Needle biopsies are messy medical procedures. Patients risk punctured organs if physicians make even slight mistakes. And tiny malignant growths can elude the aim of even the most skilled surgeon. Worse, biopsies can create significant post-operative pain if doctors have to adjust the trajectory of the needle in mid-test.

Where a physician might waver, however, a robot could aim true. At least, that's the theory of Daniel Stoianovici, director of Johns Hopkins University's URobotics Lab in Baltimore. Stoianovici and his fellow scientists have built a needle-wielding robot, designed to work in conjunction with magnetic-resonance imaging (MRI) systems, that can achieve accuracy to within one-tenth of a millimeter -- much better than is possible with the human hand.

To function inside the snug MRI chamber, the robot had to be no larger than a human arm. And because the MRI's strong magnetic field prohibits the use of metal, Stoianovici built his device out of ceramics, plastics, and...
rubber. Hydraulic pulses sent from a pumping station hooked up to a computer power six small motors that finely position the robot's slender arm and drive the needle into the body.

**GOLDEN AGE.** Stoianovici hopes his invention will soon be used for everything from performing biopsies of precancerous spots in the lungs to guiding pinpoint delivery of chemotherapy. Already, radiologists at the Georgetown University Medical Center in Washington, D.C., are testing an early generation of URobotics' robots to see how they perform the delicate task of delivering anesthetics to the spinal chords of back-pain sufferers -- with doctors using joysticks to guide the needle. And all this tech wizardry runs not on proprietary, one-of-a-kind equipment but on standard Windows computers.

Welcome to the new world of high-tech medicine, where doctors do mindmelds with machines, drugs are targeted directly at tumors, surgeons rarely use their own hands to make a cut, and -- most important -- where improvements in medical imaging make the body's inner workings transparent to a degree unimaginable even a decade ago.

Driven by the rising health-care demands and spending power of the baby boom generation, medical technology looks set to enter a golden age. That doesn't necessarily mean medicine will be cheaper. But thanks to the rapid adoption of technology ranging from pacemakers that can be monitored from a Web browser to liquid bandages that can replace painful stitches and flake away when a wound is healed, 21st century medicine may deliver more for the money. Almost certainly, it will also be less dangerous and less painful for patients -- at least, in developed countries.

**DEADLY PENMANSHIP.** Still, the medical Establishment has been slow to adopt state-of-the-art technology. Hospitals may have sprung for MRI machines and other scanners -- advanced diagnostic equipment that commands handsome patient fees -- but they're still slow to spend on tech. While the average bank spends 7% to 9% of its annual budget on information technology -- often to automate jobs out of existence -- most hospitals spend less than 5%, according to Lewis Redd, who runs the $700 million annual health-care practice for systems integrator Cap Gemini Ernst & Young. That's because the trade-off for better care is higher costs -- which many health organizations are loath to incur and many insurers, including the biggest of all, Uncle Sam, have refused to permit.

As a consequence, "medicine today remains a largely paper-driven system," says Dr. Henry Lowe, an associate professor of medical informatics at the Stanford University School of Medicine. Frequently, sharing records means shipping phone-book-size charts from one office to another. Prescriptions are still scribbled on pads, and treatment orders are tracked haphazardly -- despite a landmark 1999 study by the Institute of Medicine, an arm of the U.S. National Academy of Sciences.

The NAS report pegged the number of accidental deaths resulting from
mistakes by medical caregivers, such as incorrect drug dosages or misread prescriptions, at a minimum of 44,000 a year. The total cost to society, the study found, is at least $17 billion annually. The institute also calculated that fatalities could be as high as 98,000, with a cost as high as $29 billion. "The most dangerous instrument in medicine is the fountain pen," declares Duncan James, a group president at McKesson (MCK), the nation's No. 1 distributor of drugs and medical equipment.

WIRELESS DOCS. At last, though, a number of factors are combining to push medicine well into technology's 21st century. One is simply the pace of innovation, which is producing quantum leaps in the capability of medical devices. For instance, the tight coupling of surgical and imaging equipment promises to let doctors work more accurately in the operating room. Easy wireless connectivity and zippy handheld computers are finally providing peripatetic physicians with the information they need in a convenient digital format.

And in drug development, cheaper computing power is giving scientists an affordable and powerful tool for understanding more precisely how diseases start and evolve, since they can now test endless biochemical permutations for toxicity and efficacy, something that would have been impossible only five years ago.

To some extent, these trends owe their impetus to the legal requirements of the Health Insurance Portability & Accountability Act (HIPAA) of 1996. The law, which is taking effect in stages as the government clarifies its requirements, will ultimately compel hospitals to not only guard patient data more closely but to upgrade their electronic record-keeping systems. This will have the positive side effect of forcing hospitals, physician offices, and insurers to install up-to-date networks that for the first time will be broadly compatible with each other.

GENE GENIES. That's a prerequisite for a future in which doctors will rely more heavily on computer-based clinical-support systems to diagnose illnesses and prescribe treatments. According to Stanford's Lowe, nearly 40% of the nation's hospitals have either installed such systems or plan to in the near future.

Of course, such advances will only be as useful as the basic medical knowledge behind them. And that will depend a lot on how successfully drugmakers exploit the recently completed mapping of the human genome, the 30,000 to 60,000 genes that make up the human body. No company has been able to win U.S. Food & Drug Administration approval for a gene-based drug, yet scientists continue to build the foundations for such breakthroughs.

Consider: On Oct. 10, researchers from the University of Cincinnati published a study in the New England Journal of Medicine identifying two genes that, when they occur together in a patient, appear to raise the likelihood of congestive heart failure tenfold. As such discoveries proliferate, they'll lift the veil on the complex genetic interactions that
lead to physical infirmities or diseases.

**Better Targets.** Genetic research is painstaking and technologically intense. "We take [gene] samples from sick people, look at which [genes] are active, then compare the diseased [individual's genes] to a normal person's," says Jeffery Cossman, medical director of GeneLogic (GLGC), a Gaithersburg (Md.) company that compiles genetic databases and sells them to drug companies. "We generally find relatively few differences -- 500 to 1,000 genes -- between diseased patients and normal people."

Cossman says statistical analysis further winnows the field until scientists can possibly pinpoint the specific gene interactions that cause a condition -- methodology that has become possible only within the last few years, as scientists have fine-tuned the necessary computer tools.

GeneLogic's aim is to simply provide better targets for drug companies. But ultimately, such research could yield a detailed roadmap for personalized health care that includes everything from gene-specific medications to lifestyle recommendations and an opportunity to learn from unprecedented observation of the body in action. Explains Cossman: "During disease and cure, we can profile the steps cells took and determine how they regenerate and repair themselves."

**Ticker Transmissions.** Increasingly, such knowledge will come not just from studying genes but from analyzing the information collected by a widening array of implanted medical devices. Take the common pacemaker. Once charged solely with keeping hearts beating at a steady pace, pacemakers now contain sensors that detect when a patient is exercising and adjust heart rhythm accordingly. "Today, pacemakers are able to record and store the electrical behavior of the heart," says Richard Sanders, vice-president for global marketing for cardiac-device maker Guidant (GDT) in Indianapolis.

In the near future, Sanders believes, pacemakers will also be able to monitor and record other key data such as blood pressure and lung-fluid buildup (to spot pulmonary edema, a potentially fatal corollary to heart failure). All that information will be uploaded from the pacemaker to the Internet via radio transmitters at the patient's home, allowing physicians to remotely monitor patients in real time and advise them to come in if things look amiss. "It's a natural progression for an implantable device," says Sanders.

That mirrors the technological path the medical-device market has taken in combining multiple functions on a single platform. Johnson & Johnson (JNJ) in New Brunswick, N.J., and other companies are also rolling out a new generation of coronary-artery supports called stents. Doctors use these metal loops to hold arteries open after surgery to prevent clogs.

**Ever-Smaller Holes.** The latest stents not only support the artery but also are coated with drugs to prevent future clogs. "You're going to see this
drug-device interaction more and more," says Johnson & Johnson CFO Robert Darretta. "It's one of the reasons we merged with the drug-delivery company Alza." The upshot is that physicians can perform more medical functions with the same device and often collapse the time and cost required to diagnose and treat a condition.

Even as multifunction devices are becoming the norm, scientists and physicians are working to move existing technologies to the next level. Take the field of minimally invasive surgery, where surgeons cut a small hole in the skin to insert slender instruments that perform procedures while leaving the body cavity largely intact. In the mid-1990s, sophisticated robotic surgical devices began to appear that offered surgeons much greater flexibility than earlier technology.

These new systems, from Computer Motion in Goleta, Calif., and Intuitive Surgical in Sunnyvale, Calif., cost up to $1 million apiece and require an opening only the size of a pencil head to enter the body. They also gave surgeons "wristed motion" -- instruments that could respond to twists of the wrist, unlike the first generation of tools. The latest robotic systems can even let surgeons control multiple instruments simultaneously while watching an easy-to-view panel showing a patient's vital signs.

LESS TRAUMATIC. Such advances have allowed surgeons in early-adopter hospitals to take minimally invasive techniques beyond such relatively simple procedures as hernias and into more complex and delicate operations such as brain and cardiac surgery. The benefit for patients is reduced pain and shortened recovery time.

Equally important, new robotic devices allow surgeons to replace major exploratory surgery with far less traumatic procedures. Combine this with better imaging techniques from more powerful MRI machines, and doctors can imagine a future where surgery rarely requires big incisions.

While the gee-whiz technologies in medicine are sexy, the real lifesaver will likely be better decision-making. That will come from providing computer backup for overworked doctors, nurses, and pharmacists. Long resisted by hospitals as overly costly, all-encompassing decision-making support systems attempt to digitize accepted medical standards and practices and insert them into the diagnostic and prescription process. "If a physician wants to run a fluoroscopy on a patient who also happens to have kidney problems, the system could provide a reminder that the dyes for the fluoroscope are very hard on the kidneys," explains Stanford's Lowe.

COMPUTER BACKUP. And in cases where prescribing a precise amount of medicine is crucial, the system could help physicians calculate proper dosages, says McKesson's James. He cites the example of heparin, a medicine that would likely be prescribed for potentially fatal dislodged blood clots.
Says James: "Accurate dosing of heparin is critical because if too much is prescribed, the patient can bleed uncontrollably. If too little is prescribed, the clot can get worse. And heparin dosage calculation is quite complex. So if physicians perform the calculation manually, there's potential for improper dosing." With a clinical support system, a doctor could punch in the patient's weight and other vital information, and receive a dosage recommendation that could be forwarded to the pharmacy with a mouse click.

Such support systems can even travel to the patient's bedside if physicians are equipped with handheld computers or personal digital assistants (PDAs) and wireless connections. Stanford University is in the process of blanketing its medical campus with a Wi-Fi broadband network and is training its physicians to use PDAs on the job. "Clinicians are nomadic," says Lowe. "They don't sit at desks. One of the difficulties is that a lot of the technology we have used to date has been delivered at the desktop."

**Tech Consensus.** Of course, such systems are pricey -- as much as $50 million. Thus, only a handful of U.S. hospitals are using them, even though employers are increasingly giving their insurance and health-care business to facilities that have installed them. For now, the market is consolidating around four or five top suppliers, including Siemens (SI) and McKesson.

That's creating the type of technology consensus that risk-averse health-care executives typically want to see before they put themselves -- and their money -- on the line. "The clinical decision-support system sector is becoming much less of a boutique industry with lots of small players," says Steven Parente, a professor at the University of Minnesota business school who studies health care.

From boutique to mainstream has been a long haul for many medical technologies. But lots of the latest innovations appear to be picking up momentum. While the rest of the venture-capital market crashed in 2000 and 2001, VC funding of biotech and medical-technology startups continued to rise. "The value of a late-stage product has gone up precipitously over the past two years," says Michael Lytton, a managing partner at Boston-based venture capitalist Oxford Bioscience Partners. His firm's latest $450 million biotech venture fund was oversubscribed.

That's ironic, given Wall Street's less-than-sanguine view of the biotech, drug, and medical-technology sectors at the moment. The dot-com feeding frenzy aside, VCs are generally no fools -- and following their money could provide a glimpse into the future of medicine.

By Alex Salkever, Technology editor for BusinessWeek Online

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