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Simple motions, complex tool New robot successfully performs surgical closure in a beating heart

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A new robotic device may be the solution to a longstanding surgical dilemma: how to precisely manipulate tools within the delicate tissues of a beating heart, report researchers at Boston Children's Hospital. The team's experiments with both ex vivo and in vivo models have demonstrated the efficacy of a concentric tube robot in closing a common defect, patent foramen ovale, while the heart continues to beat. The robot also allows surgeons to gauge and adjust the amount of force they are exerting during the procedure, according to a study published online May 8 by the *International Journal of Robotics Research*.

Lead investigator Pierre E. Dupont, PhD, chief of Pediatric Cardiac Bioengineering and staff scientist in the Department of Cardiac Surgery at Boston Children's, and his colleagues set out to identify a robotic technology capable of performing intracardiac surgery without the inherent risks of stopping the heart. "Minimally invasive laparoscopic surgery has used chopstick-like tools. However, from a minimally invasive perspective, straight lines aren't the best way to maneuver through body passages or round, delicate tissues," Dupont, of Boston Children's Hospital, says. "Catheterization also poses challenges because the innate flexibility of a catheter limits clinicians' ability to manipulate tissue."

In response to this problem, Dupont devised the concept of concentric tube robots as a means to deliver and maneuver tools inside the heart. He next collaborated with Microfabrica, Inc. to develop tools, using metal microelectromechanical systems (MEMS) technology, that could be deployed by the robot for the surgical tasks of tissue approximation and removal. “Because there is so little room inside the heart to sew, and because the motions of sewing are complex, we’ve developed a device that enables customized adjustment of the approximation, comparable to suturing,” Dupont explains. “But the device utilizes very simple robot motions for deployment.”

The team chose to demonstrate the robot’s capabilities by surgically closing patent formaen ovales—holes between the heart’s atria that normally close just after birth, but remain open in a small percentage of the population. While many individuals with patent foramen ovale remain asymptomatic, the defect heightens the risk of stroke and heart attack by allowing blood clots or particles to cross from the right atrium into the left.

In a series of three in vivo trials with porcine models, the robot—guided by three-dimensional ultrasound and fluoroscopic imaging—wassuccessfully steered into the still-beating heart and used to close the foramen ovale. Surgeons were also able to use motion “cues”—for example, rotation of the open metal wings—to monitor the amount of force deployed. “We selected this procedure because it is the simplest one to demonstrate the approximation of non-overlapping tissue layers—a task that cannot be performed by catheter,” says Dupont. “Our goal is to establish the overall potential of the technology by demonstrating ‘building block’ tasks that apply to every intracardiac surgery.”

Dupont and colleagues believe their robot has many potential applications across and beyond the cardiac arena. Among other initiatives, they are targeting the development of a Magnetic Resonance (MR)-compatible version that could enter the brain through a small surgical corridor to access deep-seated tumors and lesions—capturing both MR and endoscopic images while minimizing damage to healthy surrounding tissue.

Andrew H. Gosline, PhD, of Boston Children's Department of Cardiac Surgery, was first author on the paper. The study was supported by two grants from the National Institutes of Health.

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