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3. Soft robotics for minimally invasive surgery

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Over the past few decades, there have been considerable advancements in robot-assisted minimally invasive surgery (RAMIS). RAMIS systems use slender straight-line instruments to operate through small incisions in the patient’s skin. Robotics makes procedures simpler, filtering the manual tremor of surgeons, improving overall ergonomics, and restoring 3-dimensional (3D) vision that is normally not available in manual minimally invasive procedures. In addition, RAMIS allows generating a huge amount of data that can be used for improving safety and implementing autonomous tasks (*1*). Despite the success of RAMIS platforms, such as the da Vinci Surgical System for prostatectomy and abdominal or thoracic surgery, these systems are often limited by their rigid component design, which can make it difficult to access certain areas of the body and can lead to tissue injuries.

Soft robotics is a promising avenue for developing more flexible and adaptable surgical robots, with the necessary dexterity and stiffness modulation to perform surgical procedures safely. The key feature of soft robotics is the use of materials that can deform, bend, shrink, and change stiffness (*2*), pushing the paradigm of robotic surgery in a safer and softer direction. These robots address different body districts, such as the ear, abdomen, and thorax, and they can be dedicated both for diagnosis and intervention. For example, a fluid-driven soft robotic system was developed for increasing patient-comfort during ear therapy and safely steering a needle to the desired injection site (*3*). Diagnosis of gastrointestinal tract pathology is also a key application for soft robots, because these tissues are flexible, stretchable, and often collapsed, requiring a spectrum of soft/compliant and stiff/unyielding working modalities (*4*). A capsule robot for endoscopy that uses eversion navigation and a soft shape-shifting mechanism has been recently demonstrated (*5*).

A large-scale project to explore soft robotics for RAMIS was the EU project STIFF-FLOP (STIFFness controllable Flexible and Learnable manipulator for surgical OPerations) from 2012 to 2015 (*6*). The soft robotic systems that were developed were made from bio-compatible silicone rubber and pneumatically actuated, employing new fabrication methods that allow for the creation of reliable structures that are also safe and effective. In addition, advanced Machine Learning (ML) techniques were employed to intuitively teleoperate the soft robots in the abdominal cavity of the patient, and haptic systems allowed surgeons to discern interactions of the robot with the soft tissue environment.

Substantial technical challenges remain (*7*). A major issue is the lack of precision and accuracy in soft robotic systems. In traditional surgical robots, electrical motors move the robot's arms directly or via tendons and effectors are made from rigid components that do not deform during operation. However, soft robotic systems rely on deformation of the material the robot is constructed from to achieve movement. The resultant motion is difficult to model and can result in low positional accuracy – a critical concern in surgery (*8*). To overcome this, advanced strategies based on Artificial Intelligence (AI), ML and data driven control capable of coping with the highly nonlinear motion behaviour of soft robots are being developed. Recent advances in computer power, computer vision, ML, real-time modelling, and simulation can make operation of soft robots for surgery possible avoiding cumbersome teleoperation modalities and extensive training sessions for surgeons (*9*).

Will soft robots for RAMIS replace well-established surgical robots, or will soft robotic design rules, relying on morphological computation (*10*), permeate traditional technologies for RAMIS? What benefits the patient most needs to drive research in soft robotics surgery.

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