GEAR- OR ACTUATOR-DRIVEN,

These Bots are Cutting-Edge

Jack McGuinn, Senior Editor

A surgeon at the controls of an Intuitive da Vinci surgical system. The surgeon—via the 3Dviewfinder/monitor and with the help of a surgical assistant—directs the robot's four available arms to where they need to be in order to perform a surgical procedure. (Source: Intuitive Surgical.)

Robots are everywhere these days—bots in the factory, bots in space, bots at the airport, bots in the movies and much, much more. But robots in the operating room?

And why not? They may not have the sex appeal of a George Clooney back in his ER days, but they'll certainly have a much longer run. In truth, surgical robotics has been around since the early 90s, but today's OR robots are more Dr. Who than Dr. Kildare.

Nora Distefano, marketing communications and services specialist for California-based Intuitive Surgical, Inc., provides some historical perspective relative to the da Vinci robot system.

"The original prototype for Intuitive Surgical's da Vinci surgical system was developed in the late 1980s at the former Stanford Research Institute under contract to the U.S. Army. While initial work was funded in the interest of developing a system for performing battlefield surgery remotely, possible commercial applications were even more compelling. It was clear to those involved that this technology could accelerate the application of a minimally invasive surgical approach to a broader range of procedures.

"In 1995, Intuitive Surgical was founded to test this theory. In January 1999, Intuitive launched the da Vinci surgical system, and in 2000, it became the first robotic surgical system cleared by the FDA for general laparoscopic (abdominal) surgery. In the following years, the FDA cleared the da Vinci system for thoracoscopic (chest) surgery for cardiac procedures performed with adjunctive incisions, and urologic and gynecologic procedures."

Today, according to Distefano, Intuitive's robots are "practicing" in most U.S. metropolitan centers and in more than 25 countries around the world.

Once one gets past the Brave New World fact that robots are here to stay—in the operating room and practically everywhere else—what sets robots apart from their human counterparts is their ability to perform highly delicate surgical procedures by way of the smallest incision possible. This "key-hole" procedure, as it is known, results in much less tissue damage to the patient and thus a much faster recovery time. What's more, the risk of post-operative infection is greatly reduced.

Back near the other coast, Ft. Lauderdale-based Mako Surgical Corp. has its own stable of robotic surgical stars, if on a lesser scale due to the company's brief history. While the much more established Intuitive focuses on a wider variety of surgeries, Mako's niche is orthopedic procedures, especially knees and other joints.

"We're starting out with minimally invasive knee replacement or knee resurfacing surgery, and our platform can potentially be used in many other areas of orthopedic surgery," says Rony A. Abovitz, Mako chief technology officer. "Our technology on its own is attracting significant, key opinion leaders. Orthopedic surgery has been fairly static for 20–30 years in terms of implant design and implementation—nothing really earth-shattering going on there; same carpentry-like tools—so bringing in a tactilely guided robotics platform really captures their imagination. So we're getting a lot of like-minded thought leaders because of this technology platform. When they work with us, they want to see orthopedic surgery get to the next level."

Speaking of technology, the two companies take distinctively different approaches in the design and implementation of their robots.

Intuitive takes a somewhat more traditional direction in robot technology in that they incorporate gears—plastic, aluminum and stainless steel; hobbed and molded—along with cables, bands and timing belts, to power their progeny. But there is one constant among all robotry—power and motion control.

"Drivetrain design is a critical part of the da Vinci system," says Sal Brogna, Intuitive vice president of engineering. "We endeavor to design a system that faithfully represents all the delicate hand motions that a surgeon must use during surgery. In the da Vinci, this means very precise motion between the master and slave manipulators. We accomplish this by having drivetrains of very low friction, high stiffness and virtually no backlash.

"In total, each da Vinci system has 39 servo-controlled axes of motion. We have an additional 17 axes that provide passive motion for system setup."

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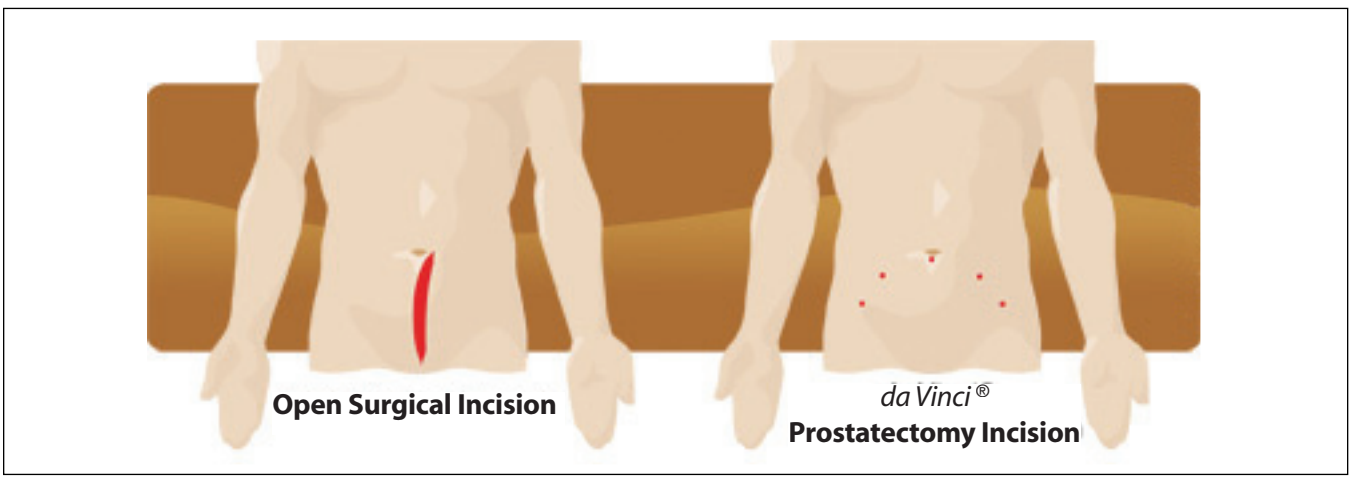


An example of one of robotic surgery's greatest benefits—"key hole" incisions, as seen in this prostatectomy illustration. The smaller incision means faster healing, reduced body trauma, infection risk and shorter hospital stays. (Source: Intuitive Surgical.)

Given that there are 27 bones in the human hand—each with a specific motion and motor control function—it is understandable why such a complex amalgam is necessary. To accomplish it, Brogna says Intuitive recruits engineers from the robotics or medical device industry. But, surprisingly enough—no surgeons.

"We have a team of clinical engineers," says Brogna. "These are a unique group of people that have both technical training and medical training. They help the design engineers translate design approaches to surgeon needs. They work intimately with both the surgeons and the design engineers. We also send our design staff out to the field to observe procedures done with the da Vinci system."

Returning to the robot technology/design issue, Mako takes a quite different approach to precise motion and power transmission control—i.e., no gears. For their bots, actuation is where the action is.

"(Our robot) is singularly designed not to use gears," says Abovitz, "but it's a very novel, interesting transmission. Everyone thinks about robots having gears, but ours uses a tension cable drive transmission, which has the benefits of the tension cable, which offers very low friction and incredibly good back-drivability. With our system, you're also able to have great haptic (tactile) control. So as a robot actually designed to enable haptics—probably one of the first (robotics) platforms designed to do that—the idea of this robot was to put your hands on it, so it can be manipulated anywhere from its tip to the entire length of the arm.

"You can move it around with smooth, low-friction transmission. There's a mode the robots use called a neutral-gravity mode; while weightless you can move it around very easily to a mode where it is incredibly stiff and is force-controlled, and it is basically providing torque resistance."

Accomplishing these tasks are in essence the work of the tension cable drive transmission; that and a number of proprietary, DC servo motors and actuators. The intricate yet relatively powerful motors do the yeoman's work throughout the Mako robotic system. Together, the motors and actuators afford the robot an ease and fluidity of motion along with the capability to stop instantaneously, when needed; which is, of course, quite often in the performance of surgery.

"So the robot lets you simulate the virtual physical constraints we want to help guide a surgeon and his tool," says Abovitz. "The key is the tension cable transmission system which is free of gears; it's a novel, proprietary system. So what (the surgeon) gets is a continuous transmission in a very smooth motion—from stiff to free range of motion instantly.

"It's a cable transmission, so if you think of what a gear does—connected to a motor moving other gears—we've got these cable transmission drives that are connected to these proprietary motors that drive other cable transmission parts of the robot. So, to a degree, what you think of as a gear—we have this tension cable drive. Adds Abovitz, "There are different sorts of continuous transmission systems that are non-geared."

Mako Surgical, specializing in knee and other joint orthopedic surgeries, including knee replacement and resurfacing, relies on its patented Tactile Guidance System for enhanced haptics.

Mako's surgeon-friendly Tactile Guidance System consists of a robotic arm with a haptic—or sense-of-touch—capability for precise bone resection and bone-saving cutting. (Source: Mako Surgical.)

Whether it is actuators or gears, there is one area where Intuitive and Mako find common ground—software. And as you can well imagine, we're not talking off-the-shelf programs. These are proprietary, extremely robust designs that—along with hardware—are the heart of both company's robots.

"Our system is strongly software-based," says Intuitive's Brogna. "We have a terrific staff of embedded software and system analysis engineers that develop the software for our product. Software controls all elements of our motion control, user interface and safety systems.

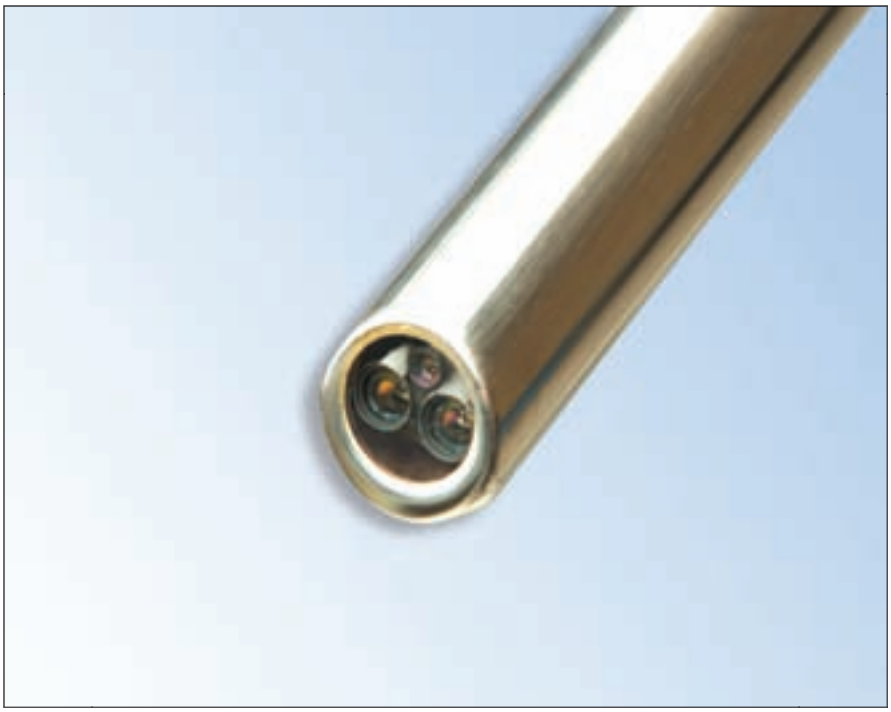
"It is incredibly challenging to develop the software. All software must operate in real time, so code must be very efficient and execute quickly."

At Mako, same thing.

"Software is a major component," says Abovitz. "In our system there are two main computing architectures—one is the control system for the robotic arm, and we have a program that communicates to our higher-level surgeon application software. We write and develop most of the software here. The robot control software is based using a *QNX* platform—a real-time operating system—and when you write to *QNX* you can have probably the fastest possible control over your robotic hardware and firmware. The *QNX* operating system is great for that.

In explaining the visualization side of the software, Abovitz explains that surgeons work from a 3D model—gained via CAT scan—of a reconstruction of the patient's knee. There is also a large screen positioned in front of the surgeon (providing the term "operating theater" an entirely new dimension) displaying real-time updates and 3D pictures as the surgeon—with the robot as his proxy—sculpts away at the knee in need of reconstruction.

"The software provides visualization guidance to the surgeon who does not have great visualization due to the small incision they are working through." Abovitz says. "And the robot provides tactile guidance; it constrains where the instrument (scalpel, etc.) can go. The surgeon is free to move inside the incision, but



A close-up of the scope that provides 3D imaging of the surgical area.

Intuitive's "Fourth Arm" is an integral part of its da Vinci system. The first two arms represent the surgeon's left and right hand and hold the surgical instruments. The third arm positions the 3D imaging scope, and an optional fourth arm is for adding an additional surgical instrument, effectively giving the surgeon three hands to work with. (Source: Intuitive Surgical.)

when or if he's going to the wrong place it feels like he's hitting a piece of glass or a constraint. Basically, it locks him into where he should be working."

In essence, both Intuitive's and Mako's robot systems have fail-safe mechanisms. Should there be some event—a power outage, perhaps—that makes proceeding with the surgery risky, the robot will shut down completely. Aside from that, the tactile capability specific to both bots alerts the surgeon as to whether he or she is working on the exactly correct area in need of repair. That's because the mentioned visualization software prevents the surgeon from entering an incorrect or unaffected area.

What, you might be asking at this point, are a surgical robot's limitations? Intuitive's Distefano points out some concerns, such as an extended learning curve on the part of surgeons and surgical staff, prolonged OR time or loss of haptics when compared to open surgery.

"Clinical studies suggest that although OR times are higher at first, they decline significantly with experience and soon become equivalent or comparable to those times measured with open procedures," she says. "Studies also suggest that loss of haptics as compared to open surgery is compensated for with significantly improved visualization, dexterity, control and ergonomics."

(By the way, should you be shopping for a robotic surgeon, Intuitive's lists at about $1.5 million and Mako's at $795,000.)

This is pretty impressive stuff, but what will the next generation of surgical robots look like?

"We believe that surgical robots will become a standard form of healthcare in hospitals in many settings and disciplines," says Distefano. "The added precision, visualization, articulation and data fusion that surgical robots provide are widely applicable to treatment.

"In addition, orthopedic, catheter-control and other medical robots will also take their place in healthcare. The use of automation in surgery and healthcare will progress slowly—autonomous robots for use in healthcare will start by taking on particular tasks, rather than whole procedures."

In other words, look for robots to be taking your temperature and monitoring your blood pressure at hospitals of the future.

For Abovitz, the anticipated upgrades should translate to elevated confidence in surgeons and peace of mind for patients.

"If you put robotics together with a human in the right way, the outcome should be like the surgeon's best day, every day. It's like taking an average golfer and every day he's Tiger Woods. The ultimate vision is the best doctor on his best day—everyday, everywhere."

(*PTE reader web poll question: If you had a choice, which would perform your surgery?*)

A. Robot-assisted surgeon
B. Surgeon only
C. No preference

(*Log onto powertransmission.com/poll/ to vote and see how others voted.*)

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The Mako surgical robot system. (Source Mako Surgical.)

Sal Bragna, Intuitive Surgical vice president of engineering.