhancements during surgery aim to **boost precision, safety, and efficiency** – effectively providing an extra layer of "intelligence" on top of the surgeon's skill.

Postoperative Recovery & Analytics

The role of AI continues after the incision is closed, improving recovery and gleaning insights for future cases. In the **immediate postoperative period**, hospitals are beginning to use AI monitoring for early warning of complications. For instance, machine learning models can continuously analyze vital signs, lab results, and even subtle patterns in a patient's postoperative data to predict issues like infections or bleeding before they become acute. Patients can also get support from AI-driven **chatbots** and virtual assistants as they recover. A patient at home might message a post-op chatbot at 1:00 AM asking "I have a 101°F fever and redness around my incision – is this normal?" and receive instant guidance or an alert to seek care (AI Is Poised to "Revolutionize" Surgery | ACS). In trials, such AI chatbots for routine questions have been very well received by patients (AI Is Poised to "Revolutionize" Surgery | ACS), potentially reducing unnecessary ER calls and alleviating on-call staff burden.

Beyond direct patient care, AI is turning postoperative data into actionable knowledge. **Predictive analytics** applied to large surgical datasets can identify which factors most influence outcomes – for example, an AI model might learn that a certain tissue tension pattern during suturing (captured from the robot's sensors) correlates with faster healing. Surgeons and engineers are using AI to analyze **surgical videos and robot telemetry** to evaluate performance and refine techniques. This concept, sometimes called "surgical intelligence," means every robot-assisted surgery can feed back into a learning loop: video recordings are processed to automatically log each step, measure metrics like precision or speed, and even score the technical skill. These analyses help in surgeon training and in optimizing procedural protocols. Over time, such data-driven feedback can lead to evidence-based improvements – e.g. adjusting how a robot is used for a particular procedure to reduce complication rates. In summary, AI after surgery helps ensure patients recover smoothly through proactive monitoring, and it extracts insights that continuously **improve surgical quality** for the next patients.

Global Developments in Robotic Surgery

Robotic surgery is a worldwide phenomenon, and many countries are advancing their own systems – often integrating AI capabilities – to meet surgical needs. While the U.S. and Europe have been early leaders, recent progress in **China and other nations** is rapidly shaping a more diverse global landscape for surgical robotics.

China’s Rapid Progress in AI-Driven Surgical Robotics

China has embraced robotic surgery in a big way, both by deploying foreign systems and developing home-grown technology. The da Vinci robot was first introduced in China in 2006 (Robotic surgery in China - PMC), and adoption accelerated in the last few years. By the end of 2022, China had **314 da Vinci systems installed** across 257 hospitals, which had collectively performed more than **378,000 robotic procedures** to date (Robotic surgery in China - PMC). Chinese surgeons initially focused these robots on urology (nearly **46%** of robotic cases have been prostate, kidney, and bladder surgeries) but have since expanded into gastrointestional, thoracic, gynecologic, and hepatobiliary surgeries (Robotic surgery in China - PMC . One leading Chinese team at the PLA General Hospital even surpassed 10,000 robotic cases by 2021 – the first in Asia to hit that volume – underscoring how quickly China has scaled up usage (Robotic surgery in China - PMC) (Robotic surgery in China - PMC).

Beyond adopting Western robots, China is aggressively developing its **own surgical robotic systems**, often with a strong emphasis on cost-effectiveness and AI features. In 2010, Tianjin University unveiled the “MicroHand A,” the country’s first domestic laparoscopic robot, and more recently its successor **MicroHand S** became the first Chinese laparoscopic robot to receive national regulatory approval in 2021 (Robotic surgery in China - PMC). Several other Chinese-designed robots have since earned approvals, including systems like **Edge MP1000**, **Toumai MT1000**, and **KangDuo SR1000** for various surgical applications (Robotic surgery in China - PMC). Notably, in July 2022 a robot from Shanghai MicroPort MedBot – dubbed **SkyWalker** – became the **first Chinese surgical robot to obtain FDA clearance in the U.S.** (Robotic surgery in China - PMC). (SkyWalker is an orthopedic surgery robot for knee replacements (MicroPort® MedBot™ Announces 2022 Interim Results) (MicroPort MedBot NaviBot Announces First Clinical Use of ...), reflecting China’s expansion into even niche surgical domains.) These developments show that Chinese companies are not just copying existing designs but innovating. Many of their systems claim advanced features like AI-driven planning and smaller, modular designs at lower cost. China’s government has also prioritized surgical robotics as part of its healthcare technology strategy (How government policies will drive China's robotic surgery market), which is fueling research in areas like **telesurgery** (Chinese surgeons have famously conducted remote robot-assisted procedures over 5G networks, connecting experts in big cities with patients in remote areas). Overall, China is quickly becoming a major player – leveraging its engineering talent and vast patient volume to push surgical robotics toward greater **digitalization and intelligence** (Robotic surgery in China - PMC).

Other Notable International Innovations

While the U.S. (with Intuitive) still leads in installed systems, many other countries and companies have entered the robotic surgery arena – often integrating AI to differentiate their offerings. In **Europe**, the U.K.-based company **CMR Surgical** has developed the **Versius** surgical robot, a modular system designed to be more flexible and compact than da Vinci. Versius has been adopted in hospitals in Europe, India, and elsewhere, and CMR's roadmap includes incorporating AI analytics for surgeons' training and performance feedback. Another competitor, **Asensus Surgical** (formerly TransEnterix), markets the **Senhance** robotic platform, which features eye-tracking camera control and machine vision digital interfaces to assist surgeons. Major medtech multinationals are also in the fray: **Medtronic's** much-awaited **Hugo** system, a multi-arm robot, launched in Europe and other regions in 2021 and is now in 25 countries (4 robotic surgery trends to watch in 2025 | MedTech Dive) – with U.S. approval for urologic procedures expected in 2025. Hugo is designed as an open platform that could leverage AI for image guidance and advanced instrumentation. **Johnson & Johnson** has invested heavily in robotics as well, acquiring Auris Health (developers of the Monarch robotic bronchoscopy platform) for $3.4 billion in 2019 (J&J pays $3.4B for Auris Health surgical robotics platform), and developing an orthopedic robot and a next-generation general surgery robot (project **Ottava**). In **Japan**, domestic firms have introduced surgical robots like the **Hinotori** system (by Medicaroid) for laparoscopic surgery, aiming to compete with imported systems while integrating Japan's expertise in automation. **South Korea** has the **Revo-i** surgical robot (Meerecompany) which received clearance there, and Israel has produced specialized robots such as **Mazor X** for spinal surgery (now part of Medtronic). This global proliferation means surgeons in different countries are gaining access to advanced robotic tools, sometimes with unique AI-driven capabilities like automated image-based tumor tracking or augmented reality overlays. Importantly, many of these newer systems emphasize interoperability with imaging and navigation systems – a trend toward "digital surgery ecosystems" that combine robotics, pre-operative imaging, and AI analytics as a seamless package.

One clear global trend is that **competition and innovation in surgical robotics are heating up.** Intuitive Surgical – long "the only game in town" – now faces rivals across North America, Europe, and Asia (Robotic Surgery Is Here to Stay—and So Are Surgeons | ACS). Large device makers (Medtronic, J&J, Stryker, Zimmer Biomet, etc.) have all launched or announced robotic surgery platforms, and a host of startups are pursuing niche applications (Positioning The Industry For Growth In Robotic Surgery). This competition is driving costs down and spurring design improvements. We're seeing robots get **smaller** (e.g. single-port robots that need only one incision), more **specialized** (robots dedicated to orthopedics, endoscopy, neurosurgery, etc.), and more **intelligent**. In fact, experts note that surgical robots globally are evolving toward **"miniaturization, non-invasiveness, telesurgery, digitalization, and intelligence."** (Robotic surgery in China - PMC) These advances, often powered by AI, will help overcome current limitations like the lack of haptic feedback or the bulky size of earlier robots (Robotic surgery in China - PMC). In summary, the international landscape for robotic surgery is rapidly expanding, with China and many other countries contributing significant innovations – frequently leveraging AI for a competitive edge.

AI Technologies Enabling the Robotic Surgery Revolution

Modern surgical robots rely on a convergence of AI technologies behind the scenes. Key among these are **machine learning (ML)**, **computer vision (CV)**, and **natural language processing (NLP)** – each playing distinct roles in making robotic surgery smarter and more capable:

- **Machine Learning & Data Analytics:** ML algorithms enable robots and surgical platforms to learn from vast amounts of data. In practice, this means analyzing thousands of surgical cases to find patterns that humans might miss. For example, ML-driven predictive models can assess a patient's risk profile and **forecast complications or outcomes**, helping surgeons personalize their approach. At the Medical University of South Carolina, for instance, researchers have decades of experience using large data registries for **risk modeling** in surgery (Harvey and Marcia Schiller Surgical Innovation Center | College of Medicine | MUSC). Such models can predict, say, the likelihood of post-operative cardiac complications, allowing preemptive interventions. ML is also used within robotic control systems – e.g. algorithms that optimize the robot's movement based on past training data (a form of **reinforcement learning** in the OR). And as surgical robots generate more data (videos, force measurements, instrument trajectories), ML is essential to crunch this "big data" and continuously improve surgical quality. In essence, machine learning gives the robot and surgical team a way to **learn and improve over time**, rather than relying solely on pre-programmed rules.

- **Computer Vision:** Advanced computer vision – a subset of AI – is the "eyes" of a robotic surgery system. By processing live camera images or preoperative scans, CV algorithms can **detect and classify objects in the surgical field** (AI Is Poised to "Revolutionize" Surgery | ACS). This technology is already common in diagnostic fields (AI that spots abnormalities in x-rays or MRIs), and it's increasingly applied in surgery. In the OR, computer vision can automatically recognize anatomical structures (organs, tumors, vessels) and even surgical instruments within the video feed. This enables feats like real-time tissue tracking (e.g. the robot knowing exactly where the target lesion is, even if the organ shifts) and safety zones (virtually marking areas to avoid). For instance, an AI vision system might alert a surgeon that a lymph node looks suspicious or that margins are not yet clear around a tumor. Some robotic platforms use infrared or fluorescence imaging combined with AI vision to **enhance visualization** of blood flow or cancerous tissue during surgery. Notably, computer vision is what powered the autonomous STAR robot to precisely place sutures – the system "saw" the edges of the intestine and guided the needle accordingly (Robot performs first laparoscopic surgery without human help | Hub). As this technology advances, we can expect more **augmented reality** in surgery – where the computer vision interprets the scene and projects helpful information onto the surgeon's display (for example, highlighting exactly where to cut or showing the path of unseen blood vessels). In summary, computer vision gives surgical robots and assistive AI the ability to **interpret visual data like a trained human observer, only faster and with tireless attention**.
- **Natural Language Processing:** NLP allows AI systems to understand and generate human language – which has a few important applications in robotic surgery. First, NLP enables **voice control** and communication in the operating room. Surgeons are often sterile and unable to touch computers or notes, so a voice-activated AI assistant can be invaluable. Research prototypes have shown that voice interfaces can let surgeons control a robotic camera or retrieve patient

information without breaking scrub (A Natural Language Interface for an Autonomous Camera Control ...) (Evaluation of a Voice-Enabled Autonomous Camera Control System ...). For example, a surgeon might simply say, "show me the last CT scan" and the system will display the image, or say "next instrument" to have an assistant robot arm swap tools. This kind of hands-free interaction, made possible by NLP-based speech recognition (like OpenAI's Whisper or similar models integrated into surgical systems ([2409.10225] Voice control interface for surgical robot assistants)), can streamline the workflow. Second, NLP is used **post-operatively in documentation and analysis**. AI can transcribe the surgeon's dictated notes and even help write the operative report, picking out key details from the surgical video and the surgeon's comments. Finally, as mentioned earlier, NLP powers patient-facing chatbots that answer questions in plain language (AI Is Poised to "Revolutionize" Surgery | ACS). These chatbots essentially "understand" the patient's text or voice query and respond appropriately about post-op care. In the future, one can imagine an NLP-driven system that listens during surgery and proactively offers guidance ("You have ligated the left artery; next step is to mobilize the kidney – shall I adjust the retractor?"). While such interactive AI assistants are experimental, the pieces (speech recognition, language understanding, medical knowledge bases) are quickly falling into place. Overall, NLP brings **communication skills** to surgical AI – enabling more natural interaction between humans and machines in the surgical setting.

Key Trends, Major Players, and Investment in AI-Driven Robotic Surgery

The intersection of AI and robotic surgery is a hotbed of innovation, with significant trends shaping the industry and substantial investment flowing into new technologies. Below is an overview of the **key trends**, the **major players** (both companies and institutions), and recent **investment activity** in this space:

Trends Shaping the Field

- **Broader Adoption & Competition:** Robotic surgery has firmly entered the surgical mainstream, and as a result, many new systems are emerging. Intuitive Surgical's dominance is being challenged by a "new era of competition" as multiple entrants roll out their own robots (4 robotic surgery trends to watch in 2025 | MedTech Dive). This competition is expected to *accelerate* innovation and reduce costs. We also see robotics expanding to more surgical subspecialties – for example, a surge in robotic-assisted general surgeries (like hernias and colorectal cases) and even growth in areas like **orthopedics** (where robots like Stryker's Mako and Zimmer's Rosa are adding shoulder and spine procedures to their repertoire (4 robotic surgery trends to watch in 2025 | MedTech Dive)). There's also a push toward **outpatient robotic surgery** as systems become more compact and refined, potentially bringing robots into ambulatory surgery centers.
- **Toward Autonomy and Intelligence:** A clear trend is the integration of more AI-driven automation into surgical robots. While today's clinical robots are surgeon-controlled, we are seeing increasing levels of **smart assistance** (automatic camera positioning, intraoperative guidance) and even early examples of autonomy (as in the STAR robot's autonomous suturing demonstration (Robot performs first laparoscopic surgery without human help | Hub)). The vision for the future is "digital surgery" ecosystems where robots, AI diagnostics, and information systems are tightly integrated. Industry experts predict surgical robots will evolve with **digitalization and intelligence to overcome current limits**, like adding automated decision support and possibly closing the loop on simpler tasks (Robotic surgery in China - PMC). In parallel, there is growing interest in **telesurgery** – using robots to allow remote surgery. Advances in telecom (5G) and AI-driven latency compensation hint at a future where an expert in New York could operate on a patient in rural Africa via a robotic surrogate. Several remote robotic surgeries have already been trialed successfully (China has reported complex cases done over long distance networks (Chinese doctors successfully implement global first remote robot ...)), and continuing improvements in AI control and network reliability are making this more feasible.

- **Data-Driven Improvement & Training:** Another trend is the focus on using data and AI to improve surgical training and outcomes. With thousands of robot-assisted surgeries being recorded, companies are leveraging **analytics ("surgical AI") to assess performance**. Startups and research groups are creating AI tools that can grade surgical technique or provide coaching by analyzing video (almost like a "flight recorder" for surgery). This trend goes hand-in-hand with the rise of **simulation and VR training** for robotic surgery, often enhanced by AI to create realistic scenarios. The ultimate goal is to shorten the learning curve for new robotic surgeons and ensure consistent quality across the board. As part of this, **academic centers** and teaching hospitals are establishing specialized programs to train the next generation of surgeons in robotics and AI. All these efforts reflect a broader trend: treating surgical performance as a science – measurable, optimizable, and improvable via AI insights.

Major Industry Players and Innovators

- **Intuitive Surgical (da Vinci):** The pioneer and market leader, controlling roughly *two-thirds* of the global surgical robotics market (Positioning The Industry For Growth In Robotic Surgery). Intuitive continues to innovate (its latest generation, da Vinci 5, launched in 2023/24 with enhanced computing power for future AI features (4 robotic surgery trends to watch in 2025 | MedTech Dive)) and has a vast installed base that gives it a data advantage. Over 60,000 surgeons have been trained on da Vinci worldwide (Robotic Surgery Is Here to Stay—and So Are Surgeons | ACS).
- **Medtronic (Hugo RAS):** A major entrant aiming for the number two spot. Medtronic's Hugo system, a modular multi-port robot, is rolling out globally and expected in U.S. hospitals pending FDA approval (4 robotic surgery trends to watch in 2025 | MedTech Dive). Medtronic is embedding its expertise in navigation and imaging – and likely AI – to compete with Intuitive. They are also leveraging their reach in **overseas markets** (Hugo is available in 25+ countries already (4 robotic surgery trends to watch in 2025 | MedTech Dive)).
- **Johnson & Johnson:** J&J has invested heavily through its Ethicon division – notably acquiring Auris Health (and its Monarch robotic endoscopy platform) for $3.4 billion (J&J pays $3.4B for Auris Health surgical robotics platform). J&J has been developing **Ottava**, a general surgery robot, and also markets orthopedic

robotic systems (through its Depuy Synthes unit) and the **VASER** robotics for neurosurgery. J&J's strategy mixes building in-house robots and partnering (they previously collaborated with Google's Verily on Verb Surgical).

- **CMR Surgical (UK):** An emerging powerhouse from Cambridge, UK. CMR's **Versius** system offers a smaller, portable design with independent arm units. It has seen uptake in Europe, India, the Middle East, and Australia. CMR emphasizes open data architecture and has hinted at AI analytics as a service for hospitals using Versius. They achieved unicorn status with a $600 million funding round in 2021 (CMR Surgical raises $600 million in Series D financing), reflecting investor confidence.
- **Asensus Surgical:** Maker of **Senhance**, which differentiates itself with features like haptic feedback (through an enhanced sense of touch via instruments) and a digital interface that incorporates **augmented vision and machine learning** for instrument recognition. Asensus promotes its technology as "digitizing laparoscopic surgery" – essentially bringing some robotic and AI benefits to laparoscopic surgeons without the same footprint as a da Vinci.
- **Orthopedic Robotics Leaders:** In orthopedics, specialized robots are well-established. **Stryker's Mako** robot (for knee and hip replacements) and **Zimmer Biomet's ROSA** are widely used for precise bone cuts and implant placement. These systems rely on preoperative 3D imaging and AI-based planning to improve alignment and outcomes. Competitors like **Smith & Nephew** (with the Cori robot) and Medtronic (which acquired Mazor Robotics for spine surgery) also play here. While orthopedics robots are somewhat separate from soft-tissue surgical robots, there is cross-pollination of AI techniques – for example, using machine vision to help align surgical tools or track patient-specific anatomical landmarks.
- **New Entrants & Startups:** A number of startups are pushing the envelope. **Moon Surgical** is working on a co-manipulator robot that can assist laparoscopic surgeons (an "extra pair of hands" controlled by AI). **Activ Surgical** has an AI-driven visualization system that can overlay critical structures (like blood flow) on the surgical video in real time. **Proximie** and **Theator** are startups focused on telepresence and AI video analytics for surgery, respectively – showing that not all innovation is in the robots themselves, but also in connecting ORs and analyzing what happens within them. We're also seeing **tech giants** like Google and Microsoft collaborating in surgical AI: e.g., Google's

cloud AI is being used by some hospitals to store and analyze surgical videos, and Microsoft's HoloLens (AR headset) is used in some guided surgery applications. The ecosystem of players is large and growing, all contributing different pieces (robots, AI software, data platforms) to the future of high-tech surgery.

Leading Academic and Research Centers

Innovation in AI-driven robotic surgery isn't just from companies – many **universities and hospitals** lead groundbreaking research and training initiatives:

- **Johns Hopkins University:** A pioneer in surgical robotics research, JHU has a rich history from developing the early **AESOP and ZEUS** robots in the 1990s to today's advanced projects. JHU engineers and surgeons co-developed the **STAR autonomous robot** that performed soft-tissue surgery with minimal human help (Robot performs first laparoscopic surgery without human help | Hub). Their labs continue to explore autonomy, machine vision, and robotic instrument innovations.
- **Massachusetts General Hospital / Harvard:** MGH in Boston has established a Surgical AI & Innovation Laboratory, where clinicians like Dr. Jennifer Eckhoff are focusing on how AI can assist surgery (AI Is Poised to "Revolutionize" Surgery | ACS). They are exploring computer vision for surgical safety and machine learning for decision support. Harvard and MIT also collaborate on surgical data science, making the Boston area a hub for this research.
- **Stanford University:** With Intuitive Surgical located nearby, Stanford has long been involved in robotic surgery advancement. Many Stanford surgeons were early adopters of da Vinci, and the university's research has spanned haptic feedback systems, simulation training, and AI-driven outcome analysis. Stanford's AI labs also contribute to medical image analysis that feeds into surgical planning.
- **University of Cambridge (UK):** The technology behind CMR Surgical's Versius has roots in research from Cambridge. The university's engineering department and Addenbrooke's Hospital have a joint center for robotic surgery, working on novel robot designs and AI for improved ergonomics and efficiency in surgery.

- **Medical University of South Carolina (MUSC):** MUSC has been ramping up efforts to be at the forefront of AI and robotics. In 2024, it launched the **Harvey and Marcia Schiller Surgical Innovation Center**, a dedicated center for surgical innovation and research in AI (Vision 2030: Charleston, SC as a Hub for AI and Robotics Innovation, Anchored by MUSC - John Rector). Under the leadership of Dr. Arman Kilic – an internationally recognized expert in AI/machine-learning applied to surgery (Harvey and Marcia Schiller Surgical Innovation Center | College of Medicine | MUSC) – this center fosters interdisciplinary collaboration between surgeons, data scientists, and engineers. MUSC's team is leveraging their expertise (over 20 years in advanced surgical analytics (Harvey and Marcia Schiller Surgical Innovation Center | College of Medicine | MUSC)) to develop AI tools that can improve patient outcomes and operating room efficiency. The presence of this center is positioning MUSC as a national leader in "intelligent surgery" research. Academic involvement like this is crucial, as these centers often run clinical trials of new AI-guided techniques, train surgeons in using emerging technology, and partner with industry to validate cutting-edge robotic systems.
- **Other Notables: Imperial College London** (with its Hamlyn Centre for robotic surgery) conducts high-profile research on surgical robots, including micro-robots and AI navigation. **University of Toronto** and **University of Montreal** in Canada have strong medical robotics groups (the latter was behind the NeuroArm neurosurgical robot). In Asia, institutes like **Tsinghua University** in China and **KAIST** in South Korea are investing in surgical robotics research, often in partnership with local companies. These academic centers worldwide provide a testbed for new AI algorithms and help train the specialized workforce needed to drive robotic surgery forward.

Investment and Market Activity

The fusion of AI and robotic surgery has attracted **massive investment** from both corporations and venture capital, as stakeholders see it as a high-growth frontier in healthcare. A few highlights:

- The global surgical robotics market is booming – valued around **$12 billion in mid-2020s and projected to reach $40–50+ billion within a decade** (4 robotic surgery trends to watch in 2025 | MedTech Dive) (Robotic Surgery Services Global Market Report 2025). Analysts predict double-digit annual growth as adoption accelerates, with AI capabilities becoming a key selling point.
- **Venture Capital Funding:** There have been record-breaking funding rounds for surgical robotics startups. CMR Surgical's $600 million Series D in 2021 (valuing it at ~$3 billion) is one of the largest medtech financings ever (UNICORN PITCH DECK: CMR Surgery raised $600 million at a $3 ...). Companies like Verb Surgical (a Google/J&J joint venture) and Auris Health each raised hundreds of millions before being acquired. In the AI-for-surgery niche, startups focusing on surgical analytics or navigation (e.g. Activ Surgical, Proximie) have also drawn significant VC backing as hospitals look for ways to maximize the value of the data coming out of operating rooms.
- **Mergers and Acquisitions:** Established device companies have spent big to acquire innovative startups. Besides J&J's $3.4B Auris deal (J&J pays $3.4B for Auris Health surgical robotics platform), Medtronic acquired Mazor Robotics for ~$1.7B in 2018 to expand into robotic spine surgery. Stryker bought Mako Surgical for $1.65B in 2013, which gave it a lead in orthopedic robotics that continues today. These acquisitions often hinge on the software and AI expertise of the smaller companies as much as the hardware – for instance, Auris's Monarch system combined robotics with advanced imaging and data capabilities for lung diagnostics. We're also seeing partnerships: Google's Verily has partnered with J&J, and Microsoft with Medtronic, indicating cross-industry investment in this space.
- **Government and Grants:** Around the world, governments are funding research initiatives on surgical AI and robotics, recognizing it as strategic. The EU has provided grants for projects on autonomous surgical robotics. In China, provincial governments have supported domestic robot development to reduce reliance on imports (Robotic surgery in China - PMC). In the US, agencies like DARPA and NIH have funded academic research into AI-driven surgical systems (the STAR project received federal grants given its potential to improve combat casualty care with autonomous robots). This public-sector investment often seeds the breakthroughs that industry later commercializes.

- **Healthcare Providers:** Large hospital systems are also investing internally – creating "digital surgery" programs, purchasing new robots (often multiple competing systems to evaluate them), and setting up data analytics teams. There's recognition that AI and robotics can improve outcomes and potentially lower costs (through fewer complications and quicker recoveries), so despite the high upfront expense, many providers see it as a worthwhile long-term investment. Some hospitals even partner with manufacturers as early adopters in exchange for research data – effectively co-investing by dedicating OR time and staff to develop best practices for robotic and AI-enabled surgeries.

All told, the financial momentum behind AI in robotic surgery is strong. **Capital investment, both intellectual and monetary, is accelerating** the pace of innovation. This virtuous cycle of funding -> innovation -> clinical adoption -> outcomes data -> further funding is expected to continue over the next decade, making surgical robotics one of the most vibrant sectors in medical technology.

How MUSC Can Lead in AI and Robotic Surgery

With the trends above in mind, the **Medical University of South Carolina (MUSC)** is well-positioned to become a leader in the field of AI-driven robotic surgery. Here are some insights and strategies for MUSC to solidify its leadership:

- **Leverage the New Surgical Innovation Center:** The recently established Harvey & Marcia Schiller Surgical Innovation Center at MUSC is a pivotal asset (Vision 2030: Charleston, SC as a Hub for AI and Robotics Innovation, Anchored by MUSC - John Rector). By fully empowering this center, MUSC can foster interdisciplinary projects between surgeons, AI scientists, and engineers. The center should continue to support research that applies machine learning to MUSC's rich clinical data, develops AI tools for the operating room, and prototypes novel surgical devices. With Dr. Arman Kilic (a renowned AI expert) as director (Harvey and Marcia Schiller Surgical Innovation Center | College of Medicine | MUSC), MUSC has strong leadership; attracting additional talent – data scientists, robotics researchers, postdoctoral fellows – to work under this umbrella will accelerate innovation. The center can also serve as an **incubator for startups**: if a team of MUSC clinicians and engineers develops a promising

AI algorithm or device, the center can help spin it out into a company, tapping into the growing investment in this sector.

- **Expand Clinical Robotic Programs and Trials:** MUSC should strive to be an early adopter and evaluation site for emerging robotic platforms and AI software. For example, participating in **clinical trials** of new robotic systems (such as Medtronic's Hugo or other innovative devices) will not only give MUSC surgeons a first-mover advantage in mastering new tech but also put MUSC on the map in the industry. Similarly, MUSC can pilot AI-driven enhancements – like an computer vision tool that maps anatomy during surgery – and publish the findings. By leading or collaborating on multi-center studies of AI's impact on surgical outcomes, MUSC will build a reputation for academic leadership in this domain. The institution's breadth of surgical specialties (cardiac, oncology, GI, etc.) makes it ideal for testing AI in various contexts. A practical step could be establishing **protocols to systematically capture data** from all robotic surgeries at MUSC (video, sensor data, outcomes) and using that for continuous research – essentially turning every robotic case into an opportunity for learning and innovation.
- **Interdisciplinary Education and Training:** To truly lead, MUSC should produce the next generation of surgeons fluent in AI and robotics. This means incorporating **robotics and AI training into surgical residency and fellowship programs**. MUSC can offer specialized fellowships in "Robotic Surgery and Surgical AI," where trainees split time between high-volume robotic surgery practice and research in AI applications. Workshops or courses on data science for surgeons, perhaps in collaboration with MUSC's Department of Computer Science or biomedical engineering programs at partner institutions, would give MUSC a unique educational edge. Additionally, MUSC could host **simulation-based robotic Olympics or hackathons** (building on initiatives like the "Robot Olympics" MUSC has done for team training) (Serious fun: Robot Olympics helps surgical teams to hone their ...) to encourage surgeons and staff to ideate new uses for AI. By cultivating surgeons who are as comfortable at the console as they are interpreting an algorithm's output, MUSC creates ambassadors who will spread its influence.

- **Collaboration and Networking:** MUSC should continue to **forge partnerships** with both industry and academia. On the industry side, deepening ties with companies like Intuitive, Medtronic, J&J, or rising startups will give MUSC insight into the product pipeline and opportunities for joint development. For instance, MUSC could partner with a company to beta-test an AI-driven surgical navigation system in exchange for research credits or co-authorship on publications. On the academic side, MUSC can collaborate with leading AI institutes (for example, partnering MUSC's clinicians with AI experts at universities like MIT or Georgia Tech on joint grants). Hosting an **annual symposium on AI in Surgery** in Charleston could draw global experts and raise MUSC's profile as a thought leader. The goal is to position MUSC as a central node in the global network of surgical AI research – a place where ideas are shared and breakthroughs happen.
- **Leverage Charleston's Emerging Tech Ecosystem:** Charleston is poised to grow as a tech hub, and MUSC can be the cornerstone of that, especially in medical tech (Vision 2030: Charleston, SC as a Hub for AI and Robotics Innovation, Anchored by MUSC - John Rector) (Vision 2030: Charleston, SC as a Hub for AI and Robotics Innovation, Anchored by MUSC - John Rector). By 2030, visions suggest Charleston could be nationally recognized for AI and robotics innovation, anchored by MUSC's achievements (Vision 2030: Charleston, SC as a Hub for AI and Robotics Innovation, Anchored by MUSC - John Rector). To realize this, MUSC can work with local government and investors to attract **startup companies and venture capital** to the region. The Innovation Center could offer an accelerator program for health robotics startups, and MUSC's hospital system can provide the real-world testing ground for those innovations. Success stories (for example, if a homegrown MUSC algorithm gets FDA-approved or a device invented at MUSC gets acquired by a big company) will create a virtuous cycle of investment. In essence, MUSC should aim not only to lead within its own walls but to make Charleston a **magnet for AI and robotic surgery talent** – much like how Boston and Silicon Valley function in their domains.

In conclusion, MUSC's combination of **early adoption, dedicated innovation infrastructure, talented personnel, and regional influence** gives it a strong foundation to lead in AI-driven robotic surgery. By aggressively pursuing research, embracing new technology, training innovative surgeons, and collaborating widely, MUSC can carve out a national (even international) reputation. The payoff will be multifold: improved patient outcomes at MUSC, attraction of top-tier faculty and residents, economic growth in the region, and a seat at the table in shaping the future of surgery. As surgical practice transforms through AI and robotics, MUSC has the opportunity to be at the forefront of that transformation – demonstrating how an academic medical center can translate high-tech innovation into superior patient care. With vision and commitment, MUSC can indeed emerge as a **leader in the next era of surgery**. (Vision 2030: Charleston, SC as a Hub for AI and Robotics Innovation, Anchored by MUSC - John Rector) (Harvey and Marcia Schiller Surgical Innovation Center | College of Medicine | MUSC)