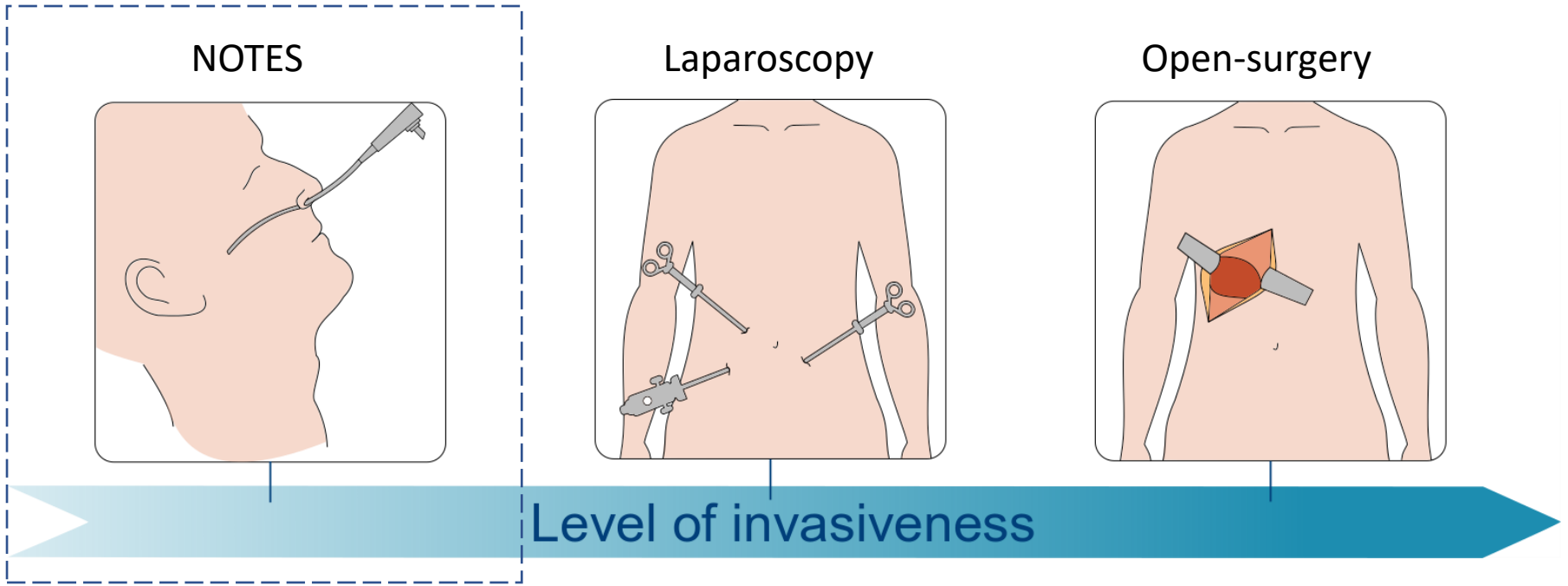
Design of dexterous surgical instruments to perform constrained workspace surgery

Dr. Ir. Julie Legrand

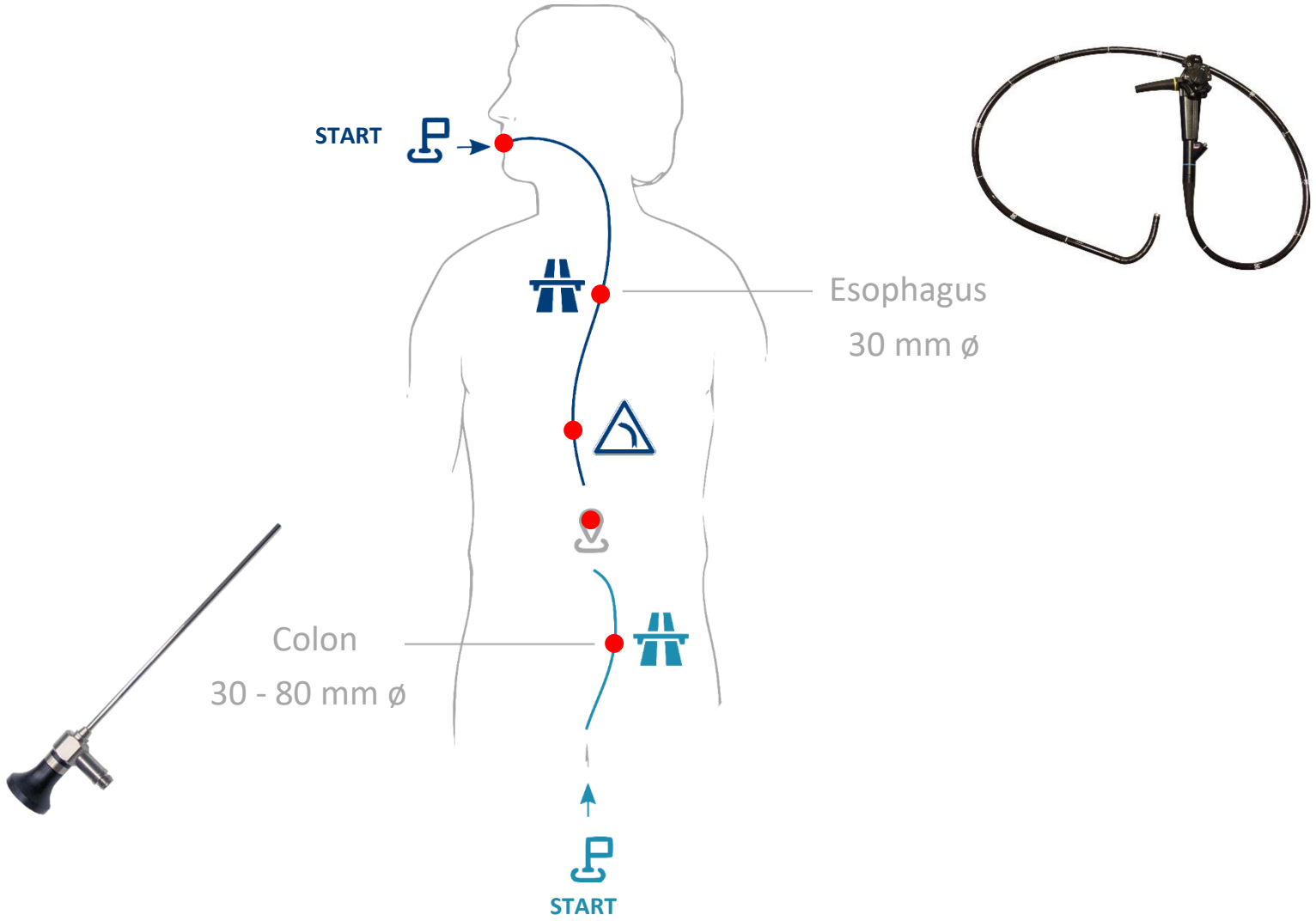
UCLouvain, 6th March 2023

Natural **O**rifice **T**ransluminal **E**ndoscopic **S**urgery



endoscope

Natural **O**rifice **T**ransluminal **E**ndoscopic **S**urgery

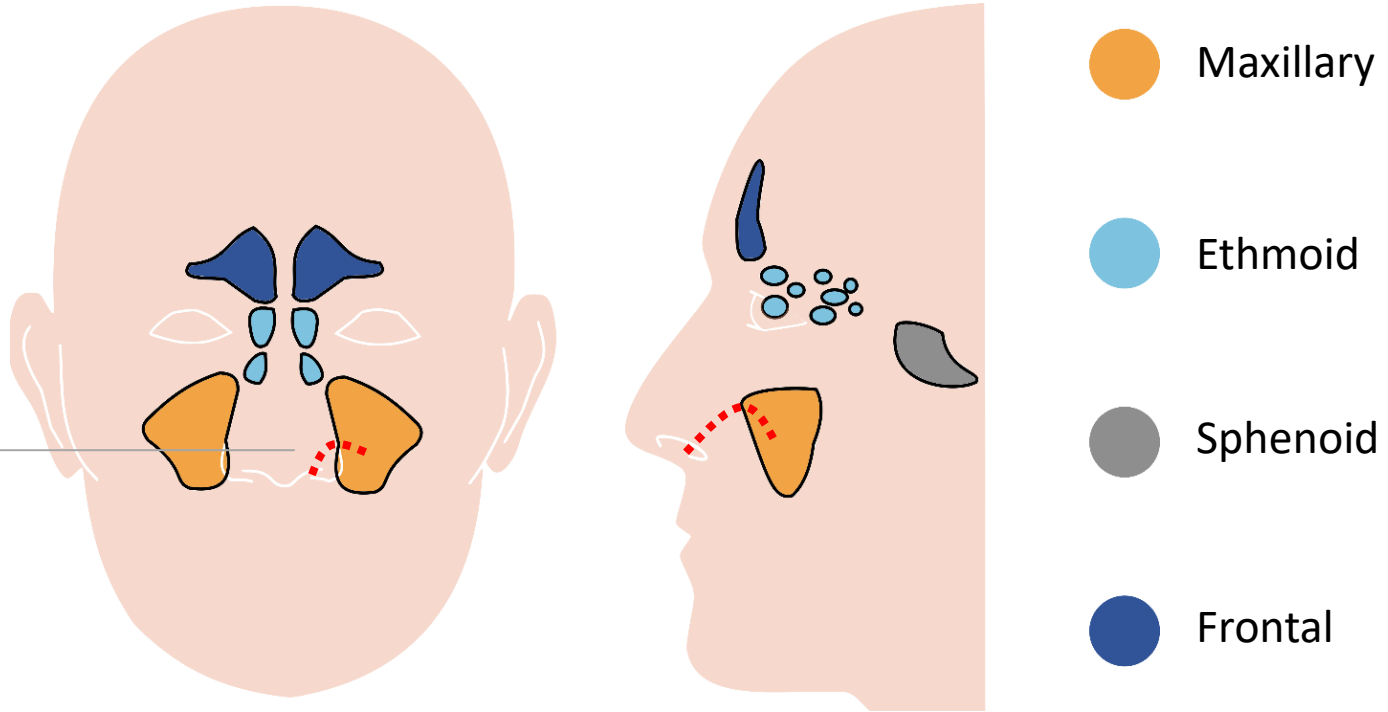


Constrained workspace surgery: maxillary sinus surgery

Maxillary sinus surgery
(**62 surgeries / year** at UZ Leuven)

Nasal cavity

5mm ø



Maxillary

Ethmoid

Sphenoid

Frontal

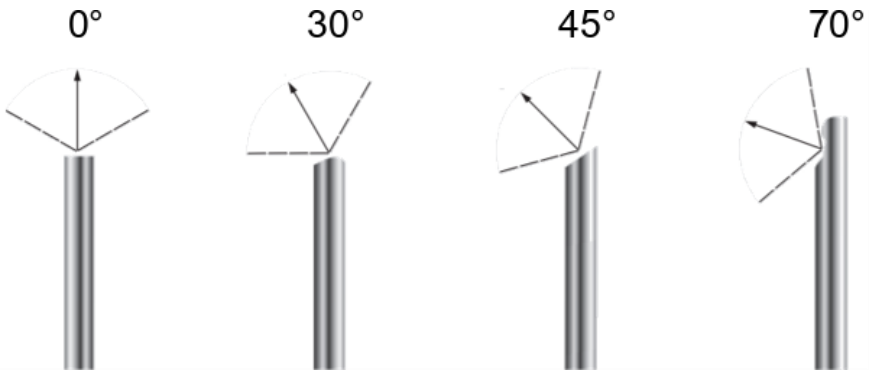
https://teachmesurgery.com/ent/nose/acute-rhinosinusitis/

Constrained workspace surgery: sinus surgery

Rigid forceps, graspers, …

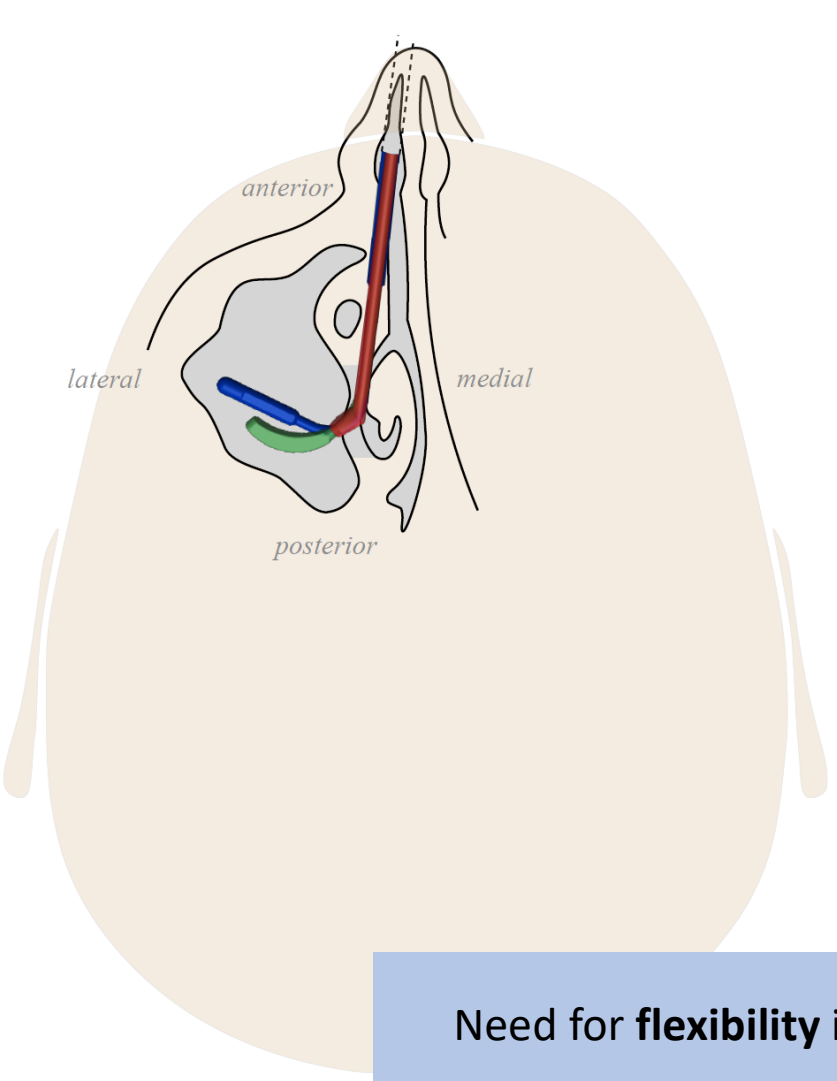
2-3mm ø

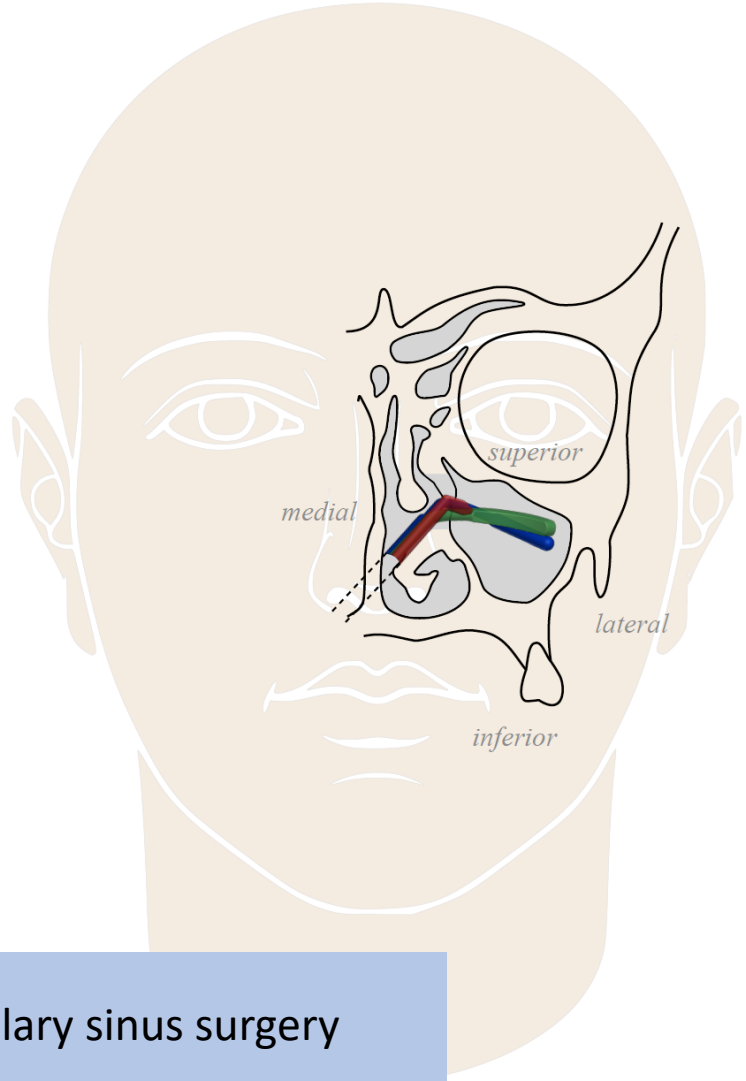
Rigid endoscopes



4mm ø

Constrained workspace surgery: sinus surgery





Need for **flexibility** in maxillary sinus surgery

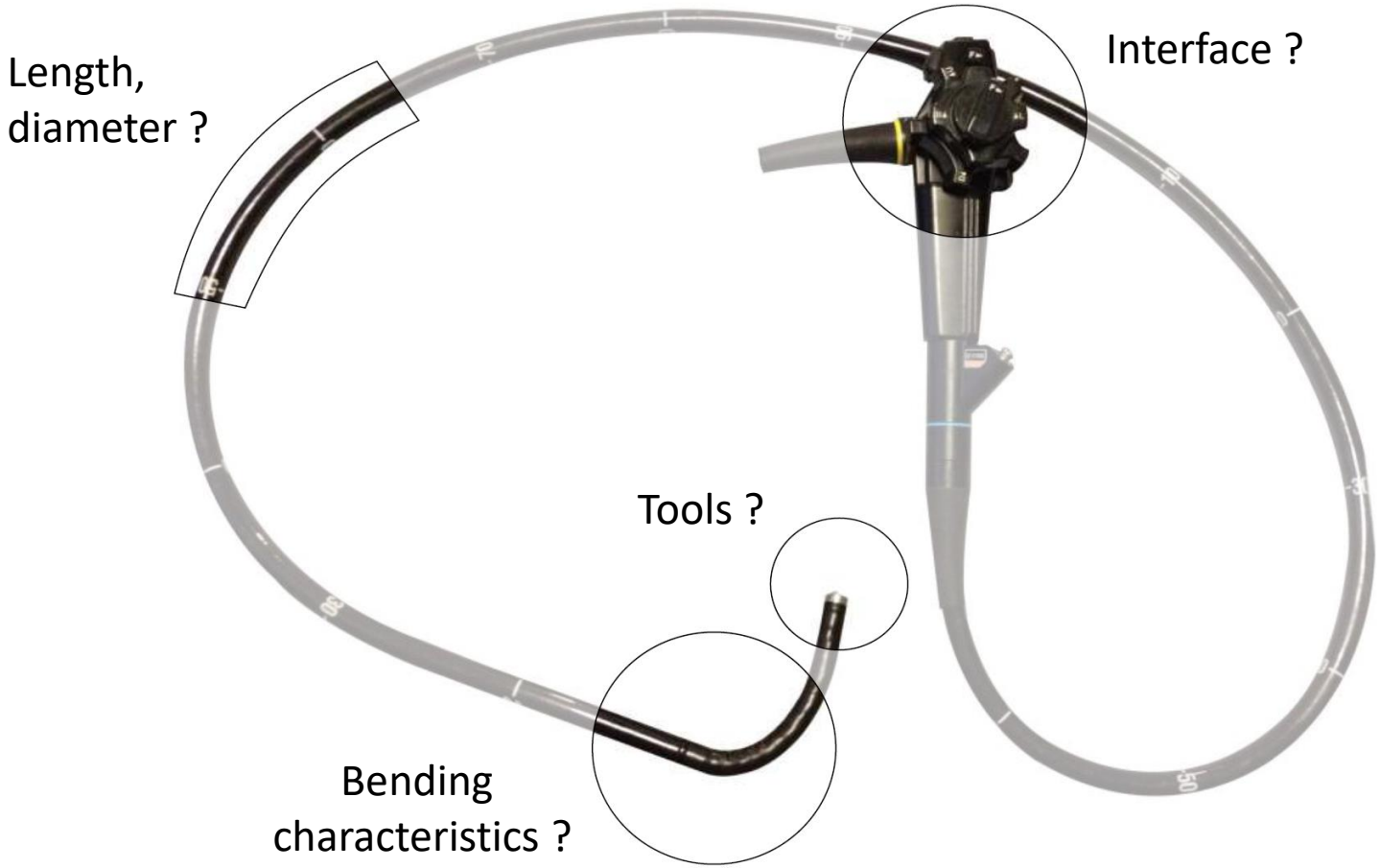
Single-handed

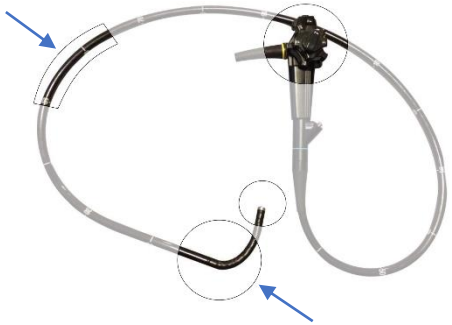
Flexible

Steerable

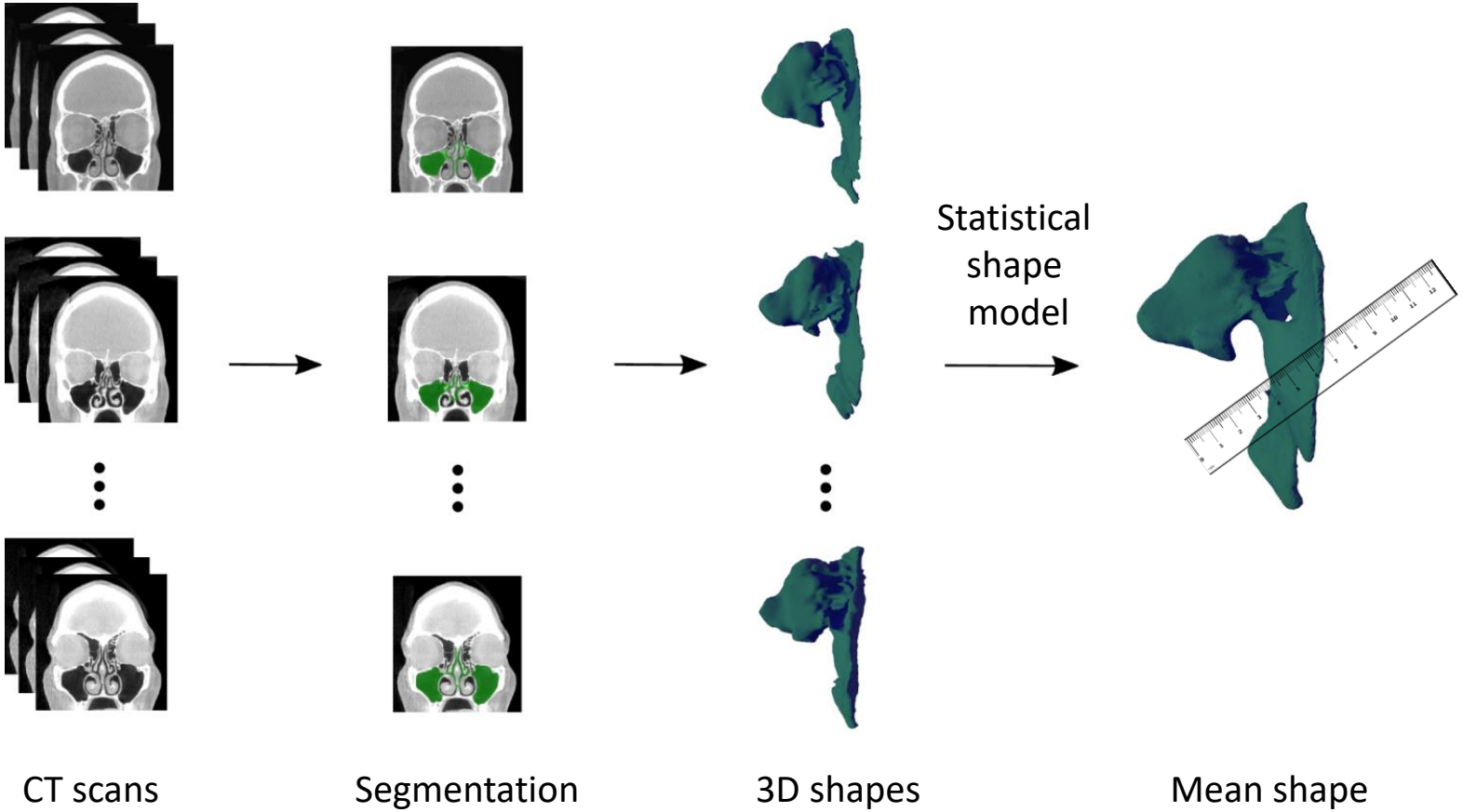
Tele-View 3.0 Meter Portable Endoscope
https://www.londongastroconsultant.co.uk/upper-gi-endoscopy-investigation.php
https://www.entiraq.com/2020/05/31/endoscopic-skull-base-surgery-protocol-from-the-frontlines-transnasal-surgery-during-the-covid-19-pandemic/

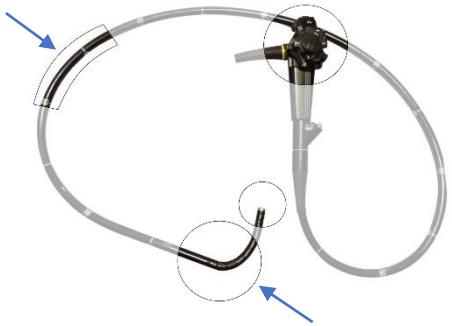
Instrument specifications

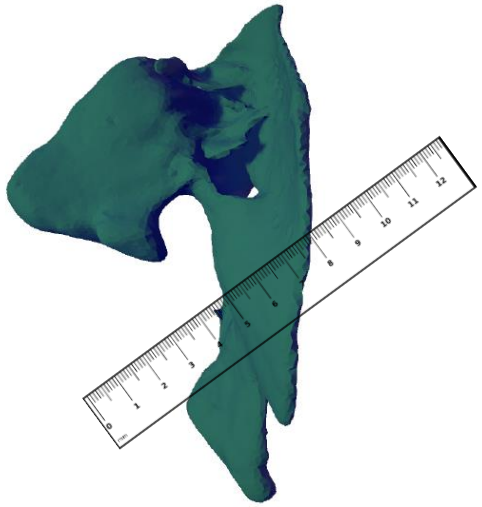

Length,
diameter ?
Interface ?
Tools ?
Bending
characteristics ?



- **1** instrument designed for **all** patients

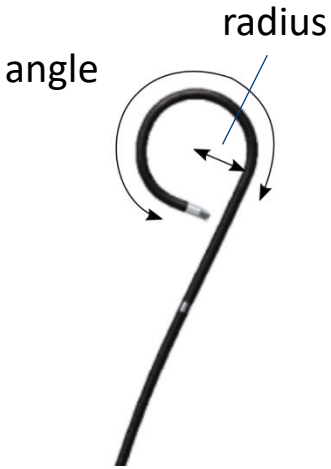




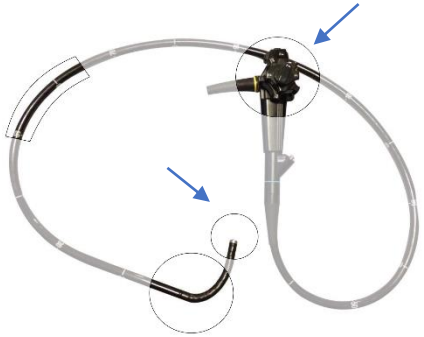


Results:

- Diameter ≤ **2.4mm**
- Bending angle ≥ **165 °**
- Bending radius ≥ **4.6mm**
- **1 unidirectional** DOF

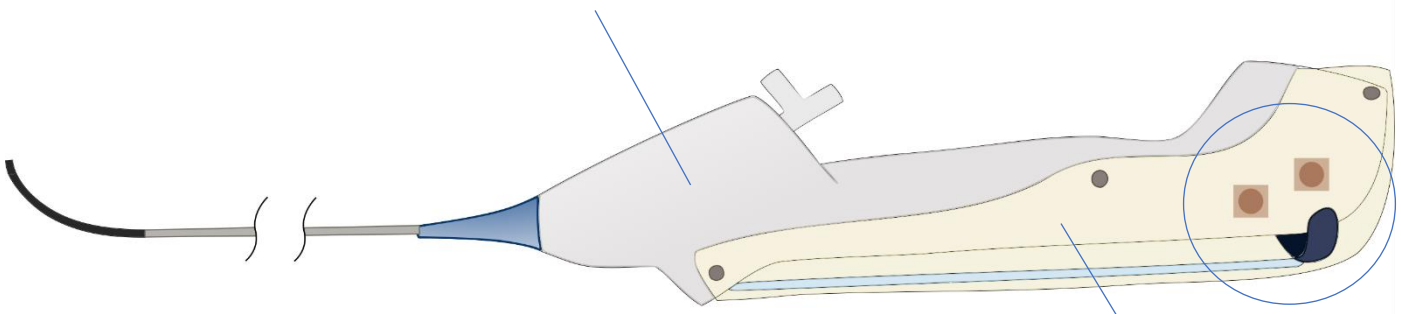


https://www.bostonscientific.com/en-US/products/Ureteroscopes/LithoVue.html
https://www.copanusa.com/sample-collection-transport-processing/eswab/



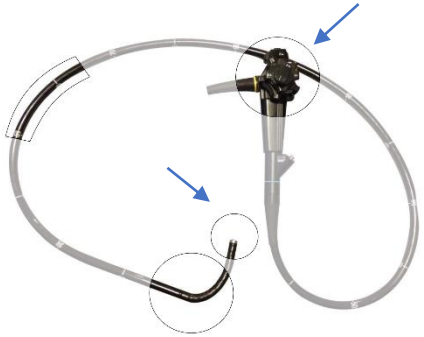
- **Modifying existing instruments**

Commercial flexible instrument



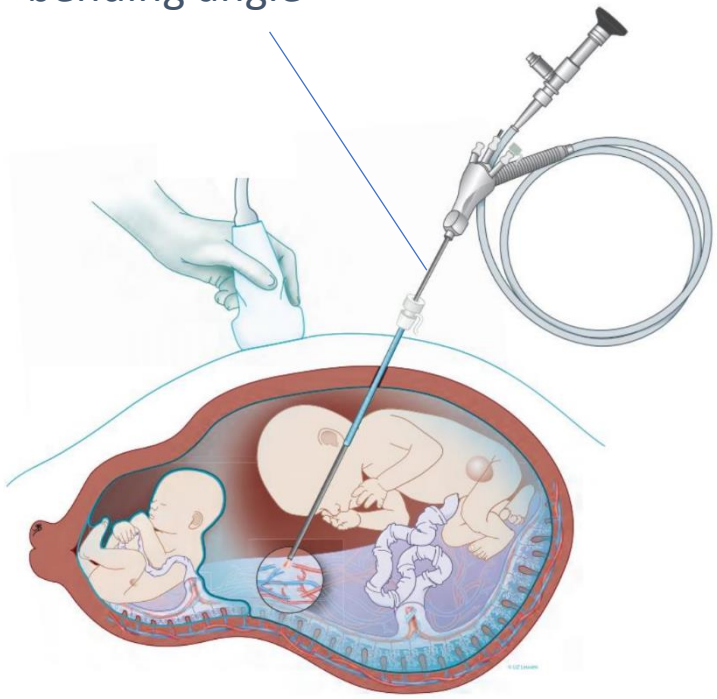
- buttons ?
- scroll wheel ?
- slider ?

Add-on system to **control** the instrument

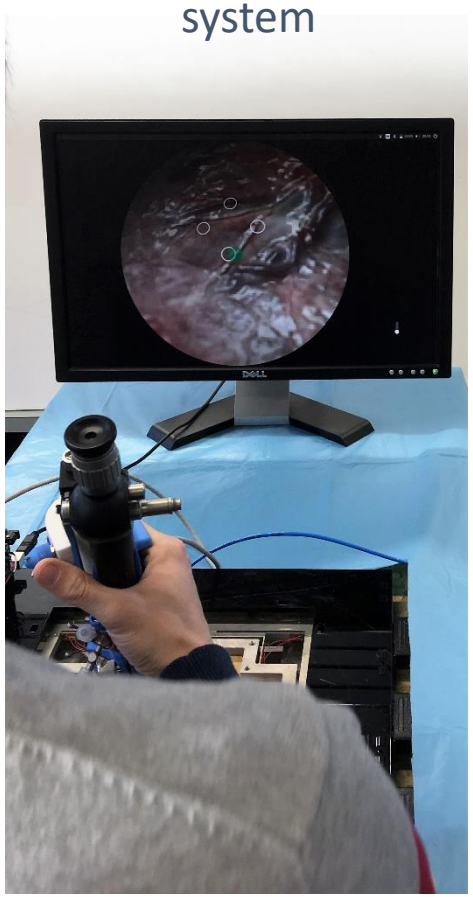


- **Experiments – Fetal surgery**

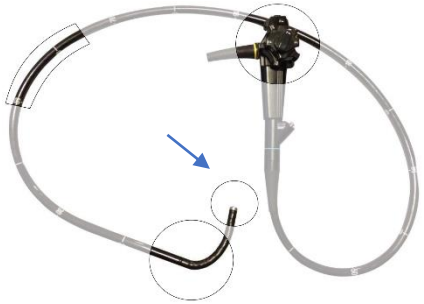
< diameter
> bending angle



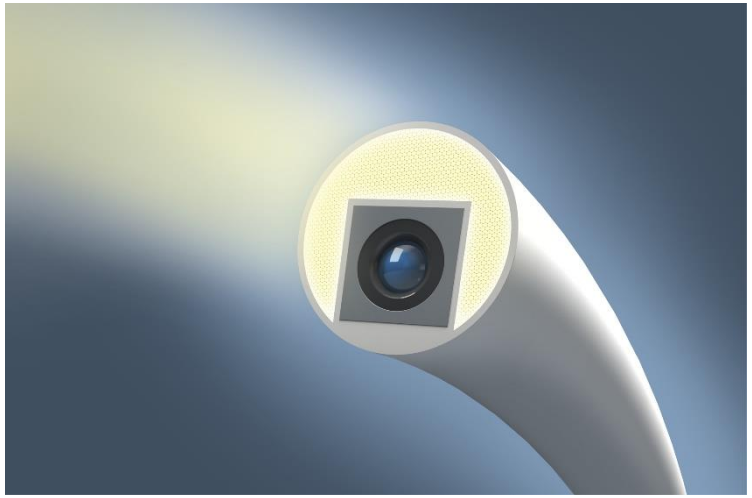
Available mixed-reality system



- Feasability of flexible, steerable instruments in CWS
- Interface: buttons or scroll wheel
- Control: Feedforward



- **Tools and length**

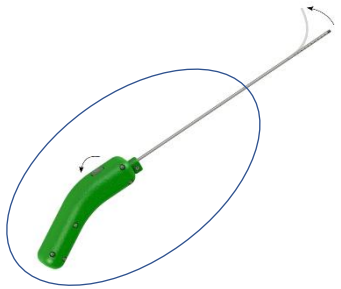


Visualization = first step

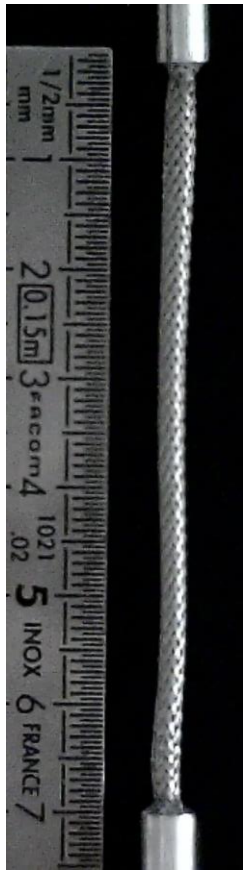
- **endoscope**
- **~ 300mm** long
- **camera** and **light source**

https://www.schott.com/brazil/portuguese/news/press.html?NID=com5700&freturl=%2Fbrazil%2Fportuguese%2Findex.html

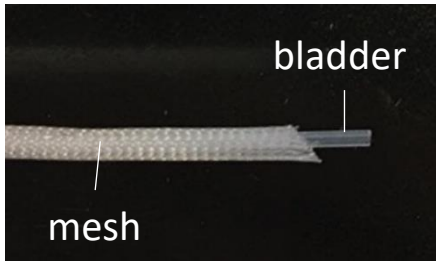
Instrument design



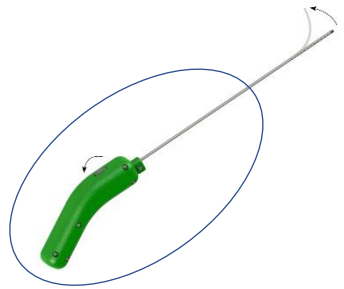
- Slender, light, compact and safe



McKibben muscle



- Pneumatic
- Lightweight **<10g**
- Compact down to **1.2mm diameter**

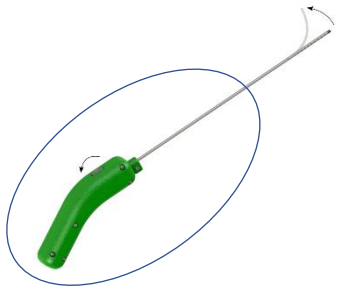


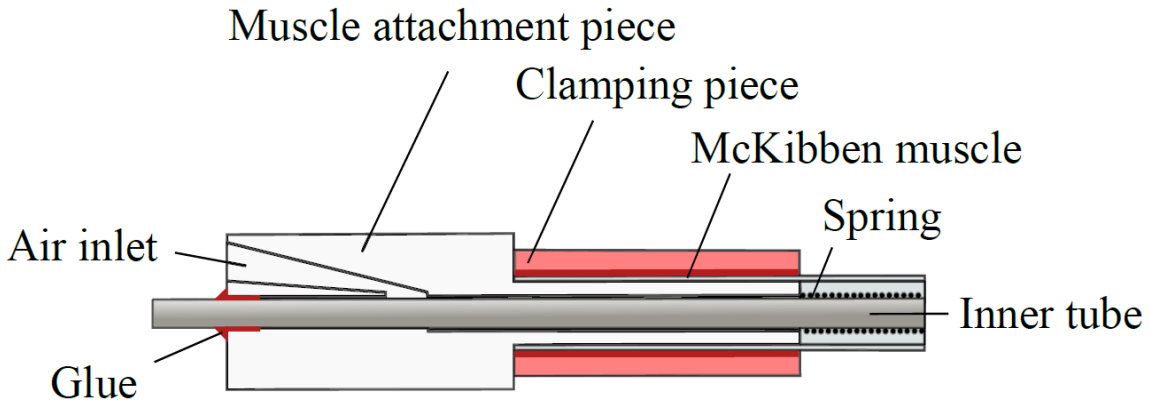
- Slender, light, compact and safe

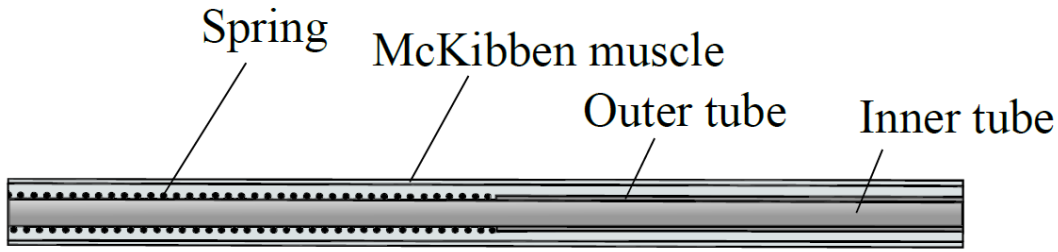
- McKibben muscle **inside** the shaft
- **3mm** diameter
- Lightweight **87g**
- Bending angle **up to 70°**
- Contains a **light source**, **camera** and **working channel**

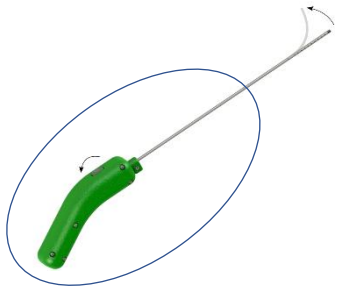
✓	✗
Fetal surgery	Maxillary sinus surgery

- McKibben **concentric** muscle



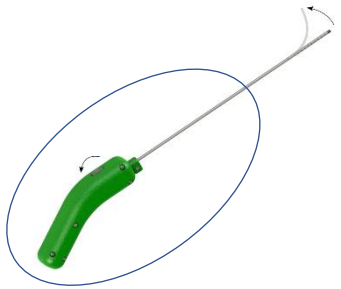




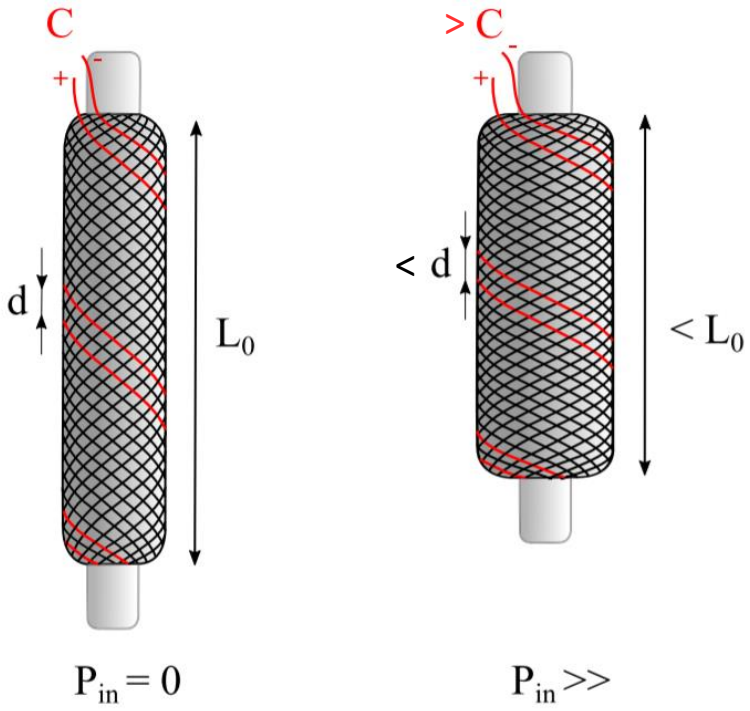


- McKibben **concentric** muscle

- Compact systems (2.5mm ø)
- Protection of the tools
- Guidance

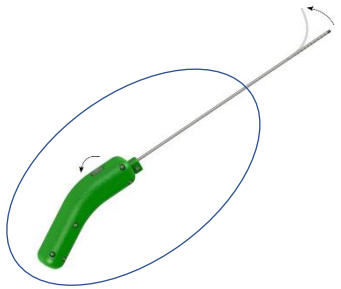


- Overcoming non-linearities: McKibben **concentric** muscle



Capacitance sensor

- Easy to build
- Miniaturizable
- Compact



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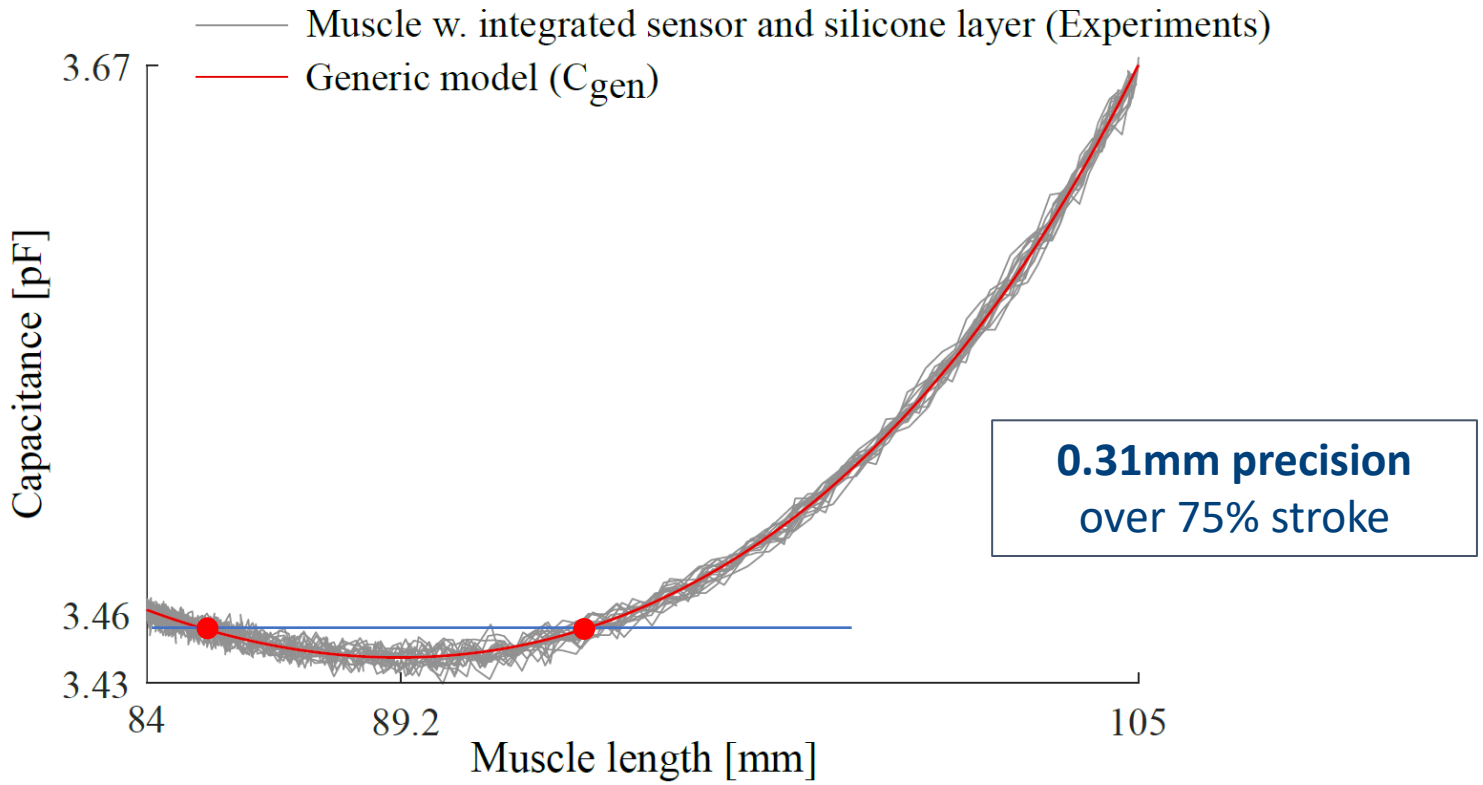
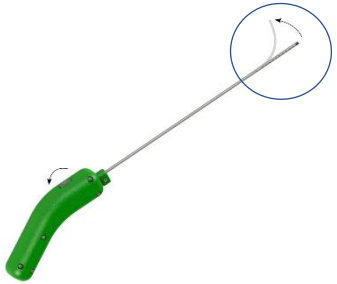
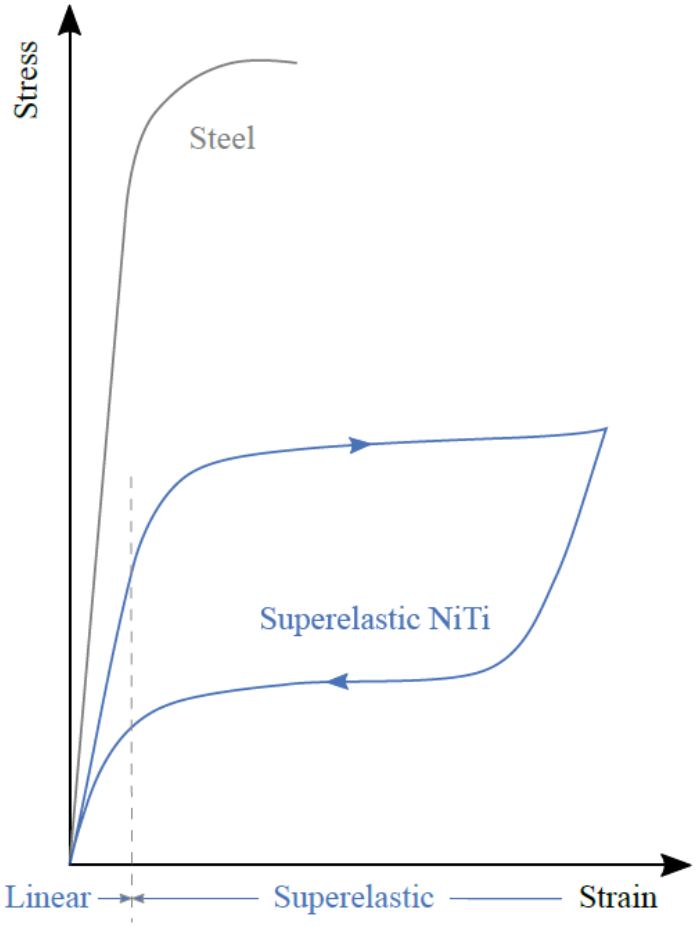
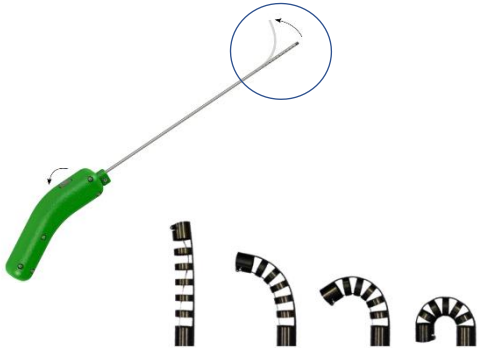


0.31mm precision
over 75% stroke

- High bending angle, small bending radius

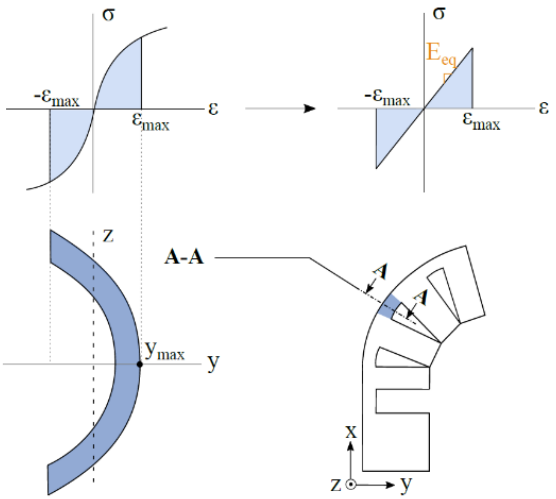




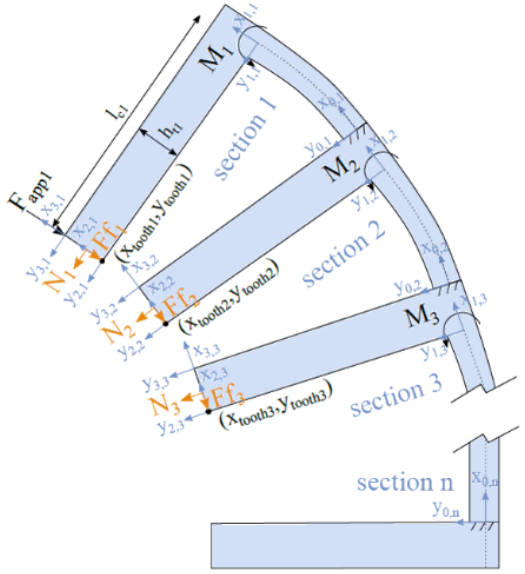


- Large deflection model for Nitinol notched-tubes

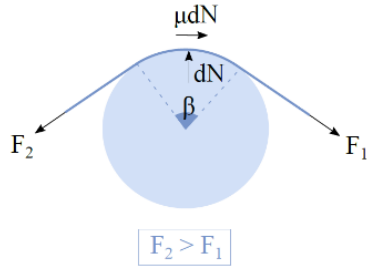
- Large bending angle

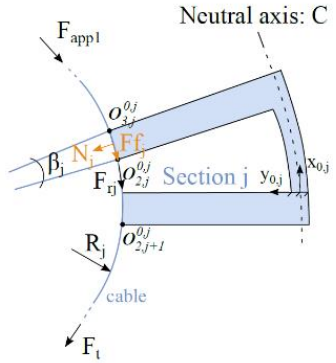


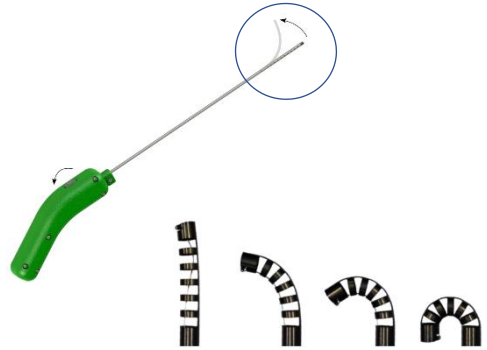
- Non-constant curvature
- Equal & non-equal-size notches



- Capstan-based friction







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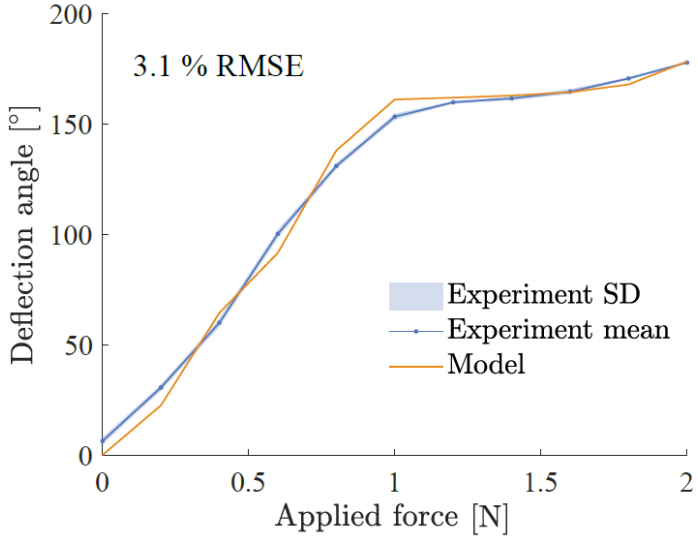
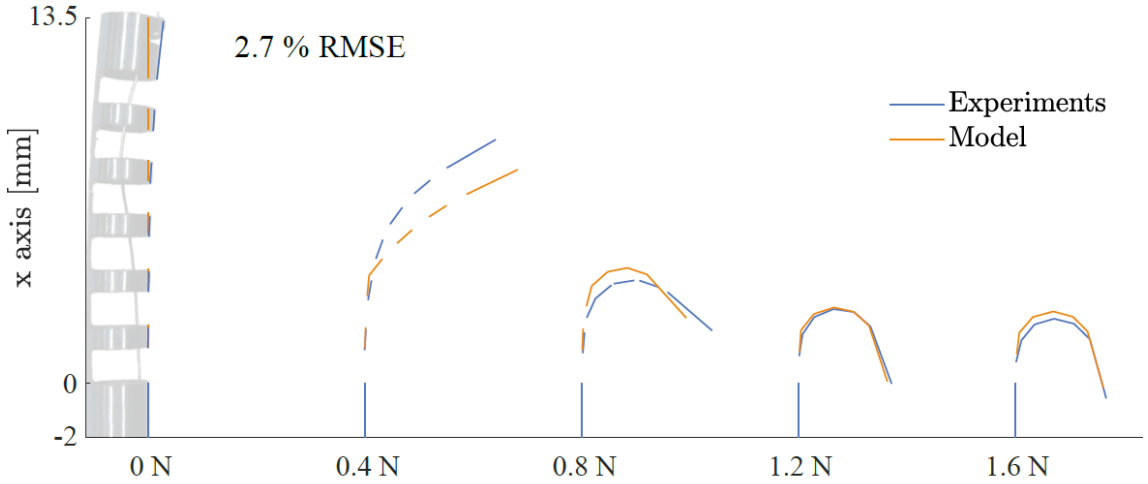
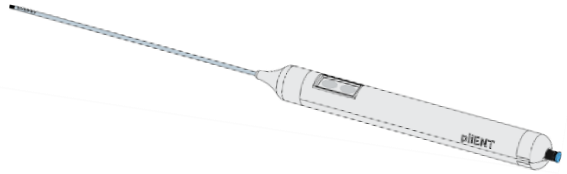


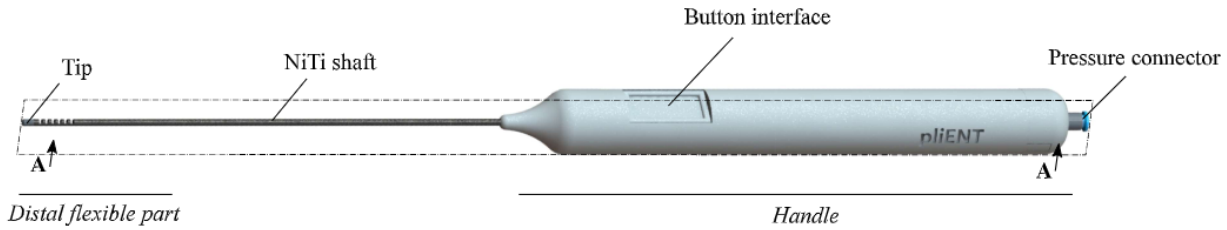


Instrument assembly

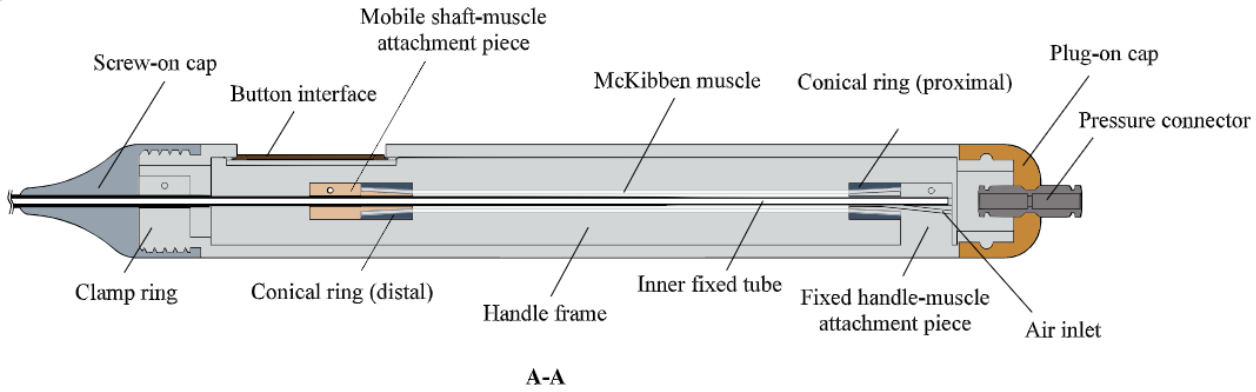


- Endoscope for maxillary sinus surgery

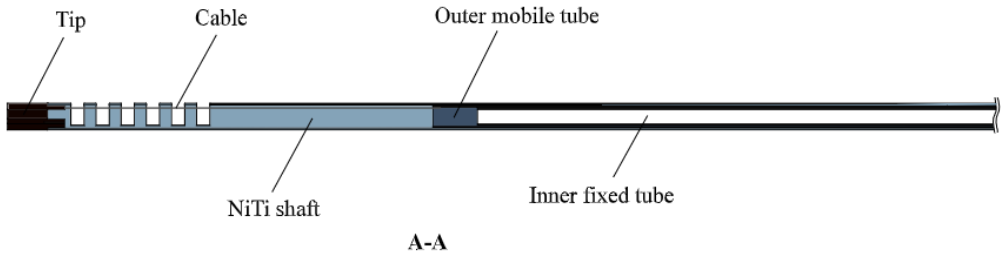
a)

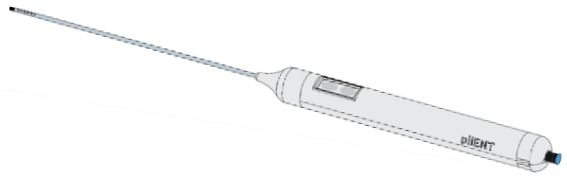


b) *Handle*



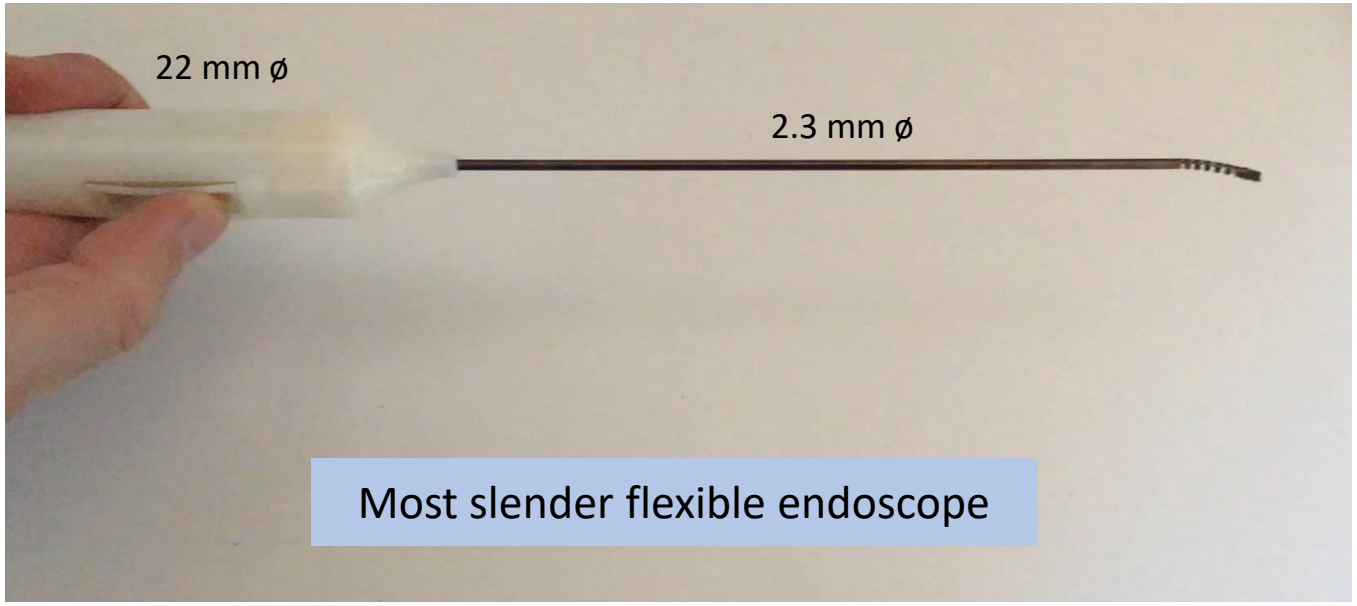
c) *Distal flexible part*



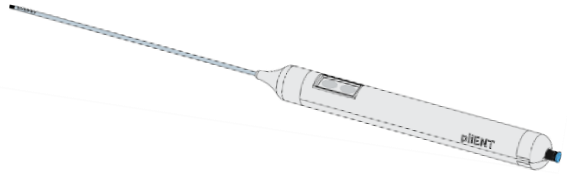


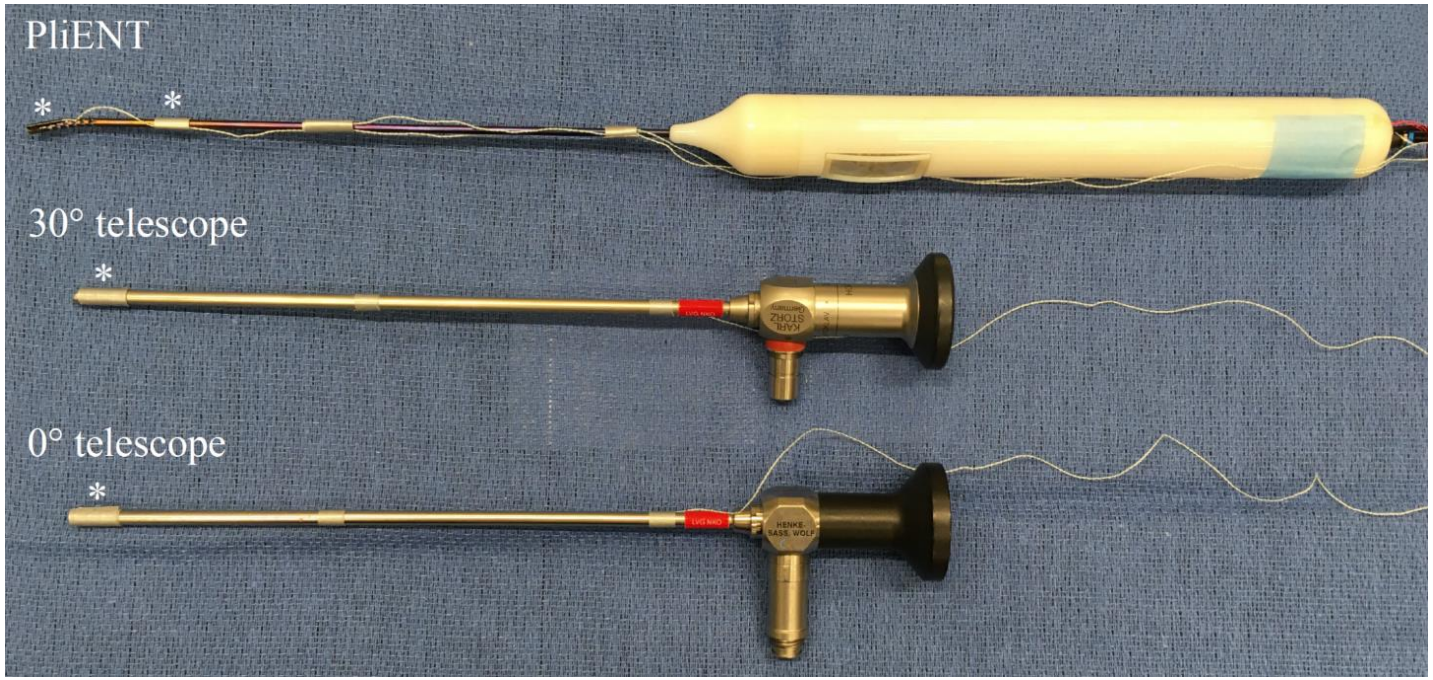
- Endoscope for maxillary sinus surgery

  - Tools: **camera & light**
  - 375 mm long
  - 51 g light
  - 93° bending angle



Surgical experiments

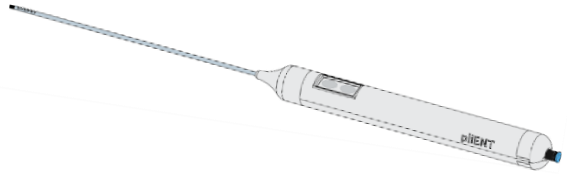


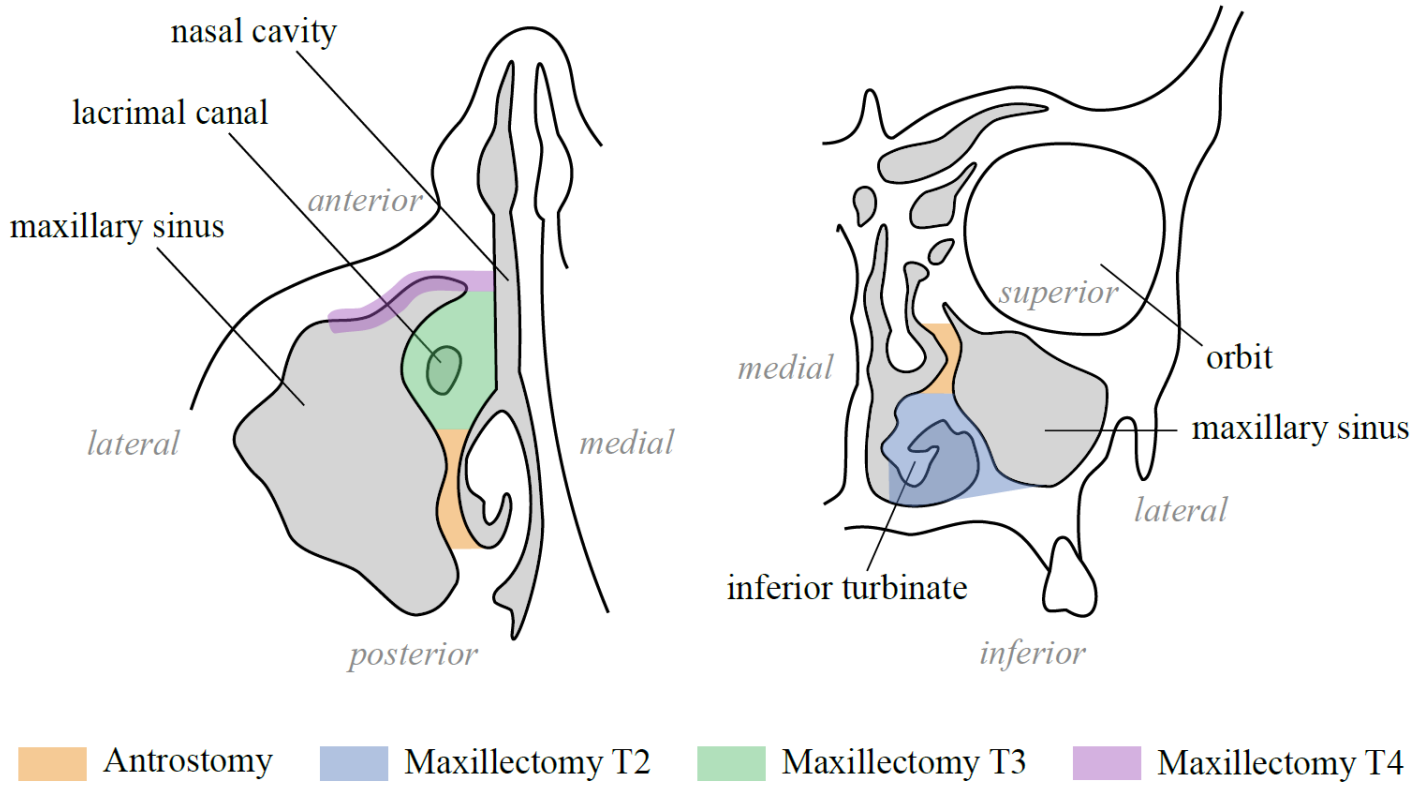


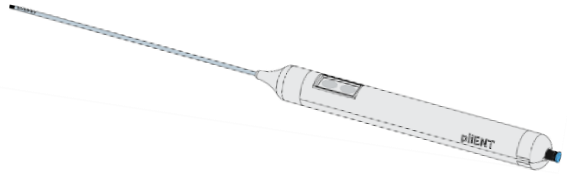
- On **1 cadaver** head (2 sinuses)
- By **2 ENT surgeons**

Measurements:

- Tip position
- Camera images
- Surgeon experience




nasal cavity
lacrimal canal
anterior
maxillary sinus
lateral
medial
posterior
superior
medial
orbit
maxillary sinus
lateral
inferior turbinate
inferior
Antrostomy
Maxillectomy T2
Maxillectomy T3
Maxillectomy T4
Invasivity



Invasivity

0° scope

	Antrostomy	Maxillectomy type 2	Maxillectomy type 3	Maxillectomy type 4
Posterior	partially (> 50%)	fully	fully	fully
Lateral	partially (< 50%)	partially (> 50%)	fully	fully
Medial	partially (< 50%)	partially (> 50%)	partially (> 50%)	fully
Floor	impossible	partially (< 50%)	partially (> 50%)	fully
Anterior	impossible	impossible	partially (< 50%)	fully

fully

partially (> 50%)

partially (< 50%)

impossible

30° scope

	Antrostomy	Maxillectomy type 2	Maxillectomy type 3	Maxillectomy type 4
Posterior	partially (> 50%)	fully	fully	fully
Lateral	partially (< 50%)	fully	fully	fully
Medial	partially (< 50%)	partially (> 50%)	fully	fully
Floor	partially (< 50%)	partially (> 50%)	fully	fully
Anterior	impossible	partially (< 50%)	fully	fully

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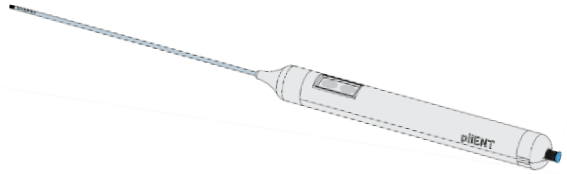
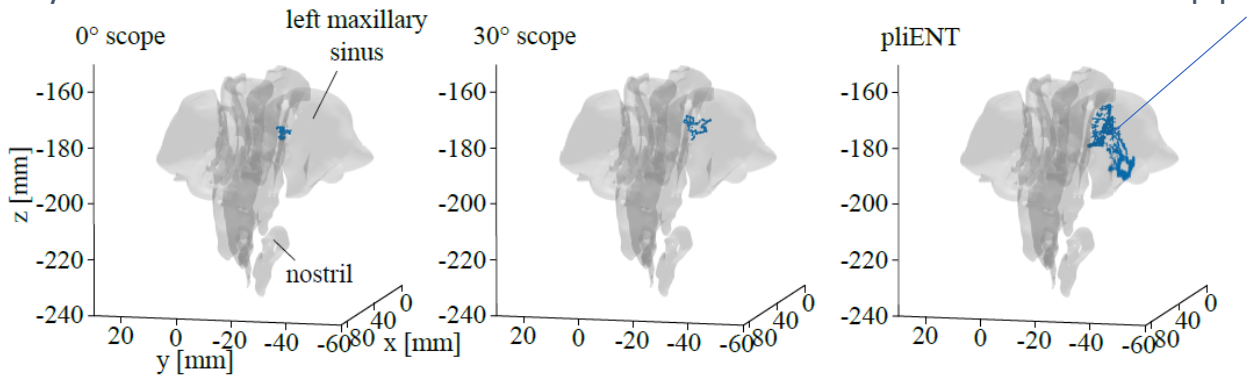
	Antrostomy	Maxillectomy type 2	Maxillectomy type 3	Maxillectomy type 4
Posterior	fully	fully	fully	fully
Lateral	fully	fully	fully	fully
Medial	partially (> 50%)	fully	fully	fully
Floor	partially (> 50%)	fully	fully	fully
Anterior	partially (> 50%)	fully	fully	fully

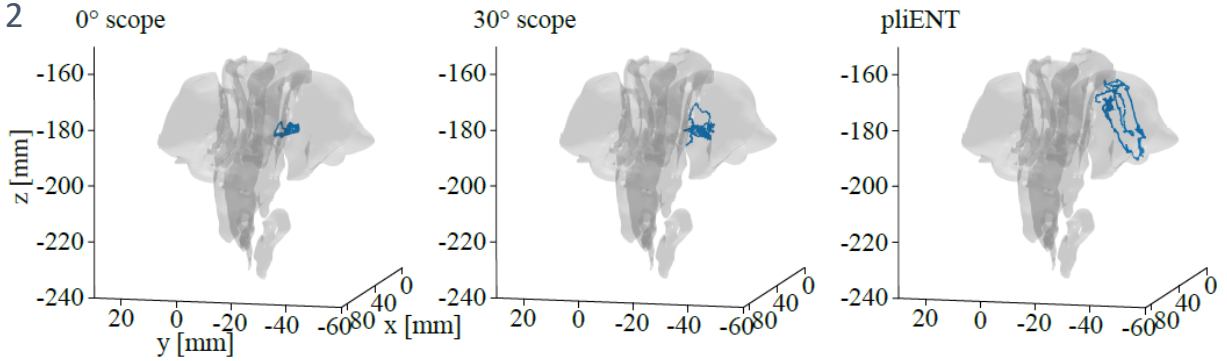


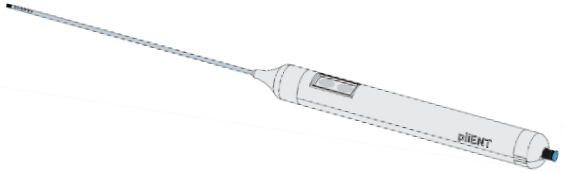
Antrostomy

Tip position

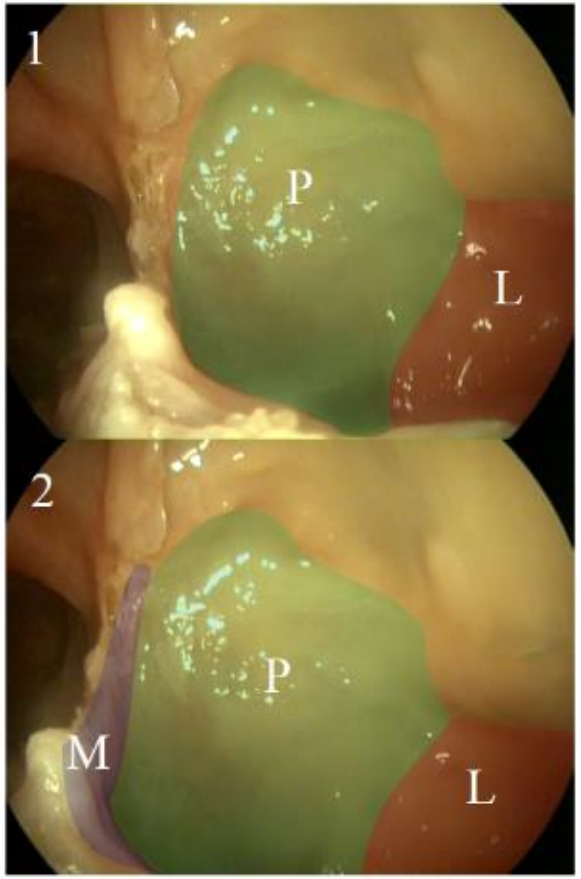


Maxillectomy type 2

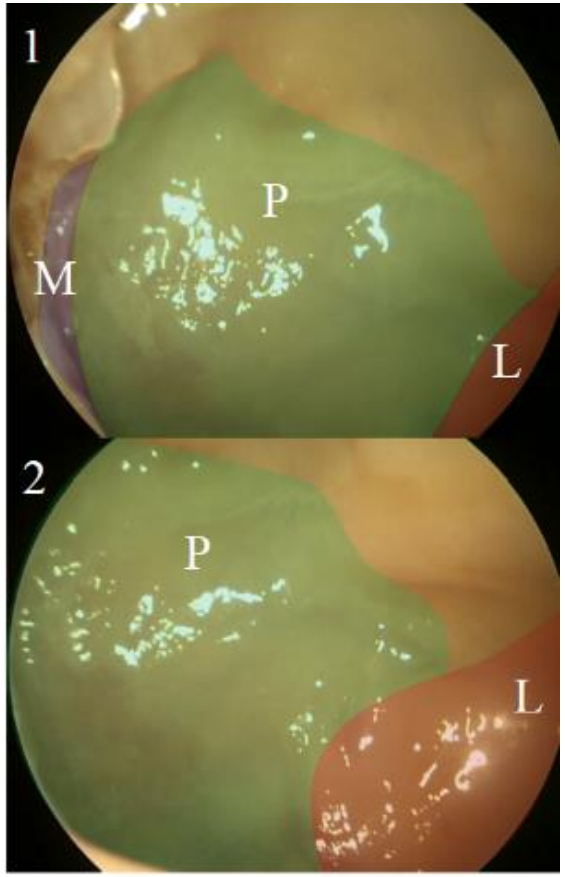


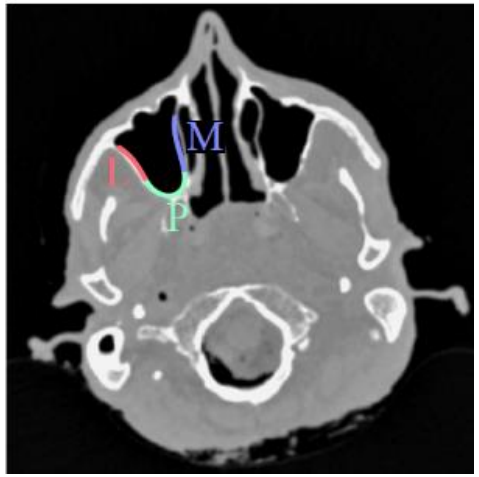


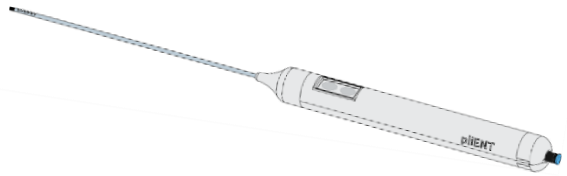
0° scope



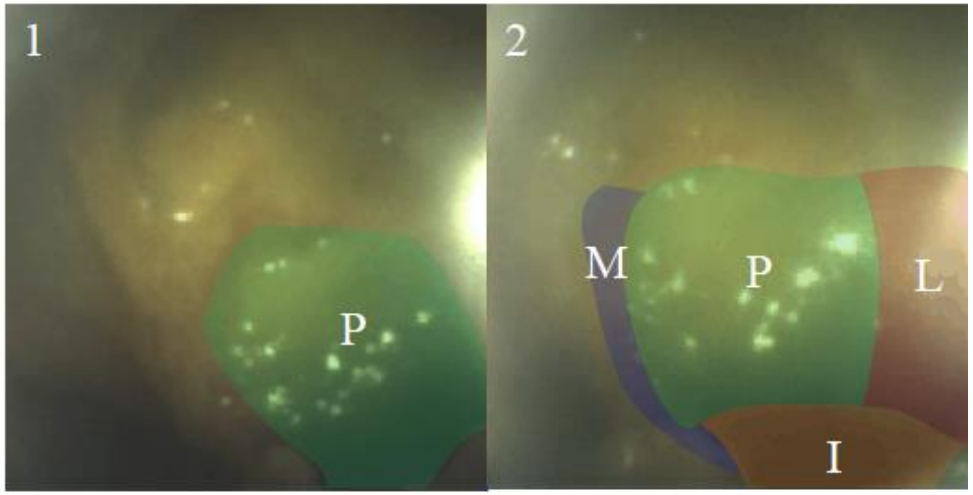
30° scope

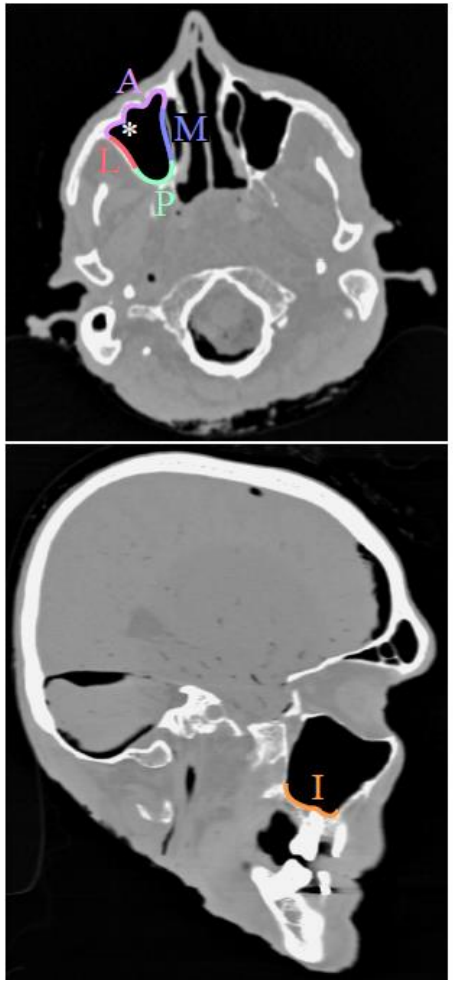






Flexible endoscope





Conclusion

- Novel pneumatic actuator
- Novel sensor for McKibben muscle
- Novel model for large deformation of NiTi notched backbones

- Risk analysis

- Novel methods for instrument specifications
  - Instrument size, bending, …
  - Instrument handle

- Experiments with clinicians

Most **slender** endoscope for maxillary sinus surgery