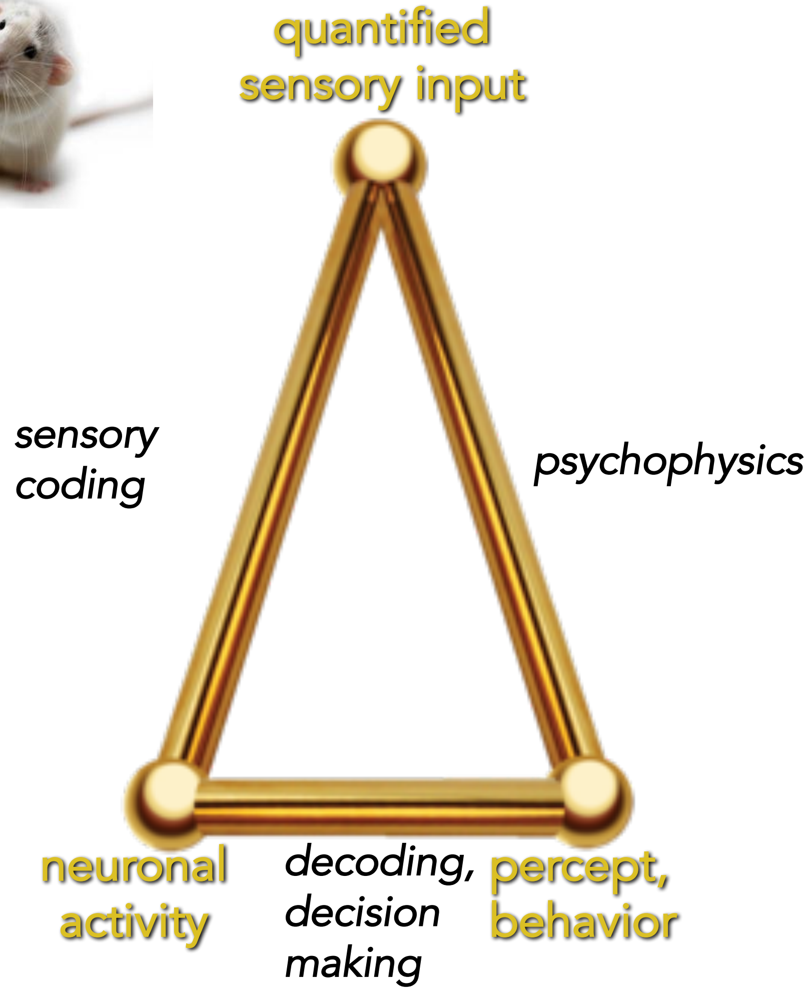
LESSON 3.

TRANSDUCTION

How can we go about studying the neuronal processes involved in sensation and perception?



So what is sensory transduction?

We know the world by our physical senses, whether nearby objects by touch or distant objects by sight.

Sensory receptors are the gateway through which all signal must pass to enter the nervous system.

Sensory transduction means getting the outside in

Sensory neuron (“receptor”)

Captures energy of *xx*-modality and converts it to a variation of membrane potential (“transduction”). This introduces the external world into the nervous system.

xx-modality is the definition of the sensory system.

Receptor cell has resting membrane potential which is “perturbed” by absorption of some quantity of energy >> opening of membrane channels, etc.

For sensory signals there is a great deal of amplification at the receptor level, so that very small external stimuli provide a trigger to release stored charges that appear as electrical potentials and lead to sensations.

For example

•odors from only a few molecules of specific odorant substances (pheromones) are able to act as sex attractants for moths.

•a few quanta of light trapped by receptors in the retina are sufficient to produce a visual sensation.

•In the inner ear, mechanical displacements of 10^{-10} m are detectable.

A bit of history

1830. Johannes Muller (Berlino) wrote “law of specific nerve energy”: we sense not the world itself but information correlated with objects in the world as transmitted by sensory nerves.

Muller: every nerve can be excited by a variety of stimuli, but is highly sensitive to just one type of stimulation. If excited by energy of another modality, the sensation is nevertheless correlated with the nerve, not the inappropriate modality (just rub your eye to find out).

The difference between seeing and hearing, between hearing and touch, and so on - are caused by differences in the nervous structures that these stimuli excite.

1906. sir Charles Sherrington:

The sensory organ is an apparatus that renders the afferent fiber particularly sensitive to one physical agent and, at the same time, makes the fiber insensitive to other agents.

Filtering, selectivity.

Physiologists: “how?”

Adrian, 1928
<u>Neuronal coding</u>

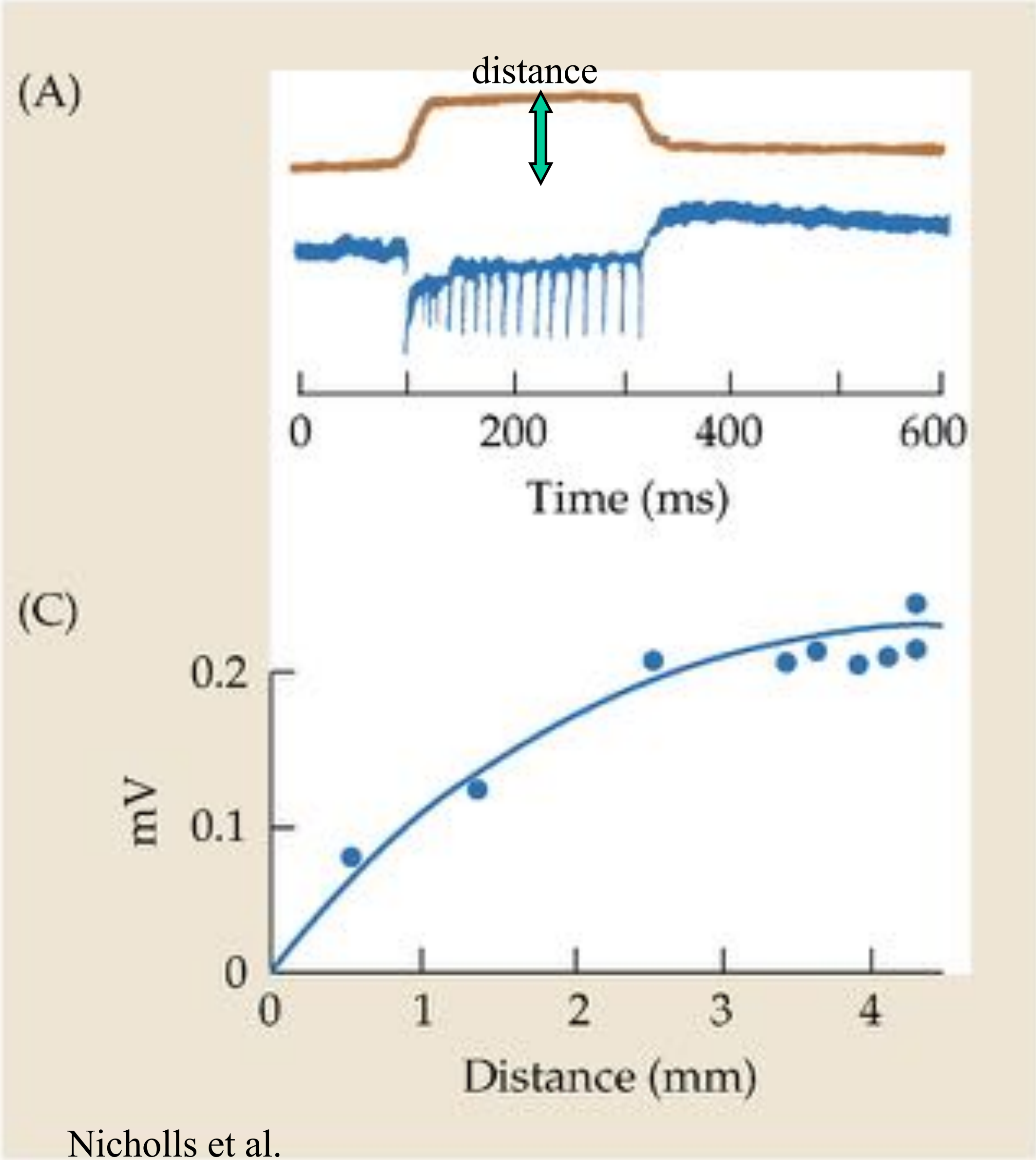
Nerve is "labelled line", physiological update of Muller.

Modality or sensation is ***not*** by characteristics of firing: Action potentials same in every modality (if you hear a neuron firing, you have no idea what part of the brain it is in)… yet optic nerve = light

Intensity of firing (firing rate) encodes stimulus intensity, but also many other things.

Firing patterns are also critical in some sensory systems.

Example – muscle spindle



Nicholls et al.
(After Katz, 1950)

Receptor potentials recorded extracellularly from a sensory nerve fiber supplying a muscle spindle. Downward deflection of the voltage record (lower trace) indicates receptor depolarization. Stretching the muscle (upper trace) produces a receptor potential, upon which is superimposed a series of action potentials (lower trace).

Relationship between receptor potential amplitude and stretch. The slope flattens out at higher levels.

Many sensory receptors take advantage of this nonlinear relationship to provide amplitude coding over a wide range of stimulus intensities: response amplitude continues to increase, but in proportion to the logarithm of stimulus intensity.

Classification schemes (continued)

by the nature of the receptor potential and the synaptic transmission

- short-distance receptors / usually graded potential / graded transmitter release
- long-distance receptors / usually action potential / binary transmitter release

by source of energy

- exteroceptors
- interoceptors

by the rate of adaptation

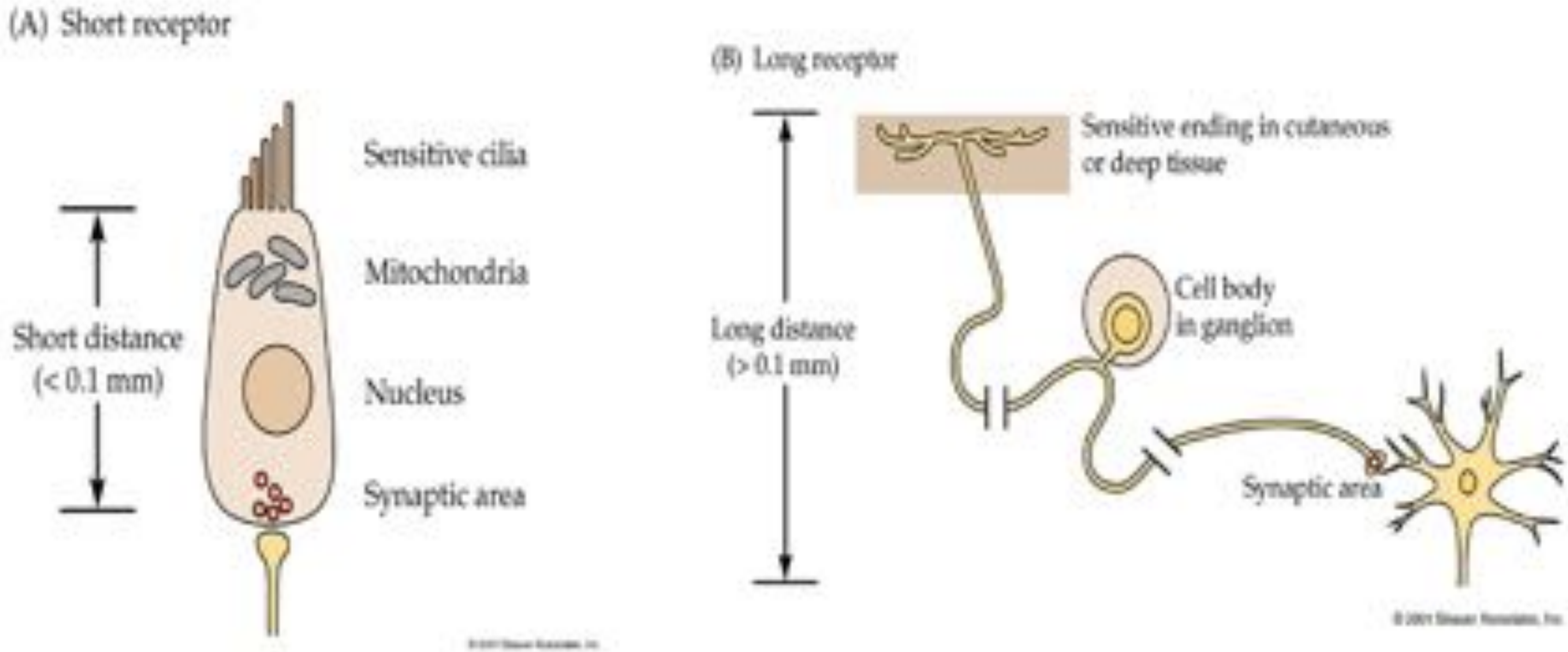
- rapidly adapting
- slowly adapting

by selectivity

- chemical – taste, olfaction
- mechanical
- thermal
- pain
- photo
- sound wave

Classification schemes

Short versus long receptors



The distinction is not as silly as it sounds. Short can transmit “analog” signals by receptor potential, but long can only transmit “digital” signals

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by the nature of conversion

- direct
- indirect

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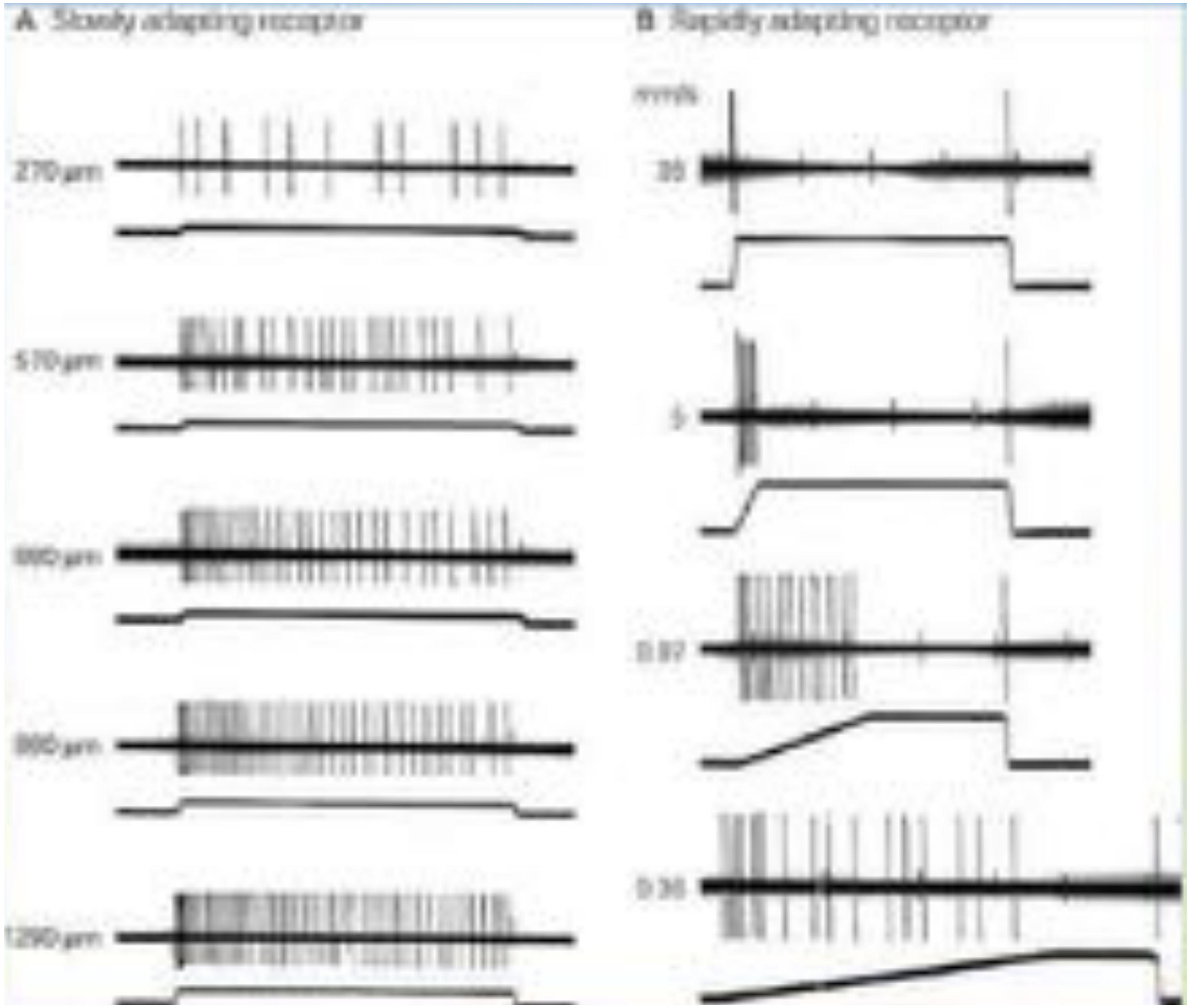
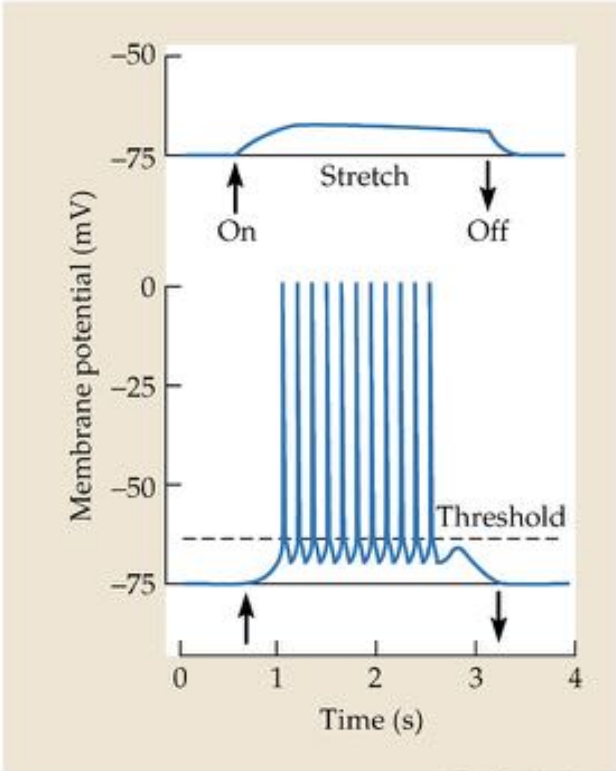
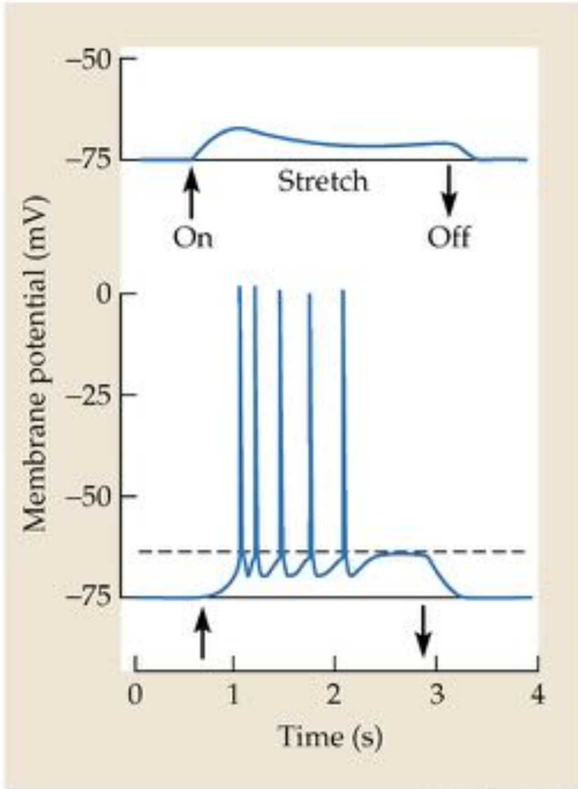

A Slowly adapting receptor
B Rapidly adapting receptor
mm/s
270 µm
570 µm
35
5
0.97
0.36
1290 µm

Adaptation

(A) **Slowly adapting receptor**



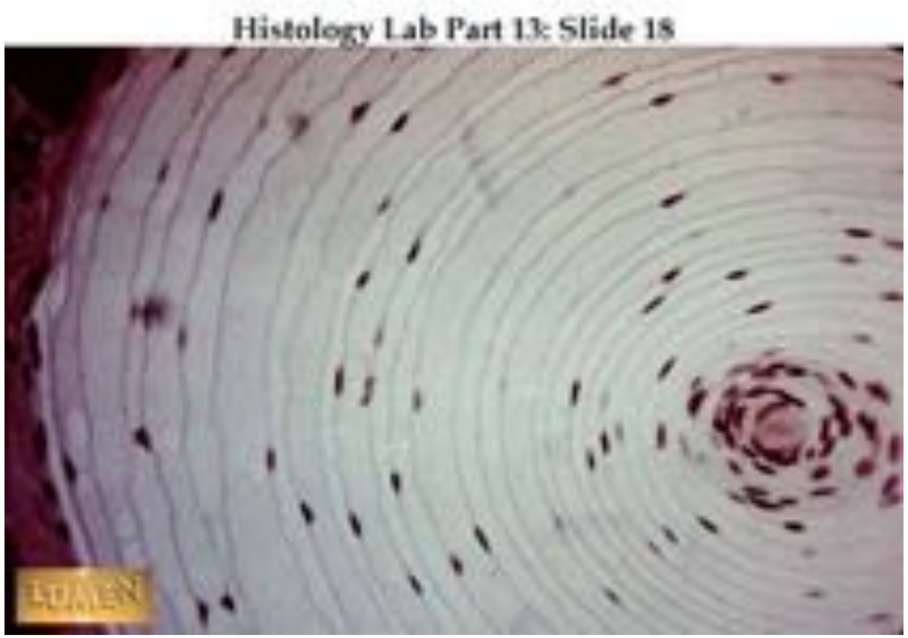
(B) **Rapidly adapting receptor**



The Pacinian receptor illustrates the principle of mechanoreceptor filtering.

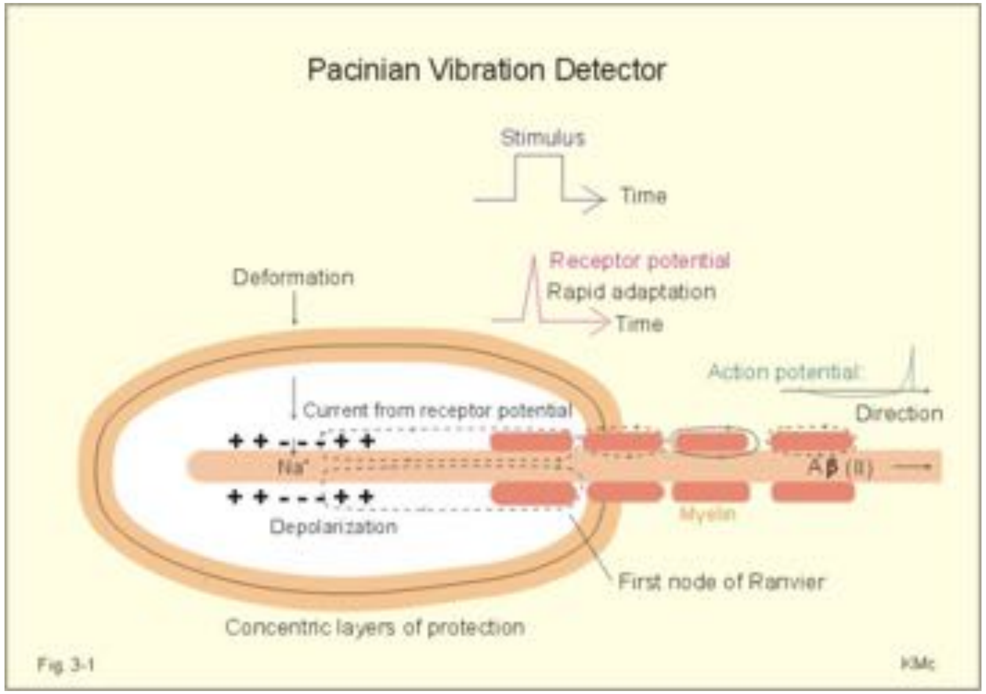
ANATOMY

- The primary afferent sensory ending lies within a 1-mm long, multilamellar, fluid-filled capsule deep in the skin.
- The nerve fiber is myelinated up to its entry in the capsule, where it loses the myelin sheath. Its membrane contains ion channels sensitive to compression.



Pacinian corpuscle, rapidly adapting receptor

If the skin vibrates at frequencies of more than about 80 Hz, the stiffness of the lamellar structure of the capsule prevents it from changing shape as quickly as the probe indentation. All the lamellae move up and down together in phase with the probe, compressing and decompressing the termination. Each vibratory cycle, even as small as 1 micron in magnitude, evokes a depolarization in the sensory nerve that leads to an action potential. If the vibratory frequency is slowed to less than 50-80 Hz, each indentation squeezes together the upper layers of the capsule, and displaces the fluid laterally. At the same time the bottom layers close to the nerve remain rigid: mechanical energy is dissipated before reaching the nerve' s mechanosensory channels. Thus, activity in the nerve fiber from the Pacinian corpuscle transmits information only about high-frequency vibrations.



FUNCTION

Although they are found generally in subcutaneous tissue, they are particularly common around footpads and claws of mammals, and in the interosseus membranes bridging the bones of the leg and forearm, where they act as sensitive detectors of ground vibration. A similar structure, the Herbst corpuscle, is found in the legs, bills, and cutaneous tissue of birds (and in the tongues of woodpeckers!). Speculation about their physiological function includes detection by the duck's bill of aquatic vibrations due to small prey, and in soaring birds, detection of vibration of flight feathers due to improper aerodynamic trim.

To check whether the fan in your computer is rotating, you might place your hand on the case to detect humming vibrations transduced by Pacinian receptors.

Pacinian role in TEXTURE.

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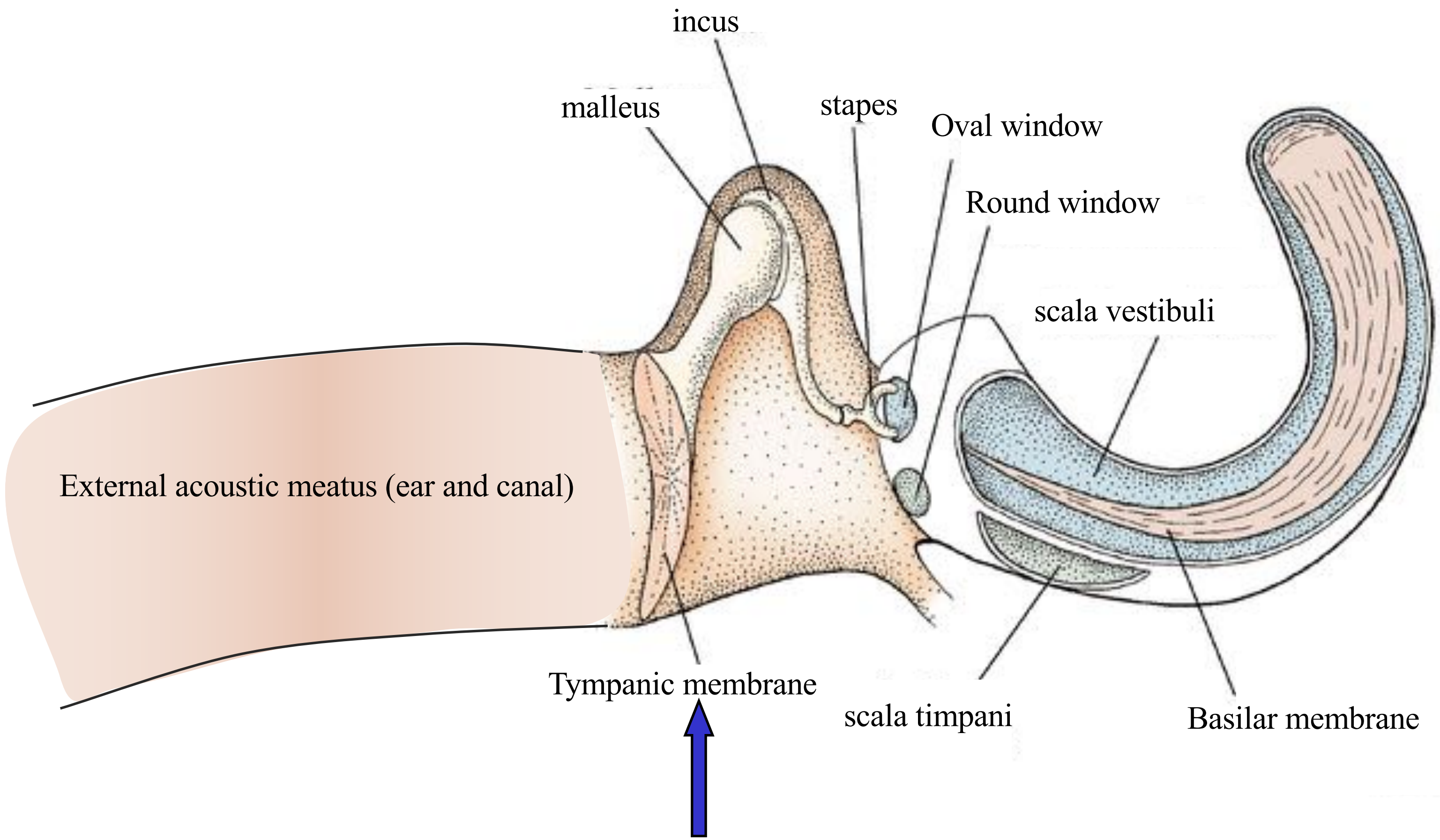
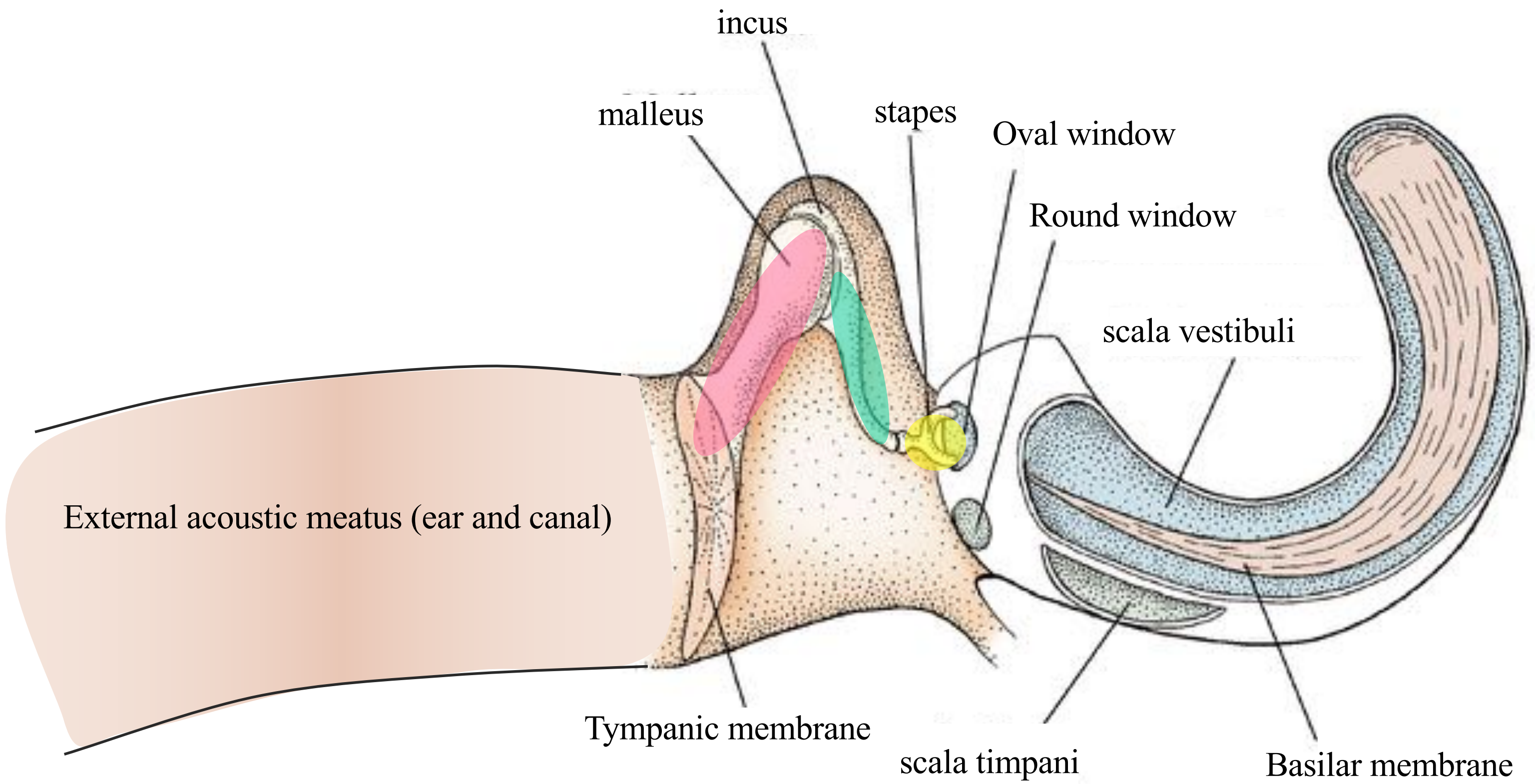
Outer ear

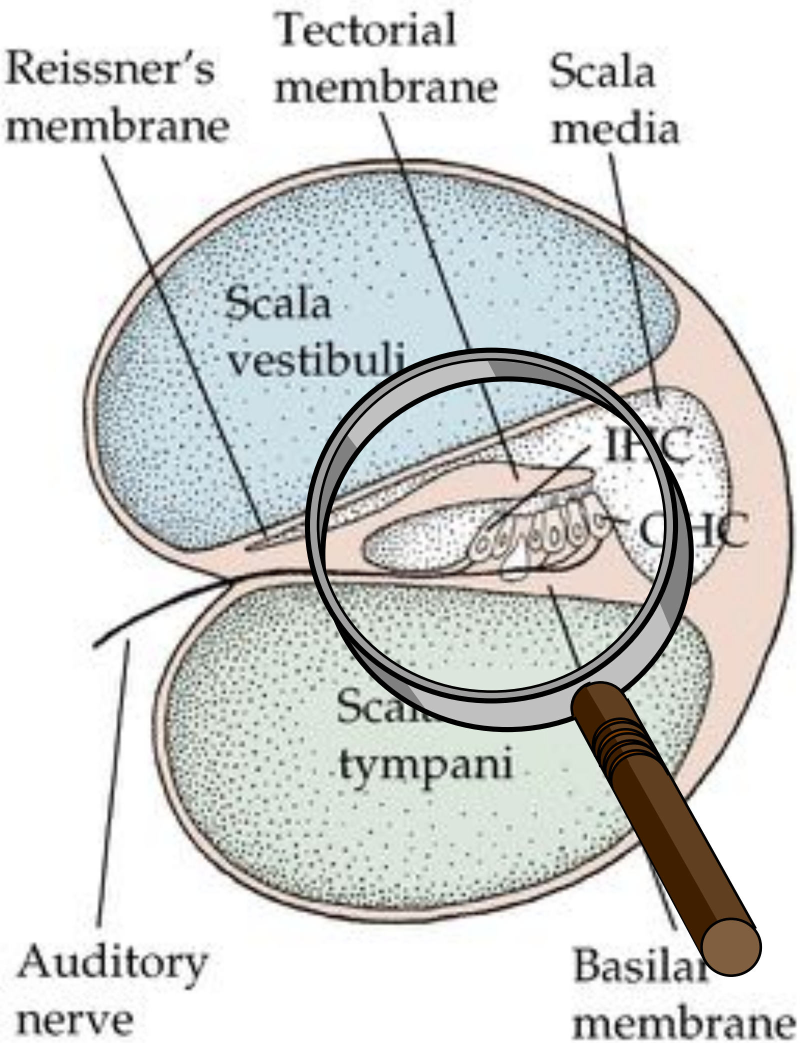


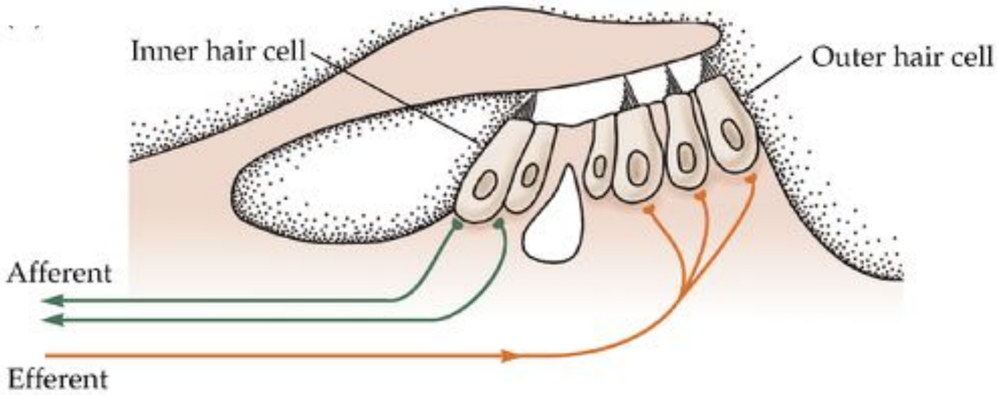
Tympanic membrane captures the acoustic pressure wave and transforms it to a mechanical vibrations

[redacted]

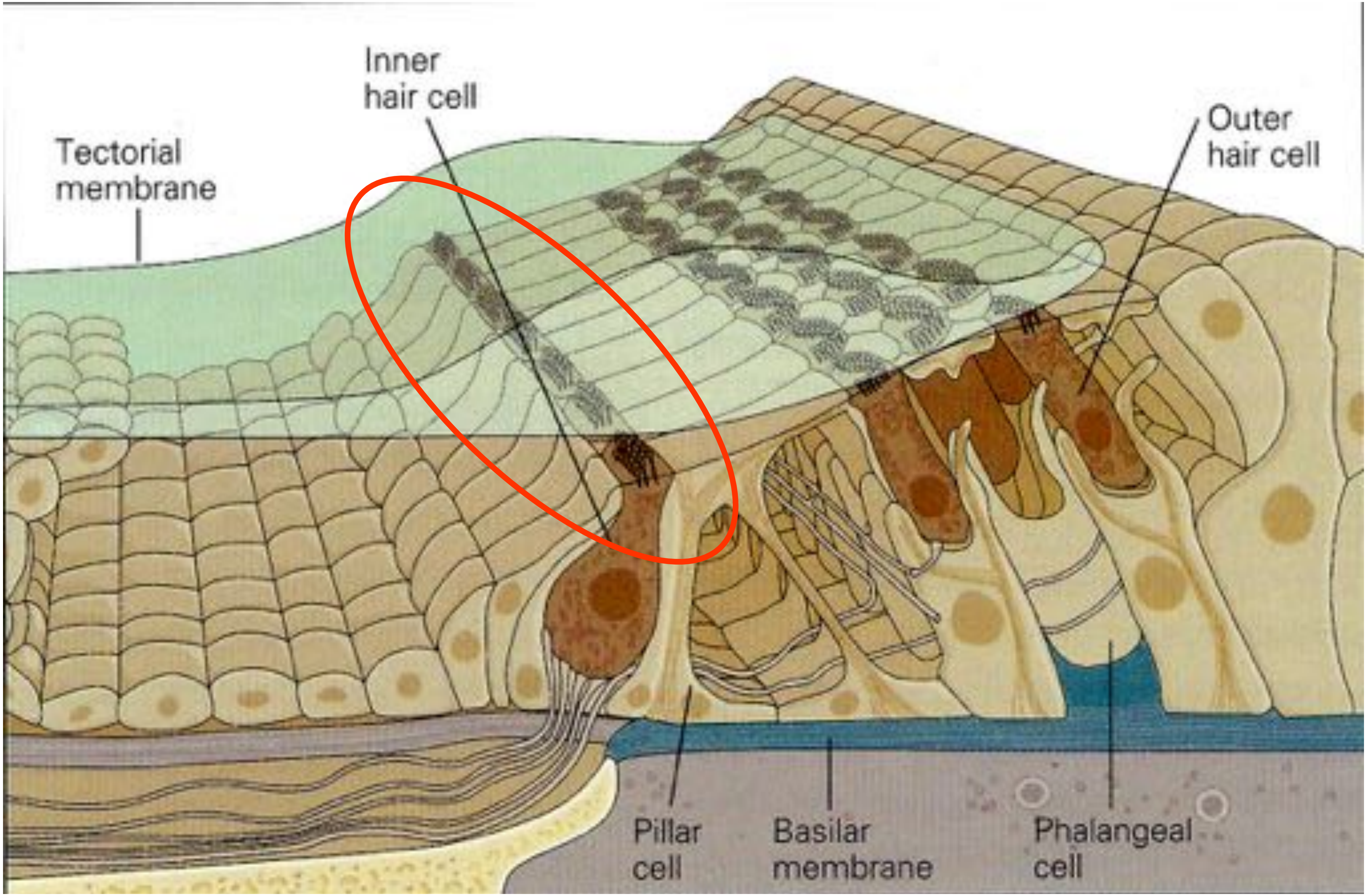


incus
malleus
stapes
Oval window
Round window
scala vestibuli
External acoustic meatus (ear and canal)
Tympanic membrane
scala timpani
Basilar membrane

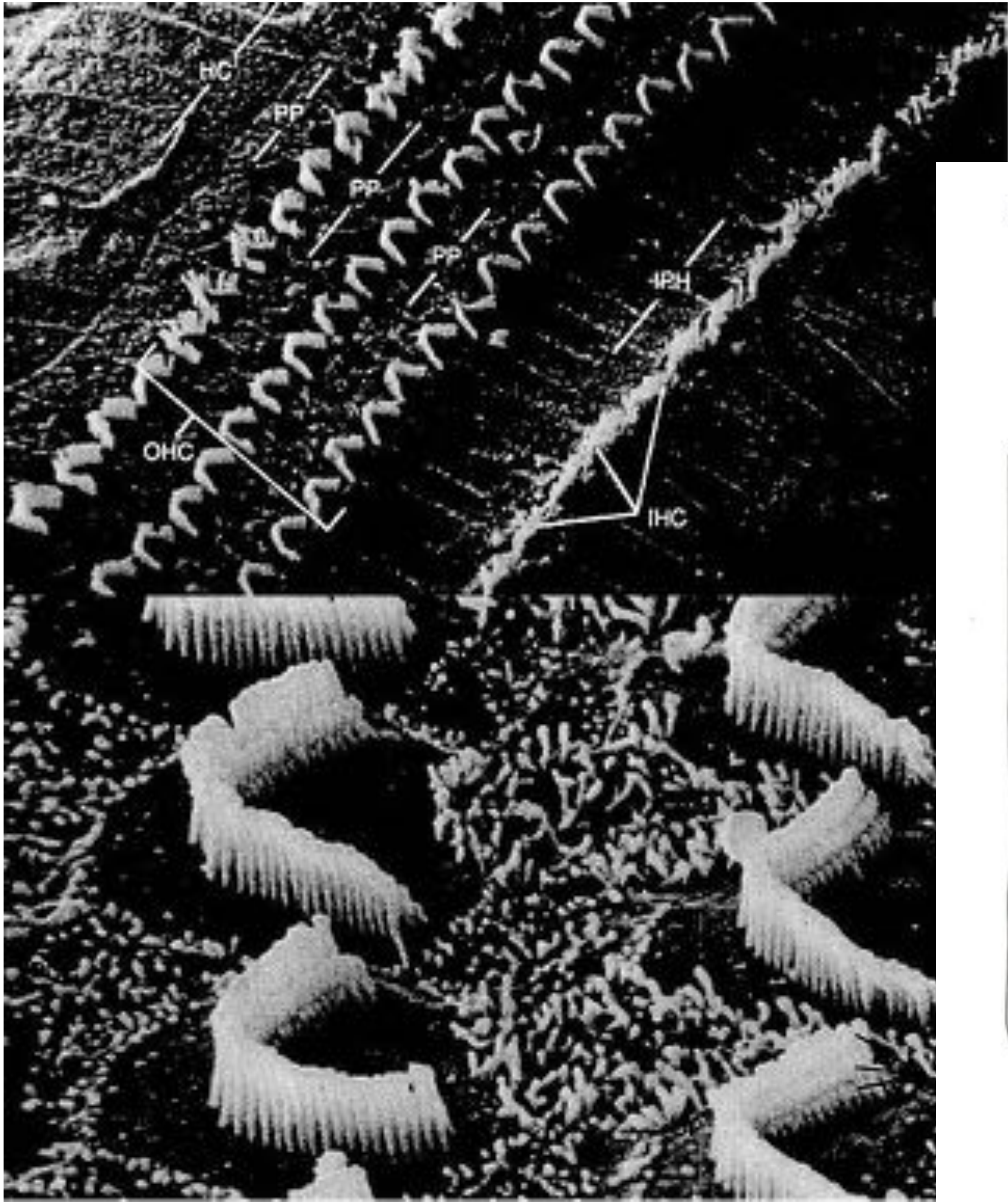

Reissner's membrane
Tectorial membrane
Scala media
Scala vestibuli
IHC
OHC
tympani
Auditory nerve
Basilar membrane

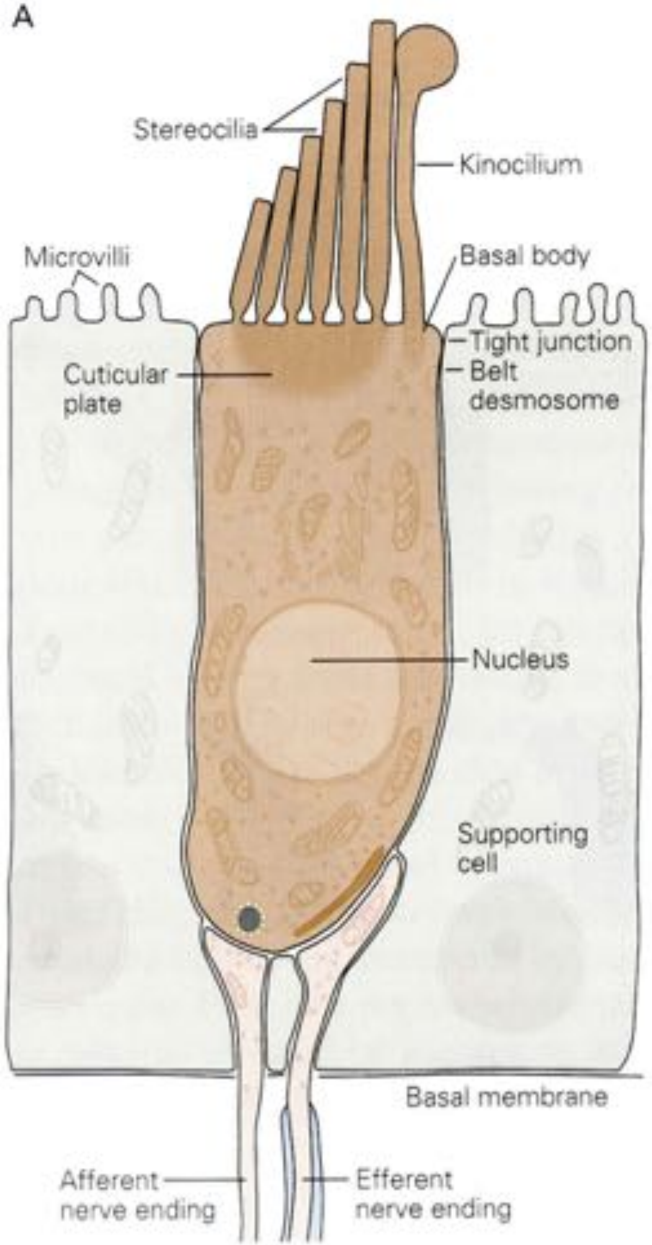

Inner hair cell
Outer hair cell
Afferent
Efferent

organ of Corti

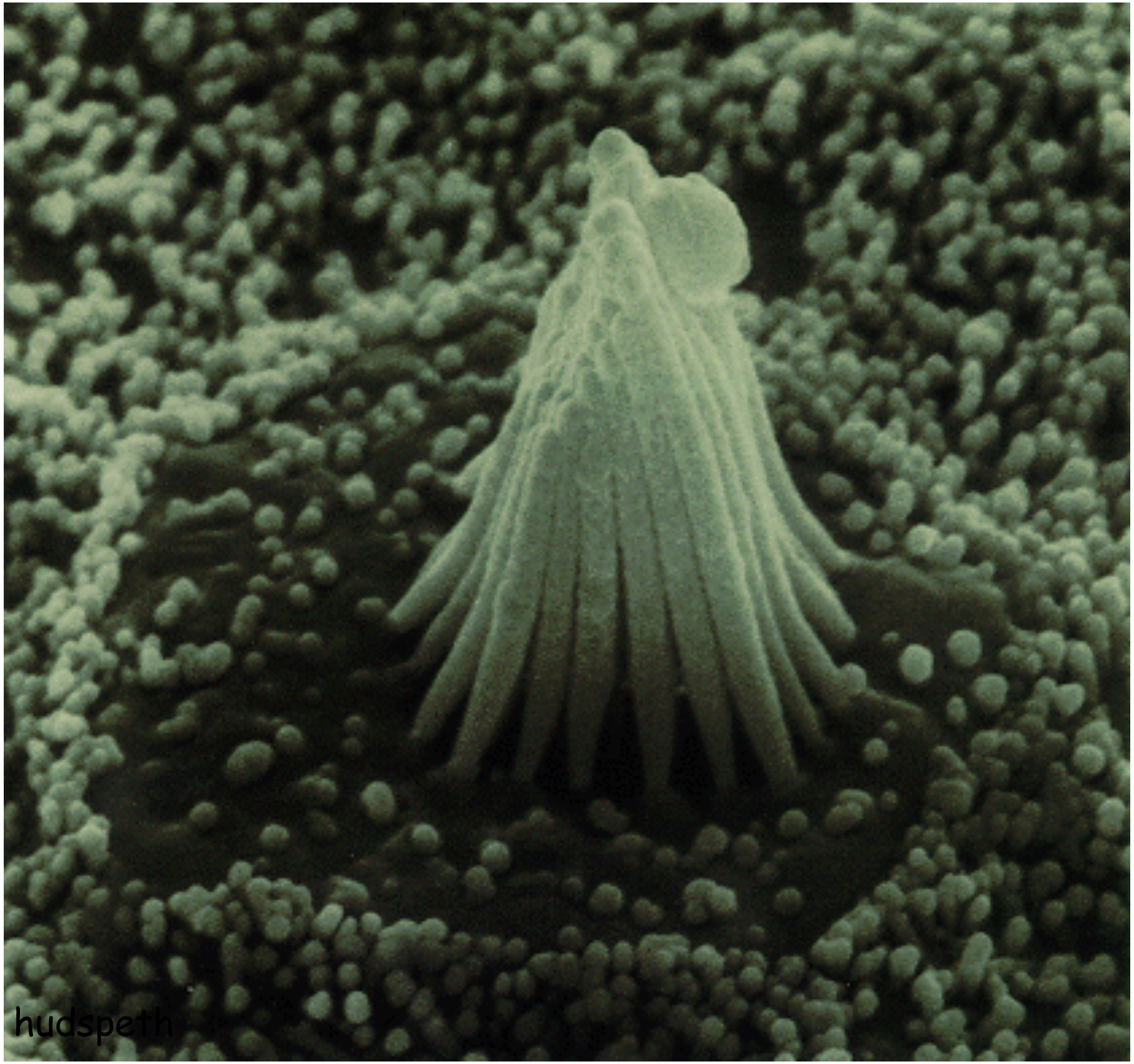


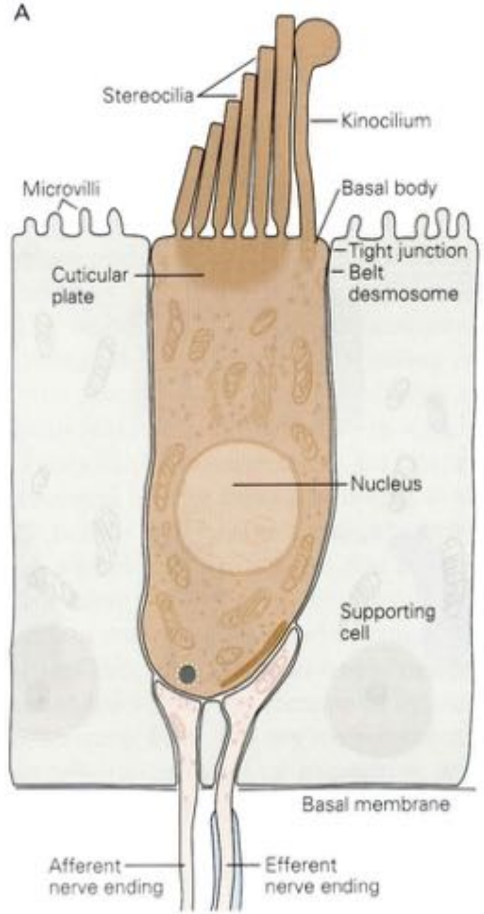
Hair cells

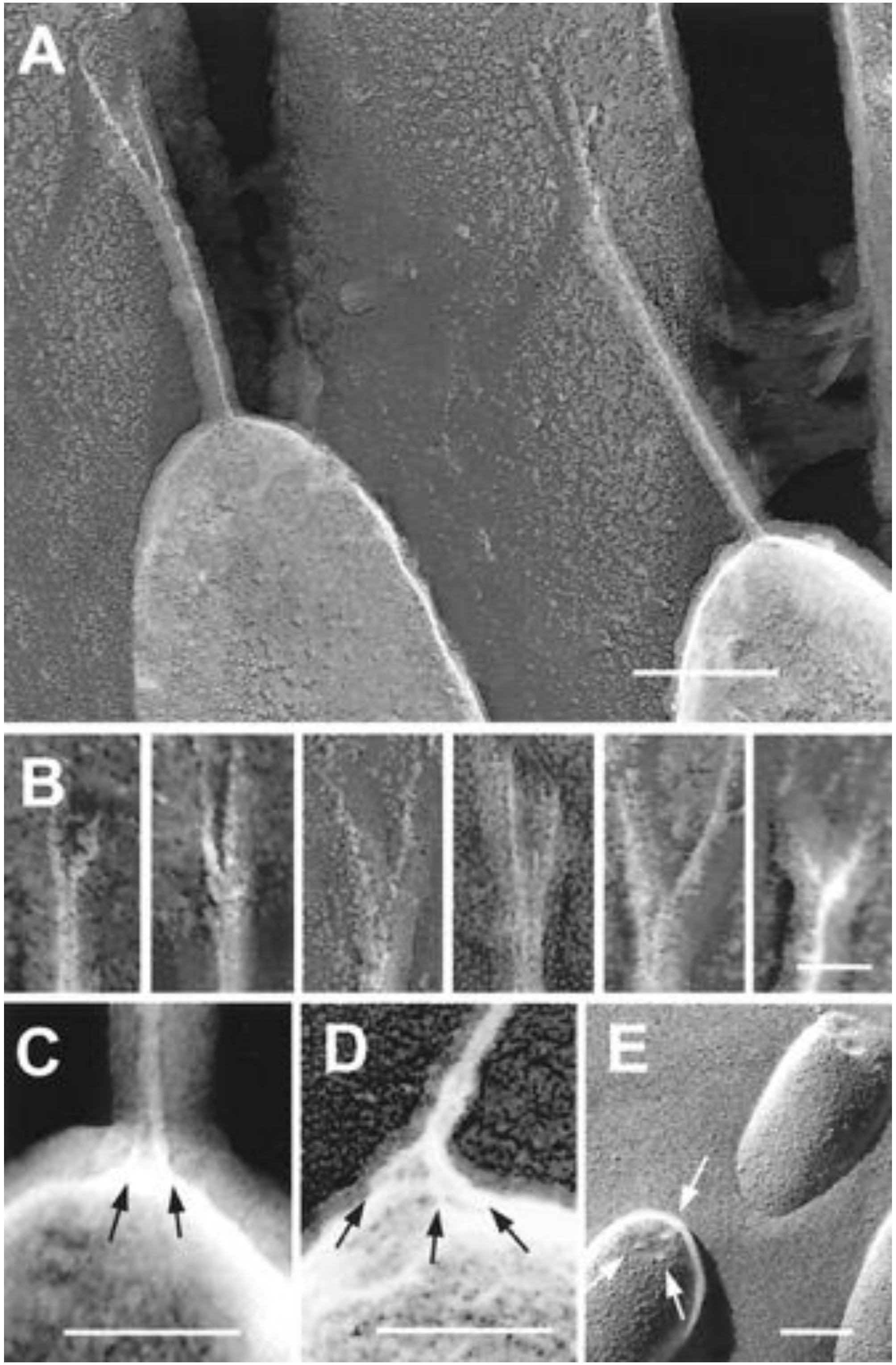

HC
PP
PP
PP
IPH
OHC
IHC

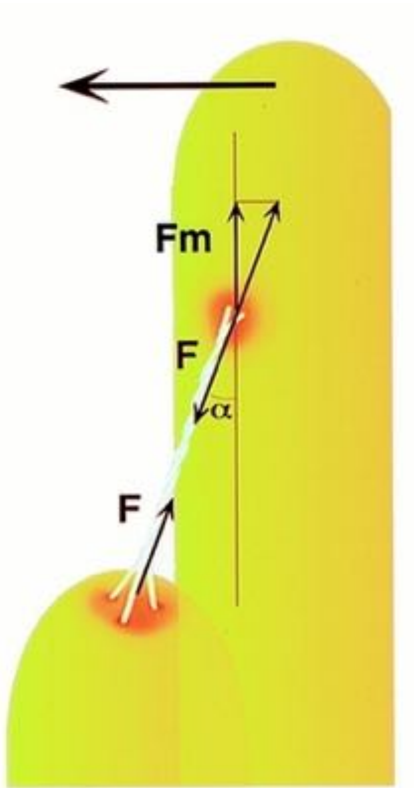

A
Stereocilia
Kinocilium
Microvilli
Basal body
Tight junction
Belt desmosome
Cuticular plate
Nucleus
Supporting cell
Basal membrane
Afferent nerve ending
Efferent nerve ending

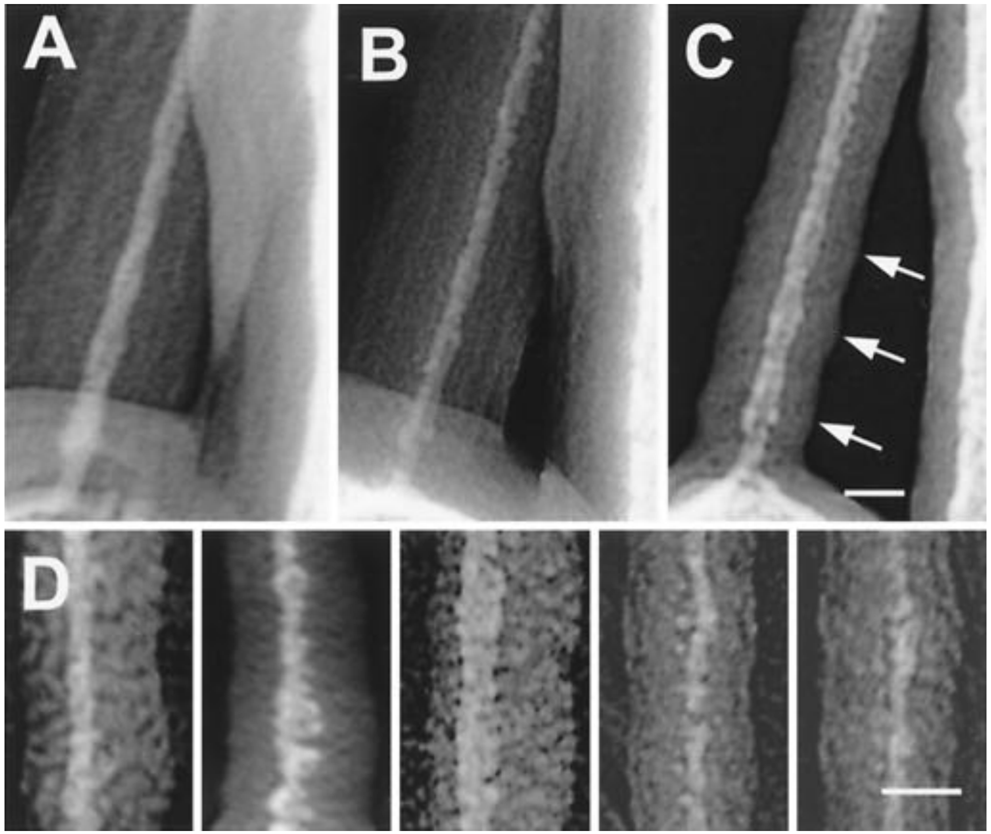
hair bundle

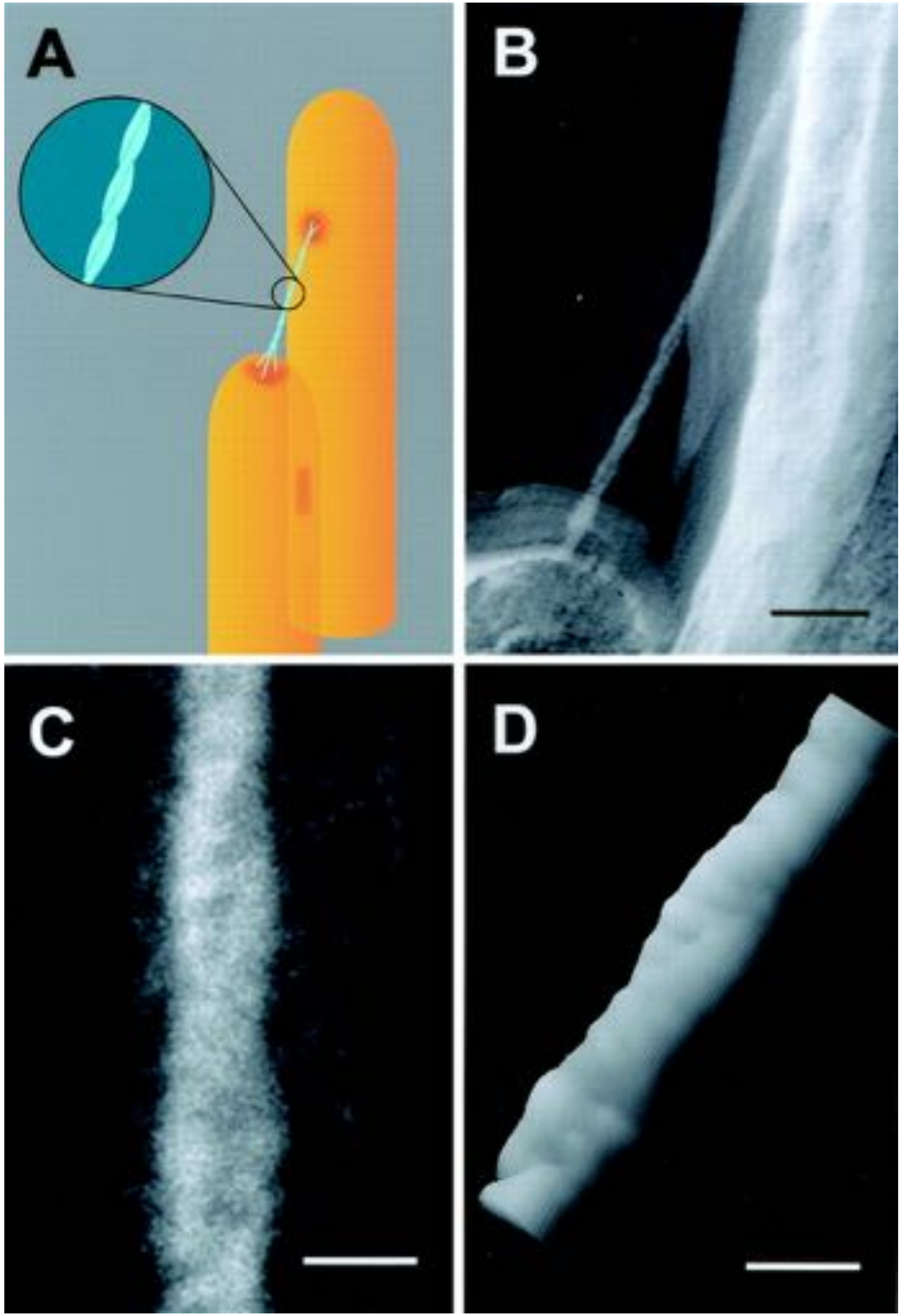

hudspeth


A
Stereocilia
Kinocilium
Microvilli
Basal body
Tight junction
Belt desmosome
Cuticular plate
Nucleus
Supporting cell
Basal membrane
Afferent nerve ending
Efferent nerve ending

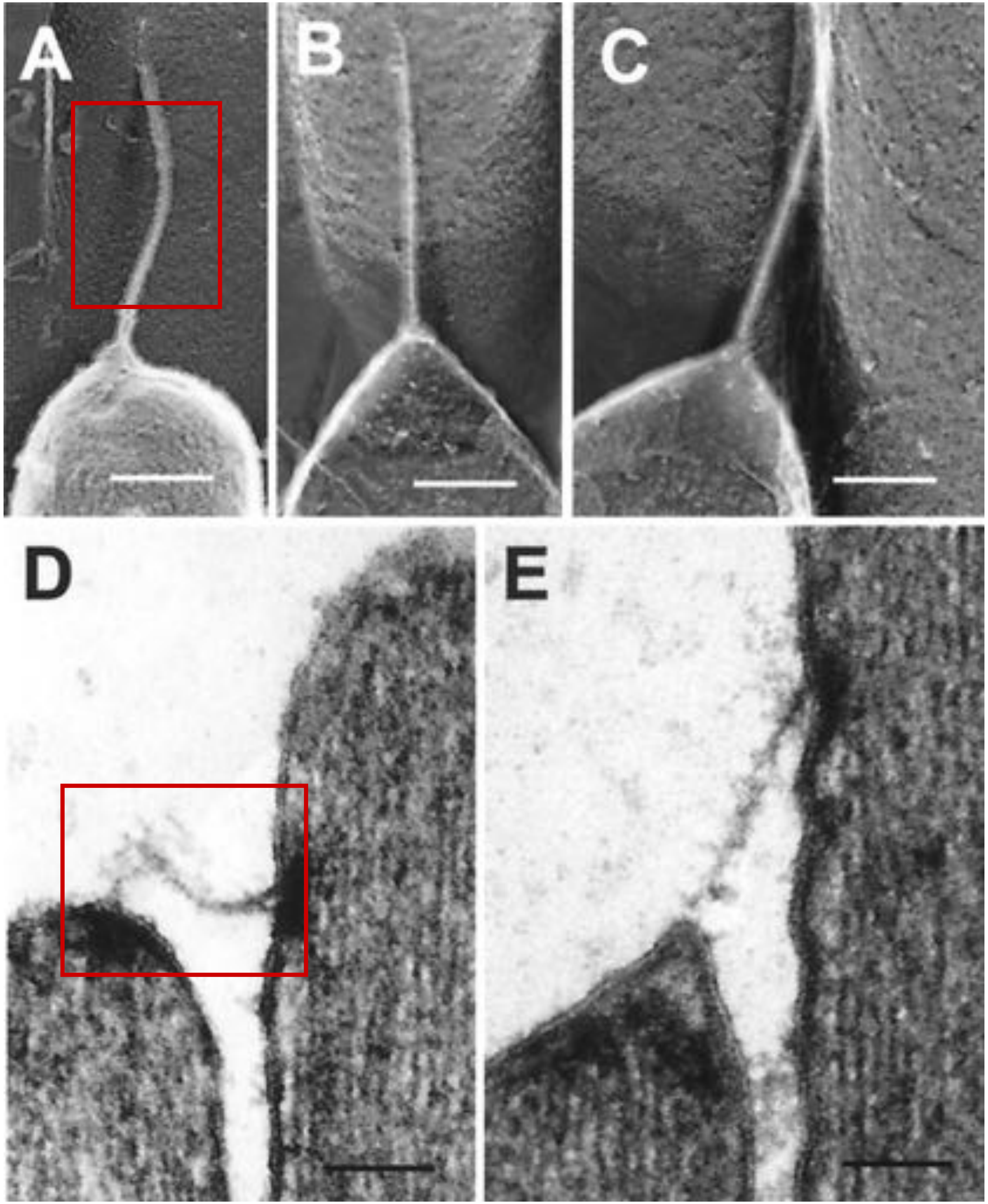

A
B
C
D
E


Fm
F
α
F

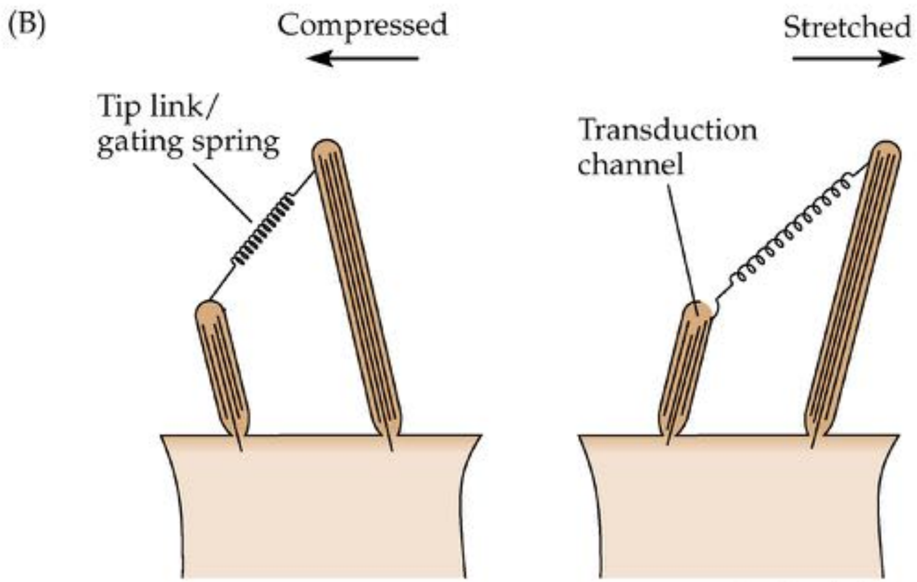

A
B
C
D

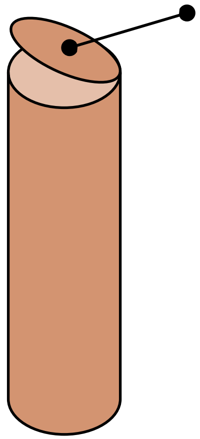

A
B
C
D

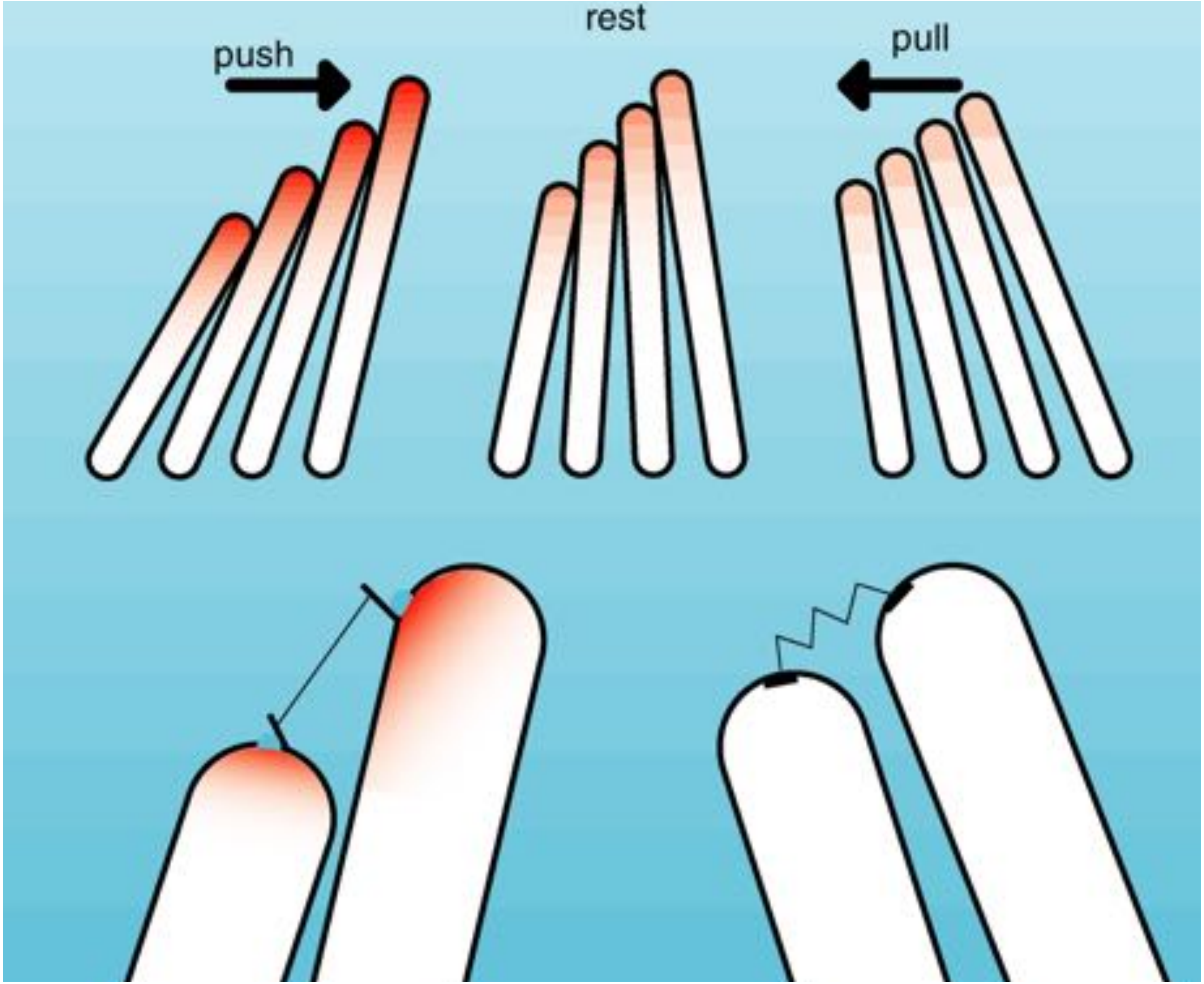
tip links can bend or break (loud noise)

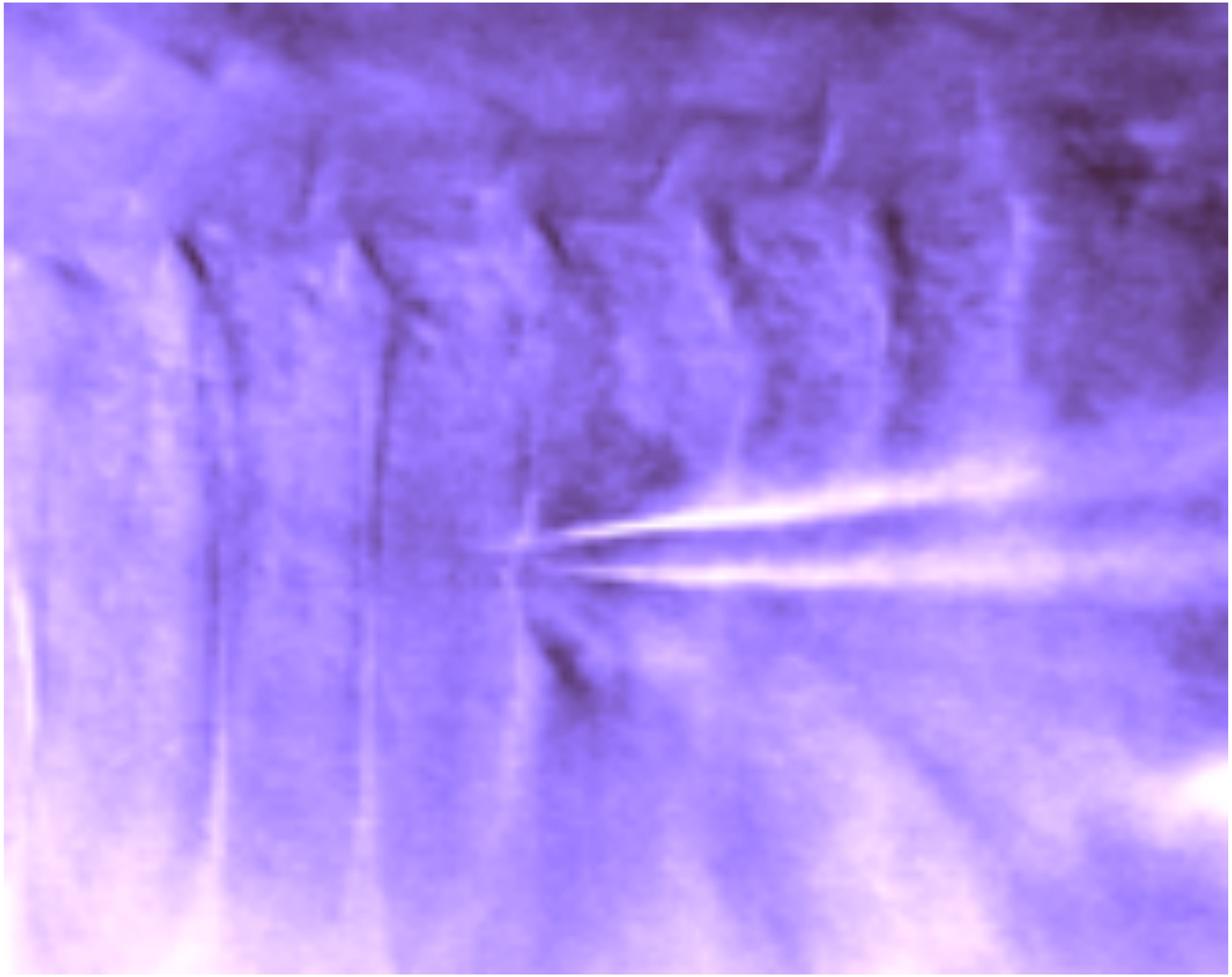


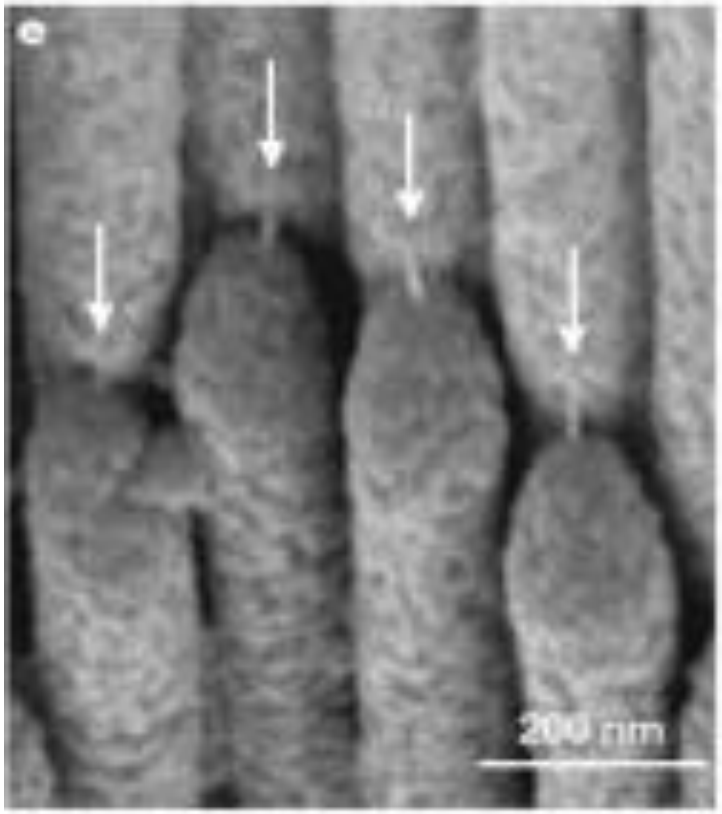
The cilia are connected by *TIP LINKS* and the ion channels is found at the top of the cilium

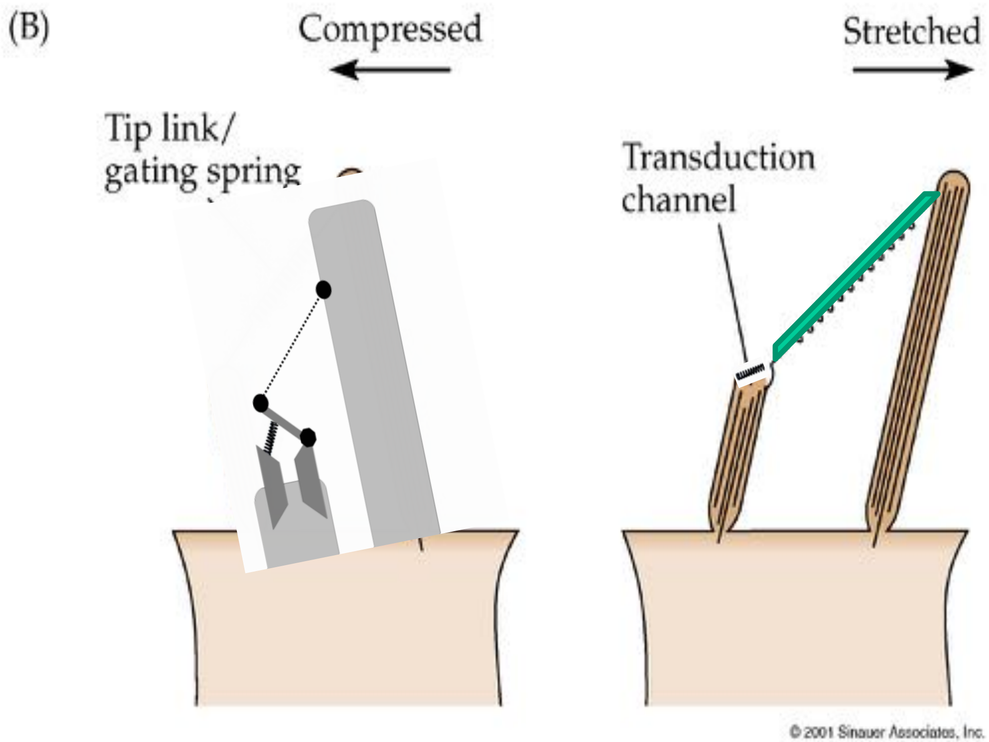





push
rest
pull




200 nm


(B)
Compressed
Stretched
Tip link/
gating spring
Transduction
channel
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Outter hair cells change shape with depolarization:
The shape change resonates with vibration and amplifies