

Bio-Inspired Design

Wb2436-05



Biosticking – Part 1

What is adhesion?

Compensate forces from the environment



with the aim to



stay,

move,

or transpose

What is adhesion?

stay



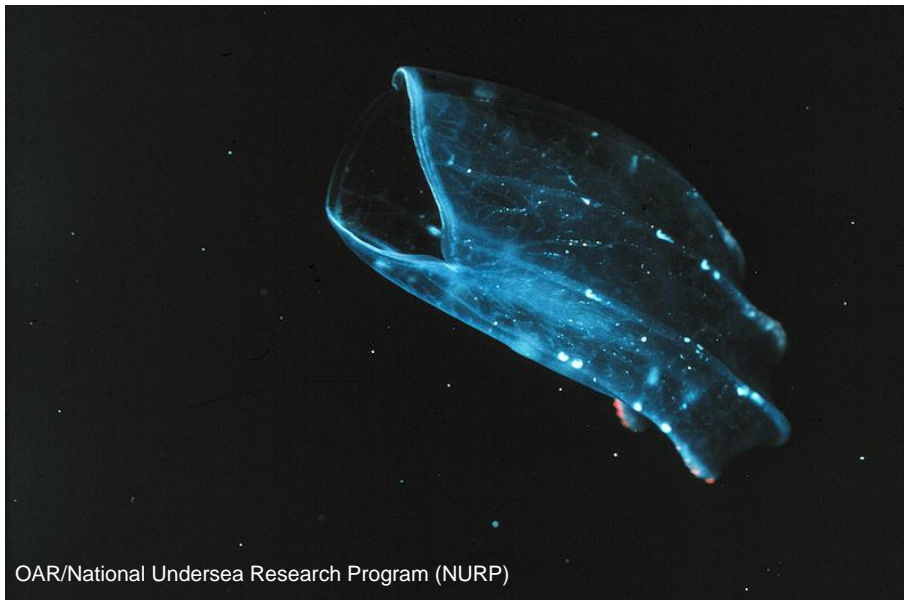
What is adhesion?

move

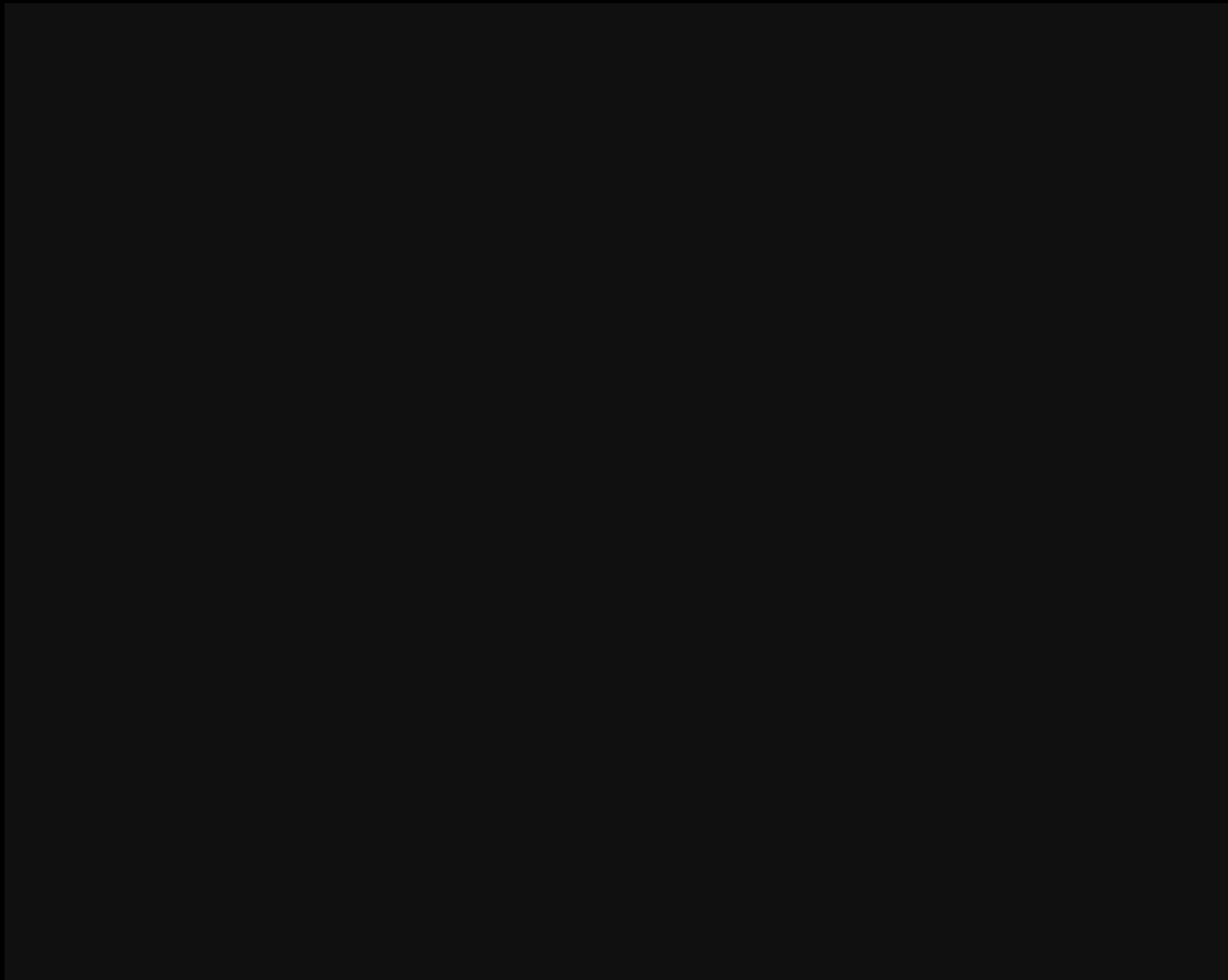


What is adhesion?

transpose



Ideas from nature



What is adhesion?

Adhesion **with** an intermediate layer



Solid intermediate layer



Liquid intermediate layer

Adhesion **without** an intermediate layer



Van der Waals



Electrostatic



Shape grip



Friction grip



Suction

What is adhesion?

Adhesion **with** an intermediate layer



Solid intermediate layer



Liquid intermediate layer

Adhesion **without** an intermediate layer



Van der Waals



Electrostatic



Shape grip



Friction grip



Suction

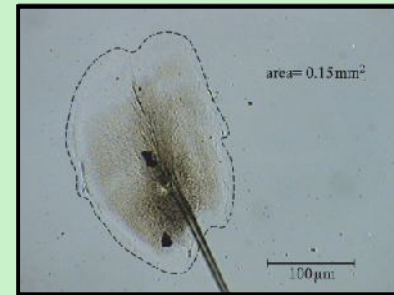
Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Mussel *Mytilus edulis*



Adhesion with a **solid** interlayer

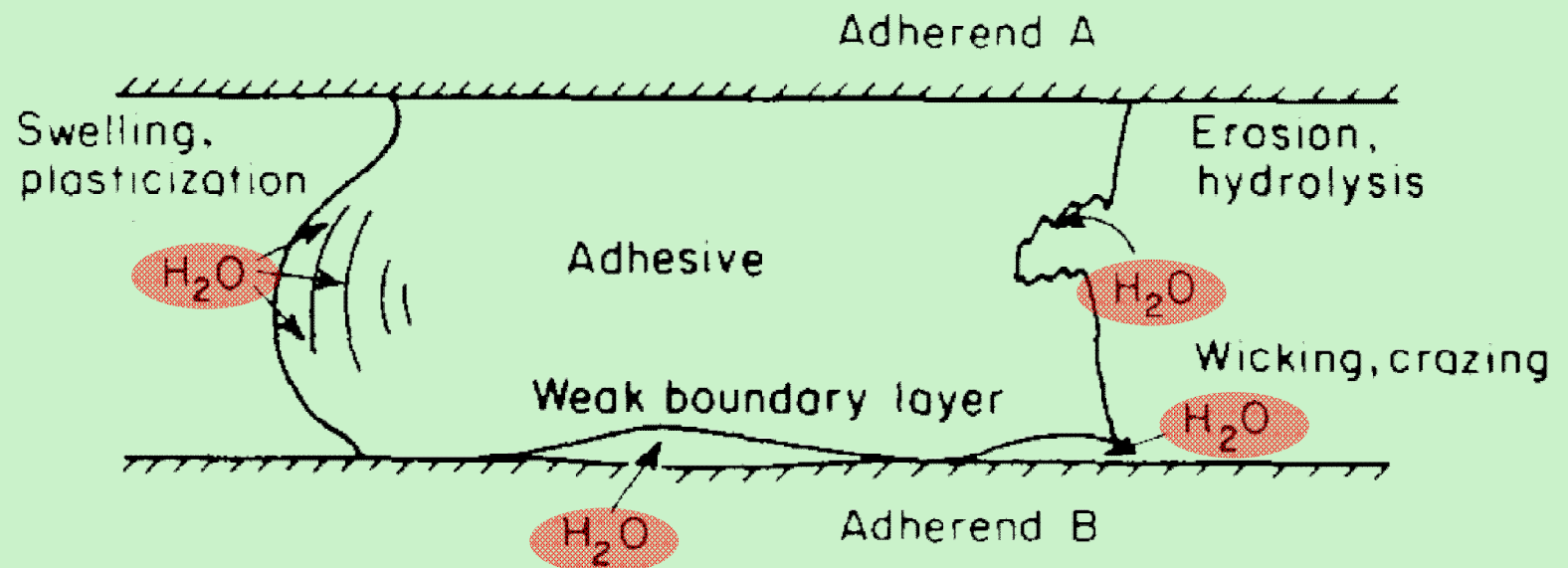
Tissue adhesives



Traditional



Bioinspired: Mussel *Mytilus edulis*



Four pathways by which water undermines the performance of adhesive bonds

Adhesion with a **solid** interlayer

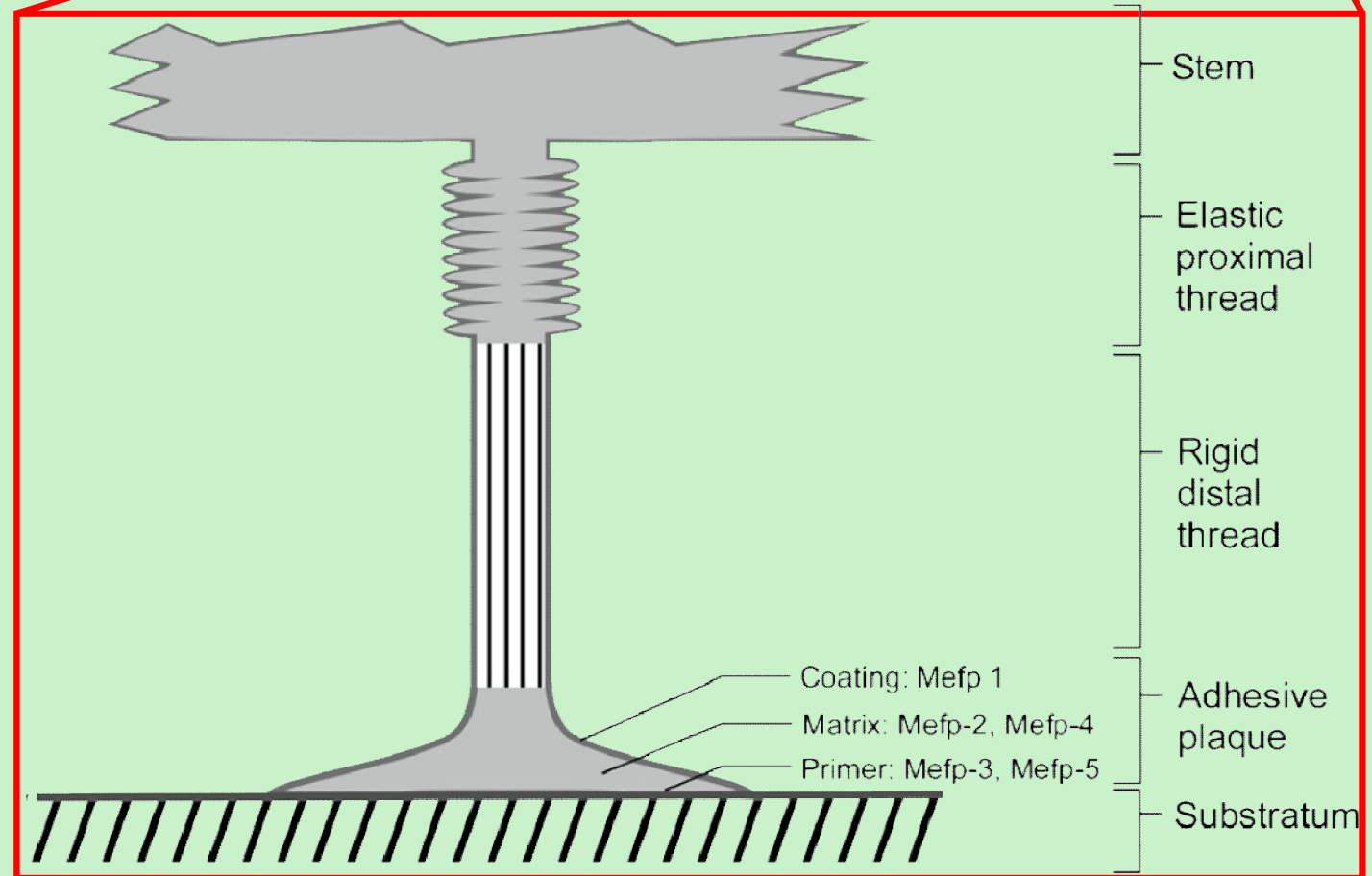
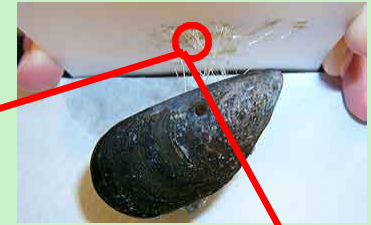
Tissue adhesives

Traditional



amino acid
L-3, 4- dihydroxy-
phenylalanine
(**DOPA**)

Bioinspired: Mussel *Mytilus edulis*



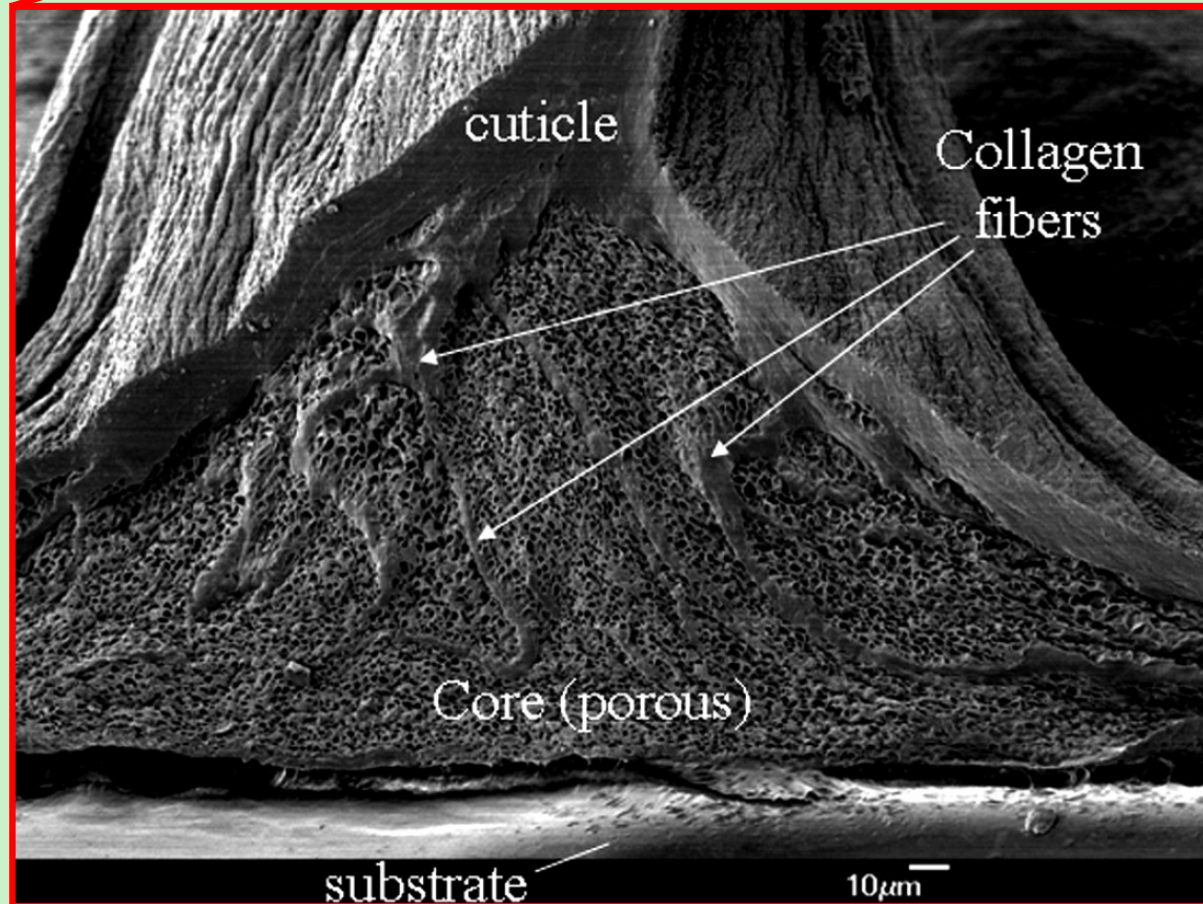
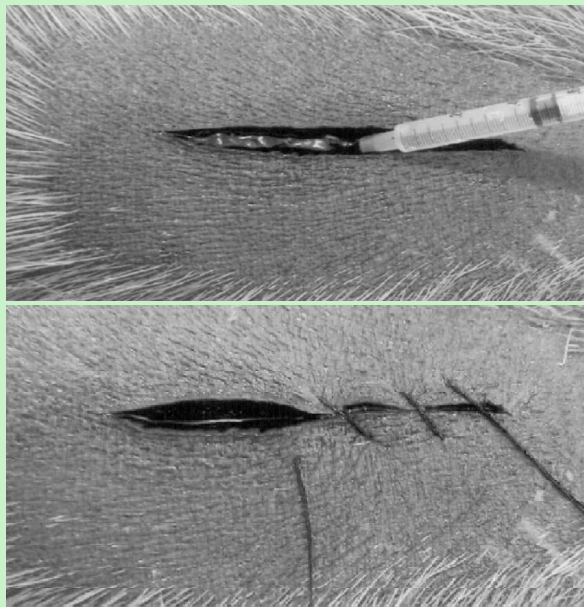
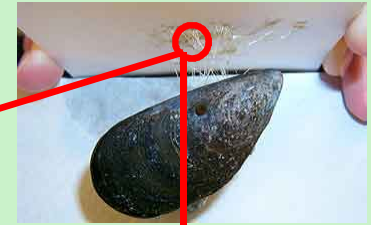
Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Mussel *Mytilus edulis*



Lee et al. (2006). *PNAS* 103, 12999–13003; Dalsin et al. (2003). *JACS* 125, 4253–4258; Silverman et al. (2007). *Mar Biotech* 9, 661–681; Waite et al. (2005). *J Adh* 81, 297–317.

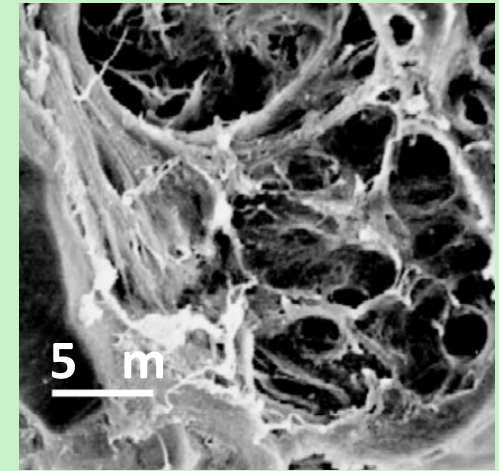
Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Ground frog *Notaden*



Adhesive	Shear strength Mean±SD (MPa)
<i>Notaden</i>	1.7±0.3
Cyanoacrylate	1.7±0.7
PVA glue	1.3±0.2
UHU® Stic	0.9±0.4

Adhesive	Peel strength Mean±SD (MPa)
Cyanoacrylate	0.15±0.03
<i>Notaden</i>	0.10±0.03
Gelatin	0.04±0.03
Fibrin	0.02±0.01

Graham et al. (2006). In Smith & Callow (Eds.) *Biological Adhesives* (pp. 207-223), Springer-Verlag.

Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Caddisfly larva



Stewart & Wang (2010). *Biomacromolecules* 11, 969–974.

Adhesion with a **solid** interlayer

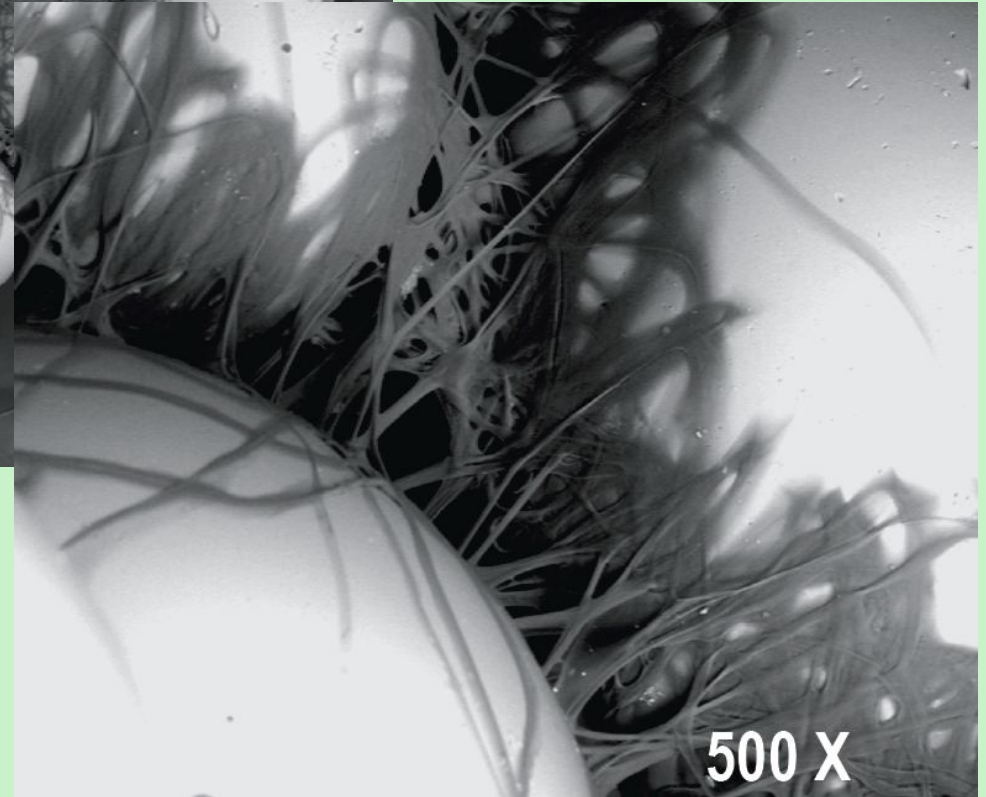
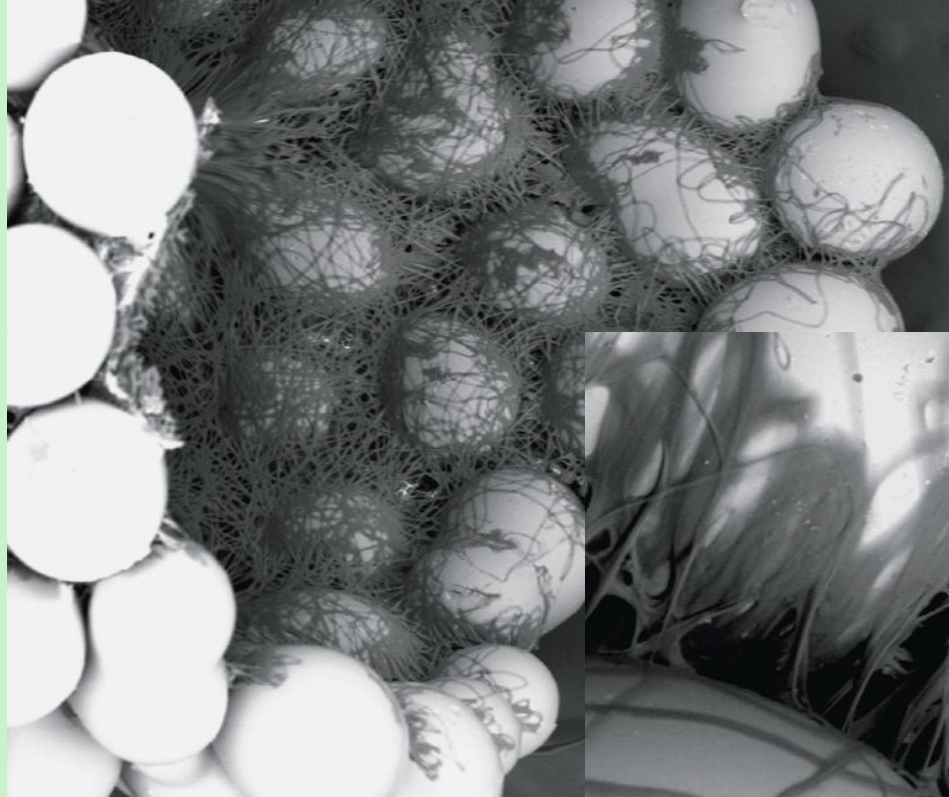
Tissue adhesives



Traditional



Bioinspired: Caddisfly larva



Stewart & Wang (2010). *Biomacromolecules* 11, 969–974.

Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Sandcastle worm *Phragmatopoma californica*



Stewart & Wang (2010). *Biomacromolecules* 11, 969–974.

Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Sandcastle worm



Stewart & Wang (2010). *Biomacromolecules* 11, 969–974.

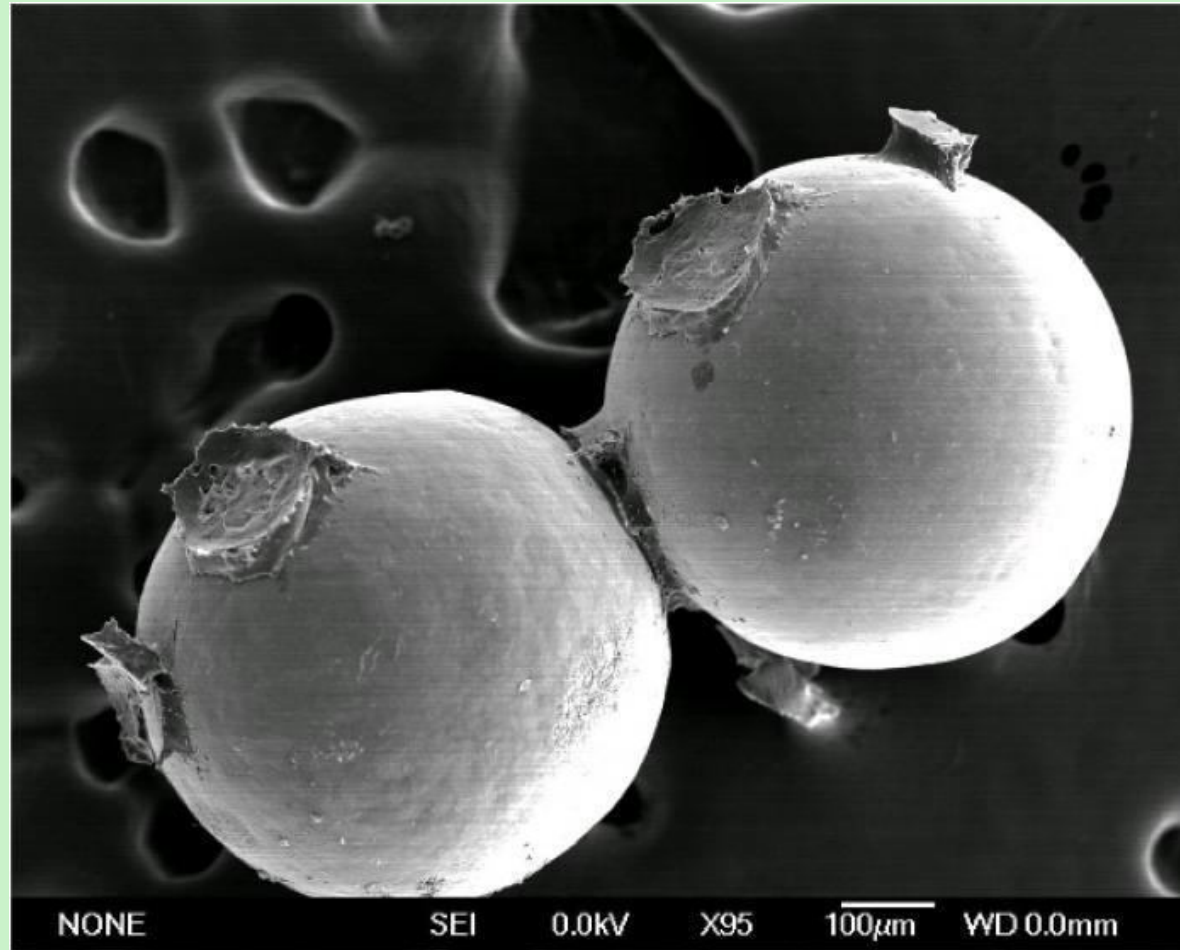
Adhesion with a **solid** interlayer

Tissue adhesives

Traditional



Bioinspired: Sandcastle worm *Phragmatopoma californica*



Stewart & Wang (2010). *Biomacromolecules* 11, 969–974.

Adhesion with a **solid** interlayer

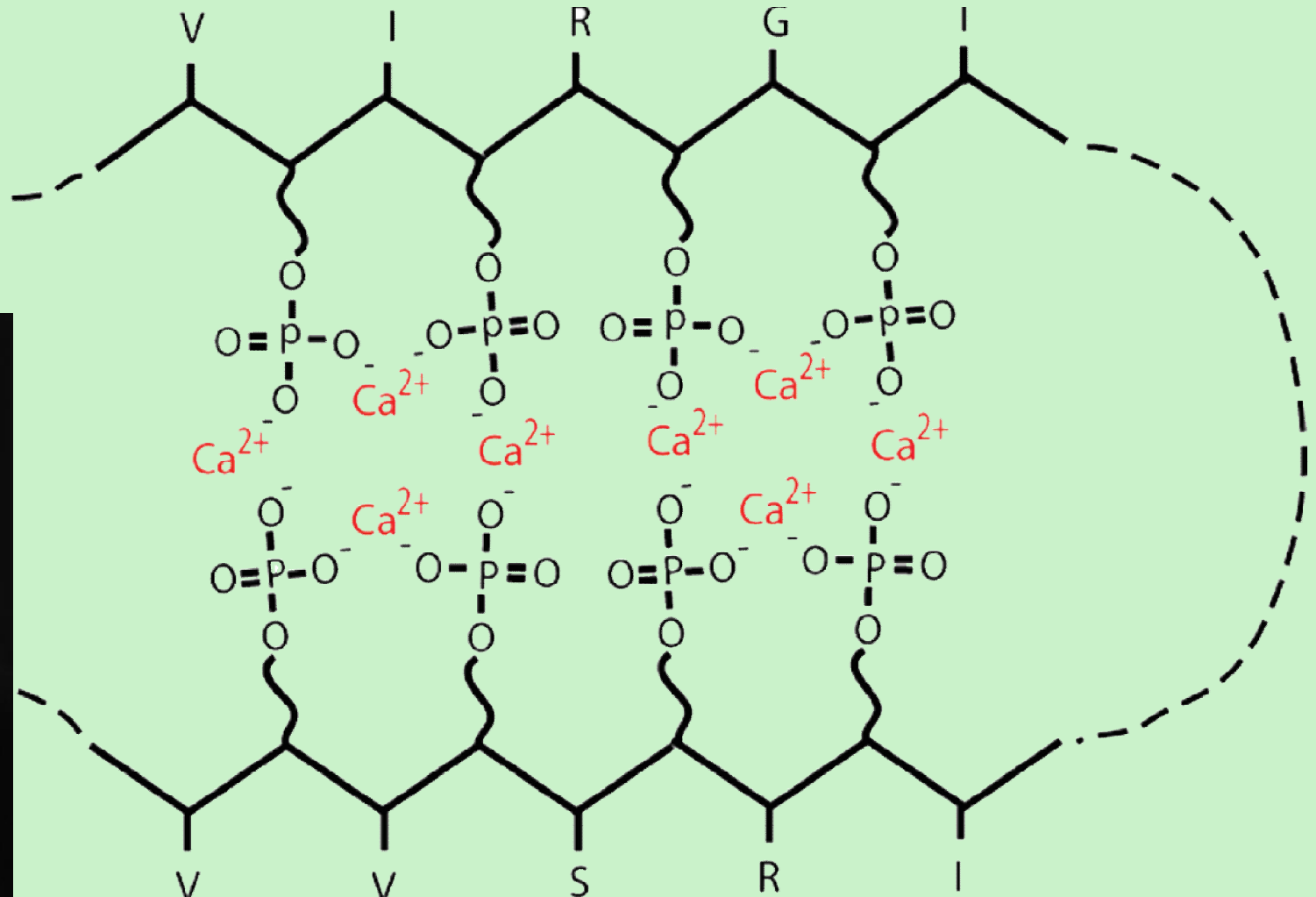
Tissue adhesives

Traditional



Stewart & Wang (2010). *Biomacromolecules* 11, 969–974.

Bioinspired: Caddisfly larva



Adhesion with a **solid** interlayer

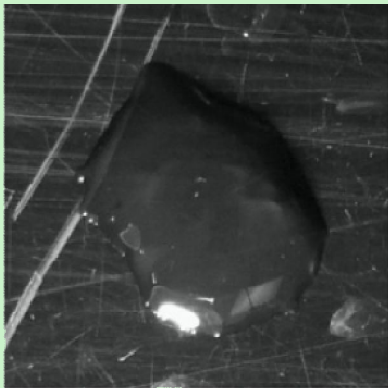
Tissue adhesives



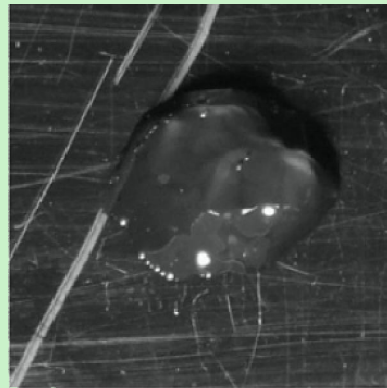
Traditional



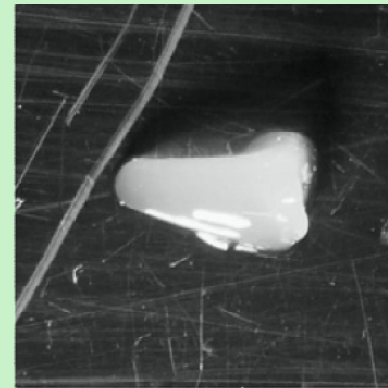
Bioinspired: Slug *Arion subfuscus*



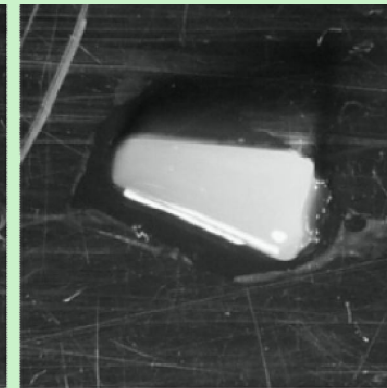
Tris



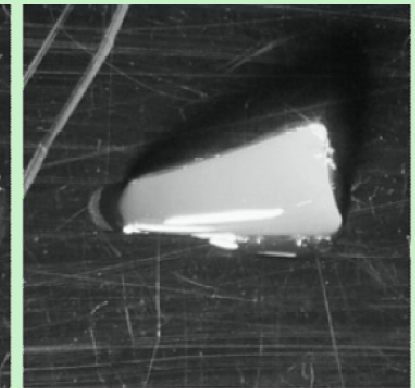
1M NaCl



Glue



Glue + 0.25M NaCl



Glue + 1M NaCl

Smith et al. (2009). *Comp Biochem Physiol B* 152, 110–117.

What is adhesion?

Adhesion **with** an intermediate layer



Solid intermediate layer



Liquid intermediate layer

Adhesion **without** an intermediate layer



Van der Waals



Electrostatic



Shape grip



Friction grip

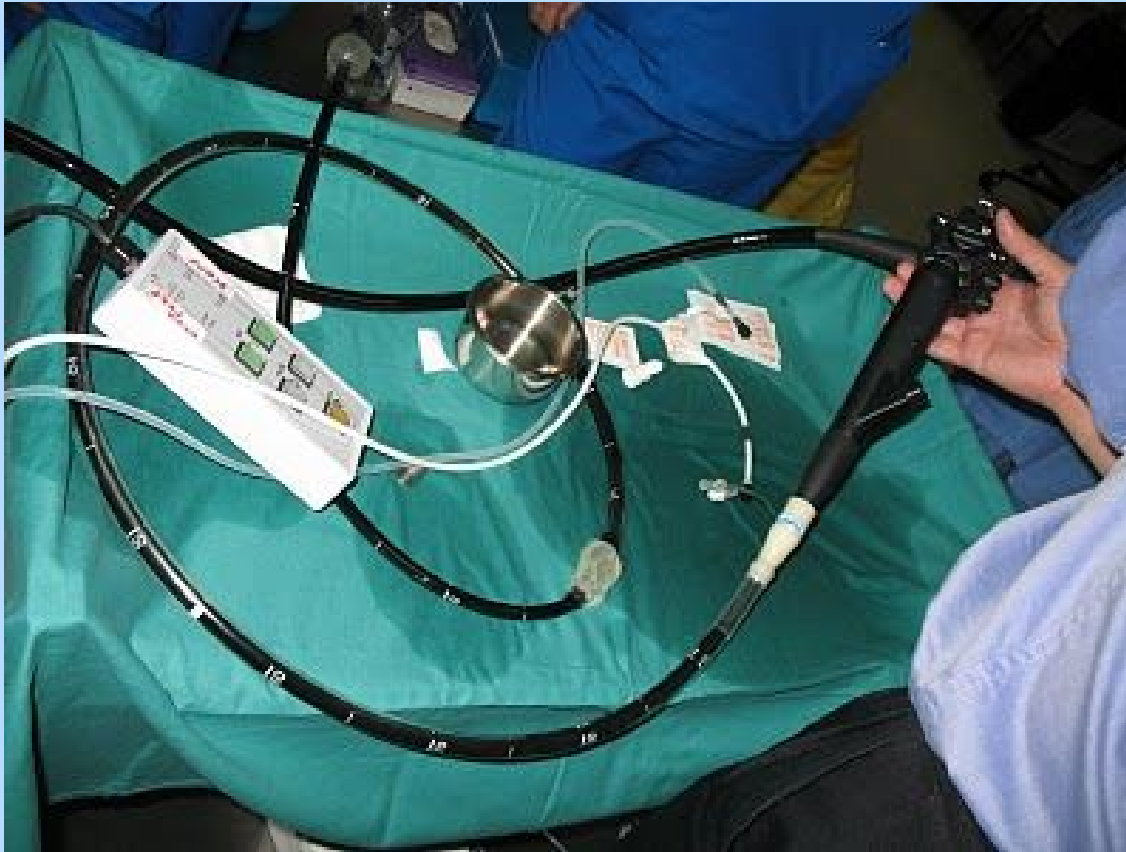


Suction

Adhesion with a **liquid** interlayer

In vivo microrobots

Traditional



Upper endoscopy

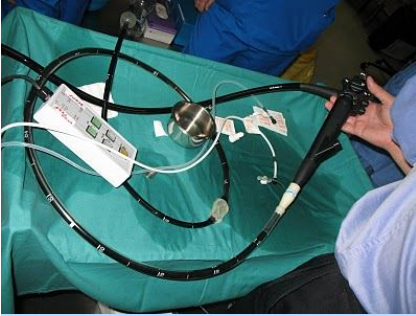


Camera pill

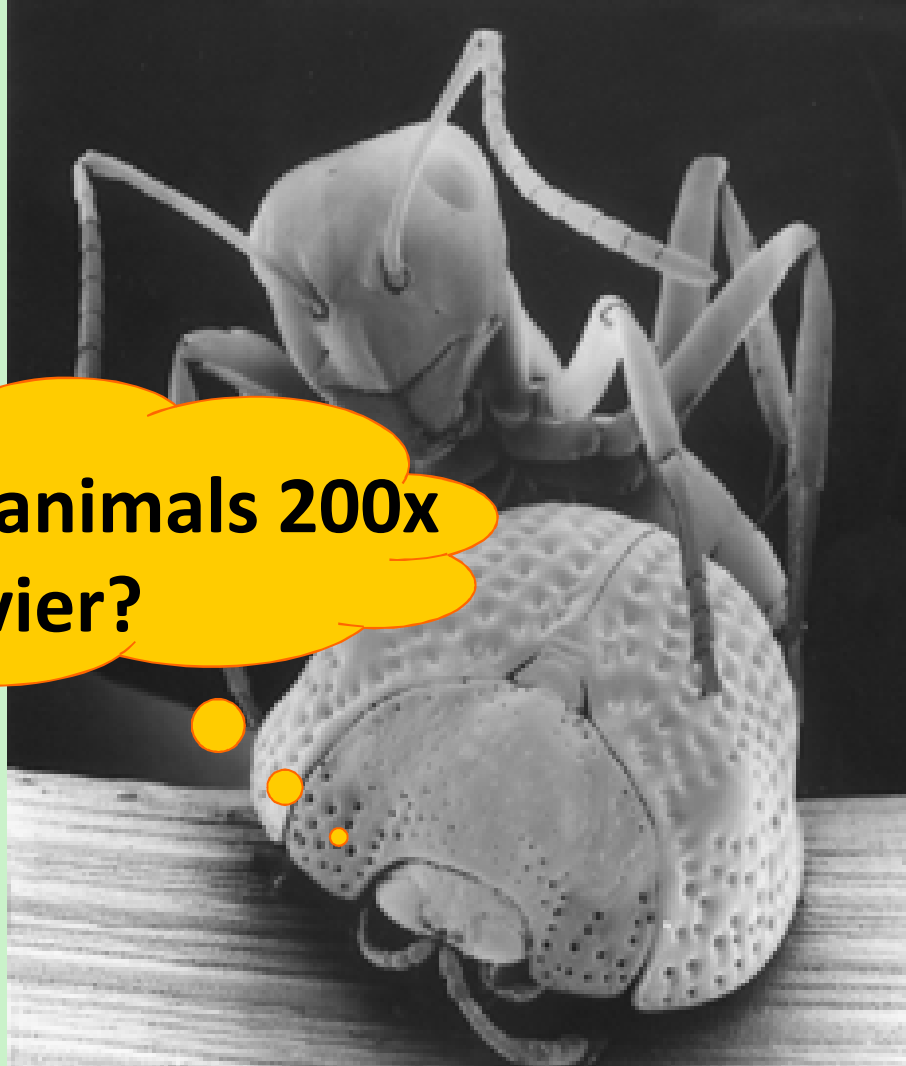
Adhesion with a **liquid** interlayer

In vivo microrobots

Traditional



Bioinspired: *Hemisphaerota cyanea*



10,000 bristles
per foot

200x its own weight
for short times

**How to beat animals 200x
heavier?**



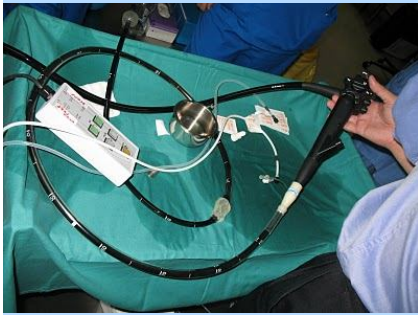
Eisner et al. (2000). *PNAS*
97, 6568–6573.

Adhesion with a **liquid** interlayer

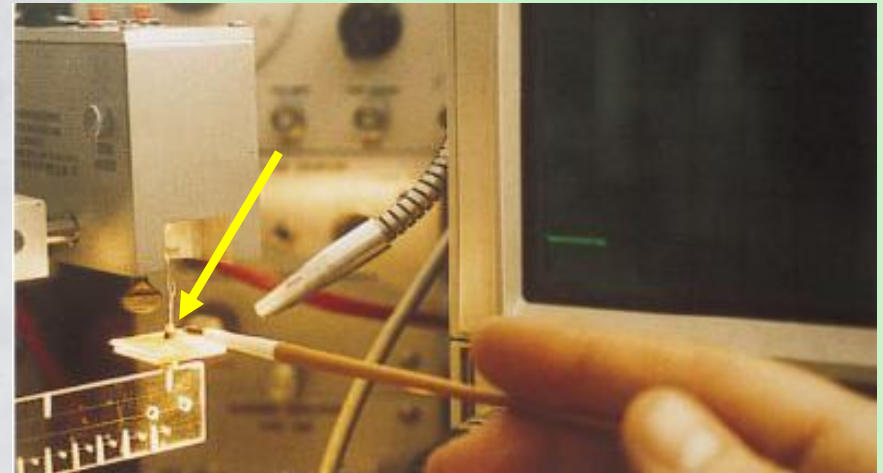
In vivo microrobots



Traditional



Bioinspired: *Hemisphaerota cyanea*



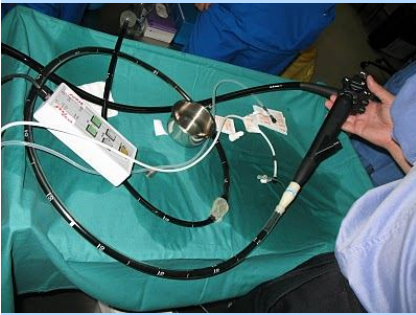
Eisner et al. (2000). *PNAS*
97, 6568–6573.

Adhesion with a **liquid** interlayer

In vivo microrobots



Traditional



Bioinspired: *Hemisphaerota cyanea*

Oily footprints during
normal walking



Oily footprints when
defending



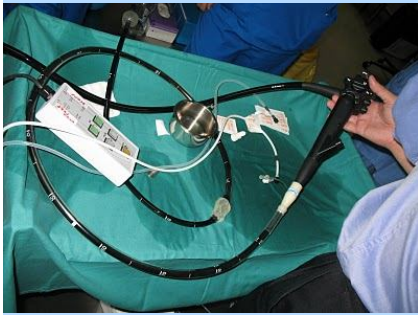
Eisner et al. (2000). *PNAS*
97, 6568–6573.

Adhesion with a **liquid** interlayer

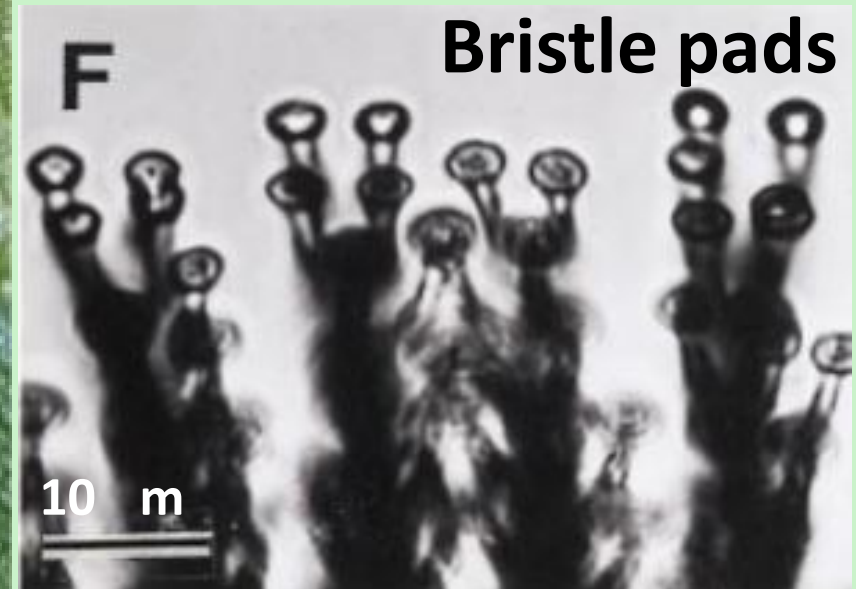
In vivo microrobots



Traditional



Bioinspired: *Hemisphaerota cyanea*



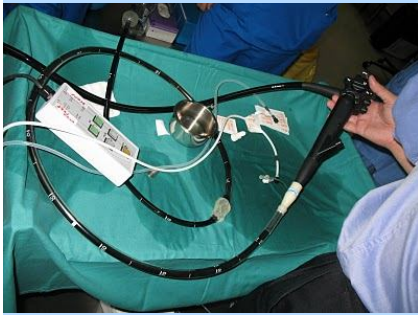
Eisner et al. (2000). *PNAS*
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Adhesion with a **liquid** interlayer

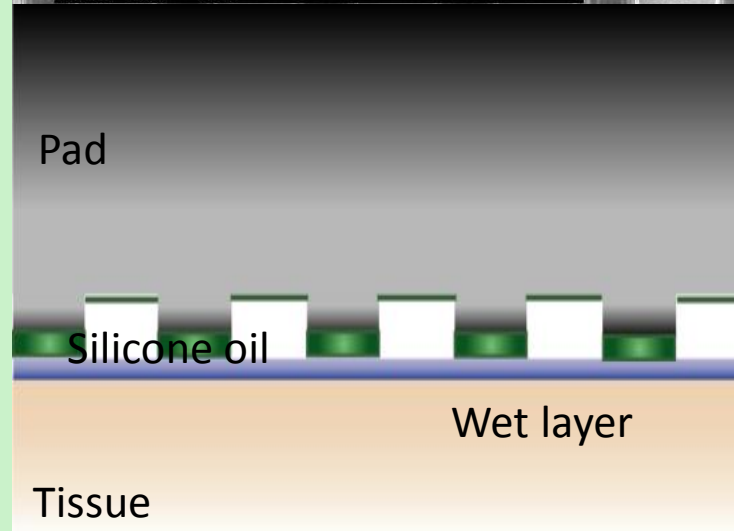
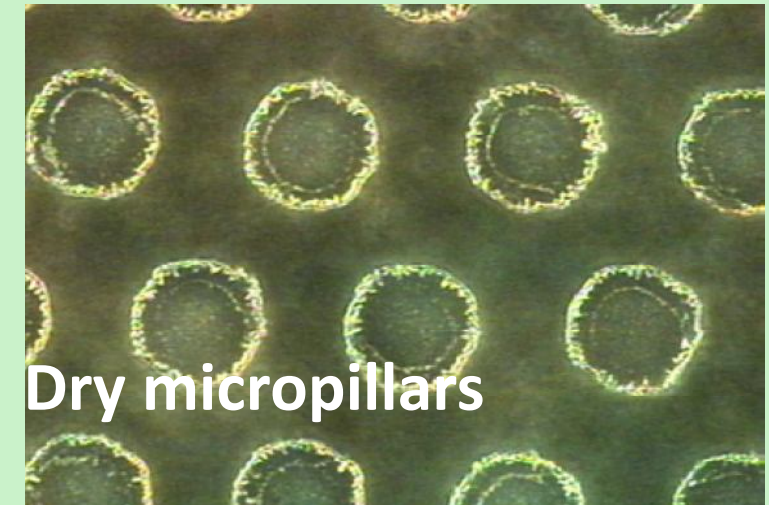
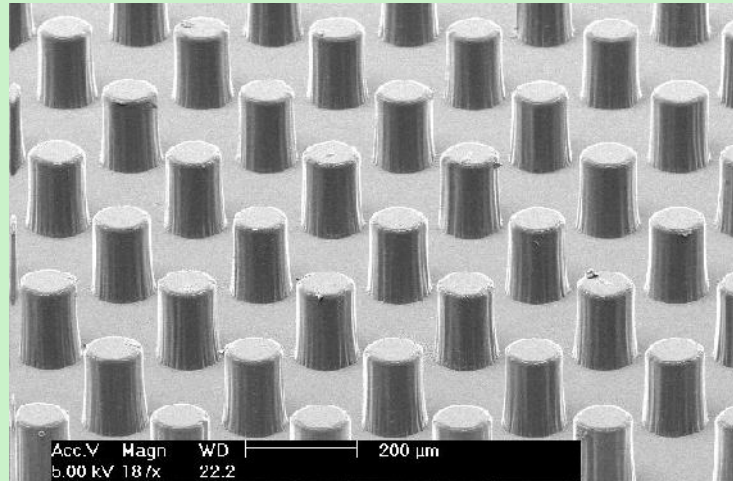
In vivo microrobots



Traditional



Bioinspired: *Hemisphaerota cyanea*



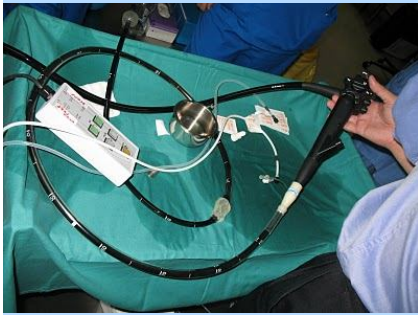
Cheung & Sitti. (2008). *J Adh Sci Technol* 22, 569–589; Kwan et al. (2006). *Biomed Mater* 1, 216–220; Cheung et al. (2005). *Proc IEEE/ASME Int Conf Adv Intel Mechatr* MD5-04; Glass et al. (2008). *IEEE Trans Biomed Eng* 55, 2759–2767.

Adhesion with a **liquid** interlayer

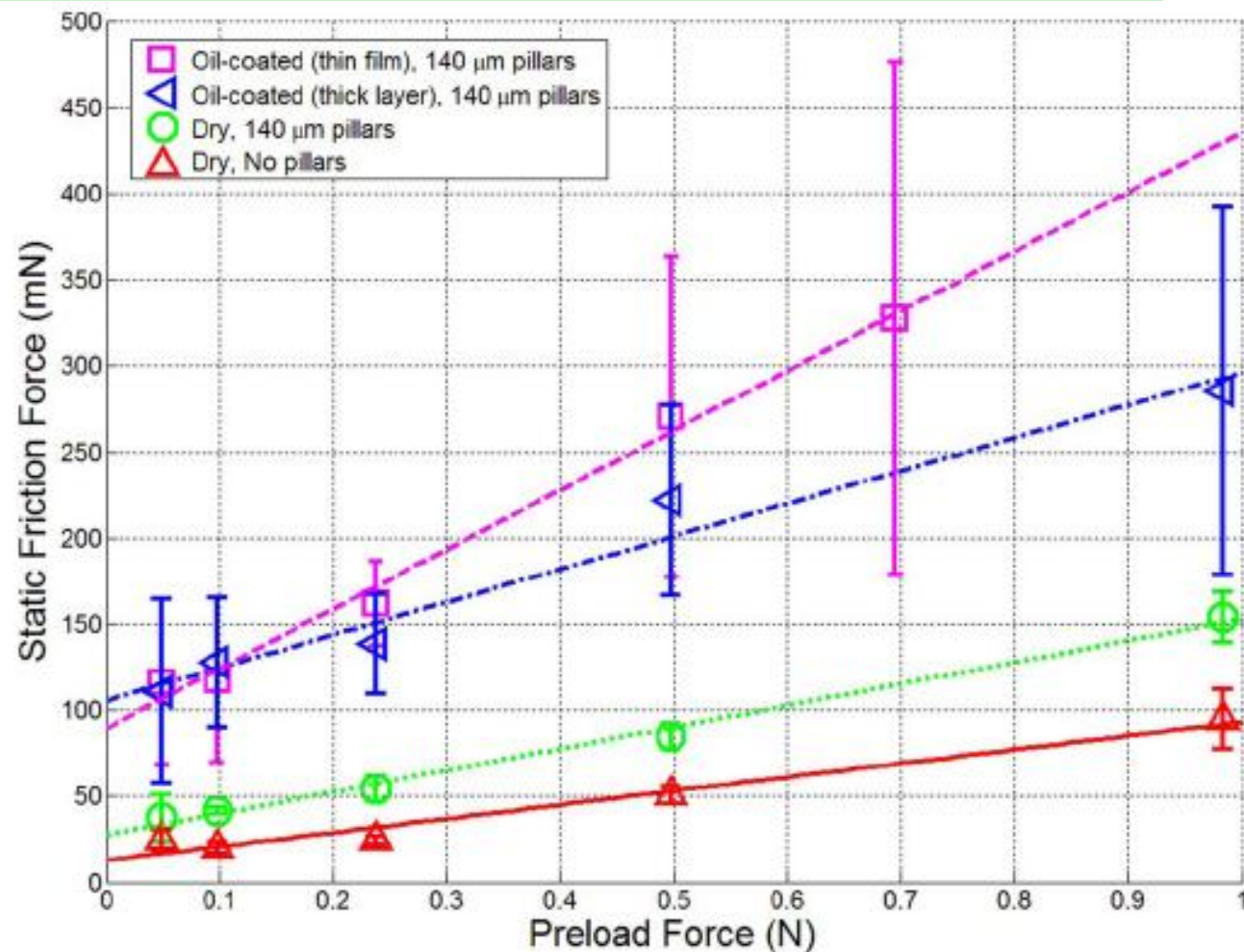
In vivo microrobots



Traditional



Bioinspired: *Hemisphaerota cyanea*



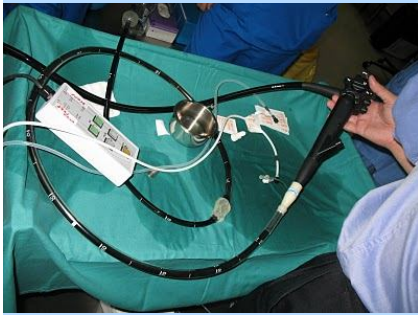
Cheung & Sitti. (2008). *J Adh Sci Technol* 22, 569–589; Kwan et al. (2006). *Biomed Mater* 1, 216–220; Cheung et al. (2005). *Proc IEEE/ASME Int Conf Adv Intel Mechatr* MD5-04; Glass et al. (2008). *IEEE Trans Biomed Eng* 55, 2759–2767.

Adhesion with a **liquid** interlayer

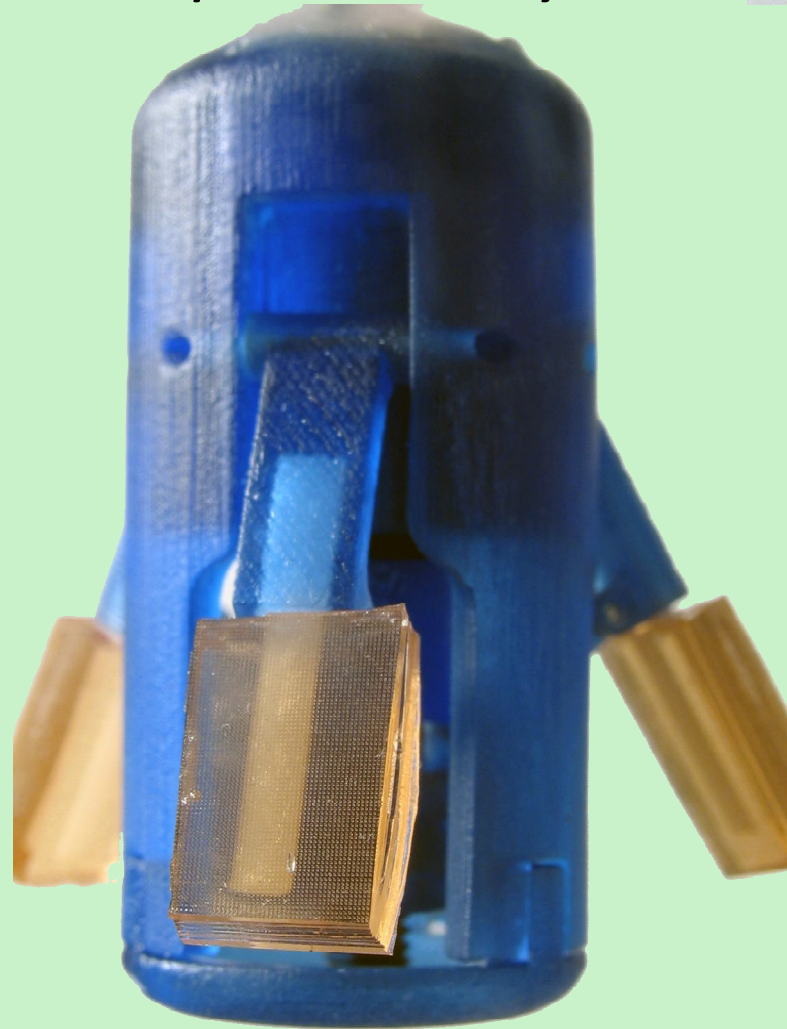
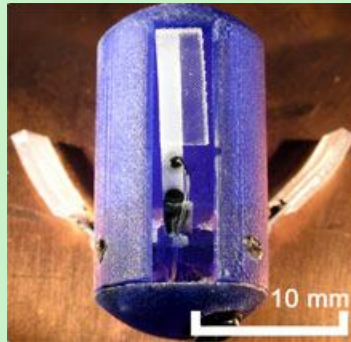
In vivo microrobots



Traditional



Bioinspired: *Hemisphaerota cyanea*



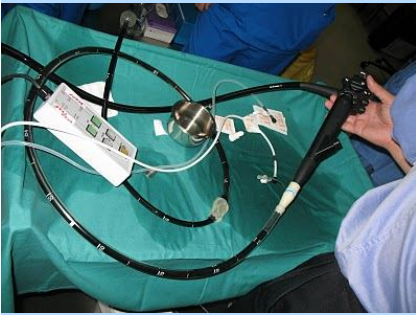
Cheung & Sitti. (2008). *J Adh Sci Technol* 22, 569–589; Kwan et al. (2006). *Biomed Mater* 1, 216–220; Cheung et al. (2005). *Proc IEEE/ASME Int Conf Adv Intel Mechatr* MD5-04; Glass et al. (2008). *IEEE Trans Biomed Eng* 55, 2759–2767.

Adhesion with a **liquid** interlayer

In vivo microrobots



Traditional



Bioinspired: *Limax maximus*



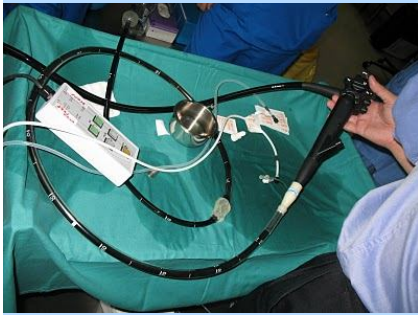
**How to move
when having
one foot?**

Adhesion with a **liquid** interlayer

In vivo microrobots



Traditional

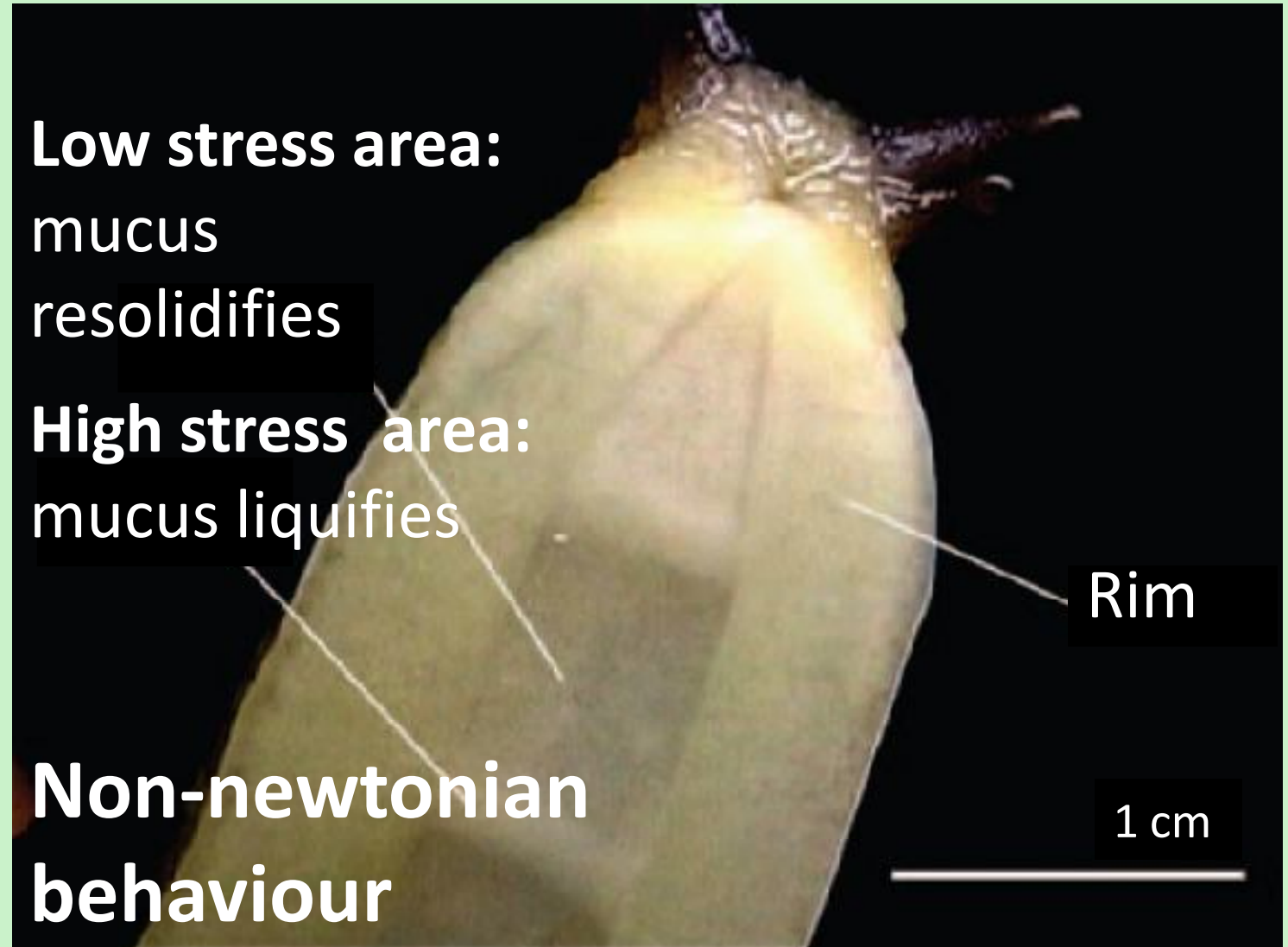


Bioinspired: *Limax maximus*

Low stress area:
mucus
resolidifies

High stress area:
mucus liquifies

**Non-newtonian
behaviour**



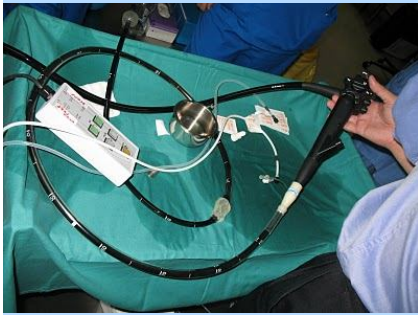
Denny (1980). *Nature* 285, 160; Denny (1981). *J Exp Biol* 91, 195; Ewoldt et al. (2007). *Soft Matter* 3, 634–643; Chan et al. (2007). *J Intel Mat Sys Struct* 18, 111–116.

Adhesion with a **liquid** interlayer

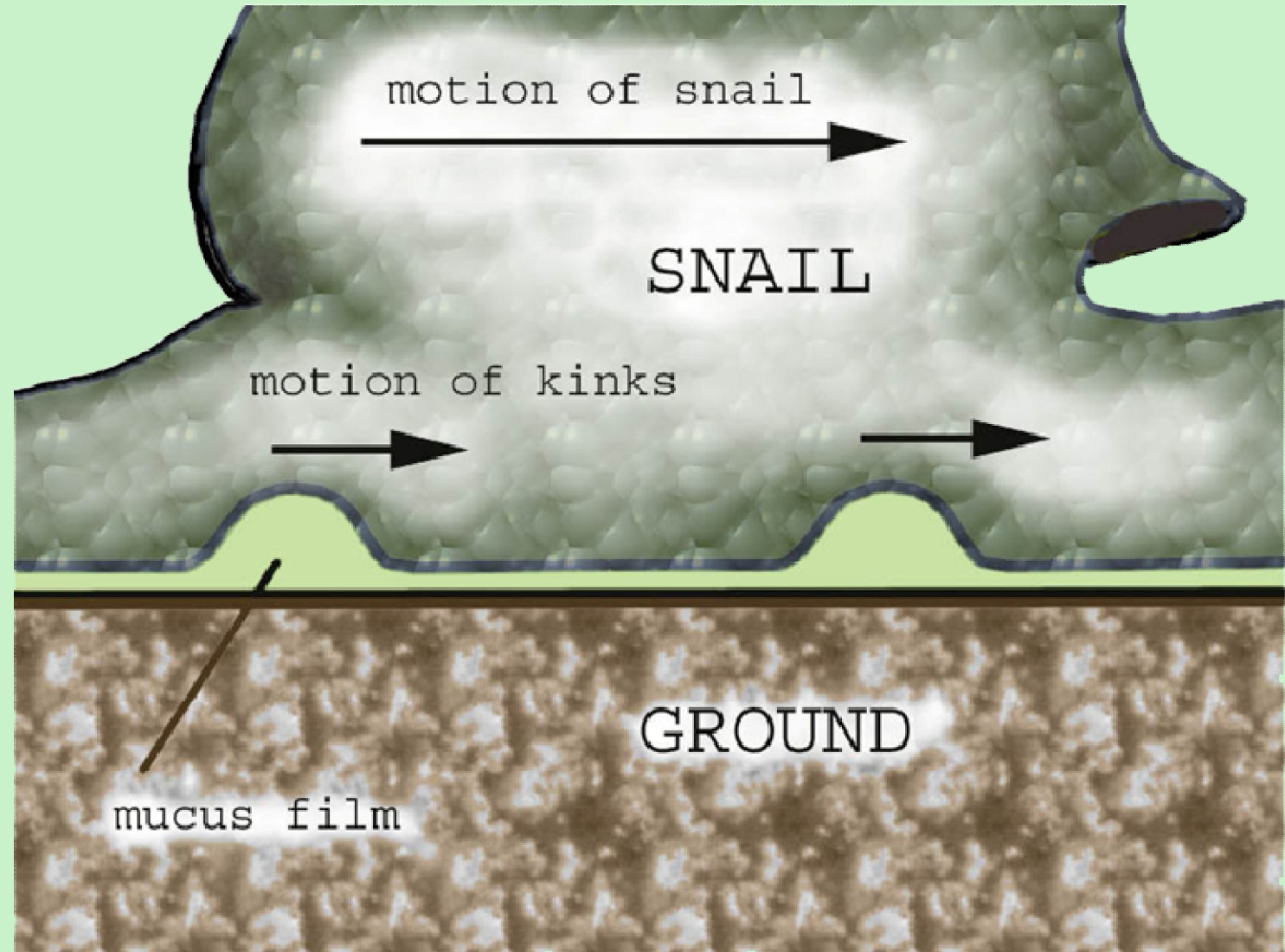
In vivo microrobots



Traditional



Bioinspired: *Limax maximus*



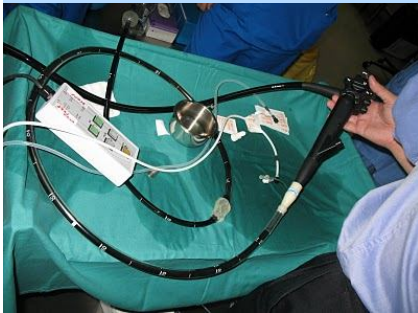
Denny (1980). *Nature* 285, 160; Denny (1981). *J Exp Biol* 91, 195; Ewoldt et al. (2007). *Soft Matter* 3, 634–643; Chan et al. (2007). *J Intel Mat Sys Struct* 18, 111–116.

Adhesion with a **liquid** interlayer

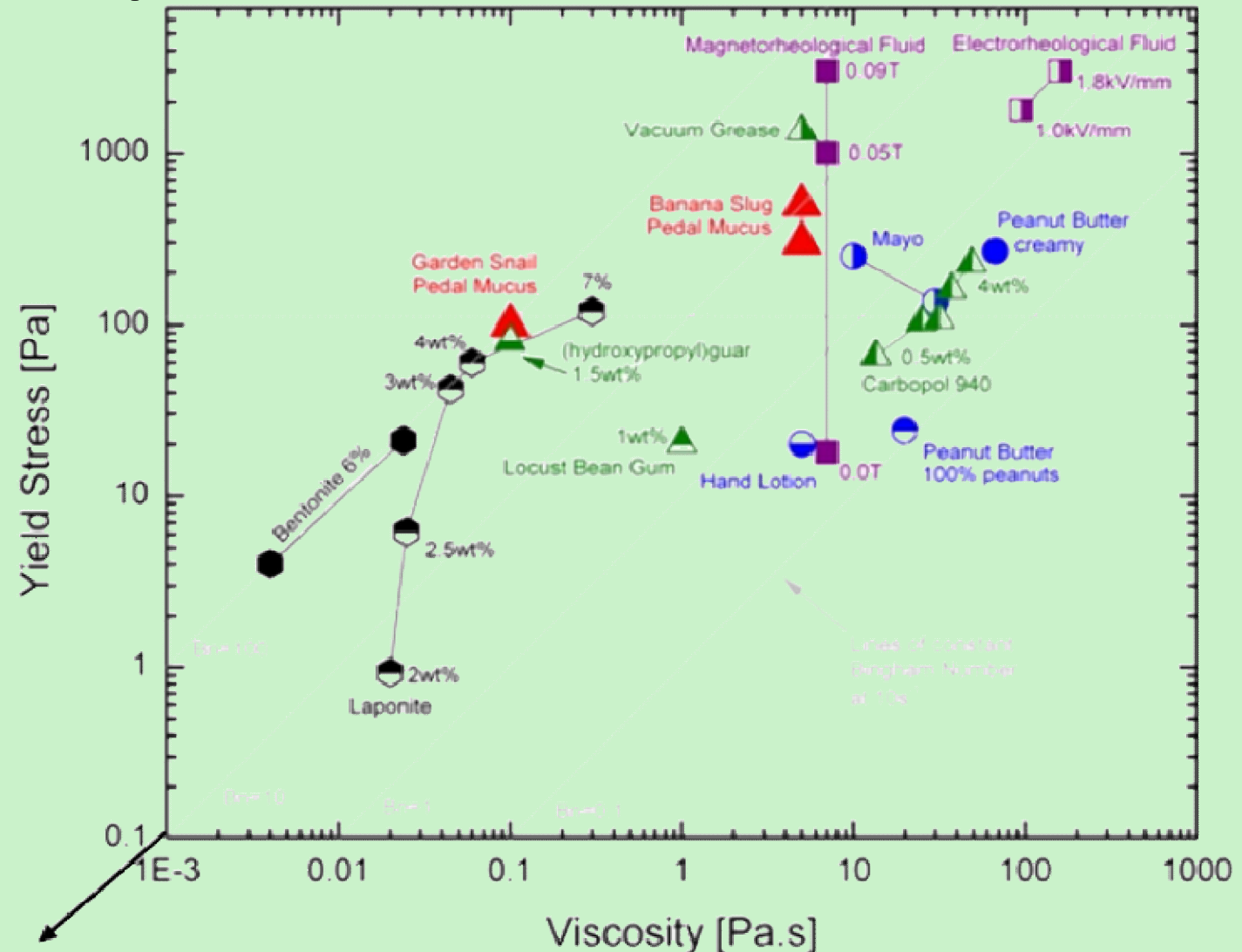
In vivo microrobots



Traditional



Bioinspired: *Limax maximus*



Denny (1980). *Nature* 285, 160; Denny (1981). *J Exp Biol* 91, 195; Ewoldt et al. (2007). *Soft Matter* 3, 634–643; Chan et al. (2007). *J Intel Mat Sys Struct* 18, 111–116.

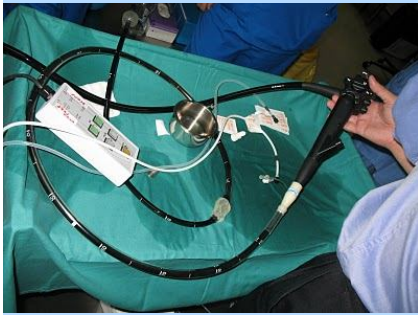
$\lambda_{restructure}$

Adhesion with a **liquid** interlayer

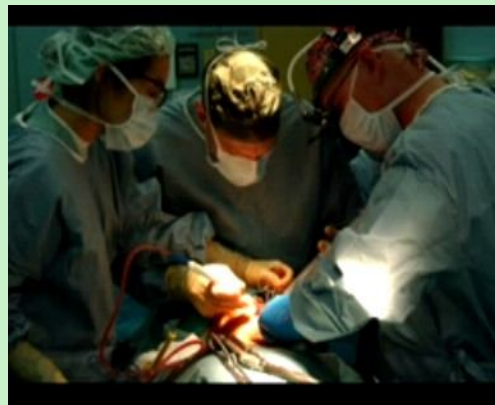
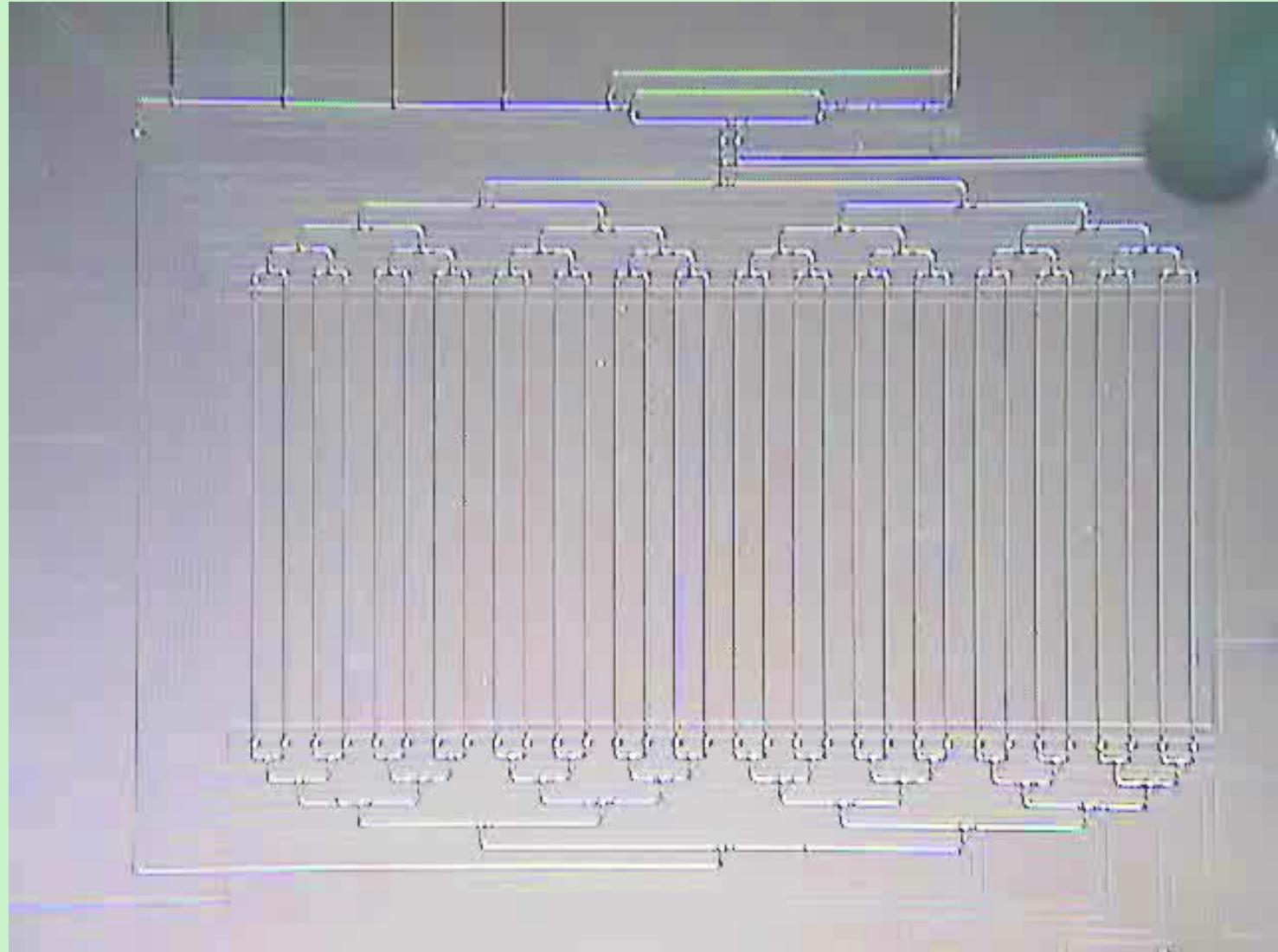
In vivo microrobots



Traditional



Bioinspired: *Limax maximus*



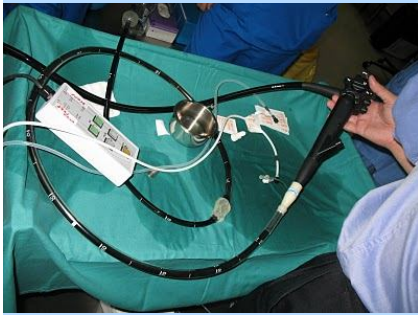
Denny (1980). *Nature* 285, 160; Denny (1981). *J Exp Biol* 91, 195; Ewoldt et al. (2007). *Soft Matter* 3, 634–643; Chan et al. (2007). *J Intel Mat Sys Struct* 18, 111–116.

Adhesion with a **liquid** interlayer

In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*



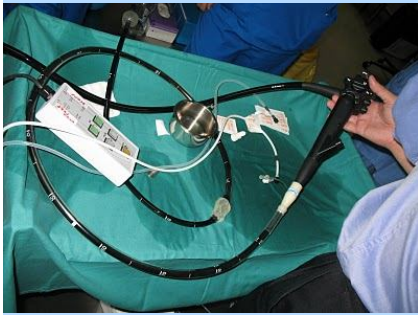
How to hang
upside-down?
How to keep
being sticky?

Adhesion with a **liquid** interlayer

In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*

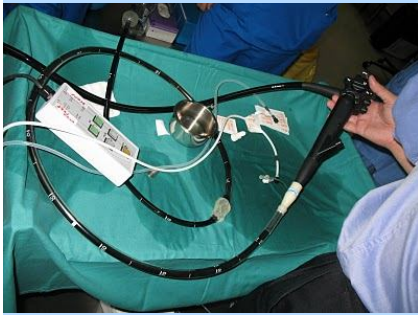


Adhesion with a **liquid** interlayer

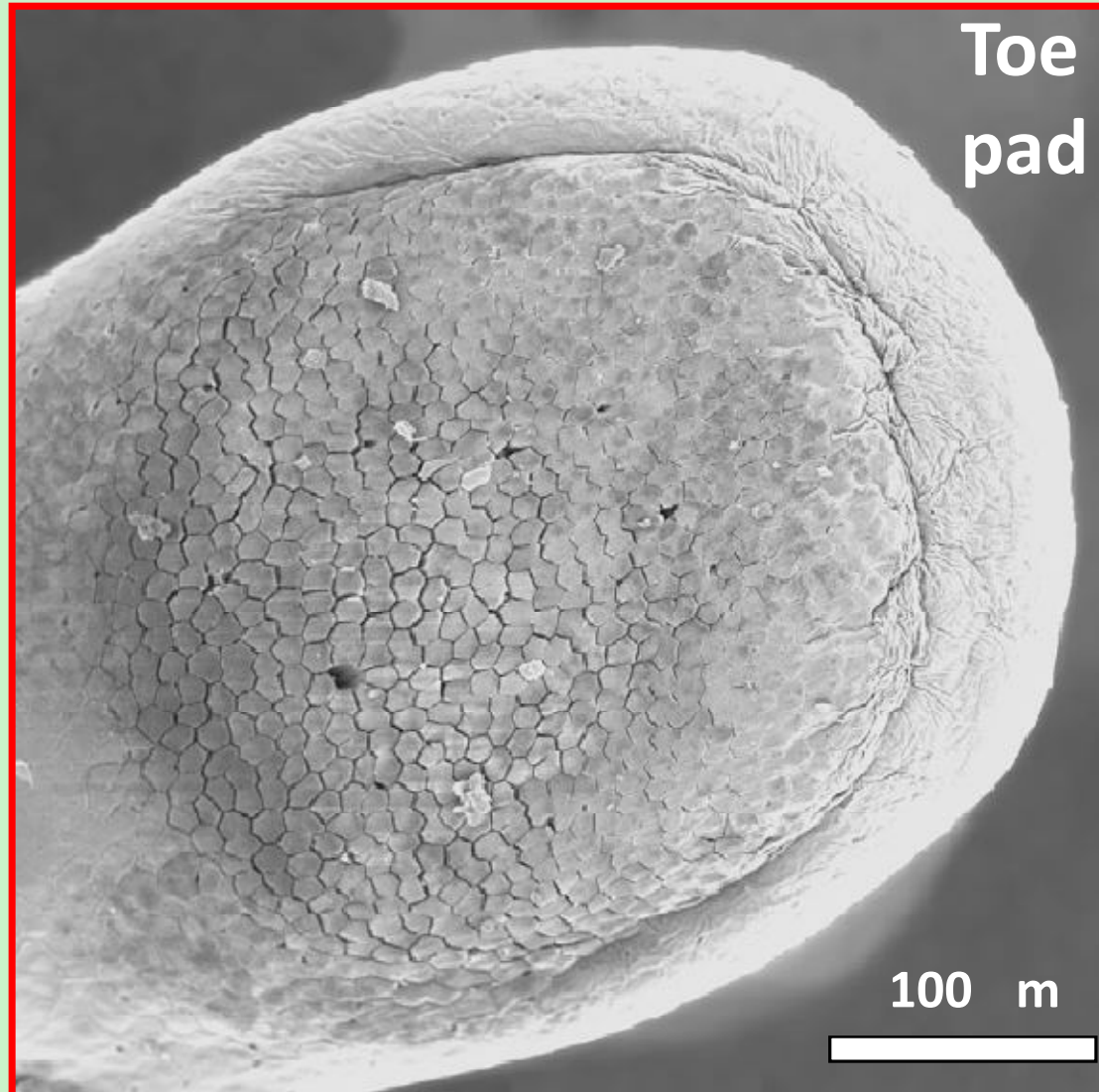
In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*

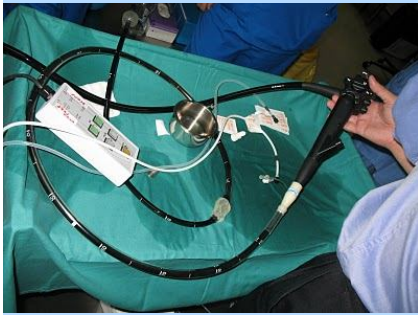


Adhesion with a **liquid** interlayer

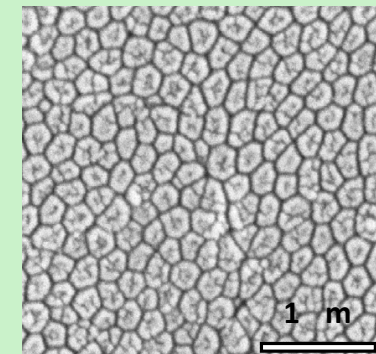
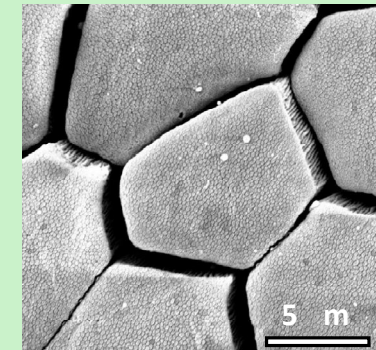
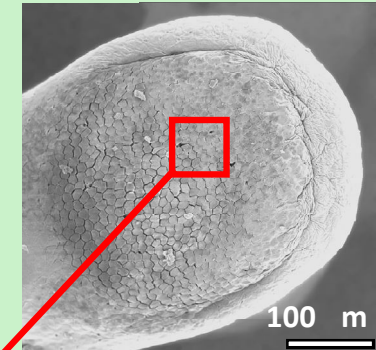
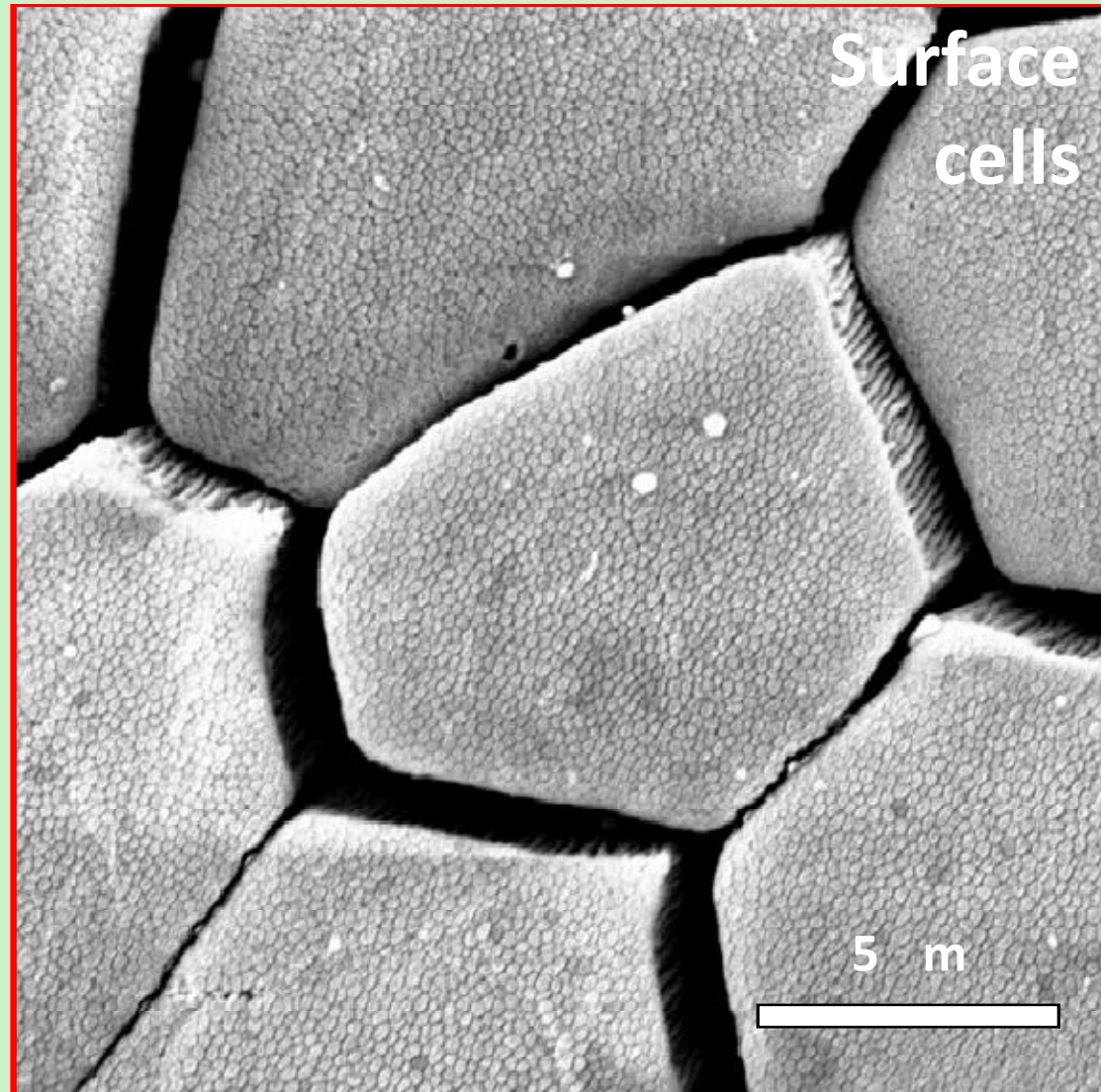
In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*

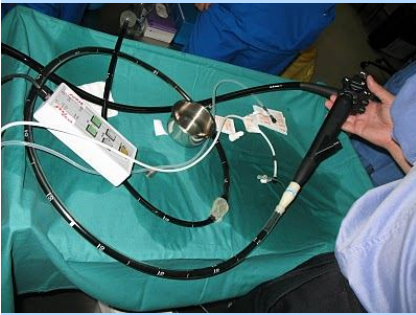


Adhesion with a **liquid** interlayer

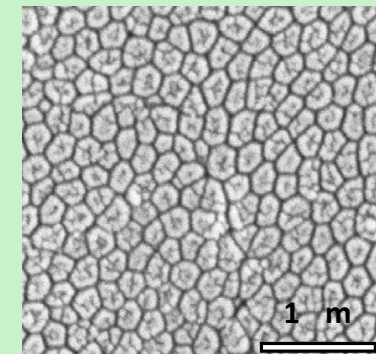
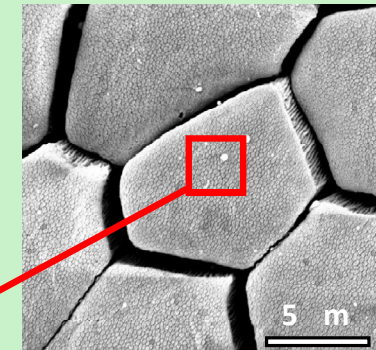
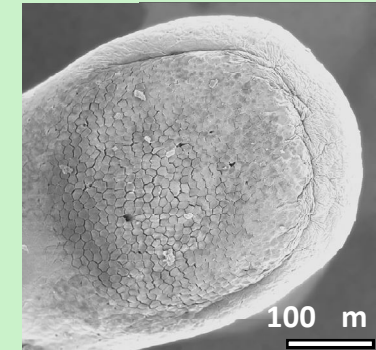
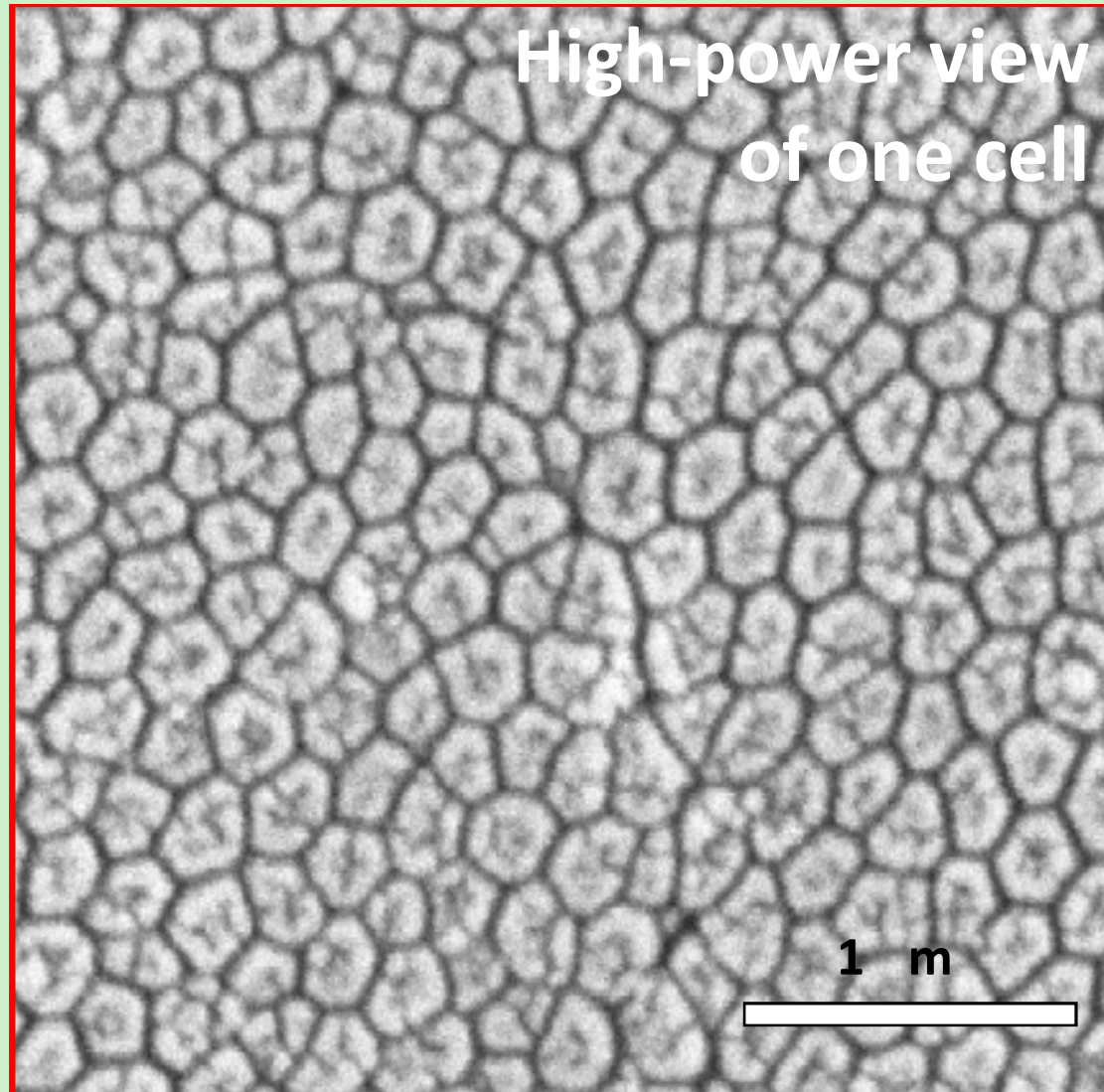
In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*

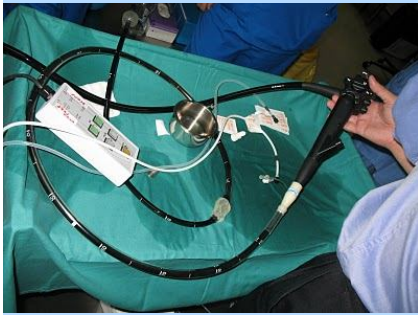


Adhesion with a **liquid** interlayer

In vivo microrobots

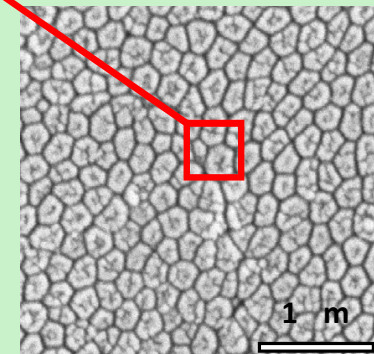
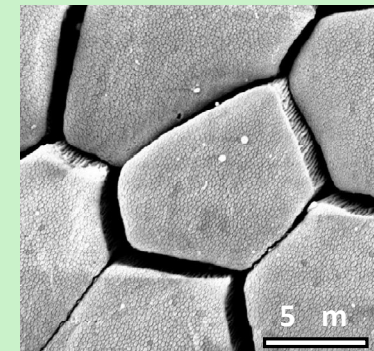
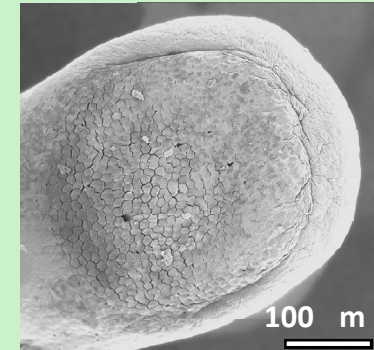
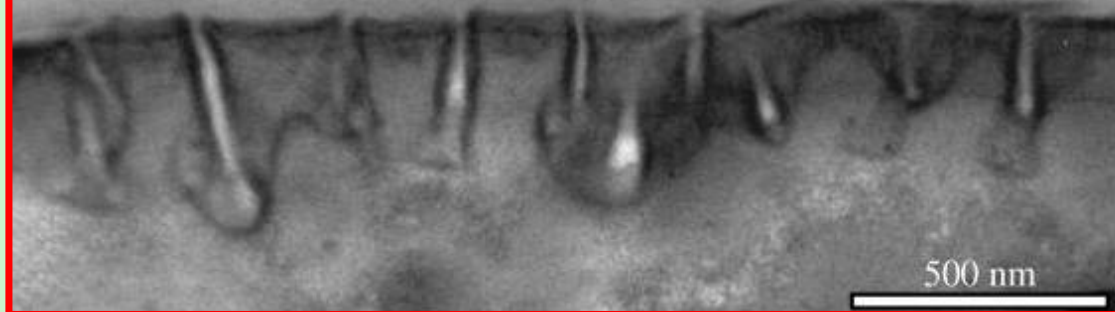


Traditional



Bioinspired: Tree frog *Litoria caerulea*

(e)
Cross-section through cell surface

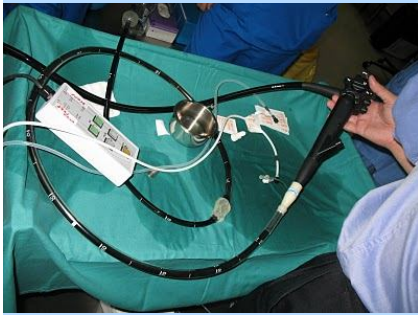


Adhesion with a **liquid** interlayer

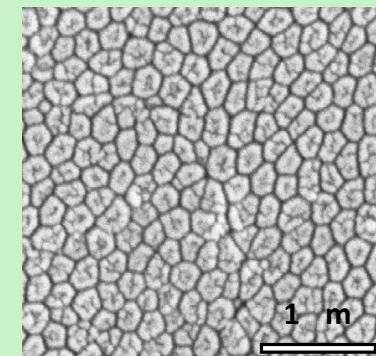
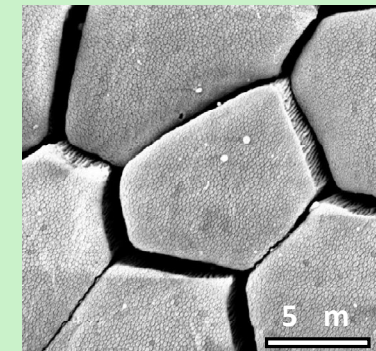
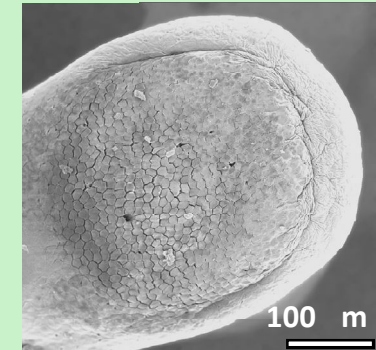
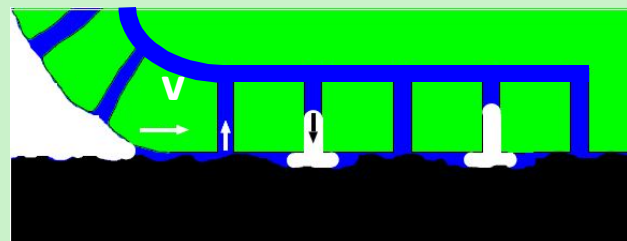
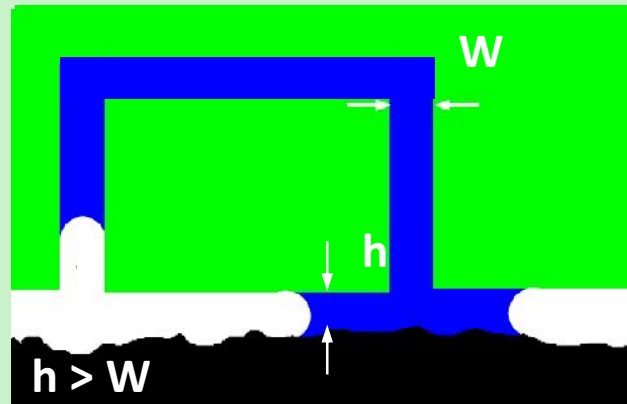
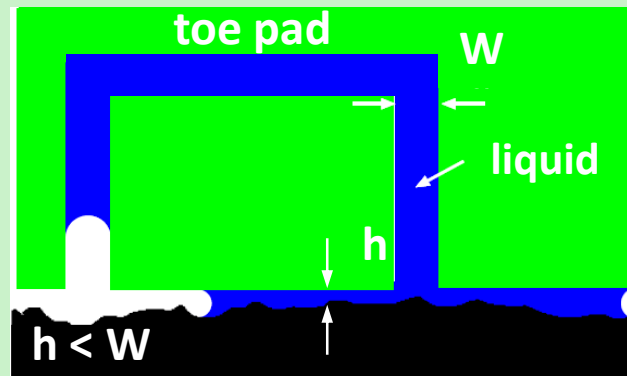
In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*

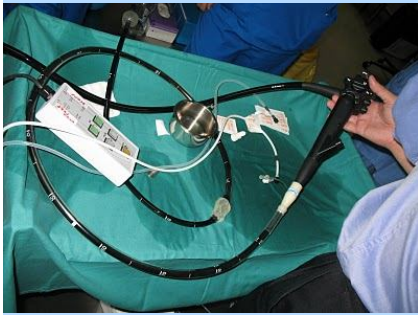


Adhesion with a **liquid** interlayer

In vivo microrobots



Traditional



Bioinspired: Tree frog *Litoria caerulea*

Young modulus

Tree frog pad 0.004-0.02 MPa

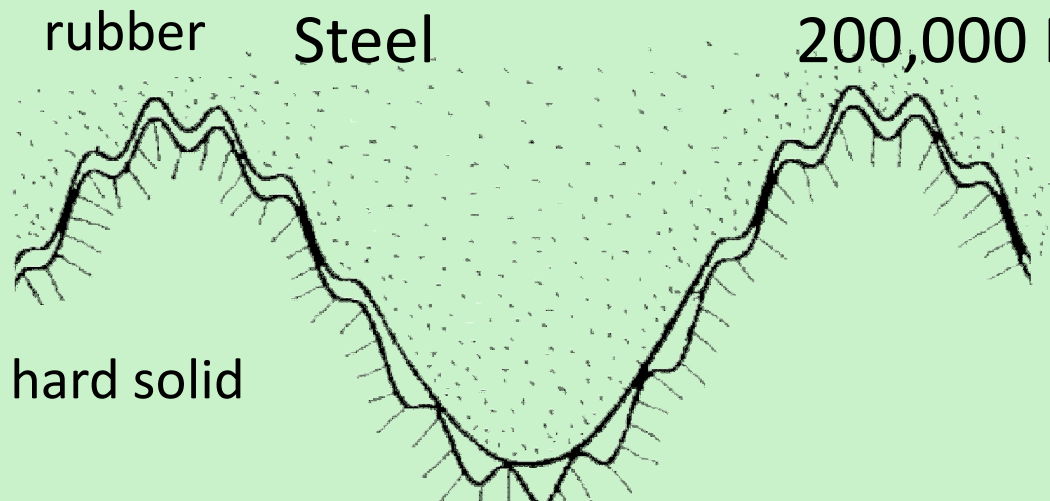
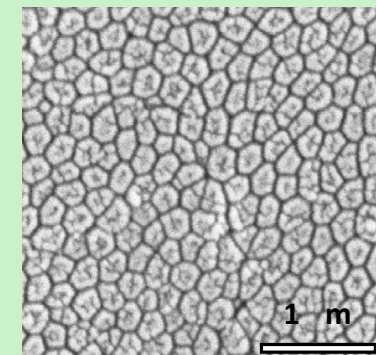
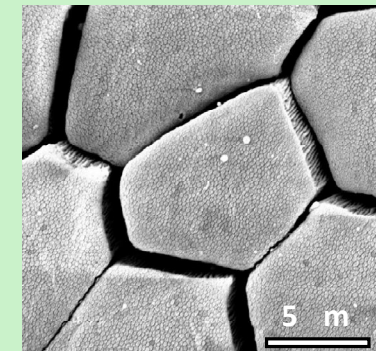
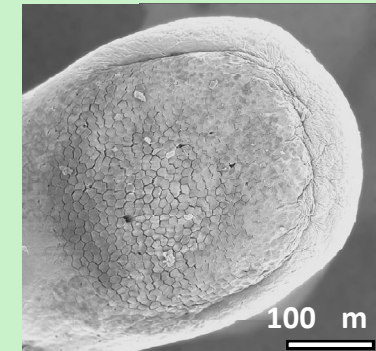
Jellyfish jelly 0.01 Mpa

Cartilage 20 MPa

Bone 18,000 Mpa

Silicone rubber 1-5 Mpa

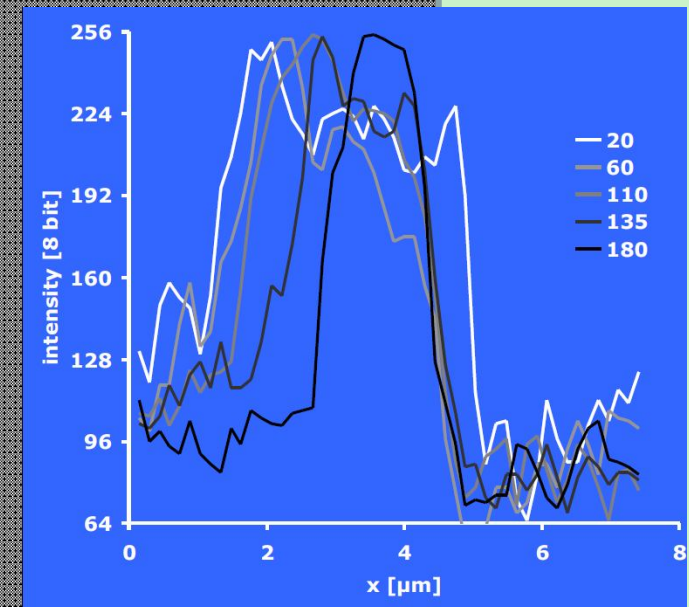
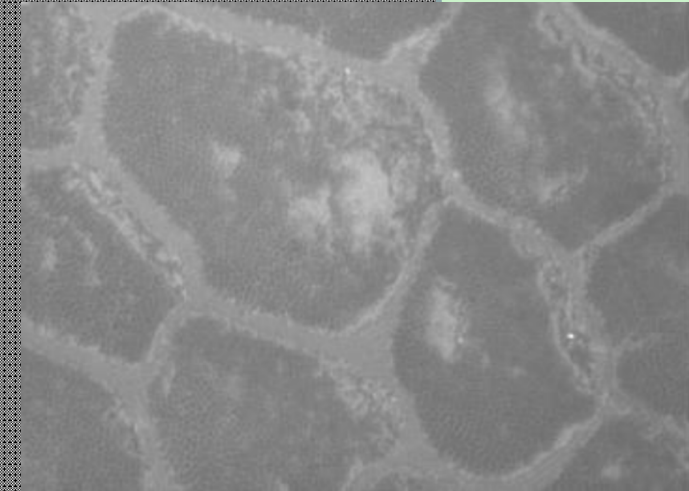
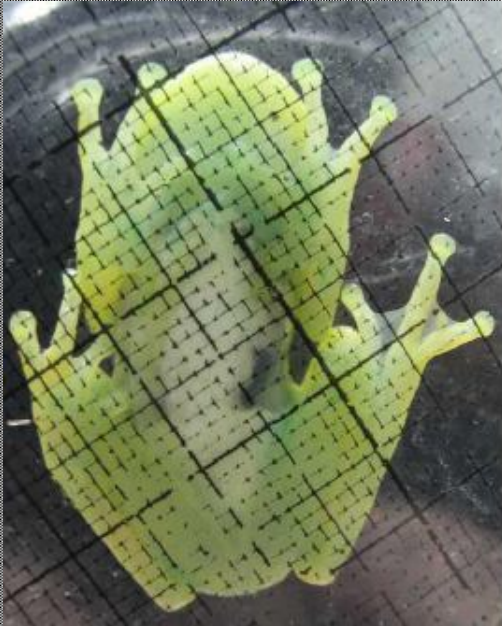
Steel 200,000 MPa



Persson. J Phys: Condens Matter 19 (2007) 376110; Hanna & Barnes. J Exp Biol 155 (1991) 103-125; Federle et al. J Roy Soc Interface 3 (2006) 689-697; Barnes. Science 318 (2007) 203-204

Adhesion with a **liquid** interlayer

In vivo microrobots



What is adhesion?

Adhesion **with** an intermediate layer



Solid intermediate layer



Liquid intermediate layer

Adhesion **without** an intermediate layer



Van der Waals



Electrostatic



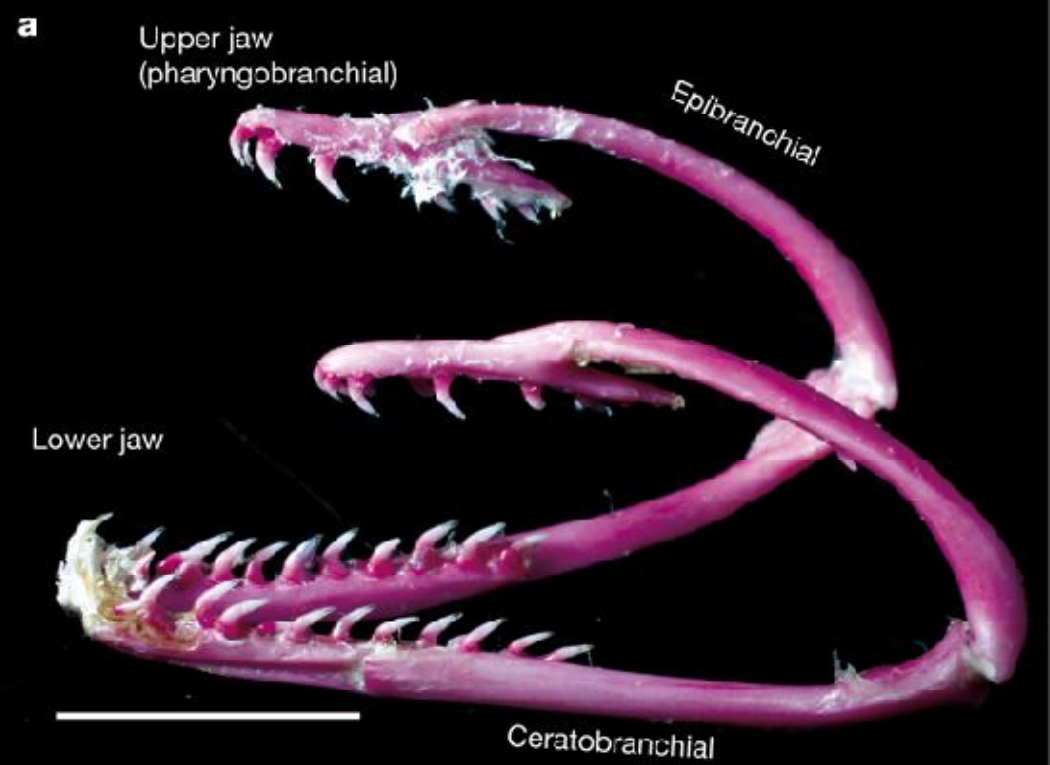
Shape grip



Friction grip



Suction





COMBINATIONS & HYBRIDS...

