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Transformation

Paging Dr. Robot: The rise of surgical assistants

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Key takeaways

- Robotic surgery is moving from novelty to necessity. Once a niche tool for select procedures, surgical robots now assist across major specialties, offering surgeons greater precision and patients faster recovery times. This shift is redefining what "standard of care" looks like in operating rooms worldwide.
- However, it's important to note that while the technology is powerful, it is still evolving. Most surgical robots today operate at Level 1 autonomy, requiring human oversight. Yet advances in AI, imaging, and connectivity hint at a future where robots could plan, execute, and even perform remote surgeries, expanding access to care globally.
- And growth is accelerating. With the market projected to more than double from $23 billion in 2025 to $52 billion by 2030, according to BofA Global Research, surgical robots are poised to redefine surgical standards worldwide.

Surgical robots 101

A surgical robot is exactly what it sounds like – a robot designed to assist surgeons, most commonly on minimally invasive procedures. These robots have arms capable of holding small medical instruments that a surgeon can maneuver via a controller and a viewing screen. Currently, rather than replacing surgeons, these robots are leveraged by surgeons as a tool or assistant.

Multi-port vs single-port surgical robots

Surgical robots are categorized based on how many access points (ports) they create on a patient's body for a procedure. Multi-port versions use several small incisions (usually three to five ports) to accommodate robotic arms and tools. In contrast, single-port surgical robots consolidate all instruments through one, slightly larger, incision. They insert a flexible tube (called a cannula) into the patient's body, to provide a singular access point for instruments, and then deploy multiple arms within this incision to complete the procedure.

Surgical robots for different treatment areas

Surgical robots are increasingly being adopted across five major and rapidly growing medical specialties, including:

- **Laparoscopic surgery:** A type of minimally invasive surgery that uses a laparoscope (thin tube with camera) to look inside a patient's abdomen or pelvis. Surgical robots assist in a wide variety of these procedures, including thoracic/chest or general surgeries.
- **Orthopedics:** Surgical robots assist during operations like joint replacements or spinal procedures. They offer improved visualization and minimize damage to healthy bone tissue.
- **Panvascular:** Surgical robots can be designed to treat conditions affecting the vascular system, including the heart and brain.
- **Natural orifice:** These robots access internal organs through the body's natural openings (e.g., mouth etc.) for diagnostic or surgical purposes, commonly involving the lungs and stomach.
- **Percutaneous:** This form of surgical robot is used for procedures that involve accessing and/or collecting internal body tissue through small incisions in the skin. They are particularly useful for diagnostic biopsies in early-stage cancers (i.e. lung cancer) and for treatments like kidney stone removal.

Advantages of surgical robots

Enhances surgical precision and patient outcomes

Compared with conventional minimally invasive laparoscopic surgery, robotic-assisted procedures significantly reduce surgical trauma (physical injury or damage to tissues and organs resulting from a surgical procedure) and accelerate a patient's recovery post-surgery. Traditional laparoscopy can be challenging for physicians, as they must manipulate instruments and endoscopes (cameras) through fixed incisions on the patient's body. And because a surgeon's hand movement and instrument tip direction have an inverse relationship (i.e. when the doctor's hand moves one way, the instrument tip moves the other) – oftentimes referred to as the "chopstick effect" – manual control is unintuitive and technically demanding.

Surgical robots can address this limitation, by aligning the surgeon's hand movements with the instrument's tip direction. Additionally, robotic platforms filter out hand tremors, enhancing the doctor's precision and patient's safety. These capabilities help 1) reduce the patient's possibility of unexpected bleeding during surgery, 2) lower complication rates, and 3) lead to shorter recovery times.

Optimizes surgical dexterity

A surgical robot's instruments typically offer four degrees of freedom – or types of movement: 1) rotation: ability to turn around its own axis; 2) pitch: up-and-down tilt, like nodding your head; 3) yaw: side-to-side movements, like shaking your head "no"; and 4) grip: ability to open and close. Collectively, the four movements allow doctors to more accurately complete precise and complex tasks, like cutting, suturing, knotting, grasping, or clamping. The flexibility and control offered by these instruments gives them more advanced capabilities than both the human hand and traditional laparoscopic devices.

Improves surgeon's operating experience

From the doctor's perspective, surgical robots can also improve the operating experience, as they offer a high-definition, magnified 3D surgical view and an intuitive, easy-to-use control interface. Unlike traditional laparoscopy, which often requires surgeons to stand for long periods, robotic platforms allow surgeons to perform procedures while seated, reducing physical fatigue during lengthy operations.

Shortens learning curve for junior surgeons

Surgical robots offer doctors intuitive control and stabilize against hand tremors – which can significantly reduce the learning curve for new surgeons, compared with traditional laparoscopy. These features lower the risk of complications during early-stage procedures and enable surgeons to more rapidly excel in laparoscopic techniques across multiple specialties. As a result, this can expand the pool of qualified surgeons capable of performing minimally invasive procedures and increase the number of hospitals equipped to offer complex laparoscopic surgeries – which ultimately benefits a larger patient population, according to BofA Global Research.

Key segments and components of surgical robots

Surgical robots consist of several core segments and components that work together to enable precision and control, including:

- **Surgeon's console:** The surgeon's console consists of three major components: master controllers, a footswitch panel, and a stereo viewer. The master controllers and footswitch panel allow the surgeon to control the four robotic arms. Two instrument-holding arms, acting as extensions of the surgeon's hands, are manipulated via the master controllers. The remaining two arms – one holding the laparoscope and the other additional instruments – are controlled through the footswitch panel. The stereo viewer provides continuous 3D visualization for the surgeon.

- **Patient-side cart**: The patient-side cart has four robotic arms that operate surgical instruments and the laparoscope. Two arms function as the surgeon's left and right hands. The third adjusts, zooms, and rotates the laparoscope. The fourth adds instruments for complex procedures, enhancing surgical capabilities.

- **Vision system:** The vision system usually includes a 3D laparoscope with an HD stereo camera at its tip, an image processor, and a monitor. The camera delivers real-time, high-resolution 3D visualization from the surgical site, while the image processor enhances and transmits these images to the monitor for the surgeon's view.

- **Surgical instruments and accessories:** Key surgical instruments include scissors, ultrasound scalpels, and other tools. Designed for natural dexterity and a full range of motion through tiny incisions, these instruments often exceed the capabilities of a human hand. Internal cables, similar to tendons, provide maximum responsiveness for rapid, precise suturing, dissection, and tissue manipulation.

Surgical robot upstream: Servo system, reducer, and controller

There are three components of a surgical robot with high technological barriers: the servo system, the reducer, and the controller. The servo system — comprising a motor, encoder, and drive — provides power and enables precise, rapid, and stable position control. The reducer lowers the high rotational speed of the servo motor to match surgical requirements, using RV and harmonic reducers for smooth, low-noise operation and high transmission capacity. Acting as the robot's brain, the controller receives signals from all components and issues movement commands.

Force feedback system

Force feedback technology gives surgeons physical sensations that mirror the forces encountered by robotic instruments, creating more intuitive surgical experiences. According to BofA Global Research, this system offers several advantages: it enhances precision and dexterity by simulating the tactile feel of tissue, improves safety by supplementing visual cues, reduces mental fatigue through intuitive feedback, accelerates learning for less-experienced surgeons, and enables remote procedures by maintaining a sense of touch even at a distance.

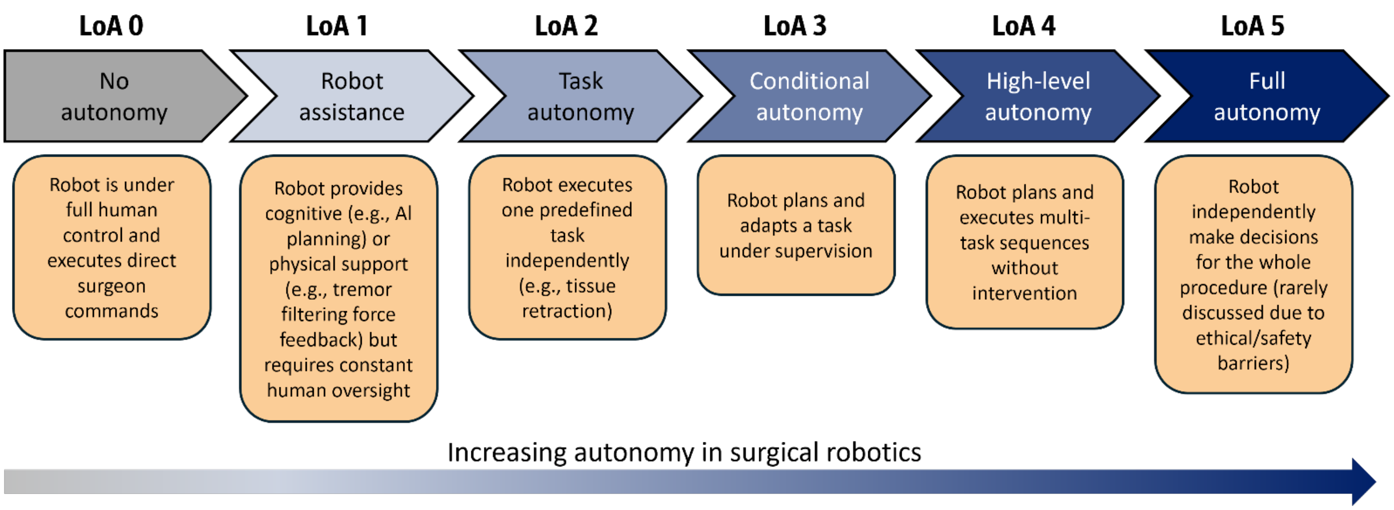
Levels of surgical robot autonomy

As shown in Exhibit 1, surgical robot autonomy is classified using the LASR (Level of Autonomy (LoA) in Surgical Robotics) framework, which spans from Level 0 (no autonomy; robot executes surgeon commands) to Level 5 (full autonomy; robot completes surgery independently). Globally, most clinically deployed surgical robots – and over 80% of total Food and Drug Administration (FDA)-approved models – operate at Level 1, where robots assist with planning or provide physical support but require continuous human oversight. Only a few systems currently achieve Level 2 (task autonomy) or Level 3 (conditional autonomy).

According to BofA Global Research, surgical robots used in hard-tissue procedures such as orthopedic surgery tend to exhibit higher autonomy, with some reaching Level 2 and 3. In contrast, laparoscopic surgical robots remain at Level 1. This difference stems from the predictability of bone structures, which can be accurately mapped preoperatively, enabling robots to execute predefined tasks with minimal mid-operation variability. Soft-tissue surgeries, however, involve dynamic conditions – such as breathing and blood flow – that introduce mid-operation changes, complicating autonomous planning and execution. Consequently, laparoscopic procedures still require human oversight.

Exhibit 1: A majority of currently approved surgical robots are still at Level 1 of autonomy, where robot provides cognitive or physical support but requires constant human oversight

Levels of autonomy in surgical robots



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AI applications for surgical robots

Today, artificial intelligence (AI) is revolutionizing surgical robotics by enhancing imaging, precision, and efficiency in the operating room. According to BofA Global Research, some of the most impactful AI applications driving this transformation include:

- **Personalized planning:** By integrating preoperative imaging (i.e., from a computed tomography (CT) scan), AI could provide personalized surgical planning and 3D modeling.
- **Automated segmentation and registration:** AI helps orthopedic surgical robots by automatically capturing medical images, identifying key structures (like bones and joints), and matching those images to the patient's body during surgery.
- **Real-time computer vision:** AI can annotate (or mark) critical parts of the patient's body, such as blood vessels and nerves, reducing the risk of errors and complications during surgery.

- **Precision execution:** AI helps surgical robots perform orthopedic procedures with greater accuracy. For spine surgery, it can guide the robot to place screws in the right spot on the vertebrae. In trauma cases, AI can pinpoint exactly where a bone is broken. For joint replacements, AI could ensure the robot follows the pre-surgery plan closely, reducing mistakes and improving recovery for patients.

- **Post-operative monitoring:** By analyzing recovery data, AI can predict complications such as early infection detection from imaging and reduce patient readmission rate.

- **Surgery review and surgical training:** By using video, kinematic data (data regarding surgical robot movements), patient information and outcomes, AI can evaluate a surgeon's performance, provide personalized feedback, and improve training and therapeutic outcomes.

5G + AI remote surgery

Remote surgery, or telesurgery, uses high-speed 5G networks or satellites to connect surgeons with surgical robots, enabling procedures on patients thousands of miles away. High-definition camera feeds give surgeons a clear view, while their commands are transmitted in real time to the surgical robot's arms.

According to BofA Global Research, remote surgery expands equitable healthcare access by overcoming geographical barriers. Though still in early stages of development and requiring significant infrastructure, BofA Global Research believes it has the potential to enhance patient outcomes and save lives, especially in regions lacking surgical expertise. Future innovations, such as mobile surgical units, could make remote interventions viable for emergencies like stroke-related neuro procedures.

Surgical robot market expansion

BofA Global Research notes that the surgical robot market could grow steadily over the next decade, potentially driven by: 1) robotic surgery gradually becoming the standard of care; 2) rising demand for precision and shorter recovery; 3) next-generation technologies – such as remote surgery; 4) greater robot autonomy to enhance surgeon's efficiency; and 5) expansion into new disease areas to address unmet demand. In fact, BofA Global Research expects the global surgical robot market to reach $23 billion in 2025 and expand to $52 billion by 2030.

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Disclosures