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Title: The first autonomously controlled capsule robot for colon exploration

Background: Capsule technology has made exploration of the entire gastrointestinal tract possible. Currently available colon capsules are limited due to passive movement and lack of therapeutic capability. Our academic lab has created a novel capsule robot for colon exploration that is actively maneuvered by magnetic coupling with both diagnostic and therapeutic function. Owing to the high gradient of their fields, permanent magnets (PM) are challenging to control and therefore an external robotic arm and localization algorithm are employed that permit intelligent manipulation of the capsule with allowance for autonomization of difficult maneuvers. Retroflexion (Rflx) is a common maneuver during colonoscopy and therefore can serve as a framework for autonomous control.

Aim: To demonstrate efficient, reliable, and safe autonomous intelligent control of a capsule robot at the retroflexion maneuver.

Methods:
Platform: The capsule head is 18 mm and contains an internal PM. Magnetic force and torque are applied by an external PM manipulated by a robotic arm for teleoperated maneuverability. The capsule is introduced via the rectum and is soft-tethered, which allows for introduction of instruments, insufflation, irrigation, and suction. Software allows for real-time pose detection of the capsule relative to the external PM so that the robot can “think” autonomously for precise movement of the capsule in the colon.
Experiment: The system was set to perform autonomous Rflx with a simple “push-of-a-button” in the colon of a 40 kg Yorkshire-Landrace swine in-vivo. A single endoscopist initially performed Rflx with a standard colonoscope at 15 cm from the anal sphincter. The system was then activated for intelligent autonomous Rflx at 15 cm from the anal sphincter. 30 total Rflx maneuvers were performed. Successful completion of Rflx, time to complete Rflx, and accuracy were recorded. Leak testing and pathologic examination were performed at necropsy.

Results: Rflx was successfully completed with both the standard endoscope and the autonomously controlled capsule robot for every trial (100%). Time to successful maneuver under autonomous control was 12.0 ± 2.3 s. The capsule and robots trajectory varied for each trial owing to the system responding and autocorrecting, in real-time, to the capsule’s movements. No leaks or histologic abnormalities were visualized on necropsy.

Conclusions: This is the first time that a capsule robot has been autonomously controlled in-vivo in a reliable, efficient, and safe manner. The proprioceptive robotic system can autocorrect its maneuvers quickly. Active autonomous intelligent manipulation of a capsule robot is a breakthrough step toward full artificially intelligent endoscopist directed capsule colonoscopy. Studies evaluating additional control algorithms are currently underway.