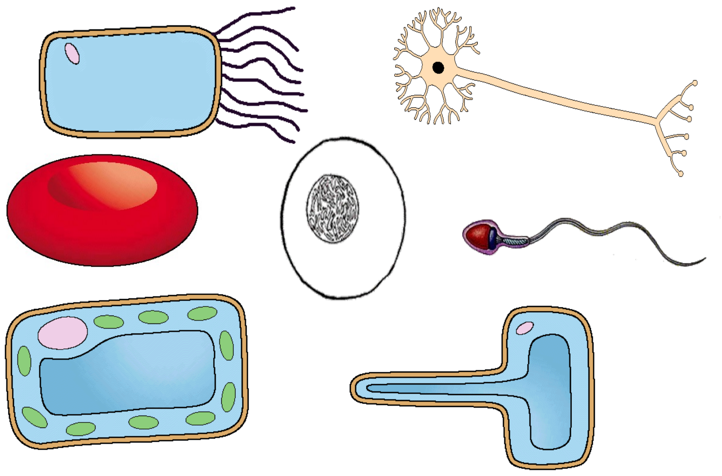
All physiological functions start from the cell

The brain does not think.
Cellular networks process signals.
The heart does not pump.
Cardiac muscle cells generate force.

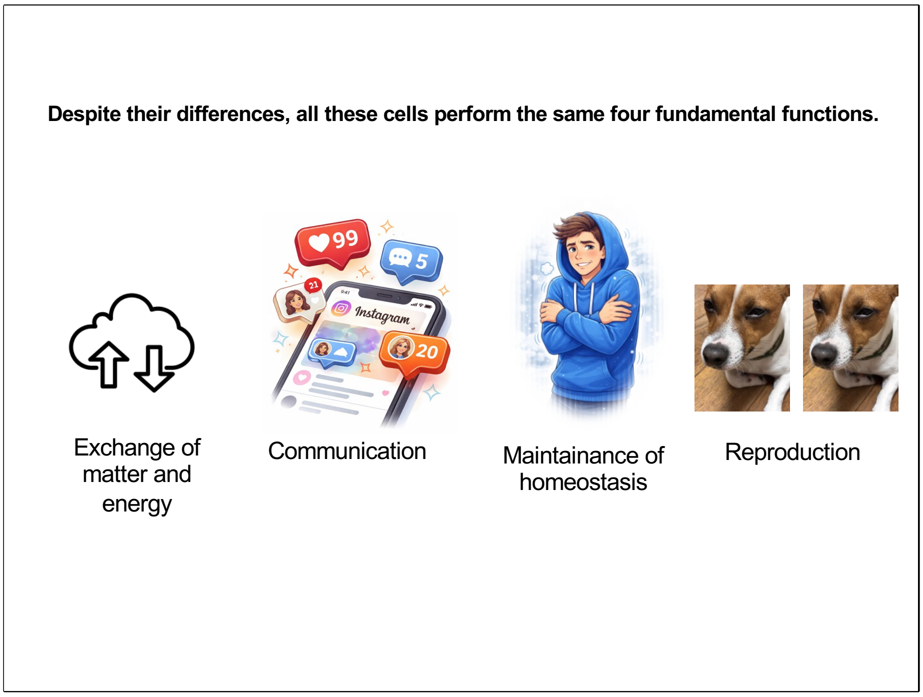
Physiology is organized cellular physiology

How can a single cell generate different functions?

Specializing its shape



SAME MOLECULES= DIFFERENTLY ORGANIZED/REGULATED= DIFFERENT FUNCTIONS



Despite their differences, all these cells perform the same four fundamental functions.

All living cells must:
Exchange matter and energy
Communicate
Maintain homeostasis
Reproduce
These are the four fundamental functions of cellular physiology.

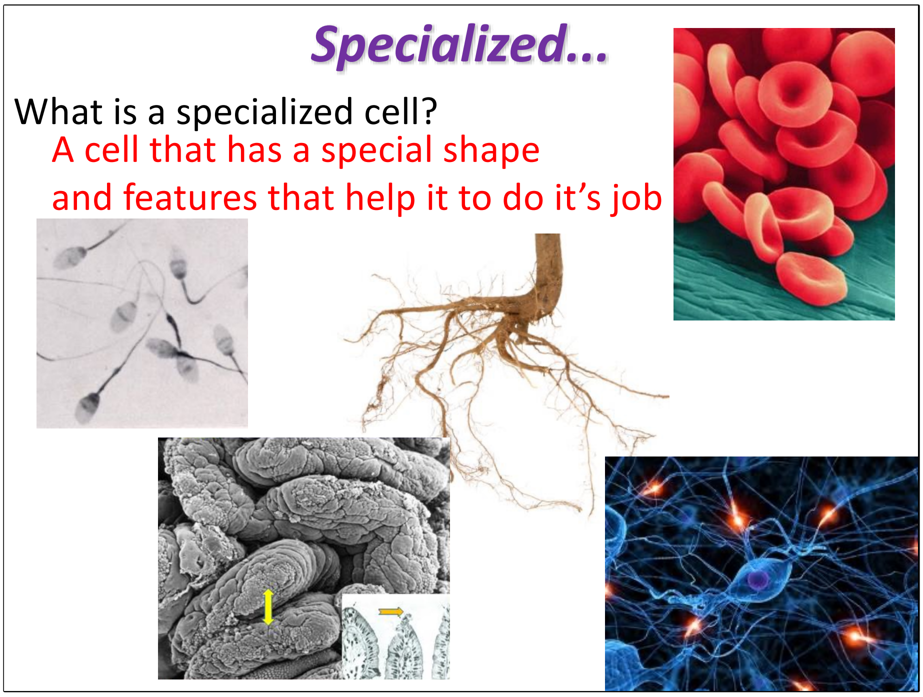
But pay attention: these functions are the same, what changes is how they are performed.

Specialized…

What does it mean??

Something that is designed to do a particular job

A specialized cell is a cell whose structure is optimized for a specific function.
Specialization does not change the fundamental functions, but it changes the efficiency and the priority with which they are performed.



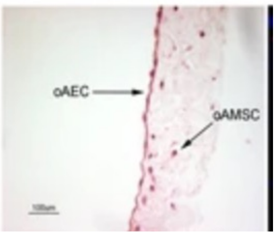
The red blood cell loses its nucleus
→ maximizes oxygen transport
The neuron elongates its axon
→ long-distance communication
The intestinal epithelium increases microvilli
→ maximizes absorption
The sperm cell elongates its flagellum
→ maximizes movement

Not only that, these cells can also use the same molecules in different ways.

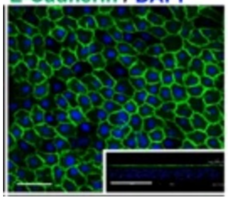
EPITHELIAL CELL

Amniotic epithelial cells

It does not only serve to separate, but to regulate exchange and communication with the external environment.



E-Cadherin / DAPI



Simple epithelial morphology
→ selective barrier between fetus and amniotic fluid

Tight cell junctions
→ controlled permeability and protection

Microvilli on apical surface
→ increased exchange surface

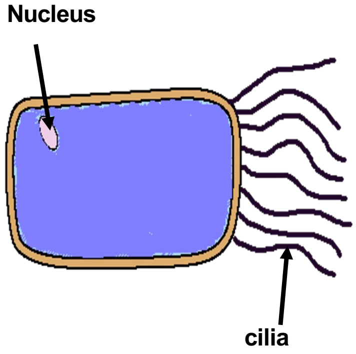
Secretory activity
→ production of bioactive factors

Low immunogenic profile
→ immune tolerance at maternal–fetal interface

Epithelial Cell

Ciliated cells

Specialized for mucus transport in the respiratory tract



Apical cilia
→ mucus transport

Polarized cell
→ directional beating

Airway localization
→ lung protection

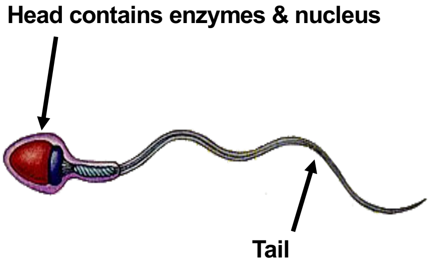
Mucus interaction
→ particle trapping

Coordinated cilia movement
→ mucociliary clearance

Germ cell

Sperm cell

Extreme specialization: to transport genetic information.



Small and streamlined shape
→ reduces resistance and allows efficient movement

Long tail (flagellum)
→ provides propulsion to swim toward the egg cell

Head with acrosome (enzymes)
→ helps penetrate the egg during fertilization

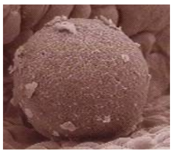
Midpiece rich in mitochondria
→ supplies energy for movement

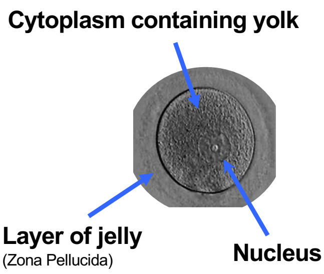
Haploid nucleus in the head
→ delivers paternal genetic material

Germ Cell

Ovum cell

It is not designed to move, but to support development.





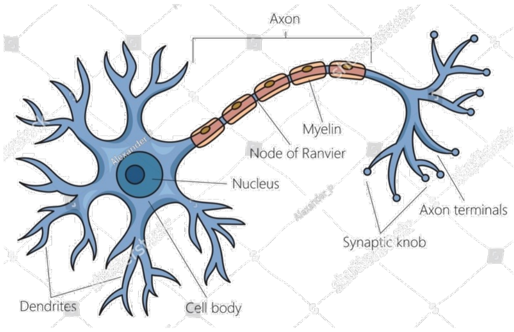
Large size
→ provides cytoplasm and nutrients for early development

Haploid nucleus
→ contains maternal genetic material

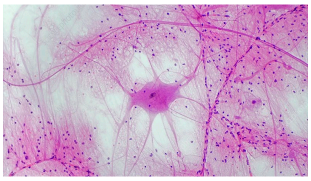
Nutrient-rich cytoplasm (yolk)
→ supports early embryo growth

Protective outer layers (zona pellucida)
→ protect the egg and regulate fertilization
Non-motile cell
→ relies on surrounding structures for transport

Nerve Cell



Long cells
→ allow signals to travel over long distances



Shape specialization for:
Reception, processing, and transmission of information through electrical and chemical signals.
Where:

- Dendrites (reception)
- Axon (transmission)
- Synaptic terminals (chemical communication)

Red Blood Cell

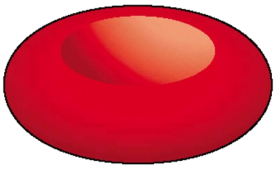
Designed to carry oxygen
→ specialized for gas transport

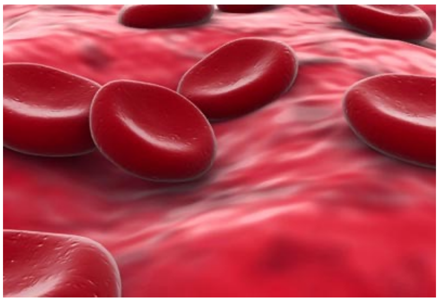
Found in blood
→ circulate to deliver oxygen to tissues

Large surface area (biconcave shape)
→ efficient oxygen diffusion

Contains hemoglobin
→ binds and transports oxygen

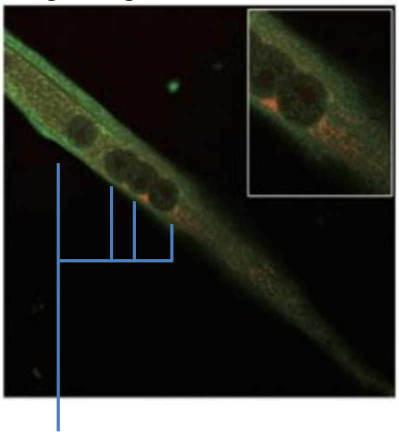
No nucleus
→ more space for hemoglobin and increased flexibility





Skeletal muscle Cell

Designed to generate force



Long cylindrical shape
→ contraction along a single axis and force generation

Multinucleated cell
→ high protein synthesis for contractile proteins

Packed with myofibrils
→ efficient force production

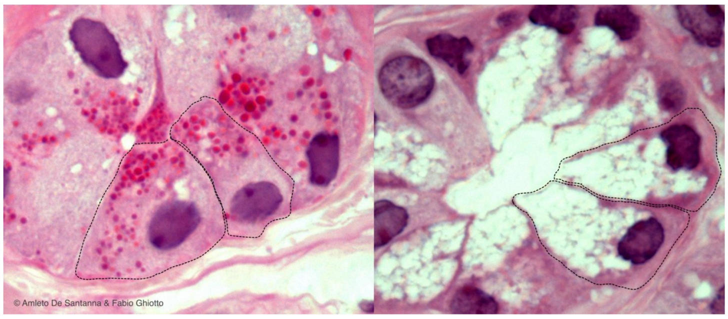
Sarcomere organization
→ coordinated and directional contraction

Abundant mitochondria
→ high ATP demand for contraction

Specialized sarcoplasmic reticulum
→ rapid Ca^{2+} release and contraction control

SEROUS CELLS

Antimicrobial properties | Lubrification properties



Serous cells — serous secretion
Main components:
water
protein enzymes (e.g., amylase, proteases, lipases)
antimicrobial proteins
electrolytes (Na^+, Cl^-, HCO_3^-)

Characteristic:
→ fluid and low-viscosity secretion

Mucous cells — mucous secretion
Main components:
mucins (high molecular weight glycoproteins)
water (trapped in the mucous gel)
proteoglycans
immunoglobulins (mainly IgA)
antimicrobial peptides

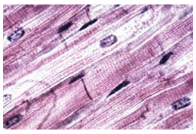
Characteristic:
→ viscous, gel-like secretion

Serous and mucous cells are both epithelial glandular cells, but with different functions.

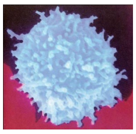
Even more specialized cells…

Animal

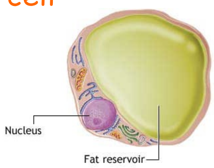
Muscle cell



White blood cell

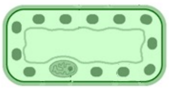


Fat cell

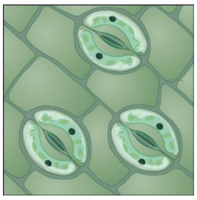


Plant

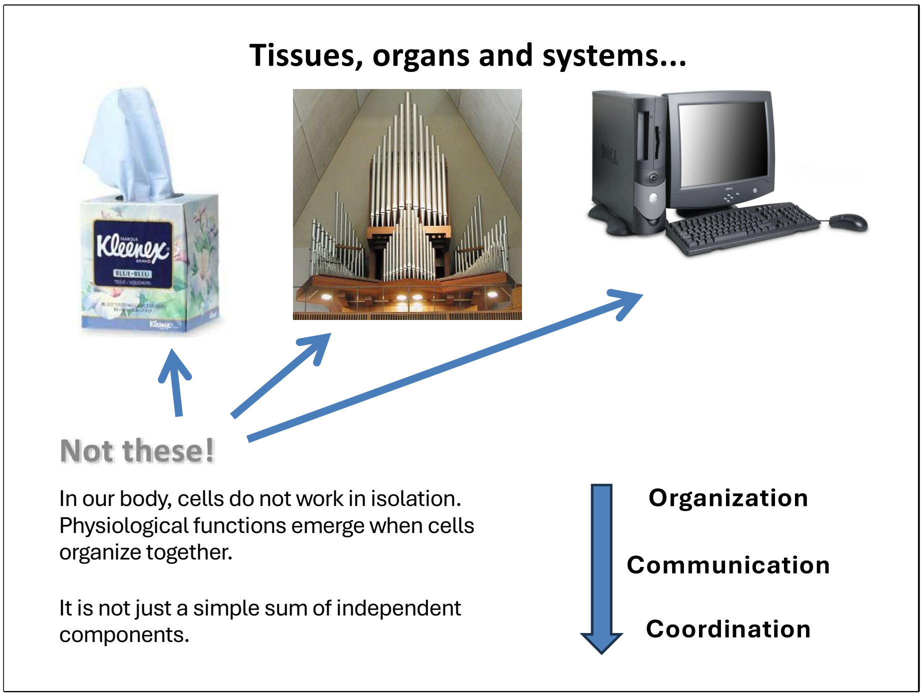
Leaf palisade cell



Guard cell

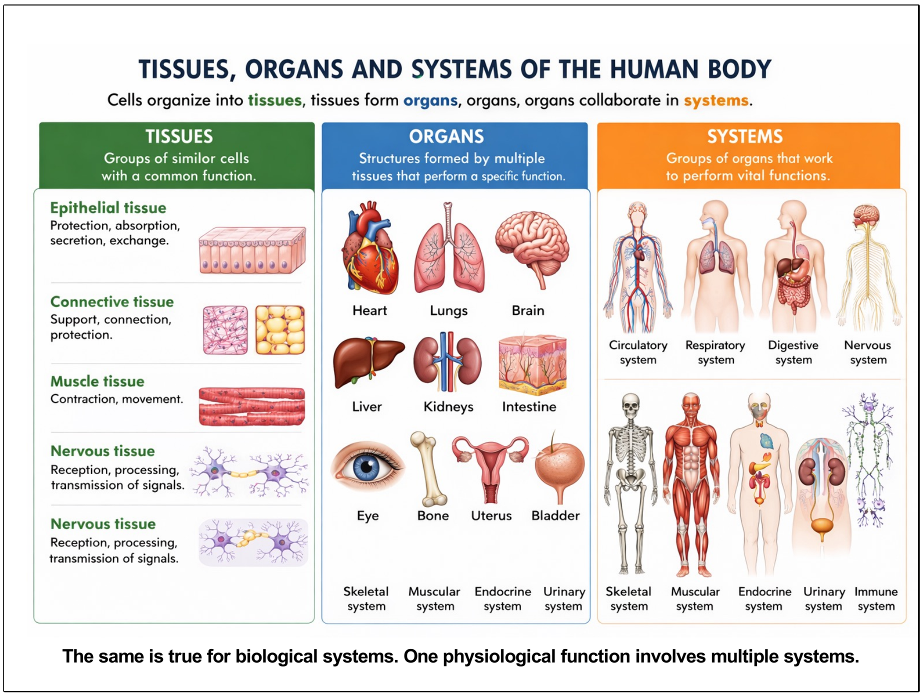


Epidermal cell



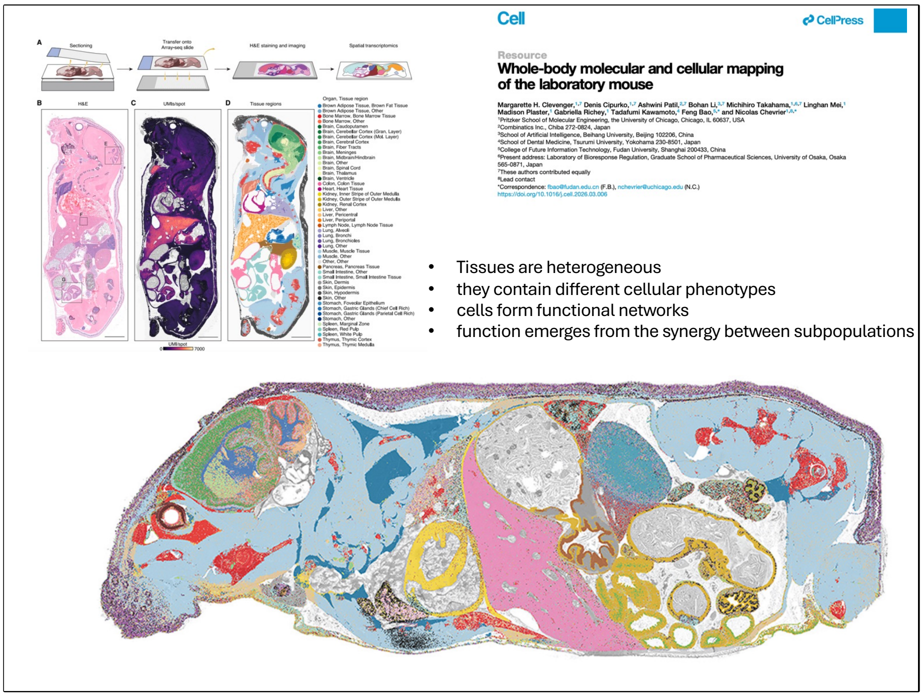
So far, we have seen very different types of cells.
Each one is specialized for a specific function.

But in our body, cells do not work in isolation.
Physiological functions emerge when cells organize together.
It is not just a simple sum of independent components.
Physiological functions requires organization, interaction, coordination.



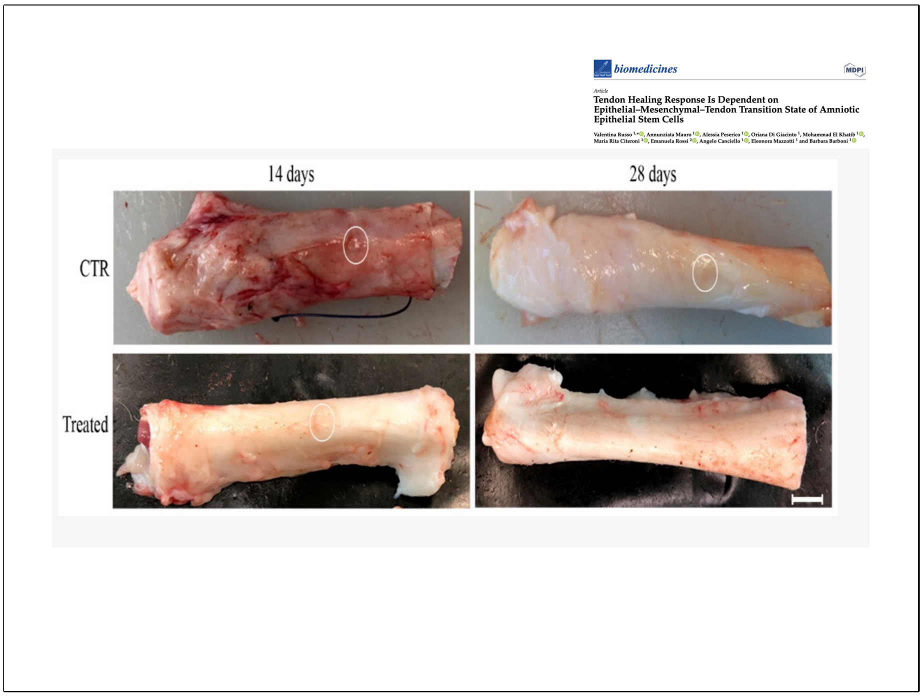
The same is true for biological systems.
Similar cells organize into tissues.
Different tissues form organs.
Different organs coordinate into physiological systems.

Focus on tissues...
Traditionally, tissues are defined as groups of similar cells with a common function.
Each tissue has a typical reference cell.
This view is correct and commonly found in histology textbooks.
But it is also a exemplification.



But today we know that:
tissues are heterogeneous
they contain different cellular phenotypes
cells form functional networks
function emerges from the synergy between subpopulations

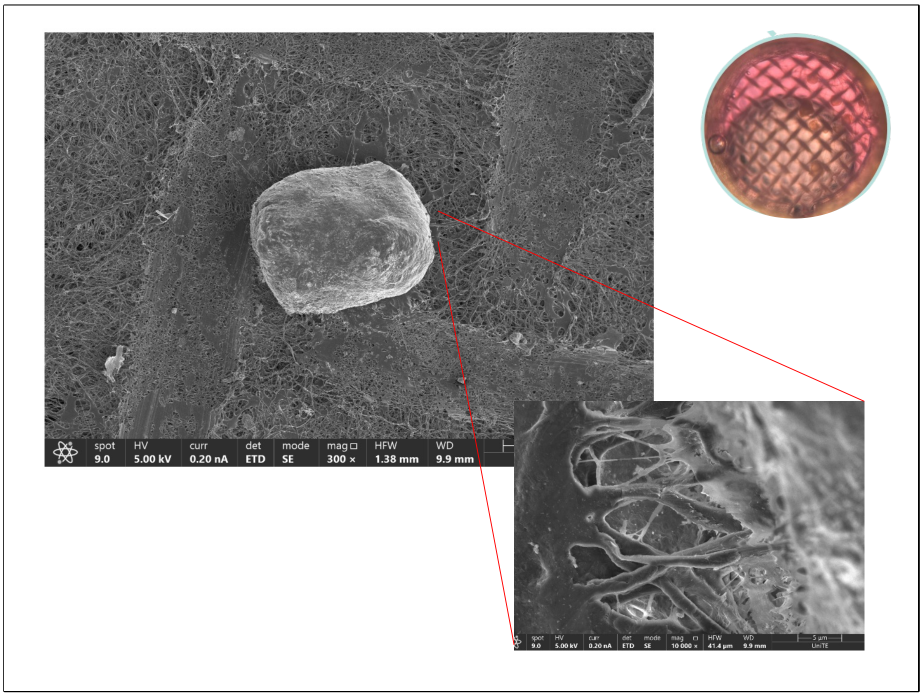
This comes from:
single-cell RNA sequencing
spatial transcriptomics
spatial proteomics
multiplex imaging



Example of tissue engineering for the regeneration of tendon tissue following injury.

When a tendon ruptures, it heals spontaneously.
But the original tissue is not regenerated.
Inflammation activates fibroblasts, and collagen is deposited in a disorganized way.
The result is scar tissue, which is stiffer and less functional.

We can guide this process using mesenchymal stem cells or amniotic epithelial cells.
These cells do not replace the tendon, but modulate inflammation.
They reduce pro-inflammatory signals, regulate fibroblasts, and promote a more organized matrix.
The result is tissue more similar to the original one, not a scar.



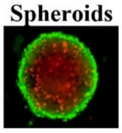
This image shows an ovarian follicle cultured in vitro using biomaterials that mimic the natural ovarian environment.
In particular, a polymer (such as polycaprolactone) is used, organized into fibers with a defined structure that provides a three-dimensional support similar to that found in the ovary.
This approach makes it possible to support the growth and survival of the follicle, which represents the “home” of the oocyte, even outside the body.
This is a very important biotechnological solution, especially for young patients who, due to diseases such as cancer, must undergo treatments that can compromise fertility.
In these cases, ovarian tissue can be cryopreserved and, in the future, in vitro systems like this can be used to support follicular maturation and preserve reproductive potential.

Modern biotechnologies aim to recreate tissues, organs, and biological systems in the laboratory.

Different levels of complexity have been achieved, with variable efficiency.

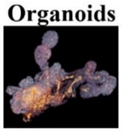
3D

Spheroids



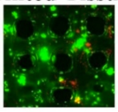
Simple 3D structures, without defined structural organization

Organoids



Organized 3D structures that mimic the architecture and functions of a tissue/organ

Printed Tissues



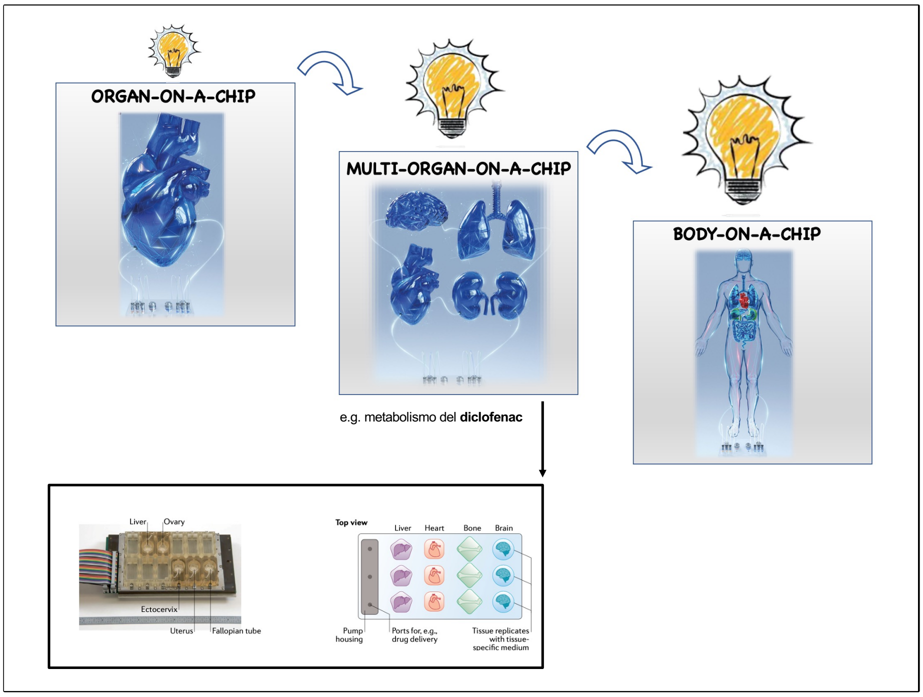
Artificially guided using bio-3D printers, with architecture controlled a priori

Microfluidics

With microfluidic channels and controlled flow that simulate a dynamic physiological environment

?

- **MODEL**
- **STUDY THE RESPONSE TO STIMULI**
- **TOXICITY STUDIES**



Where are we today

1. Edington et al., 2018 — Physiome-on-a-chip

What they did

The authors developed a multi-organ chip platform connecting up to 10 human tissues through a shared microfluidic system.

The tissues included models of:

liver
kidney
intestine
heart
lung
brain (BBB)
skin
vascular endothelium

The system was maintained for 4 weeks with continuous perfusion.

They then tested diclofenac metabolism to study:

absorption
hepatic metabolism
distribution
elimination

Key message

They recreated human multi-organ pharmacokinetics on a chip.

2. Novak et al., 2020 — Robotic multi-organ chip

What they did

The authors developed a robotic platform to automatically connect up to 10 vascularized organ-on-chip systems.

The system was able to:
fluidically connect the chips
automatically add medium
collect samples
monitor in real time
perform in situ microscopy
The culture was maintained for 3 weeks with controlled perfusion.

Key message
They created an automated body-on-chip that simulates systemic circulation.