Week 11: Continuum Microrobots

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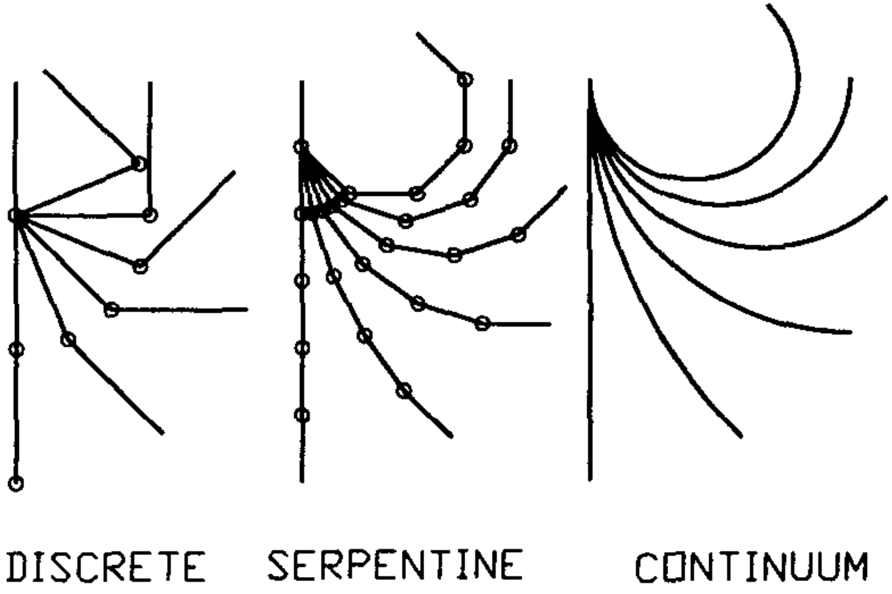
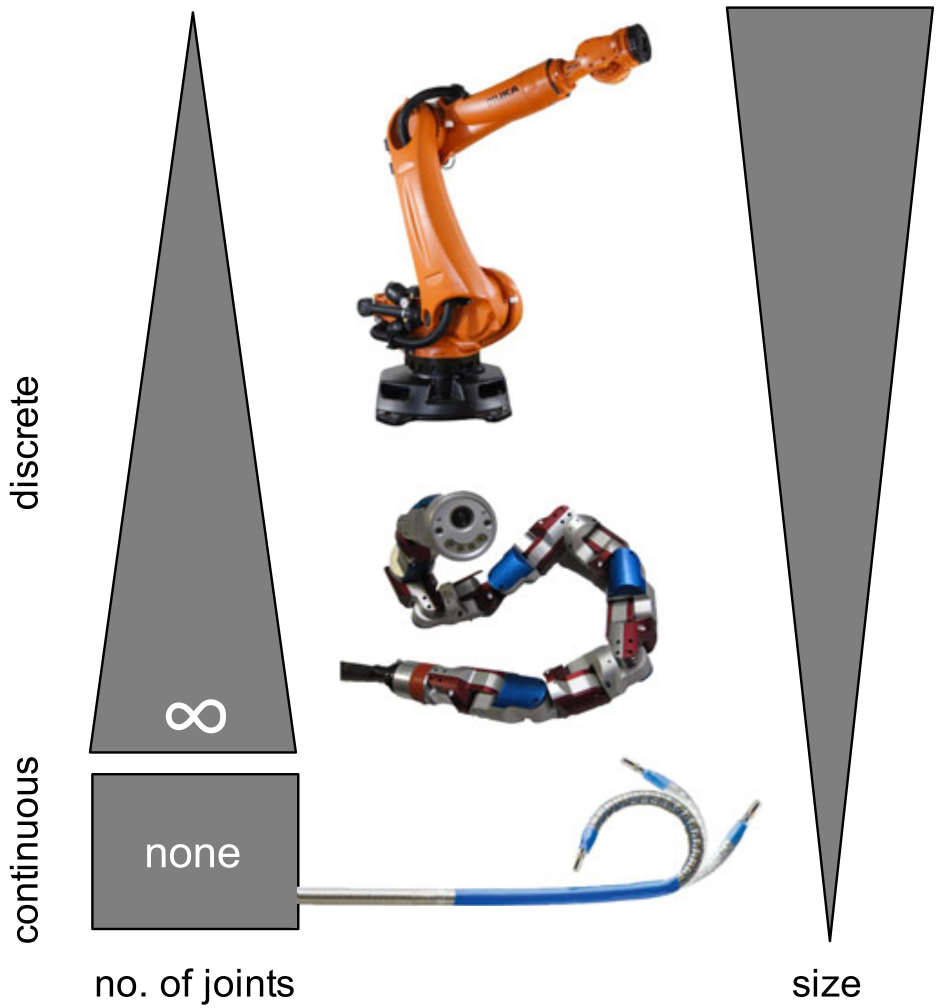
Robot Motion

Classical robots

- Discrete mechanisms constructed from a series of rigid links
- Discrete single degree of freedom joints
- Motion control at the joints
- Intermediate links may be considered infinitely stiff
    - Heavy robot mechanisms
    - Large sections of passive support structures



From discrete to continuous



Serial kinematic chains

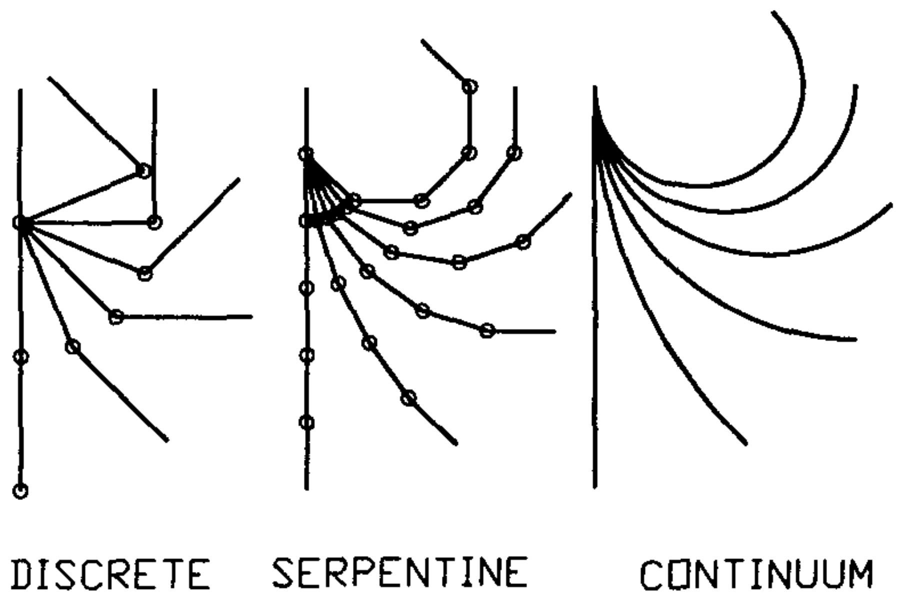
Hyper-redundant manipulators

Continuum robots

Robot Motion

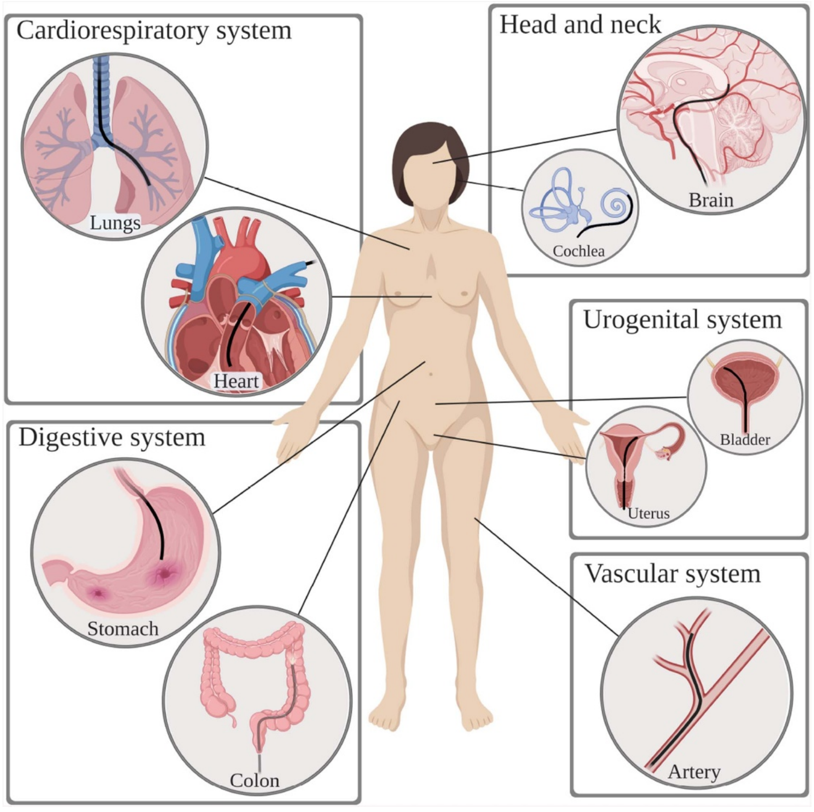
Continuum robots

- No rigid links and identifiable rotational joints
- Structures bend continuously along their length via elastic deformation
- Produce motion through smooth curves
- Infinite degrees of freedom: control issues
- Precision

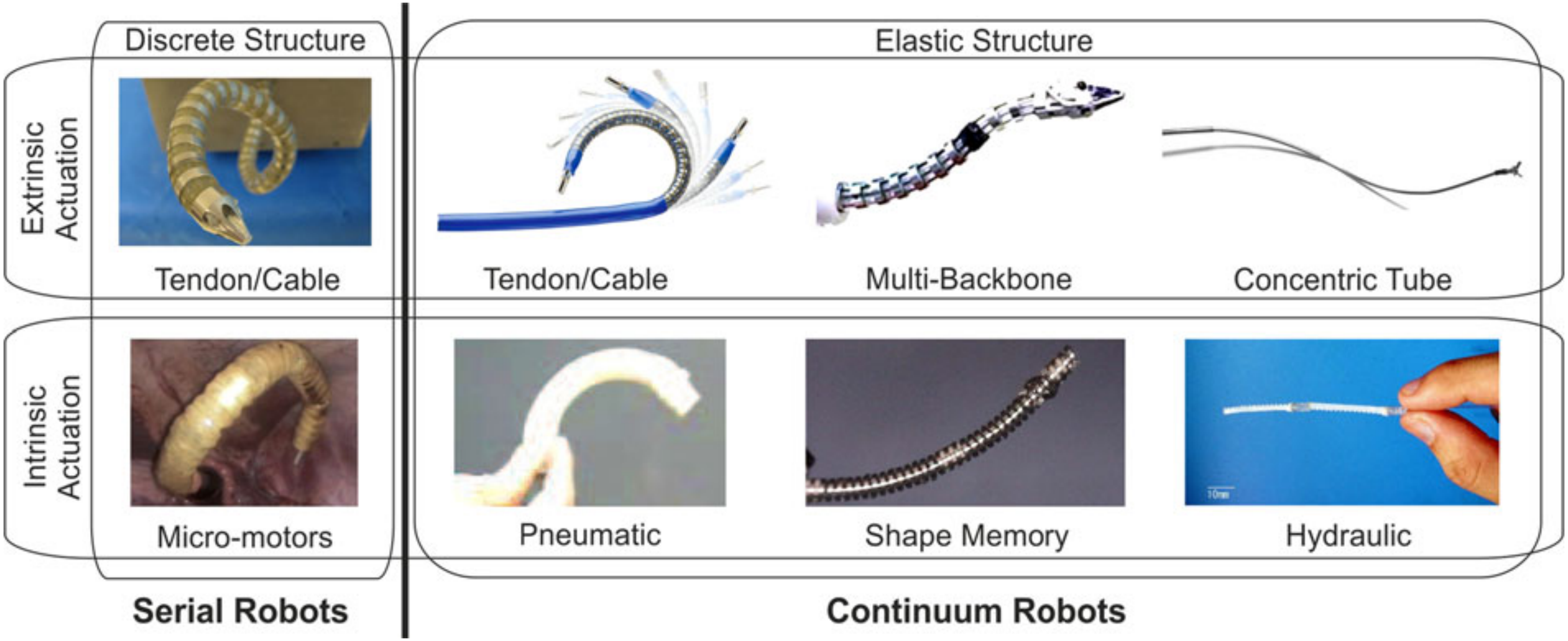


Medical Interventions

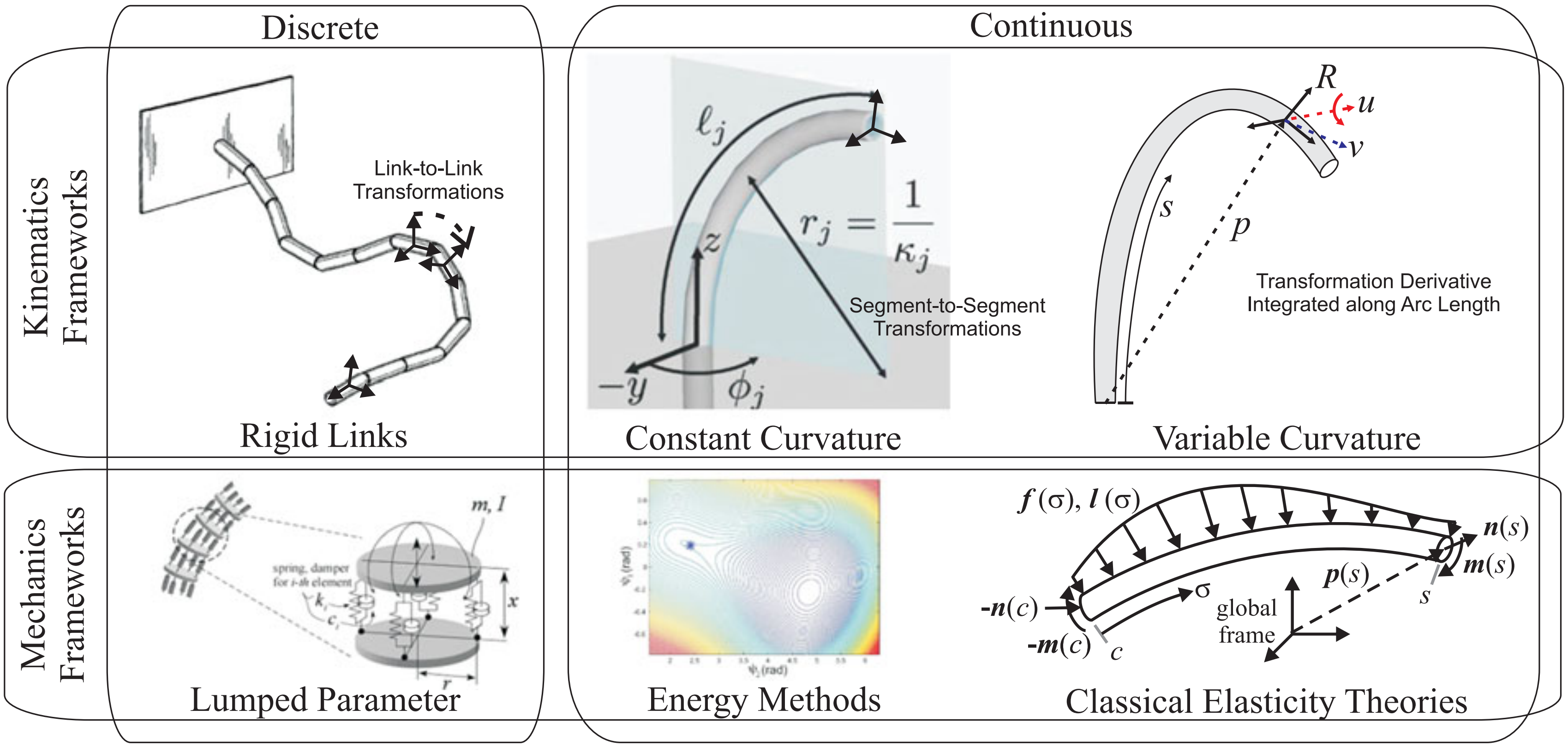
- Their narrow curvilinear shape makes them well suited to passing through body lumens, natural orifices, or small surgical incisions to perform minimally invasive procedures.



Continuum robot design

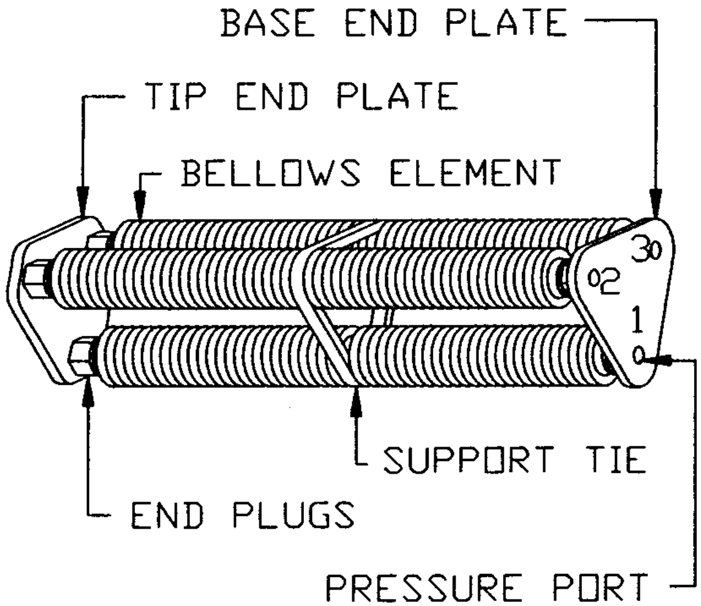


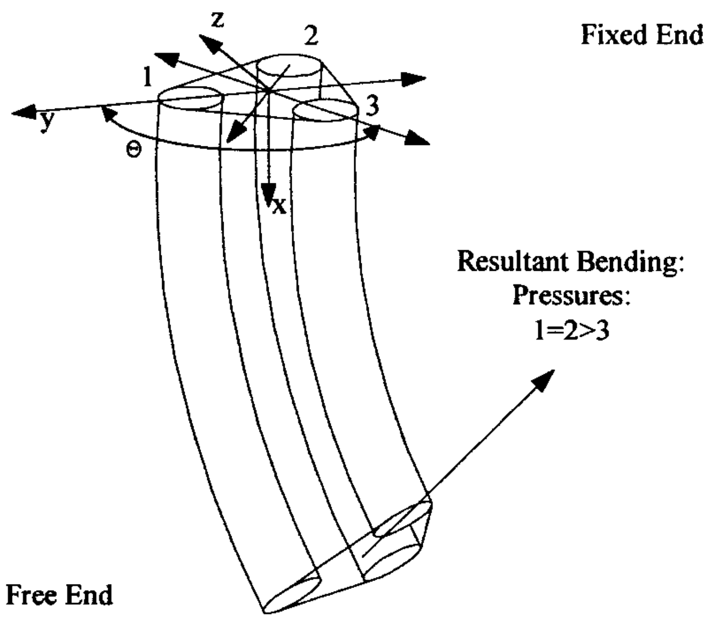
Continuum robot modelling



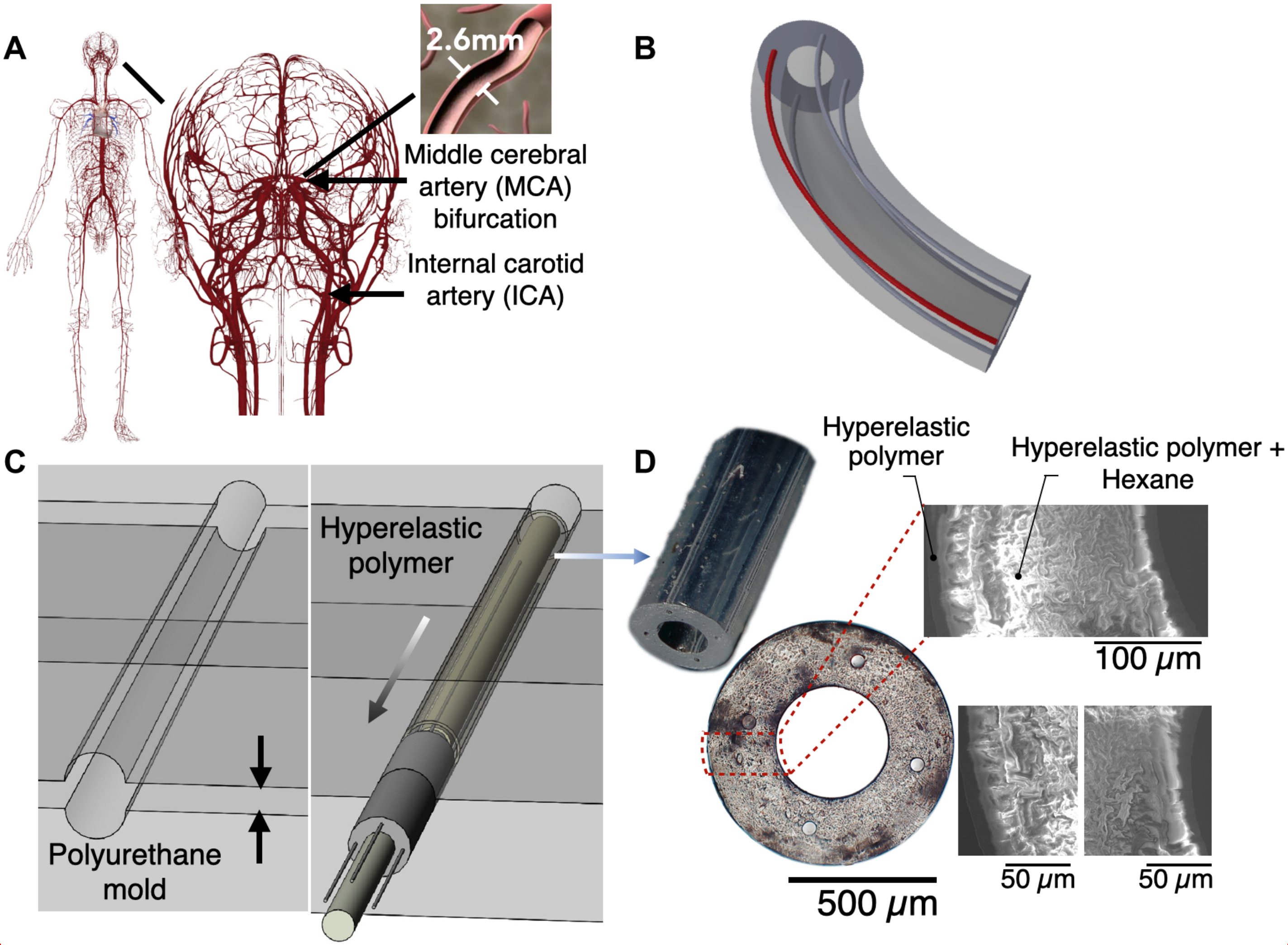
Fluid operated devices

- Increasing internal pressure generates strain variations and bending
- Compact, lightweight with no moving parts
- Anisotropic elasticity: to prevent radial expansion
- Passive elastic compliance to external forces

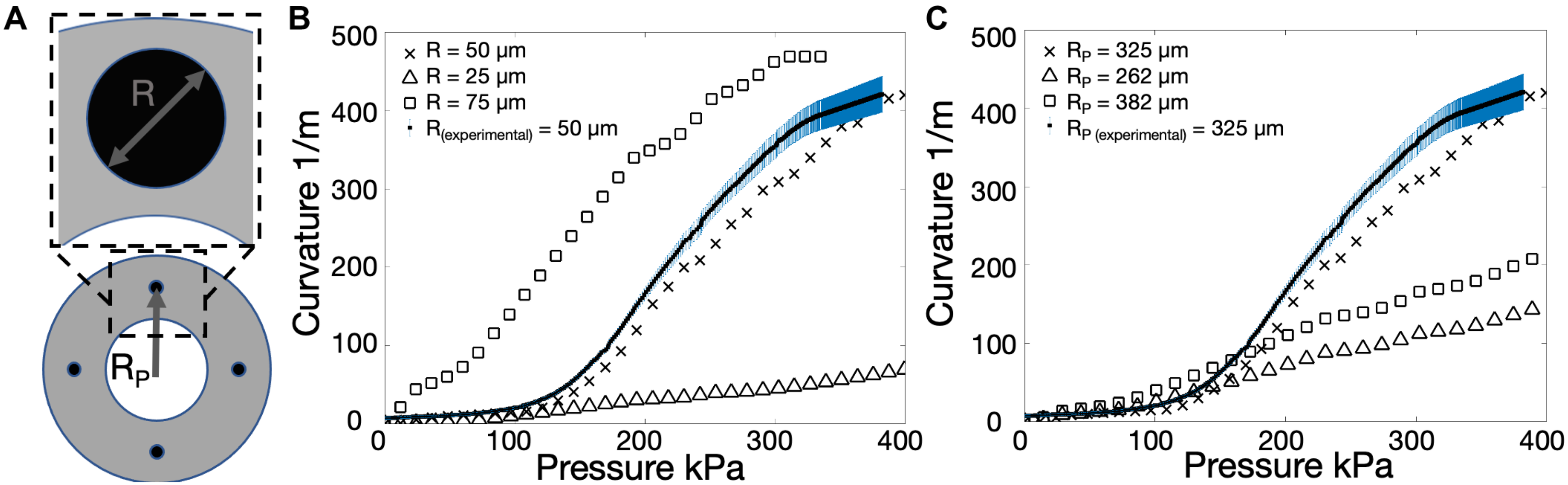




Hydraulically actuated microcatheter



Hydraulically actuated microcatheter



Hydraulically actuated microcatheter

Catheter deflection high-speed video

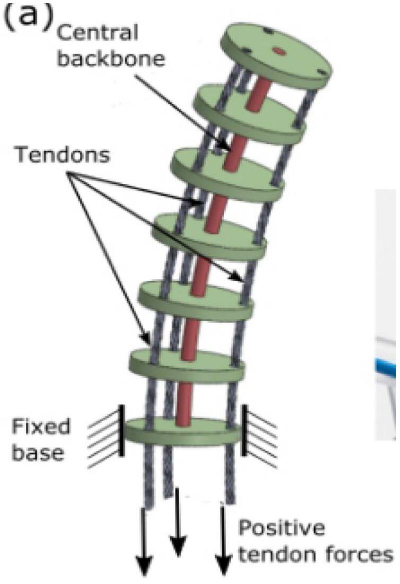
Supplemental video for: Soft robotic steerable micro-catheter for the endovascular treatment of cerebral disorders

Tilvawala Gopesh, Jessica H. Wen, David Santiago-Dieppa, Bernard Yan, J. Scott Pannell, Alexander Khalessi, Alexander Norbash & James Friend
University of California San Diego, La Jolla CA USA
Melbourne Brain Center, Royal Melbourne Hospital, Melbourne VIC Australia

Tendons

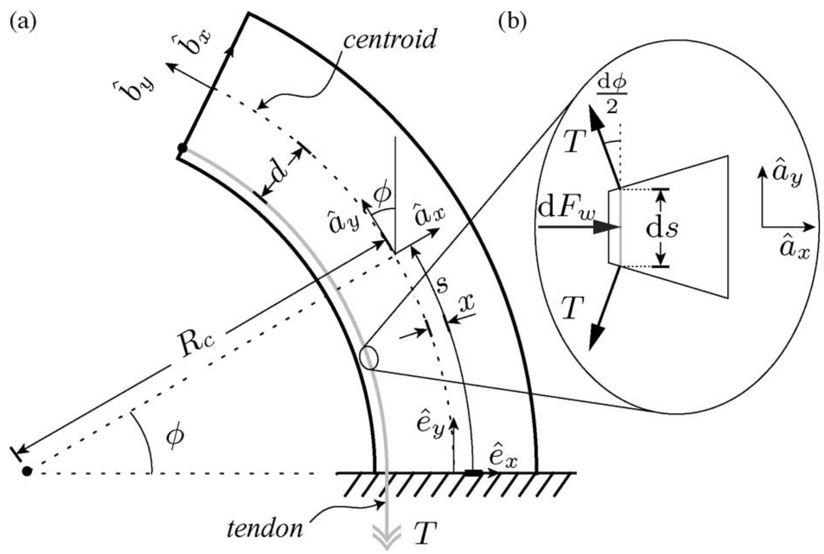
- Between one and four tendons, fixed at the distal end, run along the length of the tube offset from the tube's neutral axis.
- Tension applied to tendons at the proximal end of the tube generates bending along its length.
- Since the tendons are highly compliant in bending, the overall flexural stiffness is that of the tube.
- In order to maintain control of a joint in flexion and extension using tendons, one must employ antagonistic groups of tendons

- Common design variations include varying tube stiffness along the length, so as to localize bending in a specific region, e.g., at the tip
- Concatenating bendable sections, so as to produce more complicated curves, e.g., a two-section tube capable of an "S" curve



Tendons

- Constant curvature deflection is commonly presumed for continuum manipulators in the absence of external constraints or disturbances
- Assumption: the tension in the tendon is constant along its length or that it is a pure tension element.
- Preventing slack is practically important to maintain the integrity of the cable drive. Tendons in compression tend to buckle or fall off their drive pulleys resulting in actuator backlash.
- Minimizing tendon load is important for medical application in which tendon size and materials are constrained by the environment. Tendon load can also have an effect on performance due to friction.

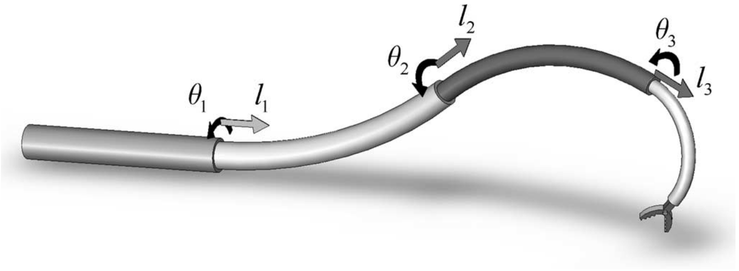


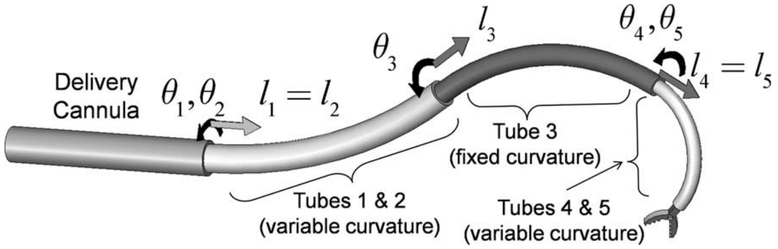
Medical robots

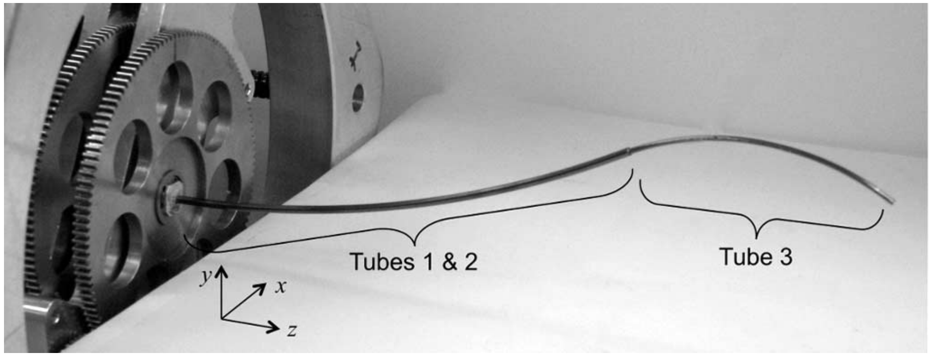
- Magellan steerable catheter system
- Catheter-shaping and manipulation is achieved by orthogonal pull-wires controlled by the remote catheter manipulator

Concentric tubes

- A series of pre-shaped, concentric tube instruments that may be extended and rotated within one another to form various configurations.
- The overall shape of the assembled tubes is controlled by translating and rotating the tubes with respect to each other at their proximal ends.
- These robots are typically constructed as telescoping sections of either constant or varying curvature

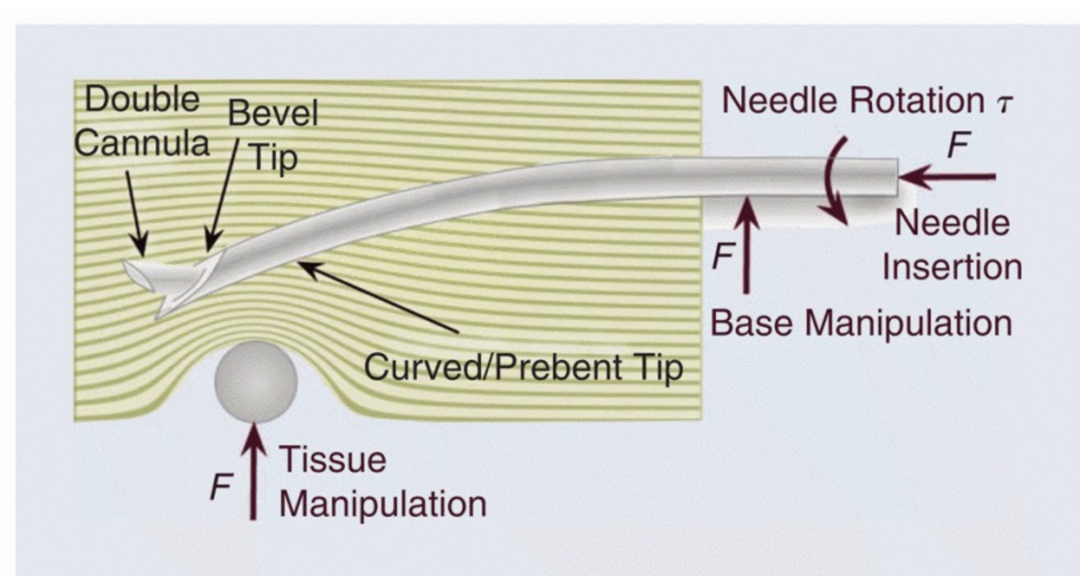


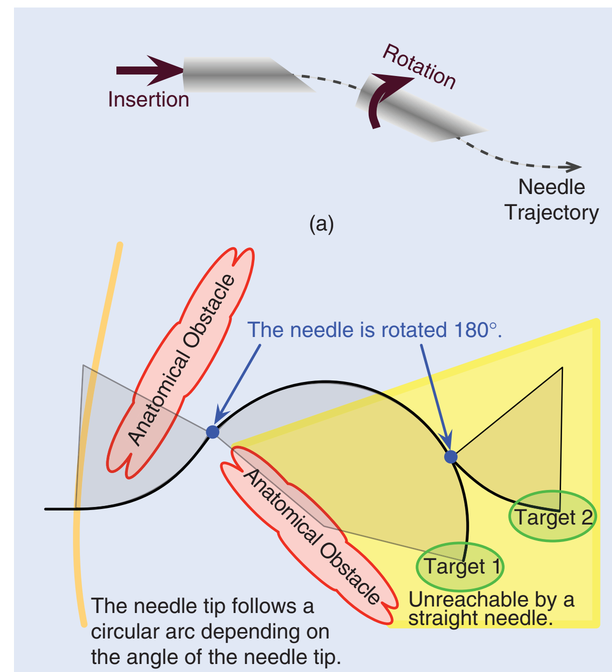




Mobile continuum robots: tip-steerable needles

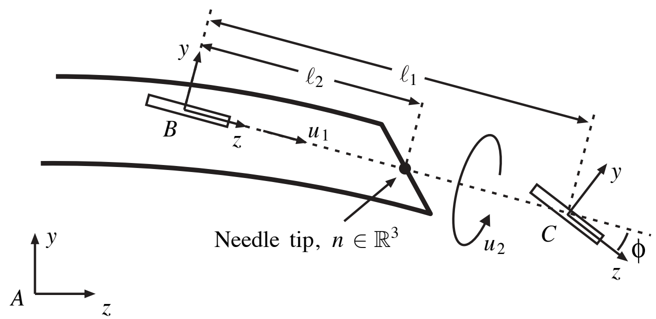
- When a needle with an asymmetric tip is inserted into a firm medium, such as a tissue, the shape of the tip and its interaction with the medium creates an imbalance in the lateral force.
- If the medium does not deform significantly, the resultant steering force causes the needle tip to follow a circular arc and, if the needle is flexible relative to the medium, the rest of the needle shaft will follow the same path.

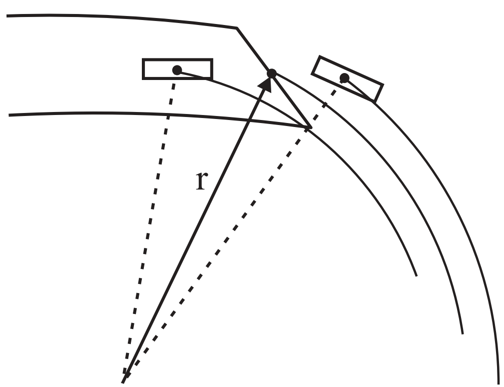


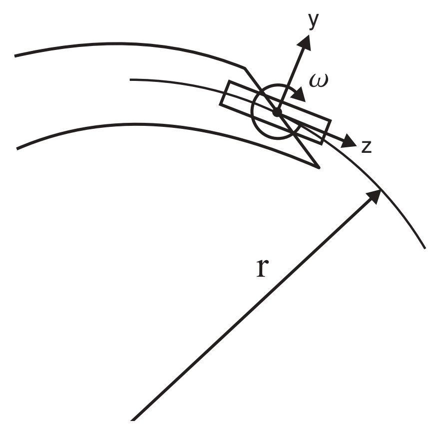


Nonholonomic modelling of needle steering

- The model can be thought of as the trajectory of a planar bicycle with locked steering angle.
- retracting the needle a certain distance, re-orienting the bevel tip, and then pushing it forward again to achieve motion in a direction that would have been instantaneously impossible.

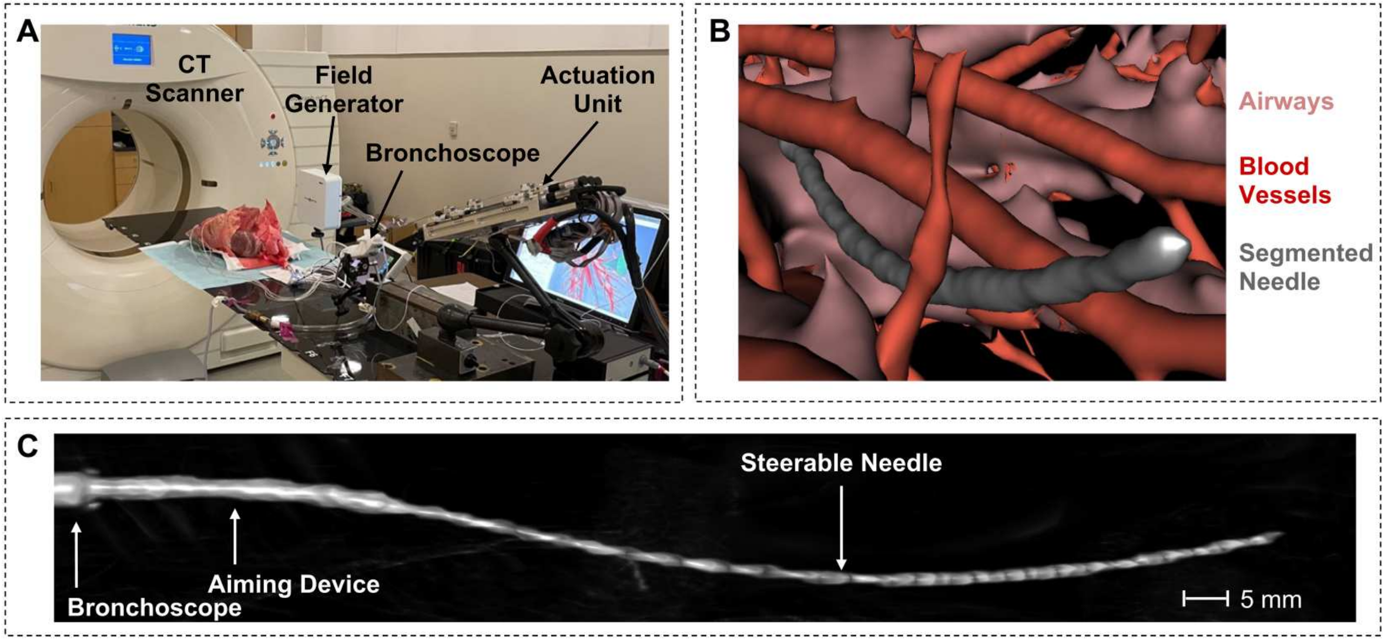




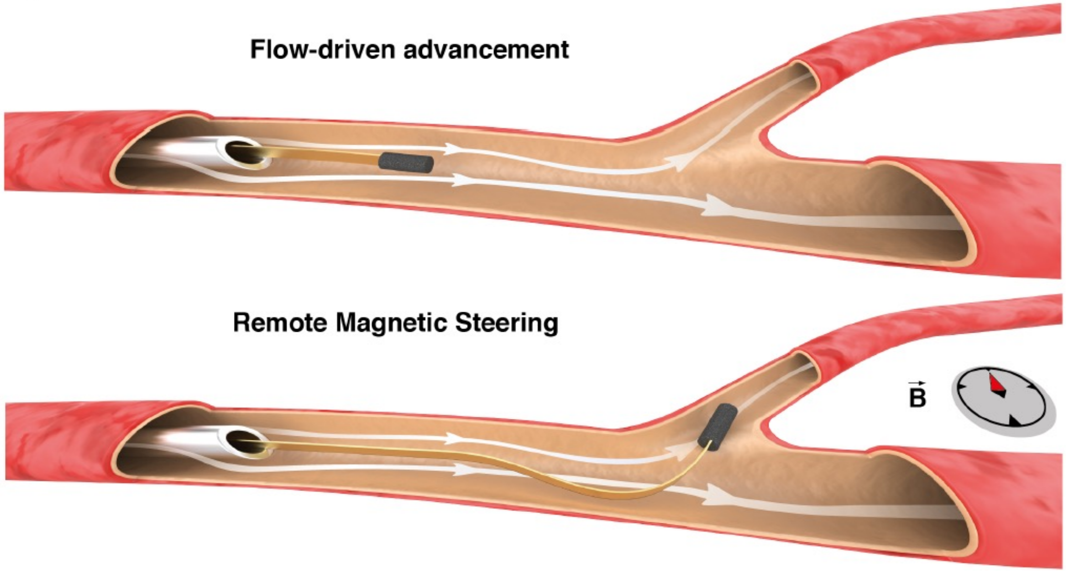


Autonomous medical needle steering

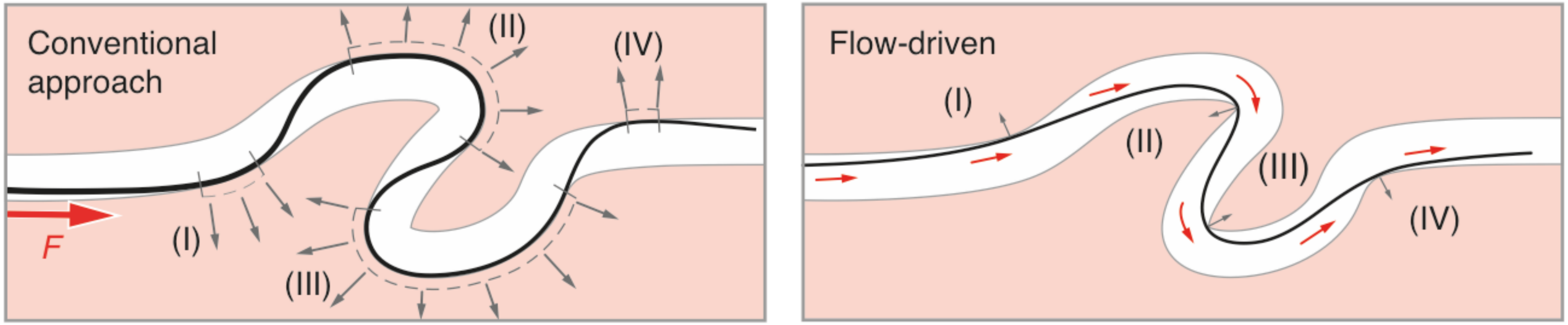
- Through living tissue around obstacles
- Laser-patterned highly flexible needle
- Accounts for obstacles (CT scan), uncertainties (EM tracking), respiratory motion (planning)
- Lung biopsy



MagFlow: Flow-driven navigation with magnetic steering



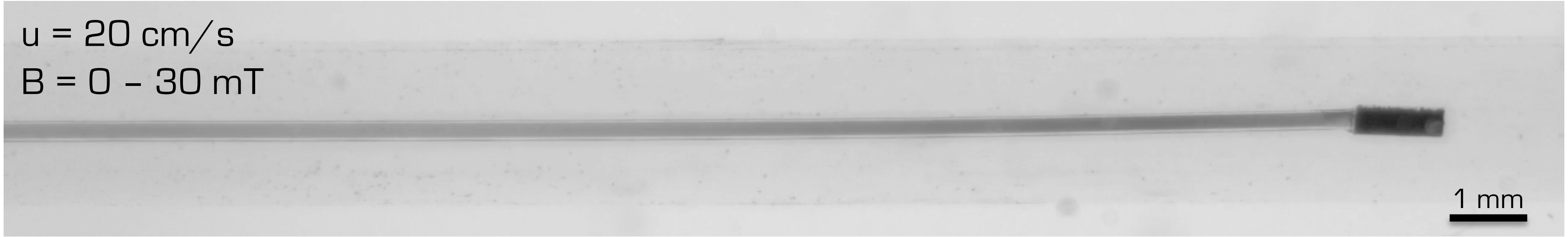
Design tip: Bending stiffness of beams scales cubically with the thickness



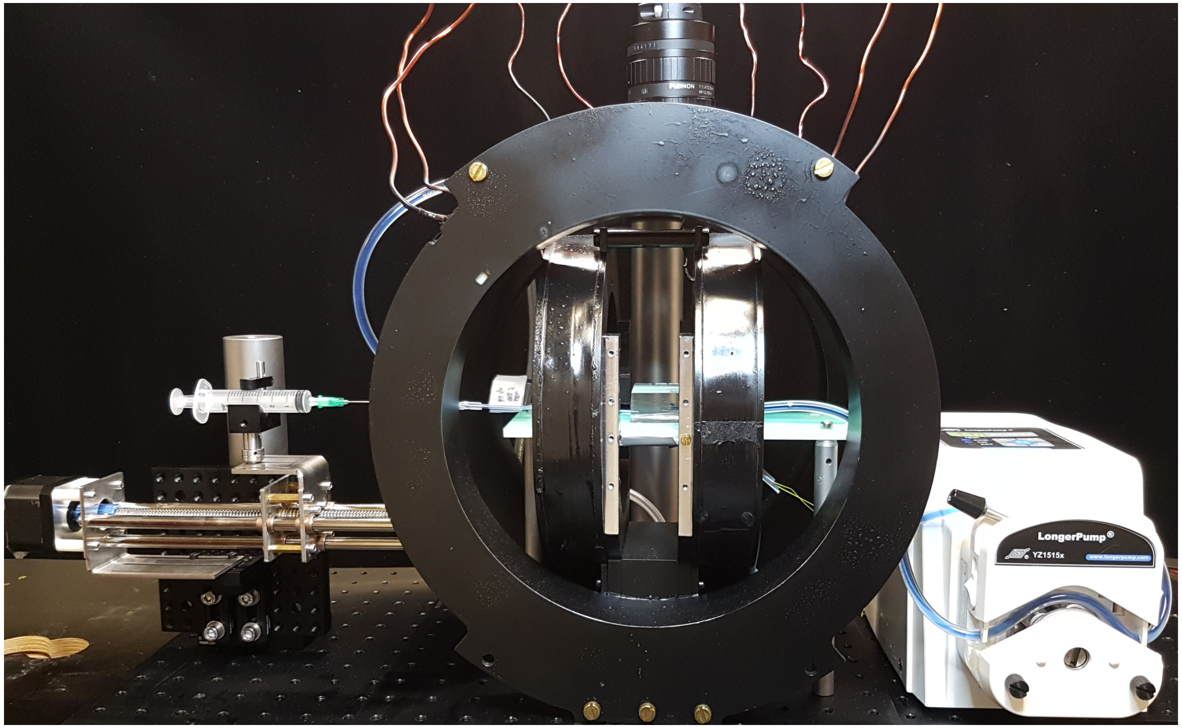
Compressive stresses → Tensile stresses

Pancaldi+, **Nat Comm**, 2020

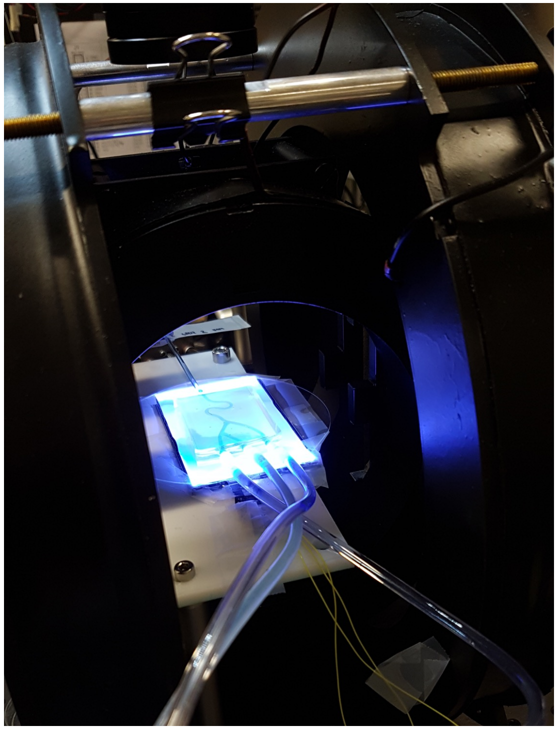
Magnetic steering



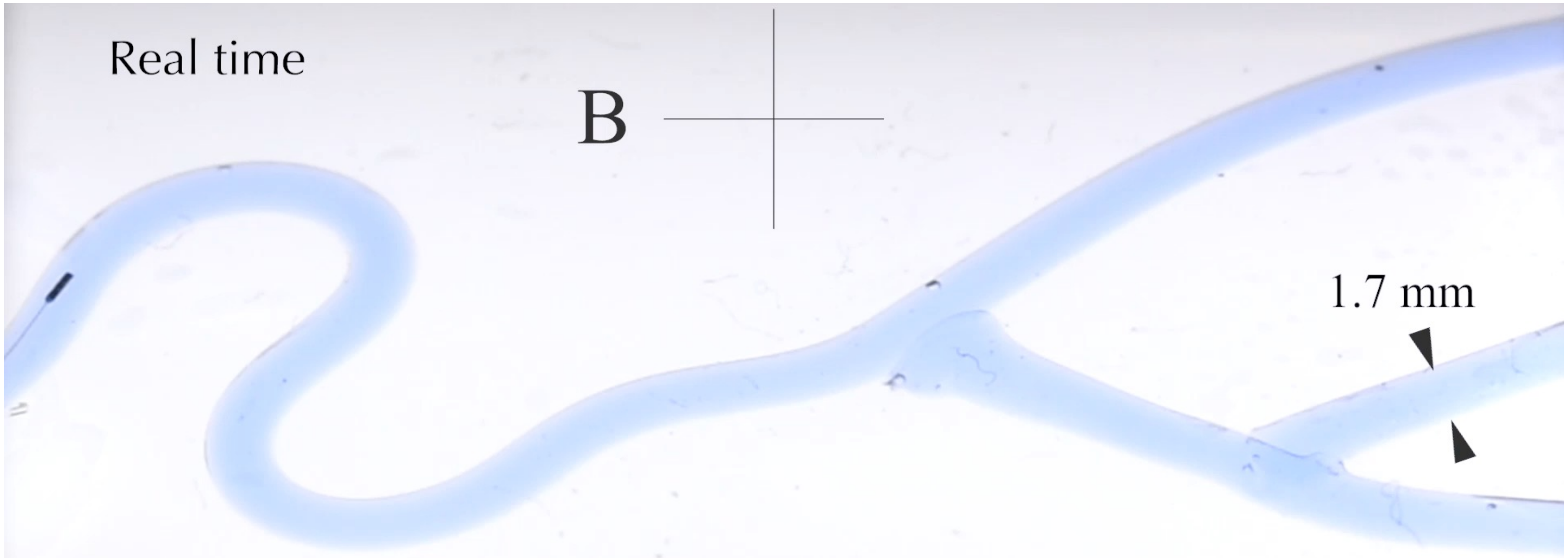
Electromagnetic control system



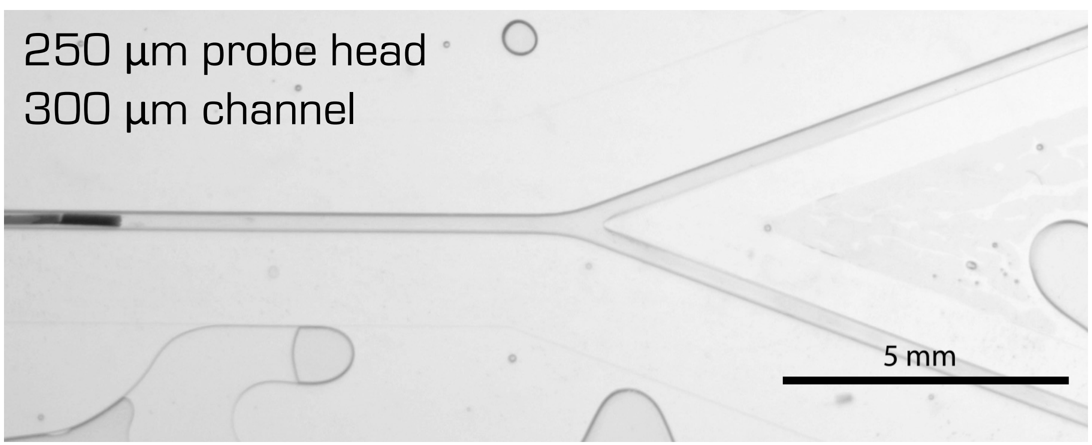
Vessel phantom



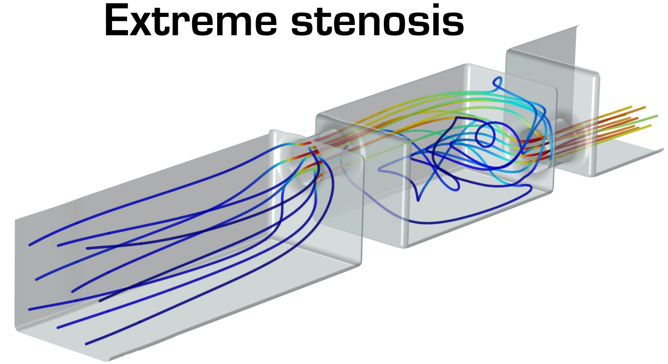
Navigation inside branched and structured channels



Tight channels

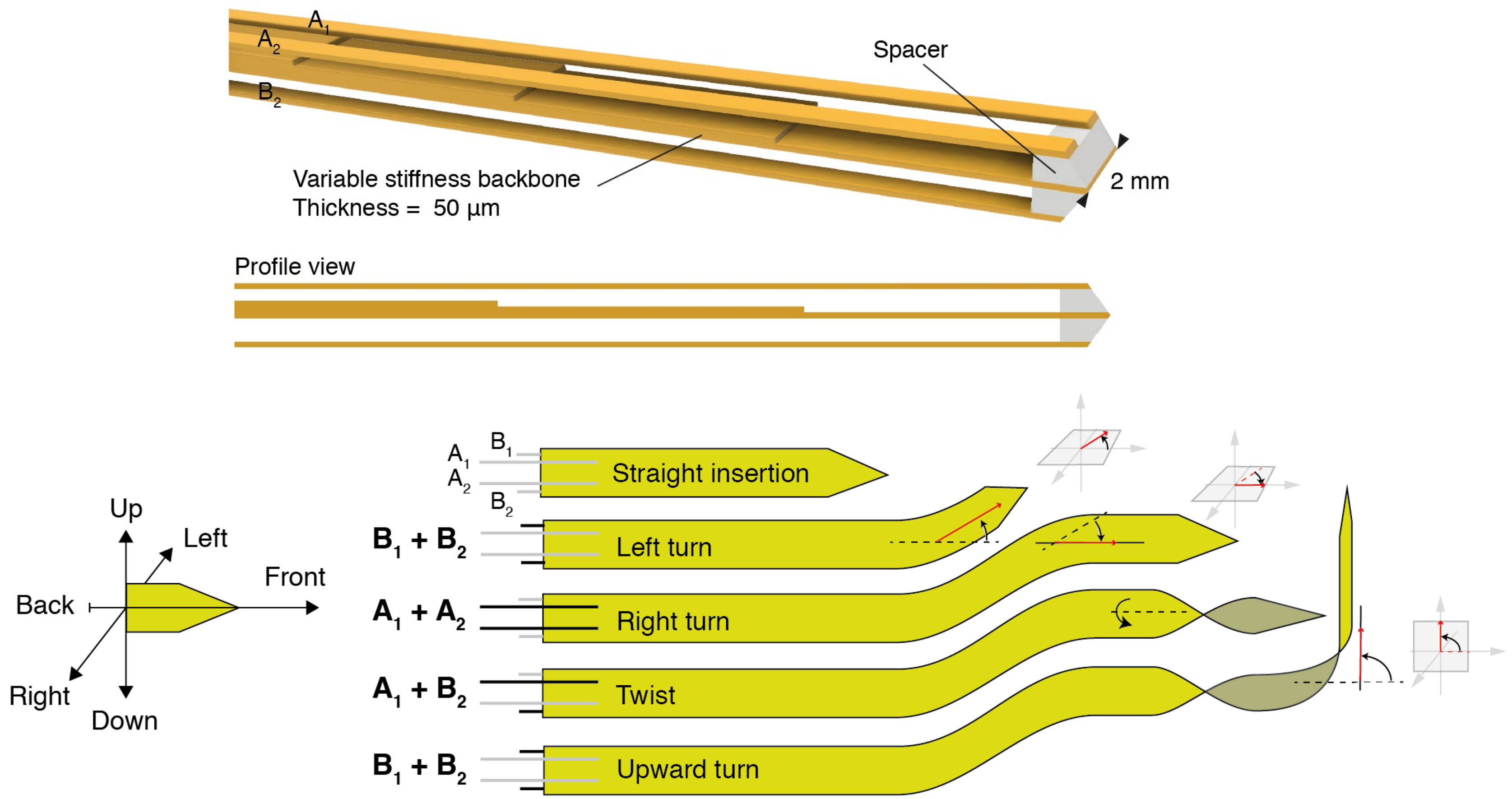


Extreme stenosis



Ultraminiaturized tendon-driven devices

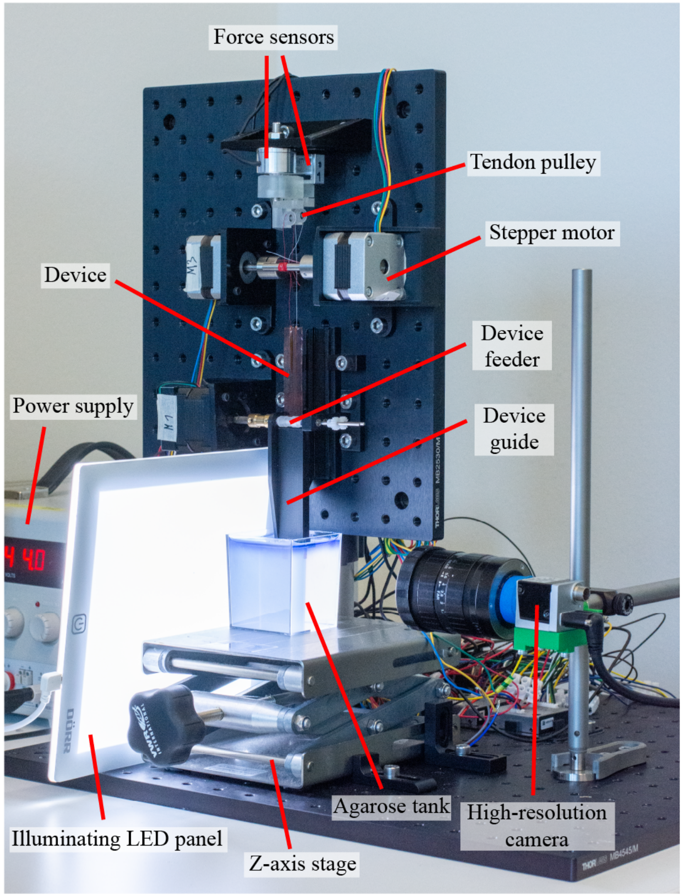
- Laminated films: microfabrication



Ultraminiaturized tendon-driven devices

- Micromanipulation system

a



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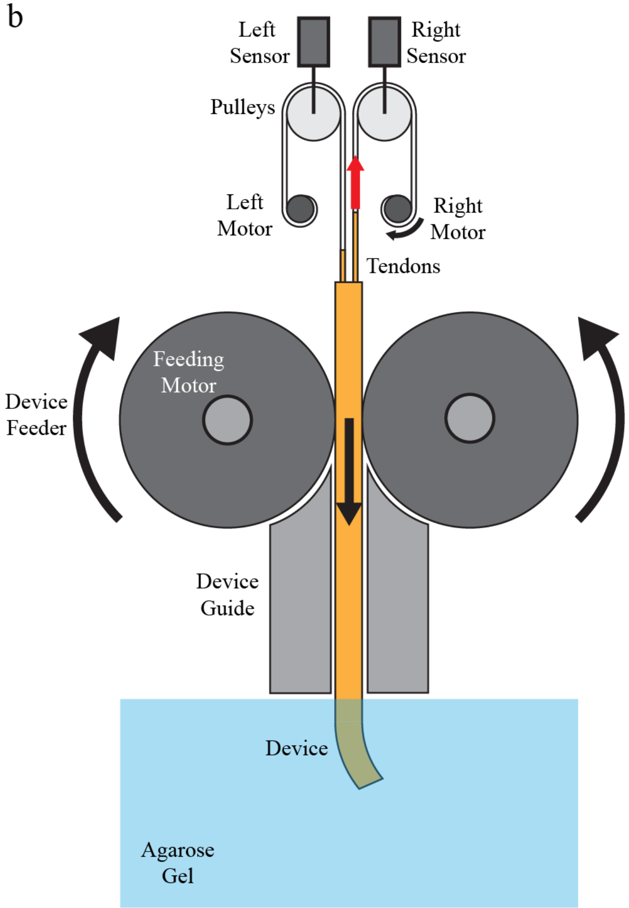

Ultraminiaturized tendon-driven devices