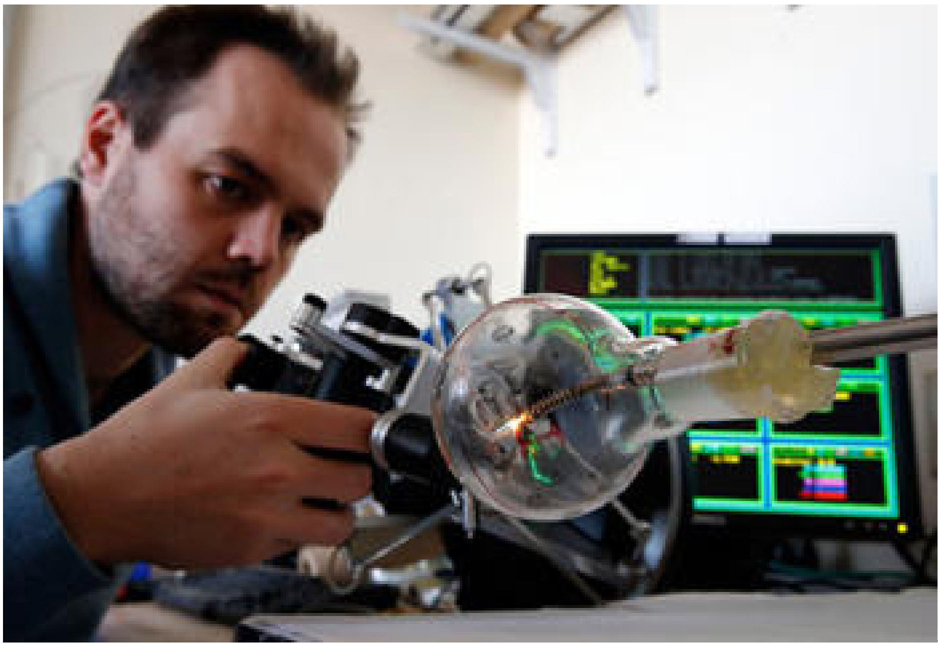
Telerobotic System Designed to Treat Bladder Cancer

Vanderbilt University



Although bladder cancer is the sixth most common form of cancer in the U.S. and the most expensive to treat, the basic method that doctors use to treat it hasn't changed much in more than 70 years.

An interdisciplinary collaboration of engineers and doctors at Vanderbilt and Columbia Universities intends to change that situation dramatically. Headed by Nabil Simaan [1], associate professor of mechanical engineering at Vanderbilt, the team has developed a prototype telerobotic platform designed to be inserted through natural orifices – in this case the urethra – that can provide surgeons with a much better view of bladder tumors so they can diagnose them more accurately. It is also designed to make it easier to remove tumors from the lining of the bladder regardless of their location – an operation called transurethral recession.

“When I observed my first transurethral resection, I was amazed at how crude the instruments are and how much pushing and stretching of the patient's body is required,” Simaan said.

That experience inspired the engineer to develop a system that uses micro-robotics to perform this difficult type of surgery. Its features and capabilities are described in an article titled “Design and Evaluation of a Minimally Invasive Telerobotic Platform for Transurethral Surveillance and Intervention” [2] published in the April issue of the journal *IEEE Transactions on Biomedical Engineering* [3].

The specialized telerobotic system “doesn't take the judgment out of surgeons' hands, it enhances their capabilities and hopefully gives them surgical superpowers," commented S. Duke Herrell [4], an associate professor of urologic surgery and biomedical engineering, who specializes in minimally invasive oncology at Vanderbilt University Medical Center and is collaborating on the project.

The traditional method, which Simaan observed, involves inserting a rigid tube called a resectoscope through the urethra and into the bladder. The instrument contains several channels that allow the circulation of fluid, provide access for an endoscope for observation and interchangeable cauterizing tools used to obtain biopsy tissue for evaluating the malignancy of the tumor and to resect small tumors. In some operations, surgeons replace the cauterizing tool with an optical-fiber laser to destroy tumor cells.

Although the endoscope can give a good view of the bladder lining directly across from the opening of the urethra, inspecting the other areas is more difficult. The medical team must press and twist the scope or push on the patient's body to bring other areas into view. These contortions are also necessary when removing tumors in less accessible areas.

If the surgeon, using endoscopic observation or biopsy, determines that a tumor is invasive and has penetrated the muscle layer, then he later performs a cystectomy that removes the entire bladder through an incision in the abdomen. Frequently this is done using a normal surgical robot. But, when the surgeon judges that the tumor is superficial—restricted to the bladder lining—then he attempts to remove it using the resectoscope.

Bladder cancer is so expensive to treat in part because the tumors in the bladder lining are exceptionally persistent and so require continuing surveillance and repeated surgeries. Among the factors that contribute to this persistence is the difficulty of accurately identifying tumor margins and failure to remove all the cancerous cells.

"Because you are working through a long, rigid tube, this can be a difficult procedure, especially in some areas of the bladder," said Herrell.

The telerobotic system is designed specifically to operate in this challenging environment. The machine itself is the size and shape of a large Thermos bottle but its business end is only 5.5 millimeters in diameter – about one fifth of an inch – and consists of a segmented robotic arm. The tiny arm can curve through 180 degrees, allowing it to point in every direction including directly back at its entry point. At the tip of the arm is a white light source, an optical fiber laser for cauterization, a fiberscope for observation and a tiny forceps for gripping tissue.

The engineers report that they can control the position of the snake-like arm with sub-millimeter precision: a level adequate for operating in clinical conditions. They have also demonstrated that the device can remove tissue for biopsies by gripping target tissue with the forceps and then cutting it off with the laser.

The fiberscope produced a 10,000-pixel image that was directed to a digital video camera system. Because it is steerable, the instrument was able to provide closeup views of the bladder walls at favorable viewing angles. However, the testing revealed the camera system's effectiveness was limited by poor distance resolution. According to the researchers, this can be corrected by re-designing the fiberscope or by replacing it with a miniature camera tip.

In the future, the researchers intend to incorporate additional imaging methods for improving the ability to identify tumor boundaries. These include a fluorescence endoscope, optical coherence tomography that uses infrared radiation to obtain micrometer-resolution images of tissue and ultrasound to augment the surgeon's natural vision.

In addition to these observational methods, the researchers have given their robot arm a sense of touch. Using a technique called force-feedback, they can measure the force acting on the tip when it comes into contact with tissue. Normally, tumors protrude from the surrounding tissue. Vanderbilt Ph.D. candidate Andrea Bajo [5] used this fact to successfully design new algorithms that allow the robot arm in the device to accurately trace a tumor's edge. He did so by positioning the tip on the edge of a tumor and instructing it to move in the direction that maintains the same pressure.

"Surgeons can typically identify the gross visual margin of a tumor within a millimeter, but a robot like this has the potential of doing so with sub-millimetric precision and additional technologies may actually be able to distinguish margins at the cellular level," said Herrell.

The team plans to make use of this level of precision to program the robot to perform what surgeons call an "en-block resection," the removal of an entire tumor plus a small margin of normal tissue in one operation. That procedure is designed to ensure that no cancerous cells are left behind that can reseed the tumor.

The engineers are also using the system's capabilities to design a number of safety measures into the telerobotic system. For example, the operator can set a maximum depth that the laser will cut and, even if the operator’s hand slips, the robot will not cut any deeper.

These safety measures are an example of Simaan’s primary research goal: develop surgical robotic systems that can be inserted into the human body and interact safely with it.

Work on this system began with Simaan’s former Ph.D. student Roger Goldman [6] and Lara Suh-MacLachlan at Columbia University. Ryan Pickens, a fellow at Vanderbilt University Medical Center, is also a team member. Simaan and Bajo received partial support from NSF Career grant #IIS-1063750.

For more information visit www.vanderbilt.edu [7].

Links:
[1] http://arma.vuse.vanderbilt.edu/index.php?option=com_content&view=article&id=75&Itemid=53
[2] http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6336795&tag=1
[3] http://tbme.embs.org/
[4] https://www4.vanderbilt.edu/vise/visepeople/duke-herrell/
[5] http://arma.vuse.vanderbilt.edu/index.php?option=com_content&view=article&id=72&Itemid=53
[6] http://www.columbia.edu/cu/mece/arma/people/rogergoldman/roger_goldman.shtml
[7] http://www.vanderbilt.edu