Collagène et Biomatériaux

- Définitions, biomimétisme et cristaux-liquides -

Ecole Thématique Surf@1Health - Cargèse, 21-26 septembre 2025

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"La logique du révolté est [...] de s'efforcer au langage clair pour ne pas épaissir le mensonge universel."

Camus dans *l'homme révolté*

QUELQUES DEFINITIONS

BIOMATERIAUX

Années 80 (puis complétée en 91) : « matériau non vivant, utilisé dans un dispositif médical et conçu pour interagir avec des systèmes biologiques, qu'il participe à la constitution d'un appareillage à visée diagnostique ou à celle d'un substitut de tissu ou d'organe, ou encore à celle d'un dispositif de suppléance (ou assistance) fonctionnelle ».

The European Society for Biomaterials

MAIS : doit répondre strictement au critère suivant, à savoir ne pas avoir d'effet délétère pour l'organisme

W .F. Williams, Definitions in Biomaterials, 2nd Consensus Meeting, Eur. Soc. Biomat., Ed. Elsevier (1991)

« BIOCOMPATIBLE »

c'est-à-dire qu'il ne doit pas déclencher des réactions toxiques ou inflammatoires (pathologiques)

≠

« CYTOCOMPATIBLE »

≠

« BIOACTIVITE »

termes pharmacologie molécules actives
ou
biomatériaux induit une réaction

PREMIER REIN ARTIFICIEL (1943)

Matériau biologique *versus* biomatériau

2005 :

Biomaterials

Available online at www.sciencedirect.com
SCIENCE DIRECT®
Biomaterials 26 (2005) 6254–6262
ELSEVIER
Biomaterials
www.elsevier.com/locate/biomaterials

Multiscale structure of sheet nacre

Marthe Rousseau[a], Evelyne Lopez[a,*], Philippe Stempflé[b,c], Marcel Brendlé[b], Loïc Franke[d], Alain Guette[d], Roger Naslain[d], Xavier Bourrat[e]

1. Introduction

This paper is focused on the composite structure of nacre for its future use as a natural bioceramic for bone regeneration [1]. The structure of nacre is already well documented by the works of Wada [2], Wise [3], Grégoire [4] and Mutvei [5]. A long tradition of structural analysis exists in this field, often conducted by electron microscopy. Grégoire et al. [6] already used this technique in 1955 to evidence the interlaminar sheet

2018 :

Biomaterials

Editor-in-Chief: K.W. Leong

› View Editorial Board

Biomaterials is an international journal covering the science and clinical application of **biomaterials**. A biomaterial is now defined as a substance that has been engineered to take a form which, alone or as part of a complex system, is used to direct, by control of interactions with components of living systems, the course of any therapeutic or diagnostic procedure. It is the aim of the journal to provide a peer-reviewed forum for the publication of original papers and

2009 :

2009 :

Nature

Editorial | Published: 25 November 2009

Biomaterials

Rosamund Daw & Stefano Tonzani

Nature **462**, 425 (26 November 2009) | Download Citation

Biomaterials research has come of age. Since antiquity, humans have been taking whatever substances are at hand — natural materials, glass, metals or polymers — and using them to replace body parts that have been damaged by disease or injury. But it is only recently, with the advent of molecular biology, that the field has become interdisciplinary, enabling materials scientists to design materials that impart a specific biological function. The field of biomaterials is also broadening as we improve our understanding of how the physical sciences can help to explain biology and indeed of how biological principles, mechanisms and molecules can be applied in the design of materials for non-biological applications.

2018 :

2018 :

nature.com

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Biomaterials

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Biomaterials are those materials — be it natural or synthetic, alive or lifeless, and usually made of multiple components — that interact with biological systems. Biomaterials are often used in medical applications to augment or replace a natural function.

2012 :

SPECIALSECTION

INTRODUCTION

Biomaterials

WHEN TRYING TO DEVELOP AN ARTIFICIAL SKIN, PROFESSOR KIM WOODHOUSE CAME up with several formulations based on an elastomeric polymer. One of them had the mechanical properties that most closely matched human skin, so she thought it would be the formulation the surgeon would want to test. The surgeon, however, came in, flopped each of the samples in his hands, and picked a different sample for surgical testing. That formulation became the standard for her lab.

We encourage readers to explore this diverse package of articles from *Science* and *Science Translational Medicine* and to broaden their view of the biomaterials world.

– MARC LAVINE, MEGAN FRISK, ELIZABETH PENNISI

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900 China's Push in Tissue Engineering

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Published by AAAS

2025 :

Science

RESEARCH

BIOMATERIALS

Does the mantis shrimp pack a phononic shield?

N. A. Alderete[1], S. Sandeep[2], S. Raetz[2], M. Asgari[1]†, M. Abi Ghanem[3]*, H. D. Espinosa[1]*

The powerful strikes generated by the smasher mantis shrimp require it to possess a robust protection mechanism to withstand the resultant forces. Although recent studies have suggested that phononic bandgaps complement the mantis shrimp's defensive suite, direct experimental evidence for this mechanism has remained elusive. In this work, we explored the phononic properties of the mantis shrimp's dactyl club using laser ultrasonic techniques and numerical simulations. Our results demonstrate that the dactyl club's periodic region functions as a dispersive, high-quality graded system, exhibiting Bloch harmonics, flat dispersion branches, ultraslow wave modes, and wide Bragg bandgaps in the lower megahertz range. These features effectively shield the shrimp from harmful high-frequency stress waves generated by cavitation bubble collapse events during impact.

Among the various notable evolutionary adaptations displayed by the animal kingdom (*1*–*6*) lies the ability to withstand high peak forces delivered over short periods of time (*7*). Perhaps the most formidable species that exhibits this capability is the renowned peacock mantis shrimp (*Odontodactylus scyllarus*), a smasher stomatopod native to the Indo-Pacific seabed (Fig. 1A). Despite its relatively small size (ranging from 3 to 18 cm), this mantis shrimp is known to execute a well-orchestrated strike sequence (~60 GPa), thin (~70 μm) hydroxyapatite coating that prevents catastrophic failure by exhibiting viscoplasticity and localized damage (*15*). Next, the impact region (~500 μm) consists of mineralized chitin fibers in a herringbone architecture, which enable damage dissipation through diffuse cracking, crack arrest, and crack deflection (*14*, *16*). Last, the periodic region features a spatially graded Bouligand arrangement of chitin fiber bundles [~80- to 10-μm pitch (p), 2° to 6° interlayer rotation angle (ψ)] (*17*), which modulates stress wave

Glossaire des malentendus en interdisciplinarité : biomatériau

cnrs *2ème définition*

ACTUALITÉS ACTIONS RÉSEAUX RESSOURCES LA MITI

Exemples de contexte : Agriculture, Ecologie

Exemple d'usage : Le biomatériau est aussi nommé matériau biologique, matériau d'origine biologique, ou matériau biosourcé. Il s'agit alors d'une substance organique ou minérale, dérivée ou produite par des organismes vivants tels que les plantes, les animaux, les bactéries, les champignons et d'autres formes de vie, et qui peut être utilisée comme matériau pour fabriquer des objets ou comme combustible. (4). Contexte : Agriculture.

Ces biomatériaux peuvent, par exemple, offrir une alternative plus écologique aux plastiques. Dans certains cas, il peut s'agir aussi d'un matériau biomimétique fabriqué par l'homme et qui est chimiquement ou physiquement similaire à un matériau produit par un organisme vivant.

Exemples d'usage :

Emballages et objets du quotidien biodégradable, réduisant ainsi les déchets plastiques. Dans la mode, ils permettent aussi de créer des vêtements, chaussures et accessoires plus écologiquement durables (5). Contexte : Ecologie.

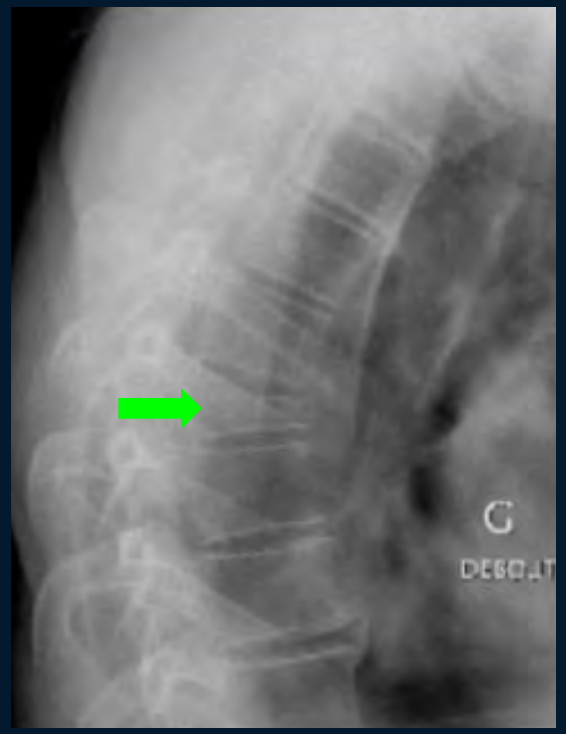
Contacts et renseignements : cyrille.jeancolas@cnrs.fr

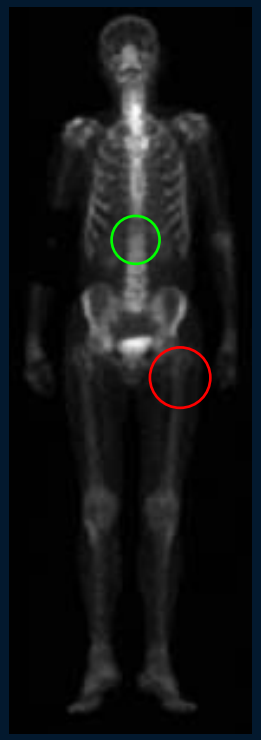
avec Karine Anselme

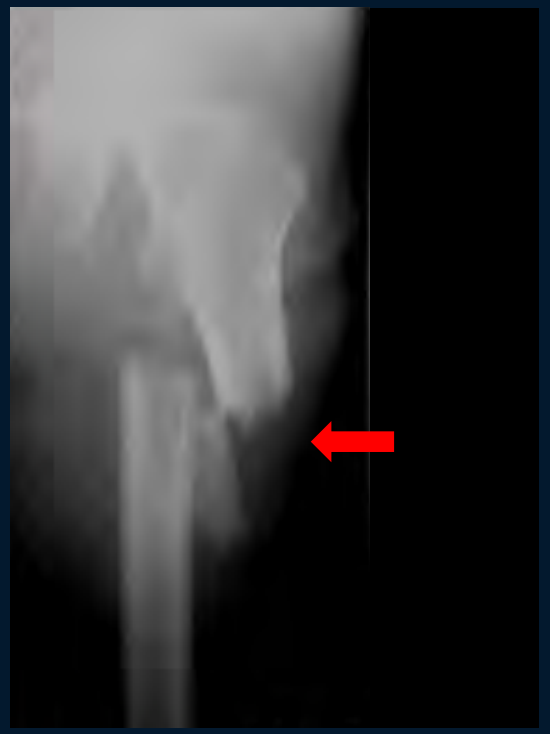
Pourquoi des biomatériaux ?

Quand l'osteogenese n'est pas suffisante…

Notion de « critical size defect » mais pas que...

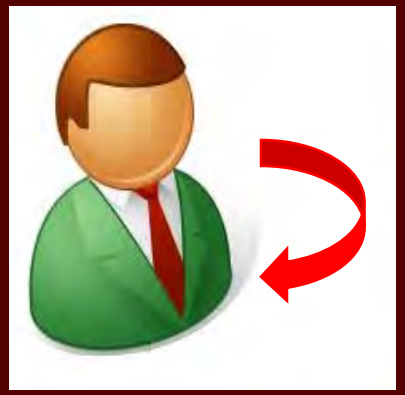




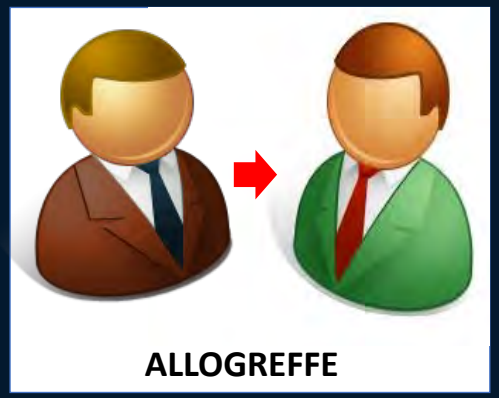


fracture diaphysaire, consolidation vertébrale, ablation tumorale, foyers infectieux *etc.*

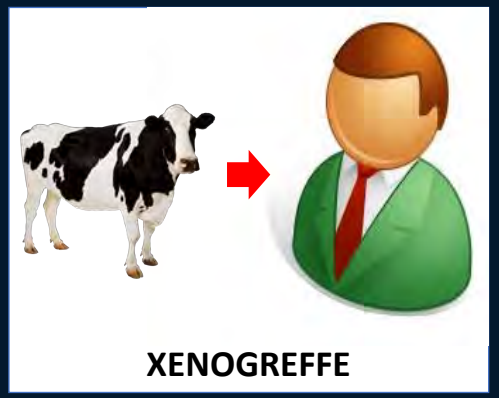
Greffe Osseuse



AUTOGREFFE



ALLOGREFFE



XENOGREFFE

L'autogreffe est le matériau de référence

Perry, C. R. *Clinical orthopaedics and related research* (1999)

Bauer, T. W. & Muschler, G. F. *Clin. Orthop. Relat. Res*. (2000)

opération supplémentaire, douleur et quantité limitée

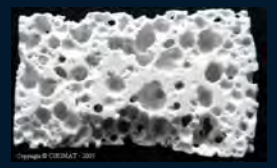
Quelles Alternatives

Ingénierie de l'os

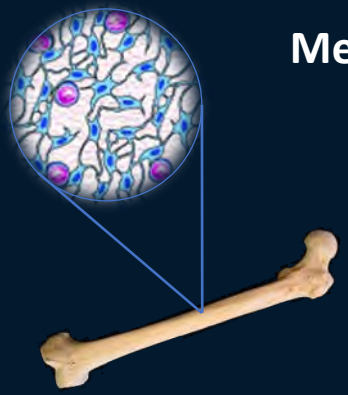
Recherche fondamentale et appliquée

LES ACTEURS :

1) Trame organique extracellulaire
2) Cellules eucaryotes spécialisées
3) Petites molécules organiques, enzymes…
4) Constituants minéraux

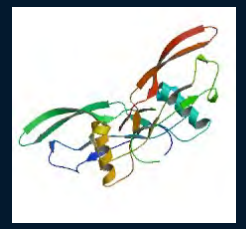


Materials
(demineralized bone matrix, porous ceramics, metallic implant, synthetic and biological polymers)



Mesenchymal Stem Cells

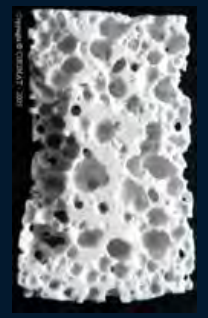
Growth Factors
(BMPs, TGF,…)



Substituts osseux commerciaux

- Prothèses inertes (silicone, titane…) :

Comportent des éléments qui ne sont pas habituellement présents dans le corps, et dont les résidus peuvent mener à des complications dues au fait que le corps ne sait pas traiter de tels composés



- Prothèses biocéramiques (*mais également bioverres*)

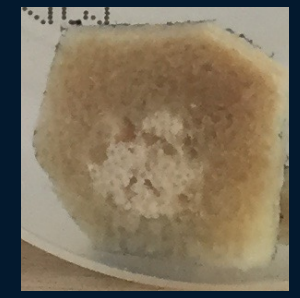
Les éléments constitutifs des biocéramiques en phosphates de calcium sont principalement Ca, P, C, O et H.

Moins de problème de biointégration, les résidus peuvent être traités par le corps hôte sans provoquer de réaction d'inflammation pathologique

Céramique poreuse, contrôle de la taille des pores, colonisation par les cellules

$Ca_{10}(PO_4)_6(OH)_2$

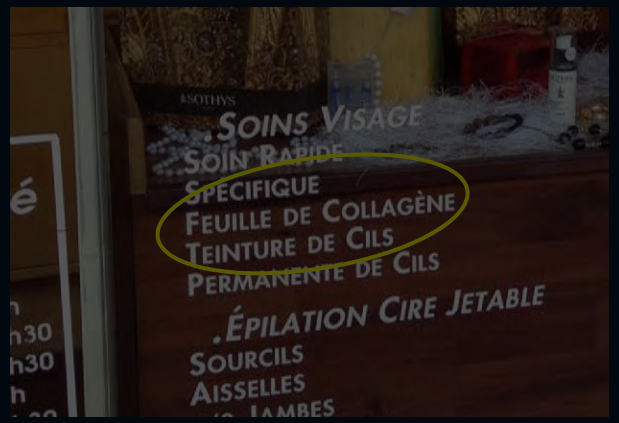
Mais inconvéniants : difficulté de migration dans les pores, propriétés mécanique faible, solubilité… donc valable pour les petits implants

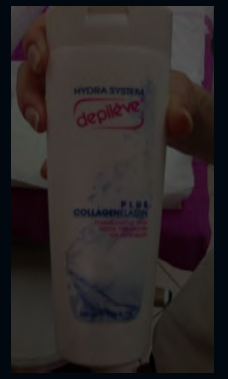


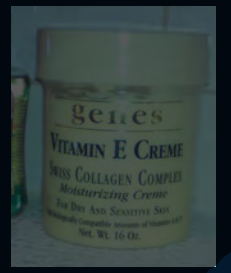
- Associer les deux ⟶ Prothèses revêtues d'hydroxyapatite

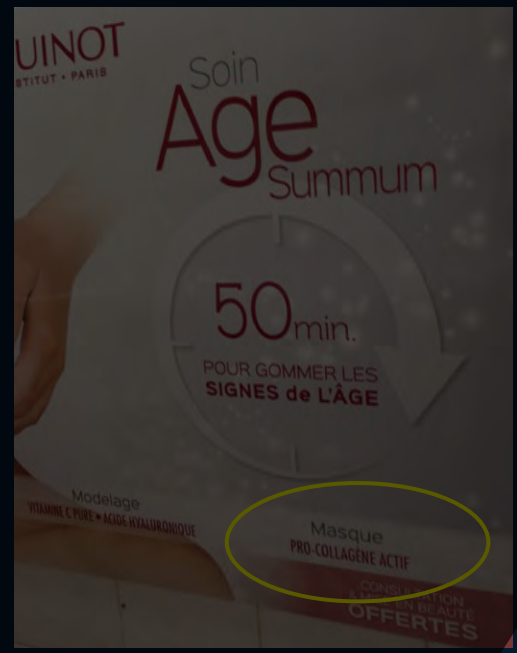
Et les matrices de collagène ?

Le collagène que l'on achète, c'est quoi ?

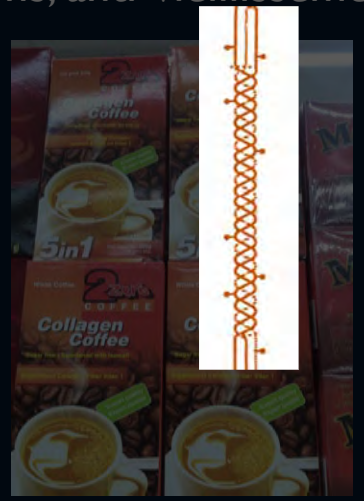


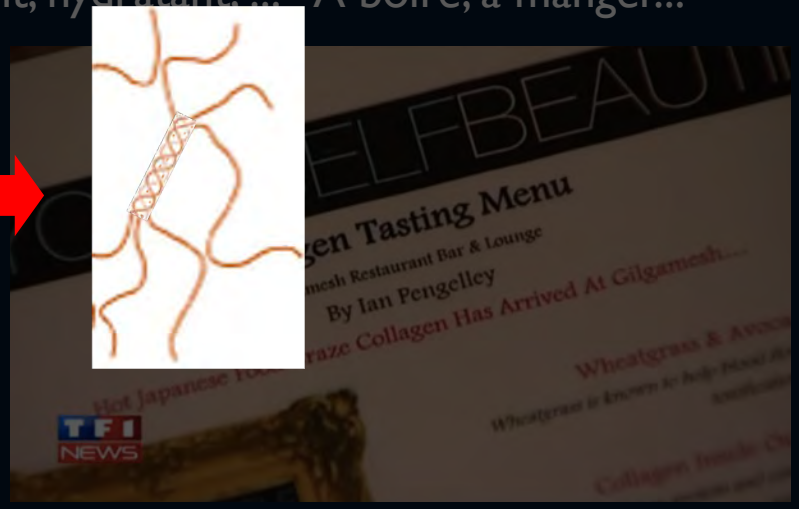




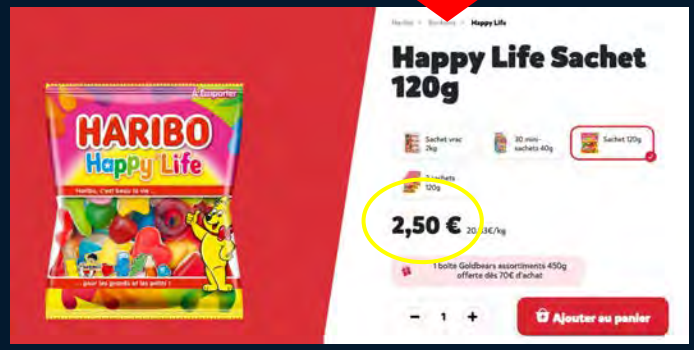


Articulations, anti-vieillissement, hydratant, ... A boire, à manger...



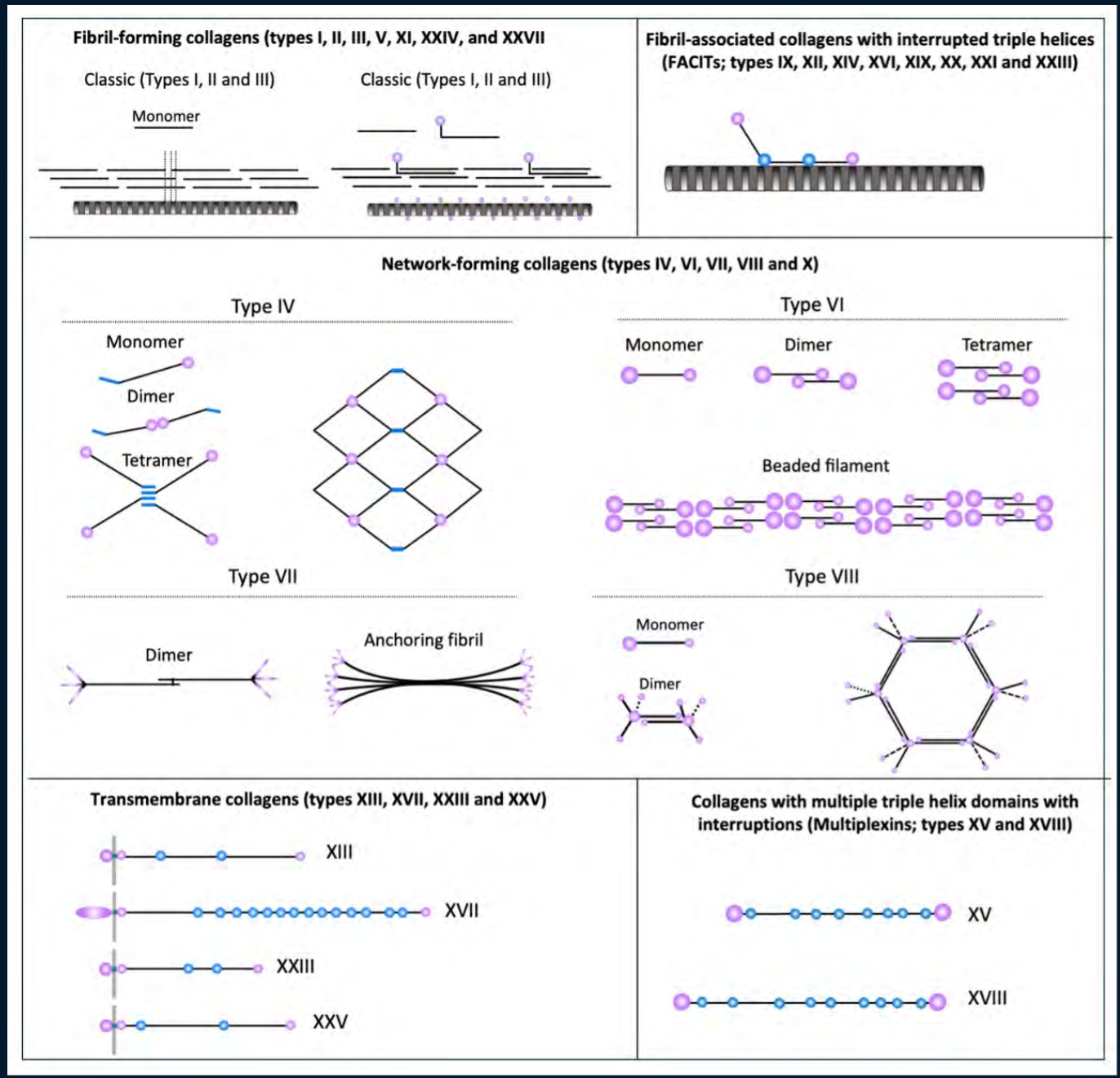


- Inefficace
- Gélatine



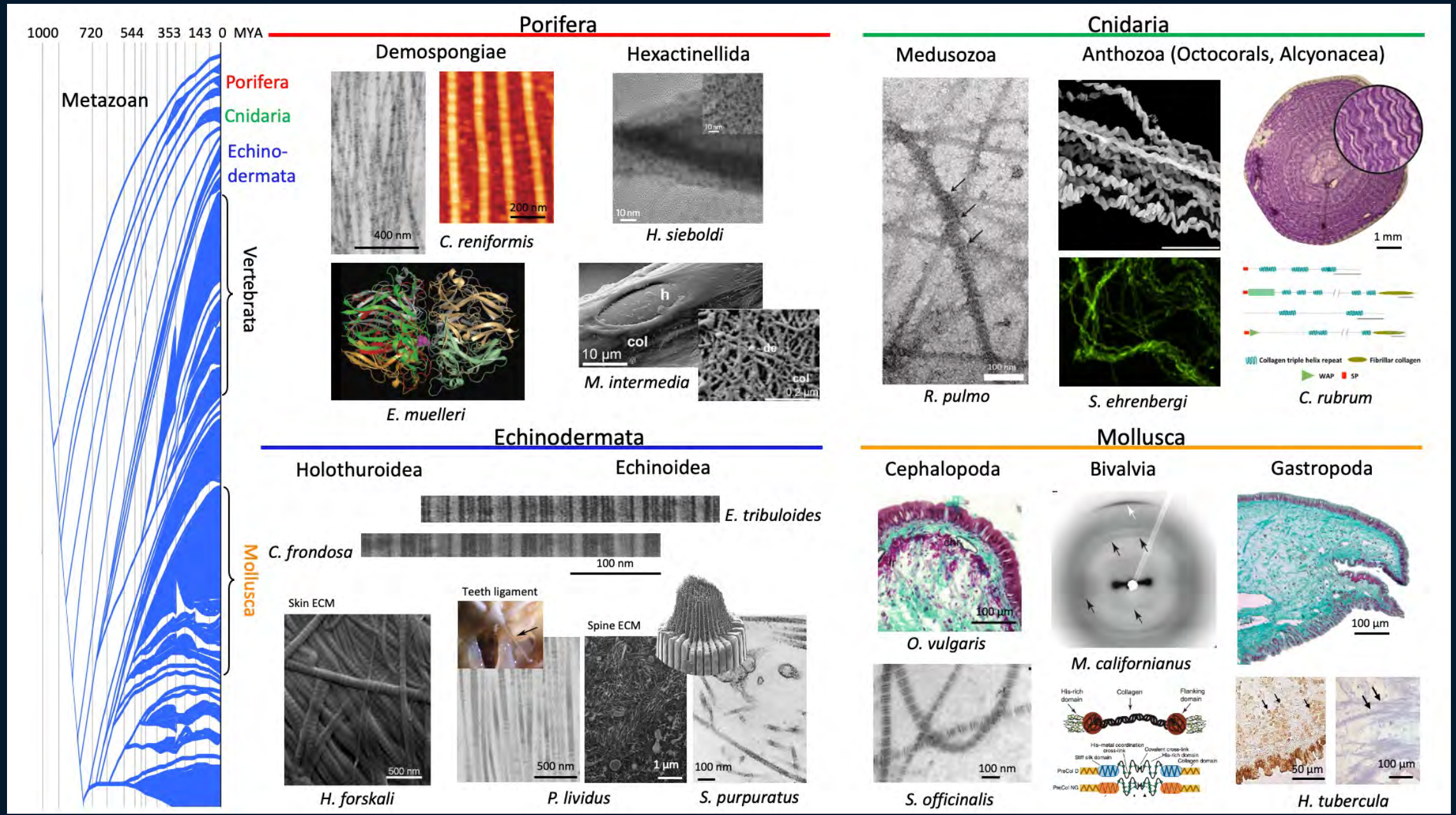
28 types

Collagen type	α-chains	α-chains assembly	Tissue distribution
Fibrillar subfamily			
Collagen I	α_1(I), α_2(I)	$[\alpha_1(I)]_2\alpha_2(I)$	Widespread: skin, bone, tendon, ligament, cornea
Collagen II	α_1(II)	$[\alpha_1(II)]_3$	Cartilage, vitreous
Collagen III	α_1(III)	$[\alpha_1(III)]_3$	Skin, vessel, intestine, uterus
Collagen V	α_1(V), α_2(V), α_3(V)	$[\alpha_1(V)]_2\alpha_2(V)$ $[\alpha_1(V)]_3$ $\alpha_1(V)\alpha_2(V)\alpha_3(V)$	Widespread: bone, skin, cornea, placenta
Collagen V/XI	α_1(V), α_2(XI), α_3(XI)	α_1(XI) α_1(V) α_1(XI) $\alpha_1(XI)\alpha_2(XI)\alpha_3(XI)$	Cartilage, intervertebral disc
Collagen XXIV	α_1(XXIV)	$[\alpha_1(XXIV)]_3$	Bone, cornea
Collagen XXVII	α_1(XXVII)	$[\alpha_1(XXVII)]_3$	Cartilage
Fibril-associated collagens with interrupted triple helices (FACIT) subfamily			
Collagen IX	α_1(IX), α_2(IX), α_3(IX)	$\alpha_1(IX)\alpha_2(IX)\alpha_3(IX)$	Cartilage, cornea, vitreous
Collagen XII	α_1(XII)	$[\alpha_1(XII)]_3$	Skin, tendon, cartilage
Collagen XIV	α_1(XIV)	$[\alpha_1(XIV)]_3$	Widespread: vessel, bone, skin, cartilage, eye, nerve, tendon, uterus
Collagen XVI	α_1(XVI)	$[\alpha_1(XVI)]_3$	Heart, kidney, smooth muscle, skin
Collagen XIX	α_1(XIX)	$[\alpha_1(XIX)]_3$	Basement membrane zone in skeletal muscle, spleen, prostate, kidney, liver, placenta, colon, skin
Collagen XX	α_1(XX)	$[\alpha_1(XX)]_3$	Corneal epithelium (chick)
Collagen XXI	α_1(XXI)	$[\alpha_1(XXI)]_3$	Vessel, heart, stomach, kidney, skeletal muscle, placenta
Collagen XXII	α_1(XXII)	$[\alpha_1(XXII)]_3$	Tissue junctions
Network forming collagens subfamily			
Collagen IV	α_1(IV), α_2(IV), α_3(IV), α_4(IV), α_5(IV), α_6(IV)	$[\alpha_1(IV)]_2\alpha_2(IV)$ $\alpha_3(IV)\alpha_4(IV)\alpha_5(IV)$ $[\alpha_5(IV)]_2\alpha_6(IV)$	Basement membrane
Collagen VI	α_1(VI), α_2(VI), α_3(VI), α_4(VI), α_5(VI), α_6(VI)	$\alpha_3(VI)\alpha_2(VI)\alpha_3(VI)$ $\alpha_3(VI)\alpha_2(VI)\ \alpha_5(VI)$ $\alpha_3(VI)\alpha_2(VI)\ \alpha_6(VI)$	Widespread: bone, cartilage, cornea, skin, vessel
Collagen VII	α_1(VII)	$[\alpha_1(VII)]_3$	Skin, bladder, oral mucosa, umbilical cord, amnion
Collagen VIII	α_1(VIII), α_2(VIII)	$[\alpha_1(VIII)]_3$ $[\alpha_2(VIII)]_3$ $[\alpha_1(VIII)]_2\alpha_2(VIII)$ $\alpha_1(VIII)[\alpha_2(VIII)]_2$	Widespread: Descemet's membrane, vessel, bone, brain, heart, kidney, skin, cartilage
Collagen X	α_1(X)	$[\alpha_1(X)]_3$	Hypertrophic cartilage
Transmembrane collagens or MACIT for Membrane-Associated Collagens with Interrupted Triple helices			
Collagen XIII	α_1(XIII)	$[\alpha_1(XIII)]_3$	Endothelial cells, skin, eye, heart, skeletal muscle
Collagen XVII	α_1(XVII)	$[\alpha_1(XVII)]_3$	Hemidesmosomes in epithelia
Collagen XXIII	α_1(XXIII)	$[\alpha_1(XXIII)]_3$	Heart, retina, metastatic cancer cells
Collagen XXV	α_1(XXV)	$[\alpha_1(XXV)]_3$	Brain, heart, testis, eye
Multiplexins			
Collagen XV	α_1(XV)	$[\alpha_1(XV)]_3$	Capillaries, skin placenta, kidney, heart, ovary, testis
Collagen XVIII	α_1(XVIII)	$[\alpha_1(XVIII)]_3$	Perivascular basement membrane, kidney, liver, lung
Others			
Collagen XXVI	α_1(XXVI)	$[\alpha_1(XXVI)]_3$	Testis, ovary
Collagen XXVIII	α_1(XXVIII)	$[\alpha_1(XXVIII)]_3$	Cartilage



Boook chapter « collagen as structural matrix » (2025 in press)

Collagène marin ?

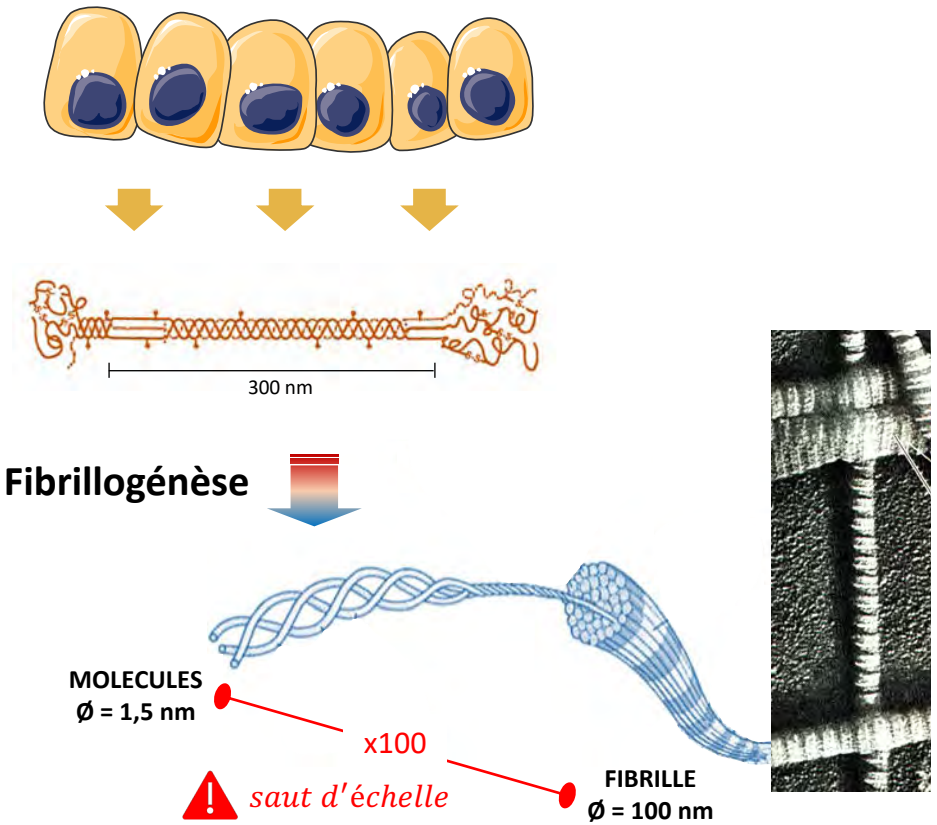


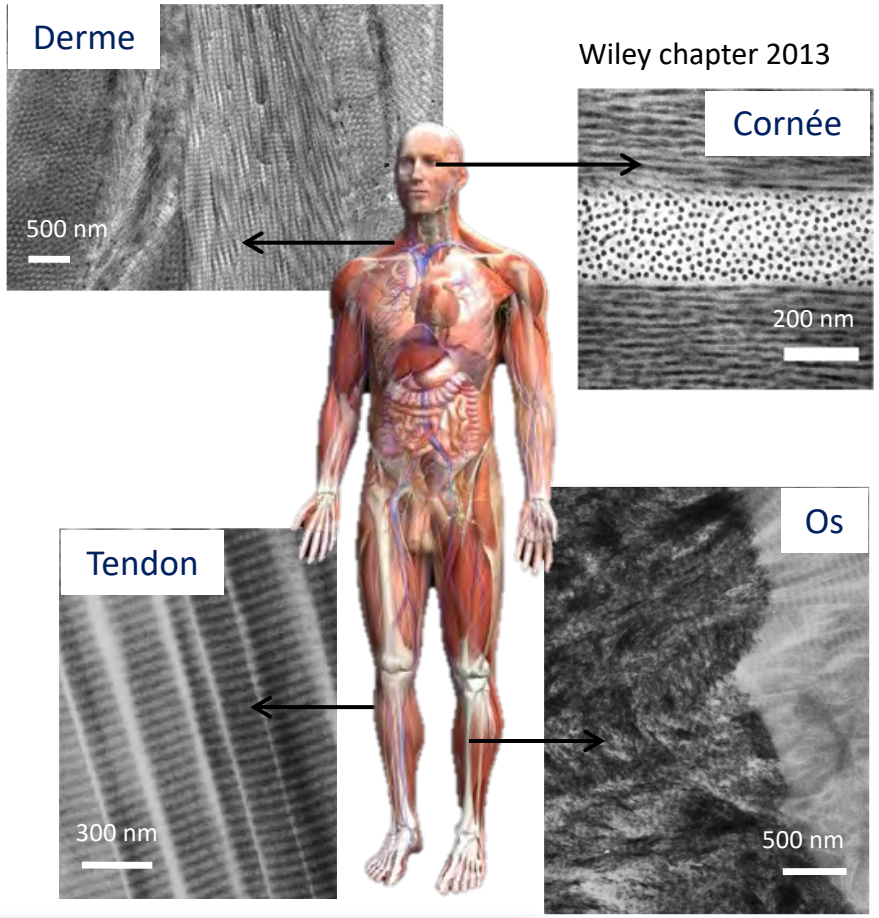
Boook chapter « collagen as structural matrix » (2025 in press)

Collagène Marin ? Animal ?

Collagène animal

❖ **3 états** identifiés du **collagène de Type I** dans les **tissus biologiques** :

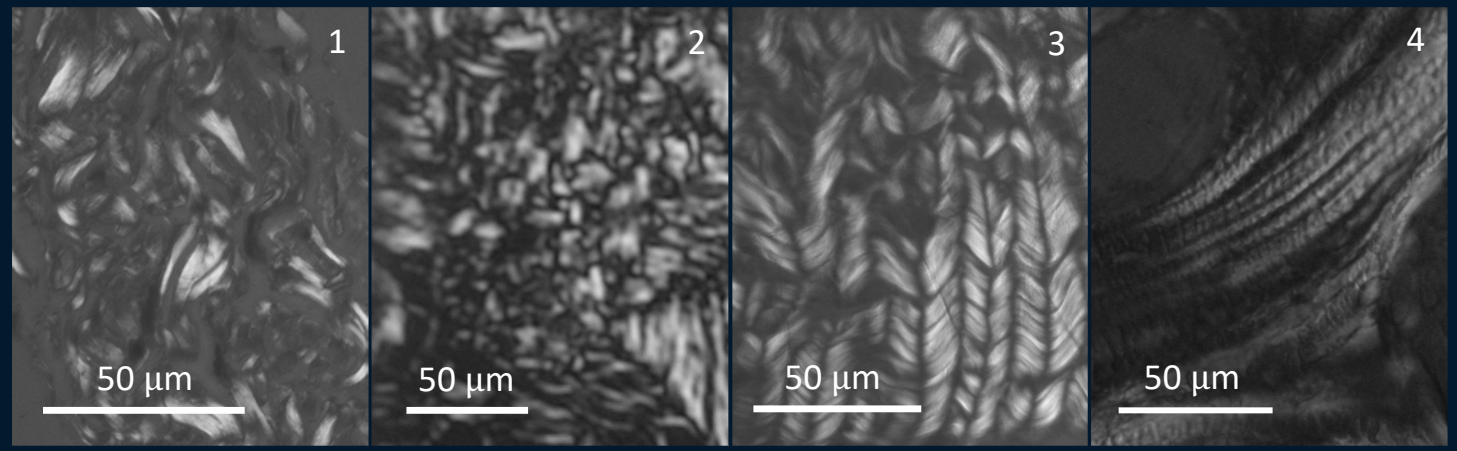


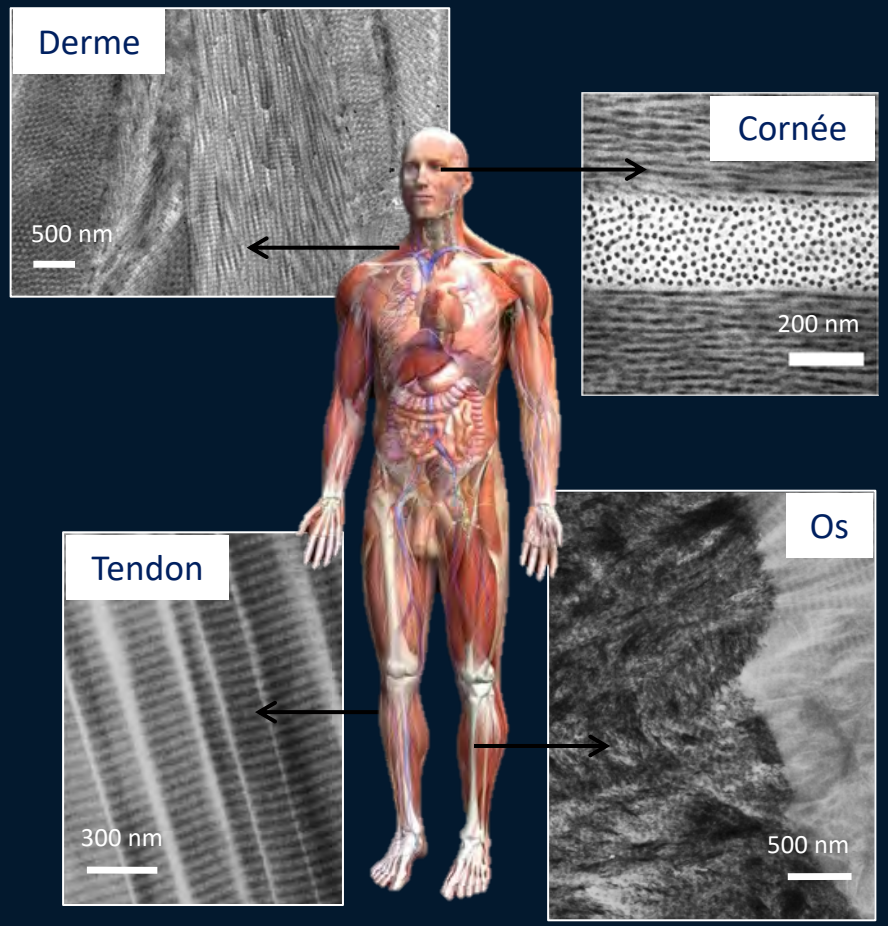


Molécule → Fibrille → Suprafibrillaire 3D (MEC)

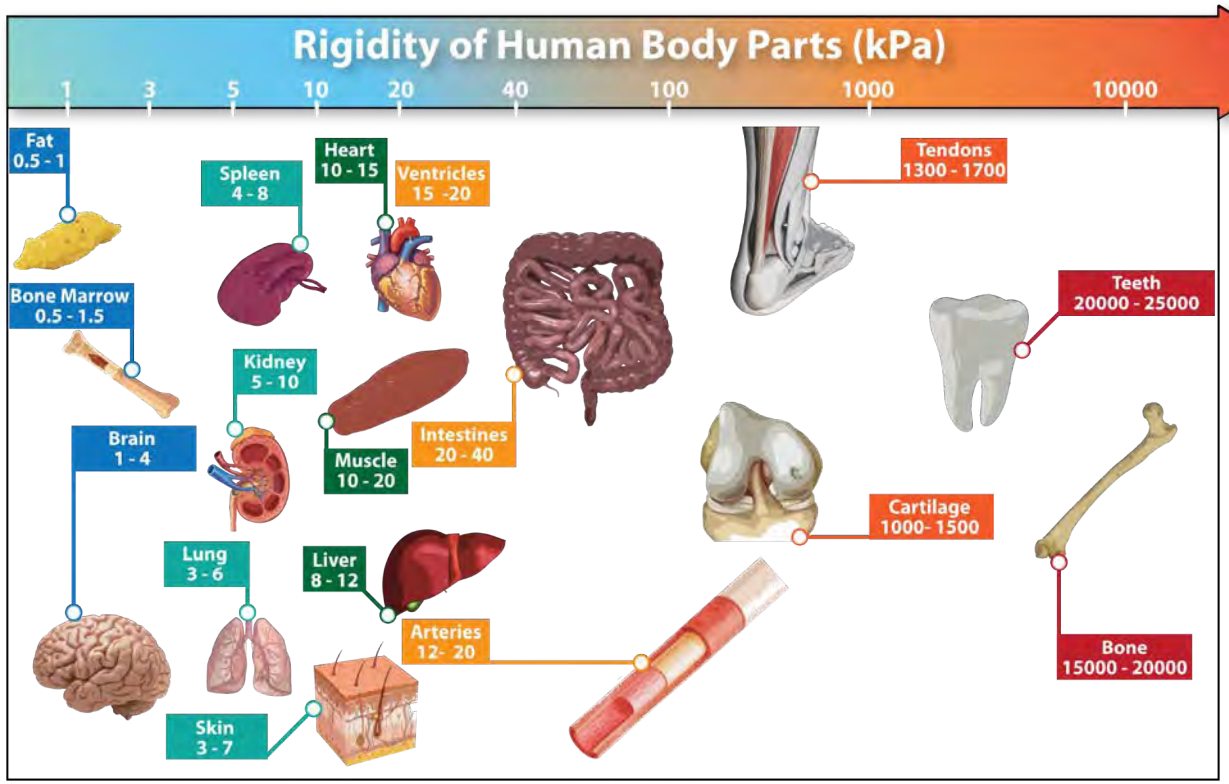
Une organisation caractéristique à chaque tissu

Microscopie optique à lumière polarisée





Des propriétés caractéristiques à chaque tissu



Mécanique

Optique

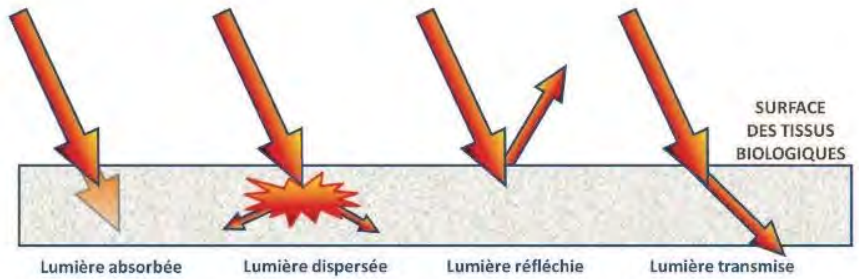
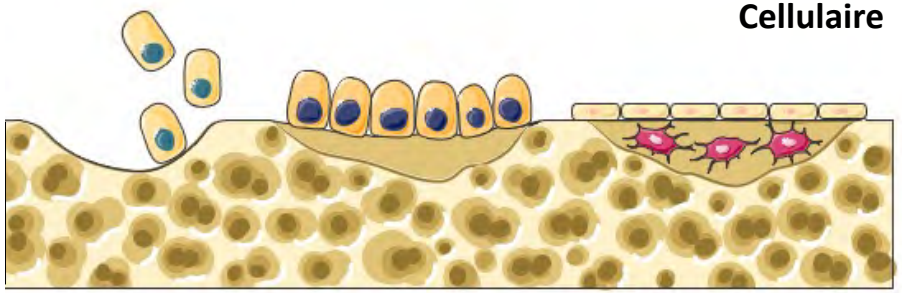
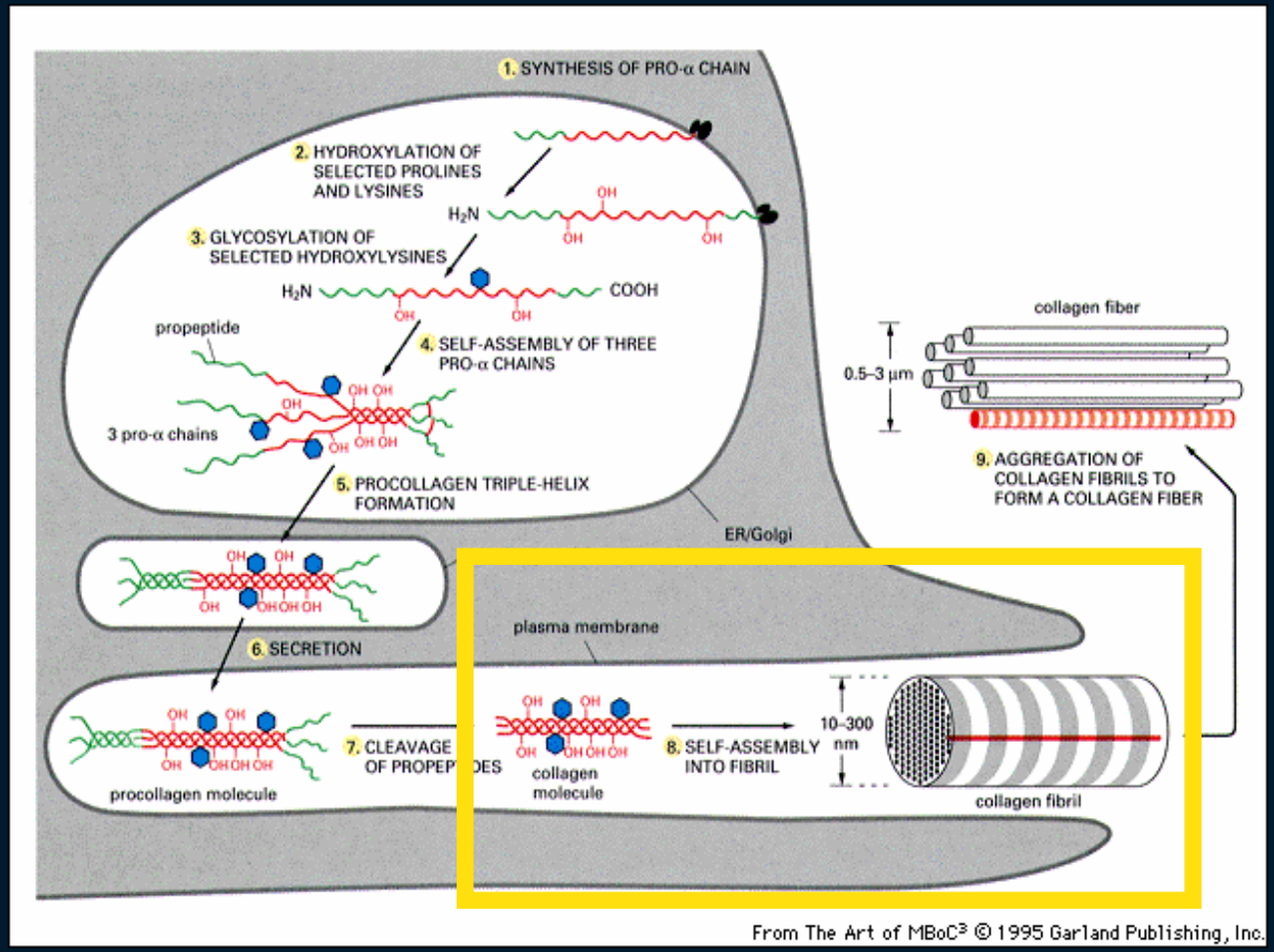


Figure 2. Phénomènes d'absorption, de dispersion, de réflexion, et de transmission de la lumière dans les tissus biologiques. Source: Mandrick, K., *Near-infrared Spectroscopy application for discriminating the mental workload in humans*, 2013, Université Montpellier I.

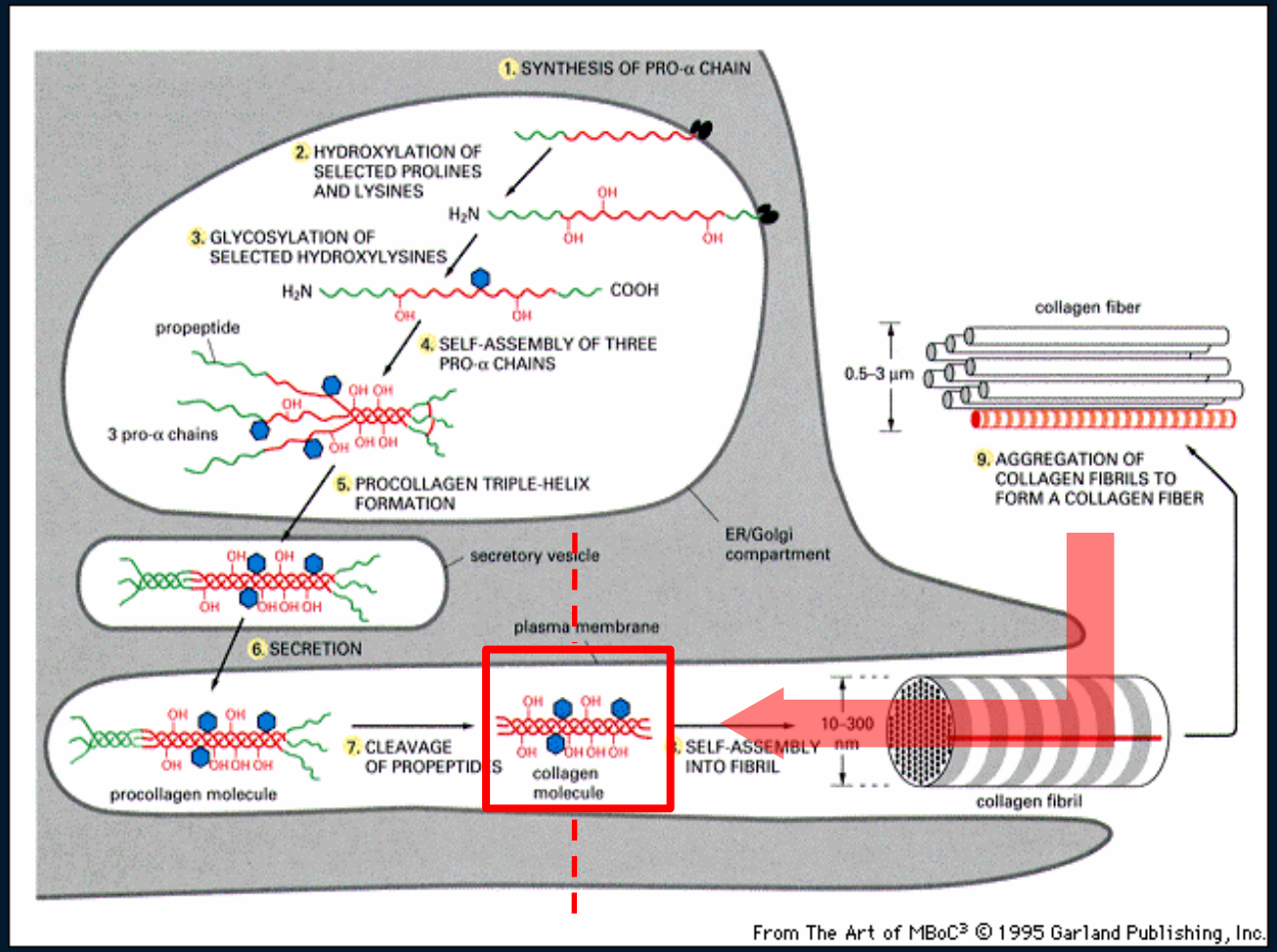
Cellulaire



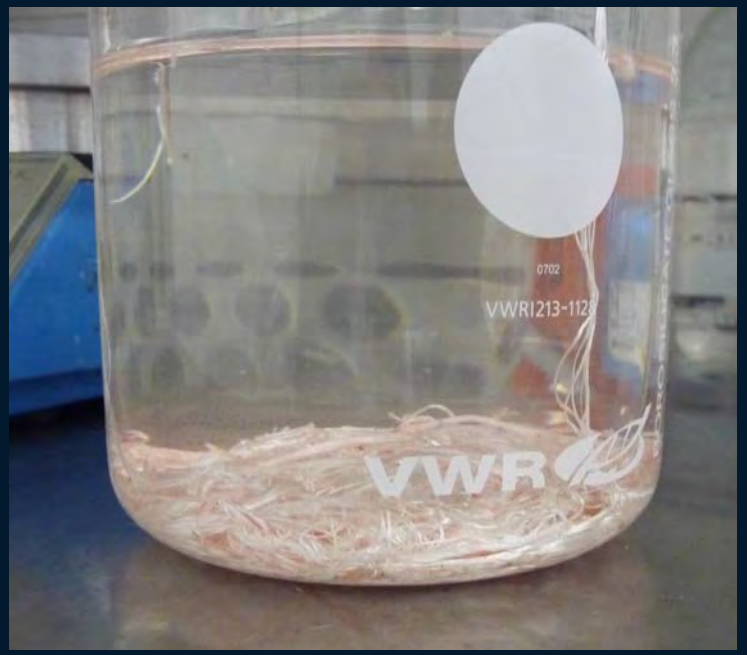
In vivo…


1. SYNTHESIS OF PRO-α CHAIN
2. HYDROXYLATION OF SELECTED PROLINES AND LYSINES
3. GLYCOSYLATION OF SELECTED HYDROXYLYSINES
propeptide
4. SELF-ASSEMBLY OF THREE PRO-α CHAINS
3 pro-α chains
5. PROCOLLAGEN TRIPLE-HELIX FORMATION
ER/Golgi
6. SECRETION
plasma membrane
procollagen molecule
7. CLEAVAGE OF PROPEP DES
collagen molecule
8. SELF-ASSEMBLY INTO FIBRIL
10–300 nm
collagen fibril
collagen fiber
0.5–3 μm
9. AGGREGATION OF COLLAGEN FIBRILS TO FORM A COLLAGEN FIBER
From The Art of MBoC³ © 1995 Garland Publishing, Inc.

In vitro…


1. SYNTHESIS OF PRO-α CHAIN
2. HYDROXYLATION OF SELECTED PROLINES AND LYSINES
3. GLYCOSYLATION OF SELECTED HYDROXYLYSINES
4. SELF-ASSEMBLY OF THREE PRO-α CHAINS
5. PROCOLLAGEN TRIPLE-HELIX FORMATION
6. SECRETION
7. CLEAVAGE OF PROPEPTIDES
8. SELF-ASSEMBLY INTO FIBRIL
9. AGGREGATION OF COLLAGEN FIBRILS TO FORM A COLLAGEN FIBER
propeptide
3 pro-α chains
secretory vesicle
ER/Golgi compartment
plasma membrane
procollagen molecule
collagen molecule
collagen fibril
collagen fiber
0.5–3 μm
10–300 nm
From The Art of MBoC³ © 1995 Garland Publishing, Inc.

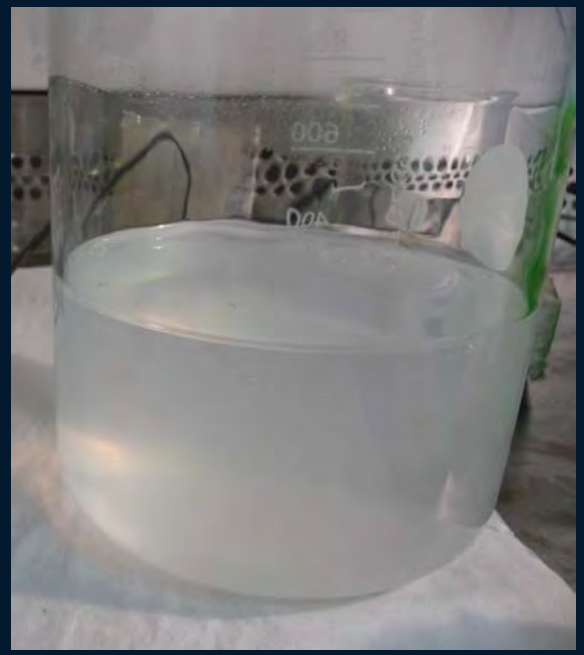
In vitro au laboratoire…



Tendon de queues de rats

Dissolution
Purification

2-3 semaines!

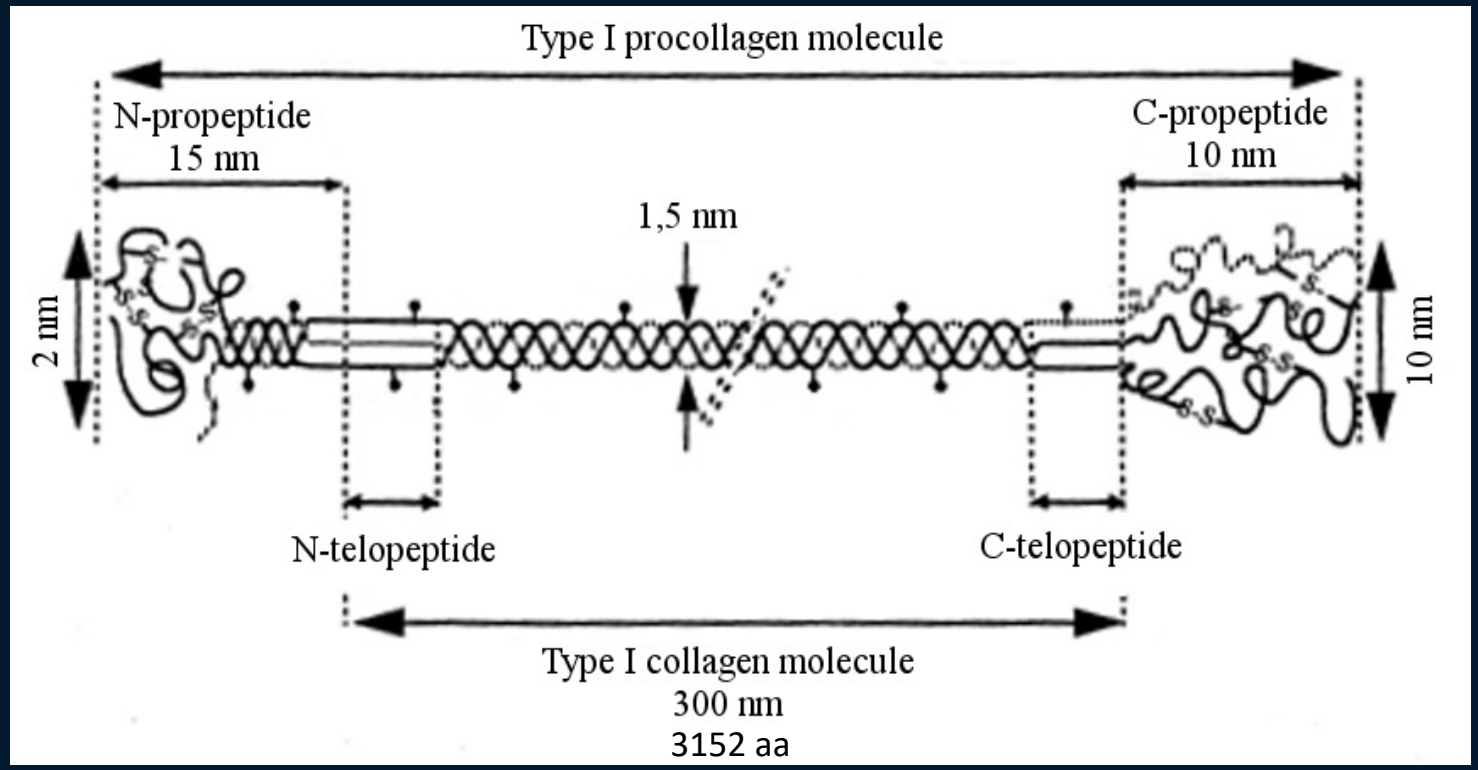


Solution de collagène acide
(concentration < 5mg/mL)

In vitro dans l'industrie…

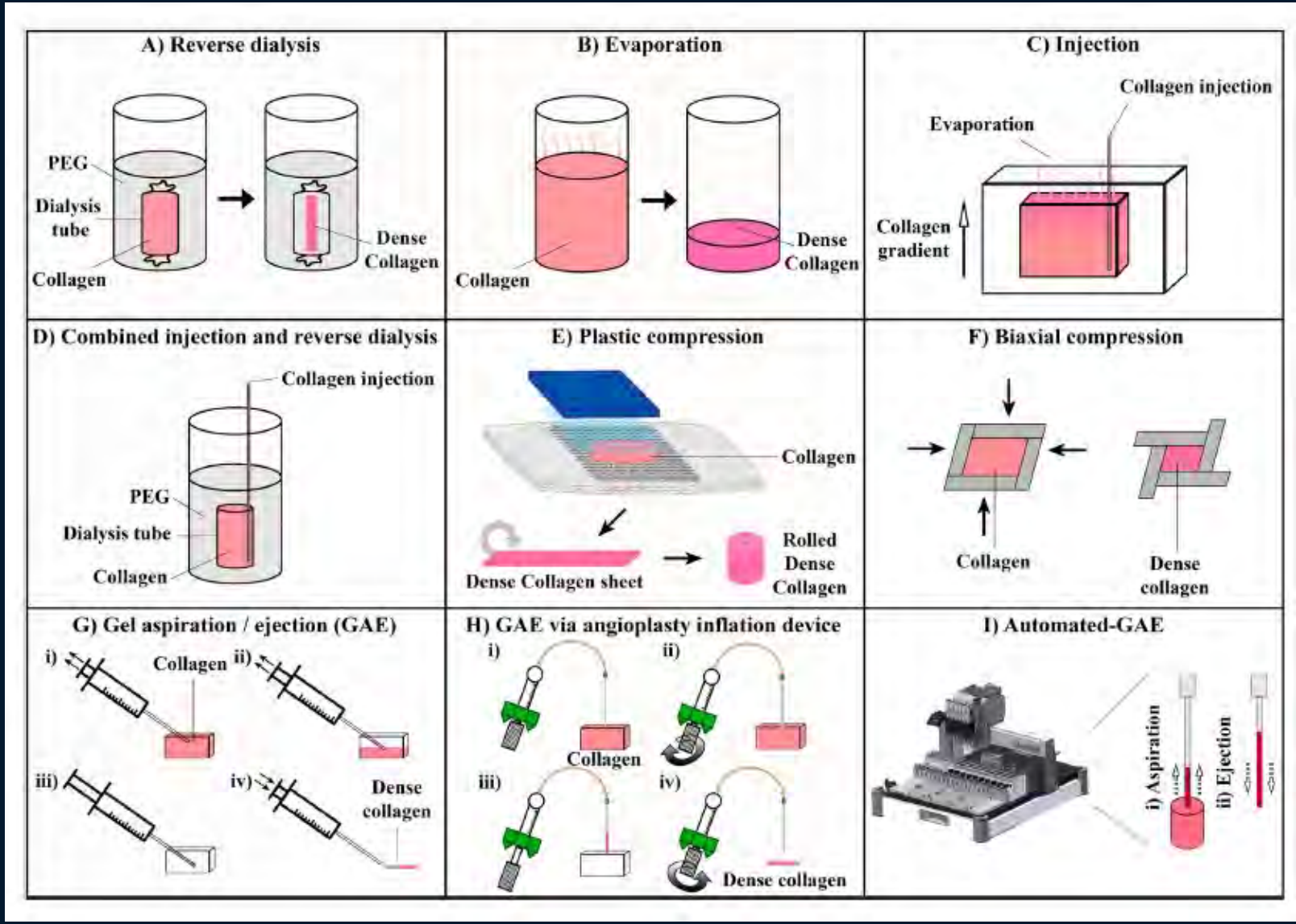
Exemple de machine pour le tannage (Splitting machine)

Pour quelle molécule ?



Structure de la molécule de procollagène de type I (Figure adaptée de Olsen, 1991 et Hulmes 1989)

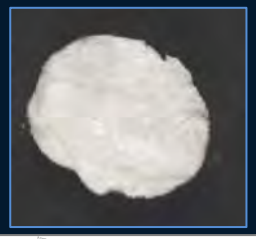
Pour quelle procédure ?

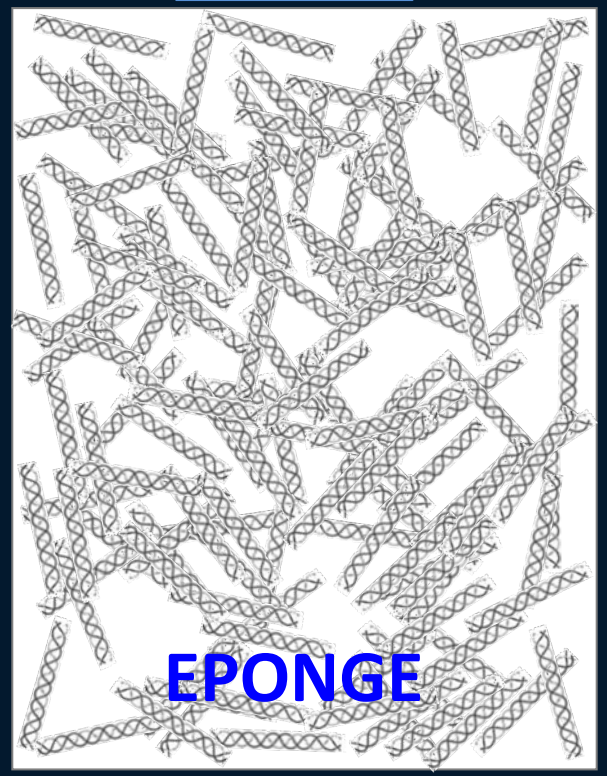


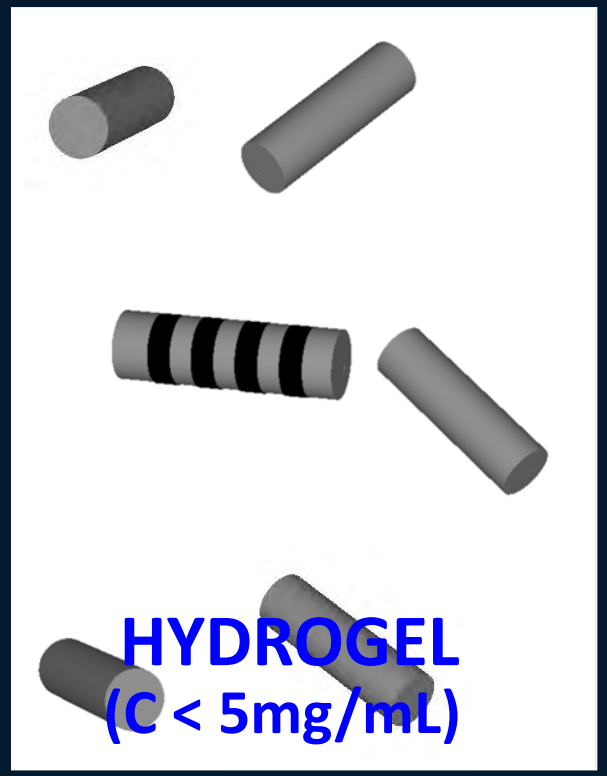
G.Griffanti & S.N. Nazhat (2020) *Int.Mater. Rev.*

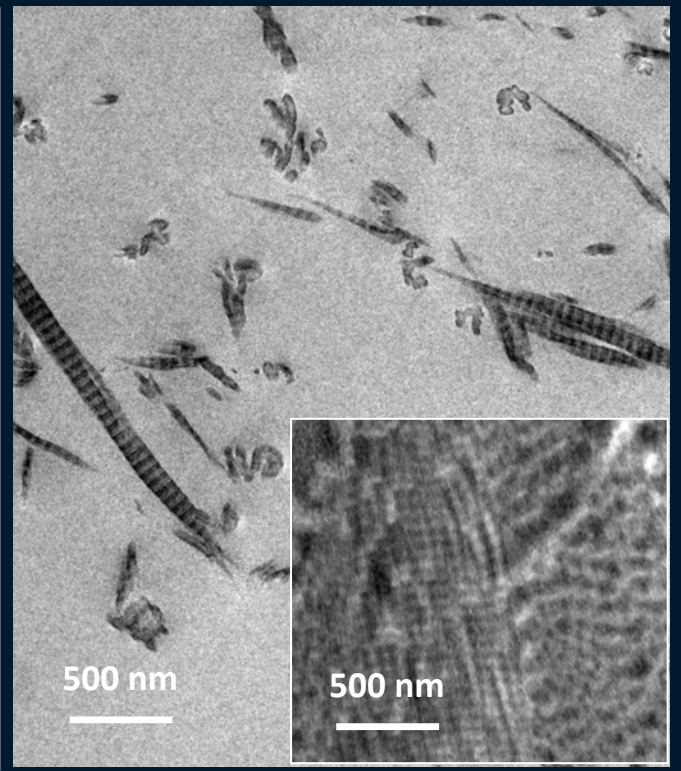
Pour quel résultat ?

Collagen de type I = Variété de matrices *in vitro*









MM Giraud-Guille, et al, in « Materials design inspired by Nature: Function through inner architecture », RSC (Eds. P. Fratzl, JWC Dunlop , R Weinkamer, 2013)

La densité et l'organisation 3D du tissu n'est pas reproduite

Donc importance fondamentale des procédures de mise en forme !

Une striation caractéristique

(1) Nature de la molécule et conditions physico-chimiques

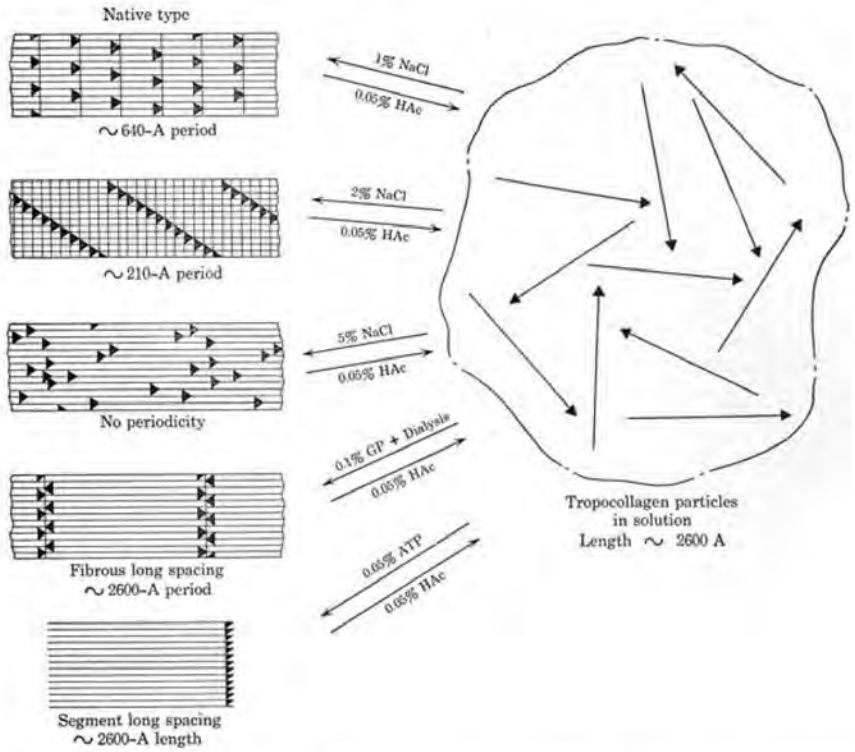
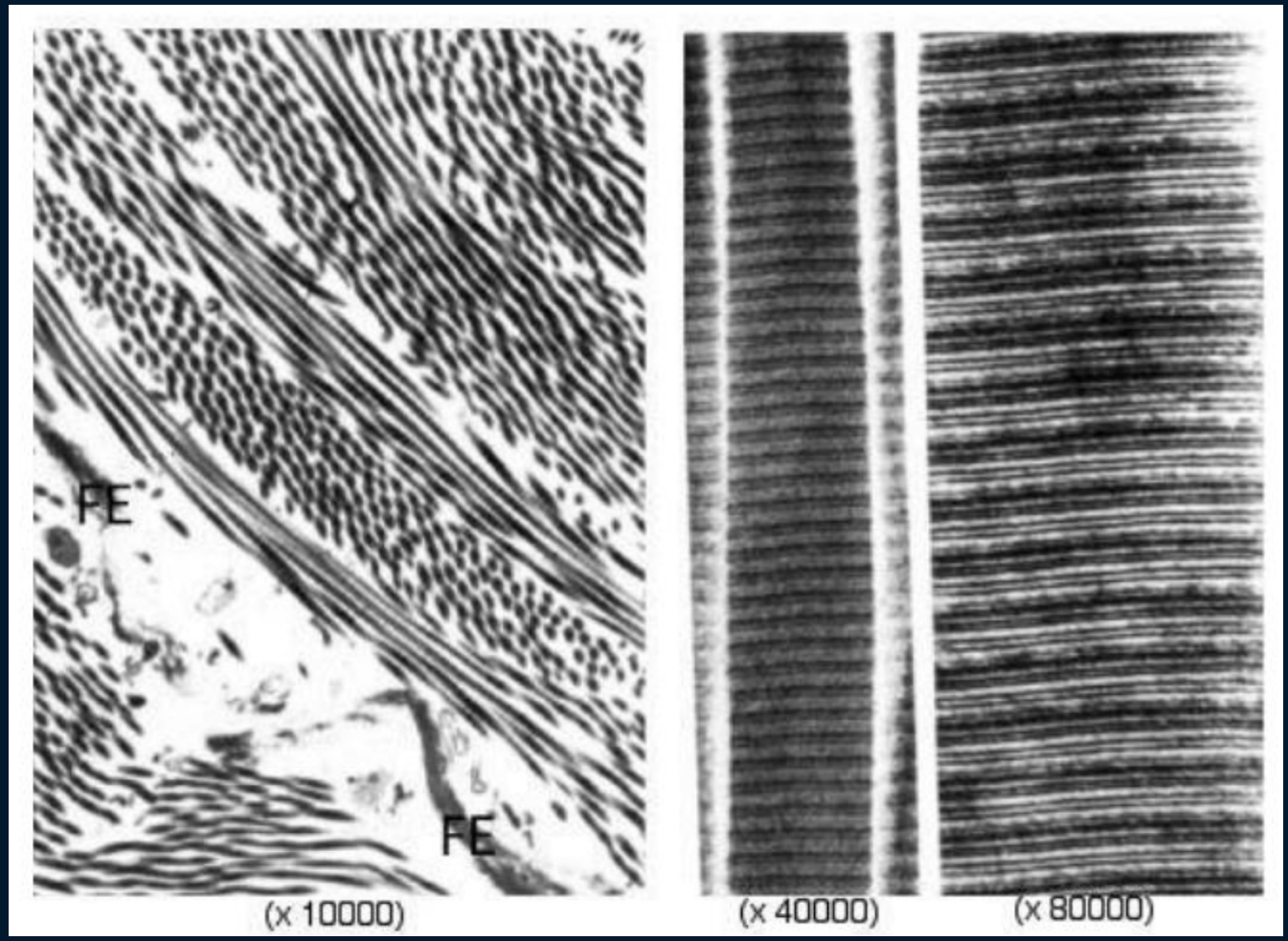


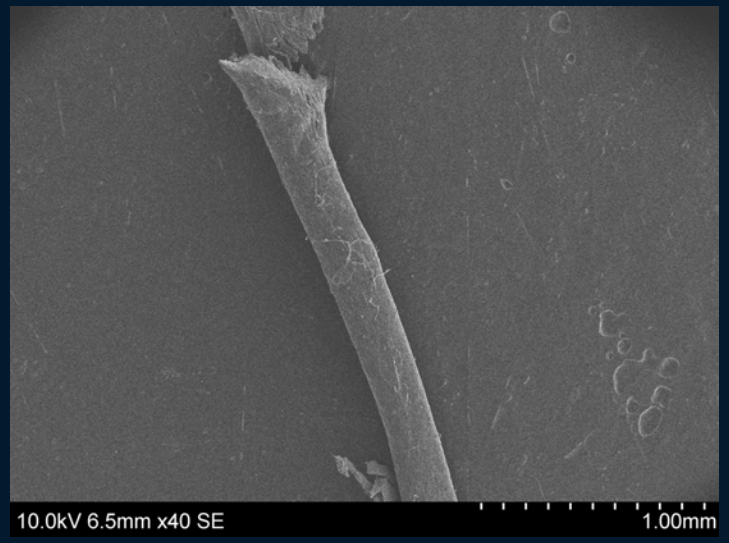
Figure 11. Schematic diagram showing different modes of aggregation of collagen molecules in a collagen fibril prepared *in vitro* under various solution conditions. Each collagen fibril form represents a different state of aggregation of the same collagen molecules (from Schmitt et al. 1955). The arrow-head and -tail, respectively, represent the N- and C-terminal end of the collagen molecule. Each of the separate collagen fibrils represents a different 3D packing of the same collagen molecules. [Reprinted with permission from Glimcher (1960). Copyright AAAS.]

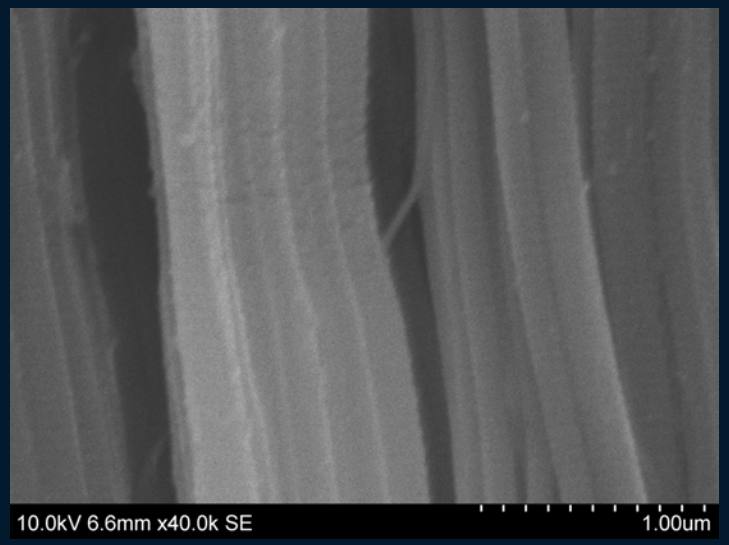


L'organisation à **l'échelle fibrillaire** n'est pas reproduite

Une striation caractéristique

(2) Eau et Minéralisation





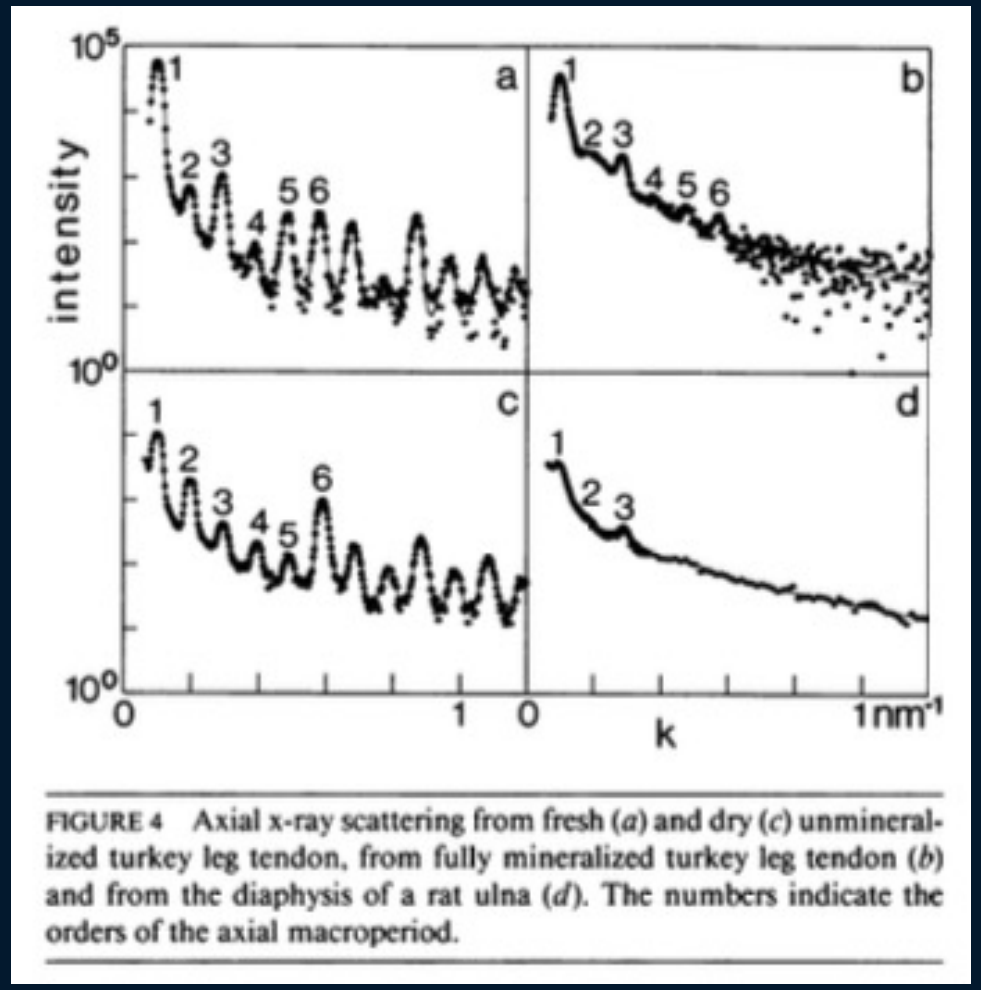
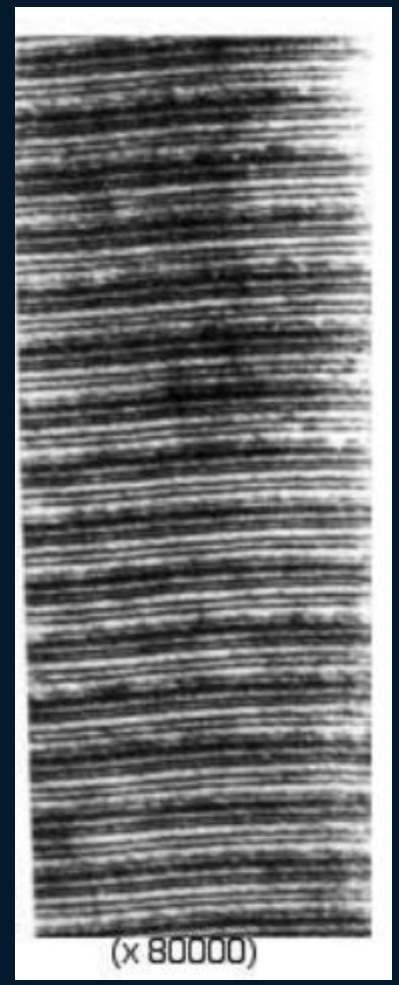


FIGURE 4 Axial x-ray scattering from fresh (*a*) and dry (*c*) unmineralized turkey leg tendon, from fully mineralized turkey leg tendon (*b*) and from the diaphysis of a rat ulna (*d*). The numbers indicate the orders of the axial macroperiod.

SAXS

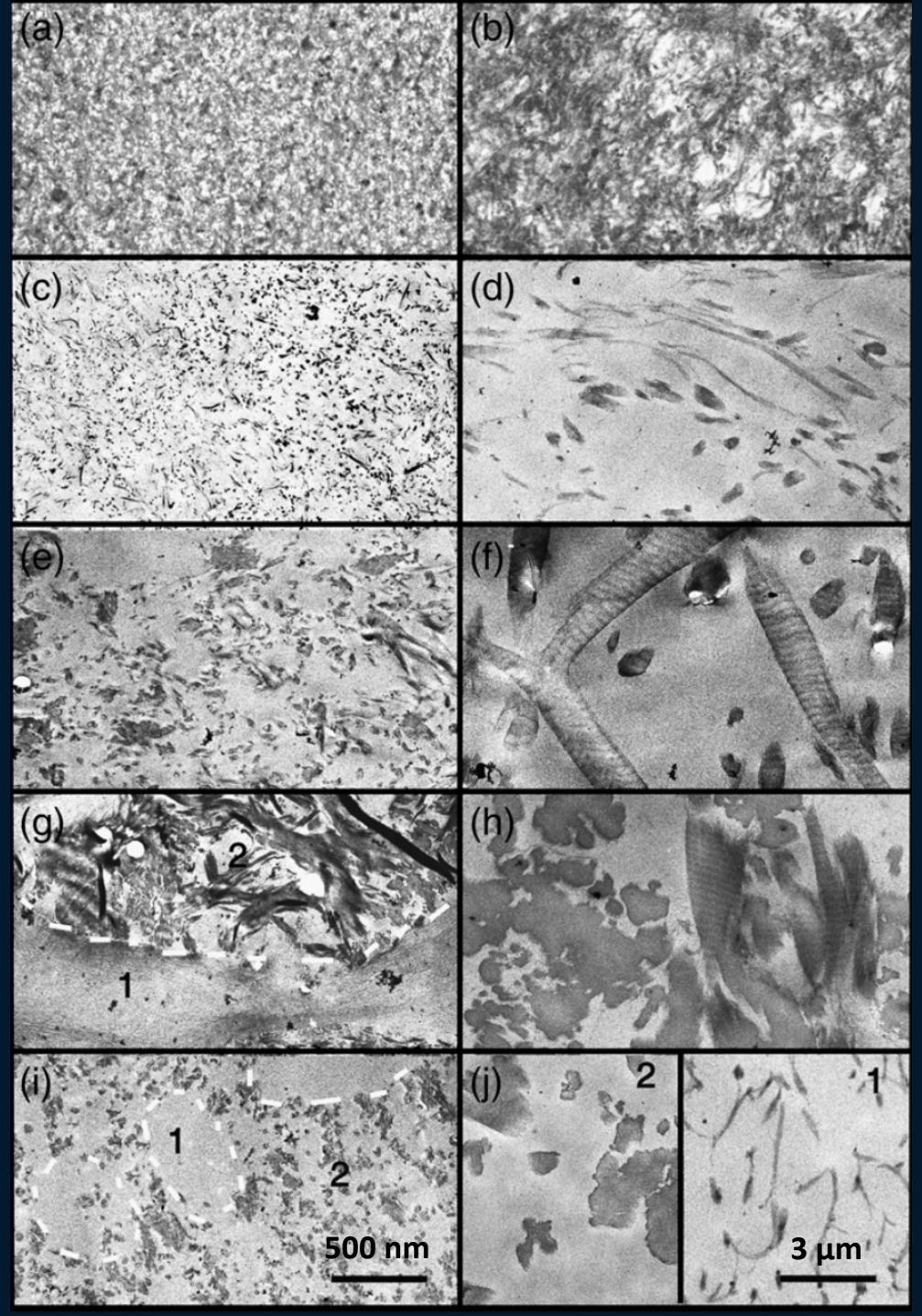


Fratzl, *et al. Biophys. J.* (1993)

Taille des fibrilles

(1) Force ionique et concentration

Gobeaux, *et al. J. Mol. Biol.* (2008)



Sections ultrafines en MET de gels de collagène de type I à 100 mg/ml à différentes forces ioniques :
(a and b) I = 24 mM
(c and d) I = 124 mM
(e and f) I = 261 mM
(g and h) I = 529 mM
(i and j) I = 1300 mM

Table 1. Sums up the fibrils size dependence upon concentration

Concentration (mg/ml)	Regime	Fibril width	Trend	References
<5	I	Micrometers	↗	44–46
10–80	II	20⇒80 nm	↘	20,49
90–150	III	Micrometers	↗	19 and present article
200–300	IV	~100 nm	↘	19 and present article

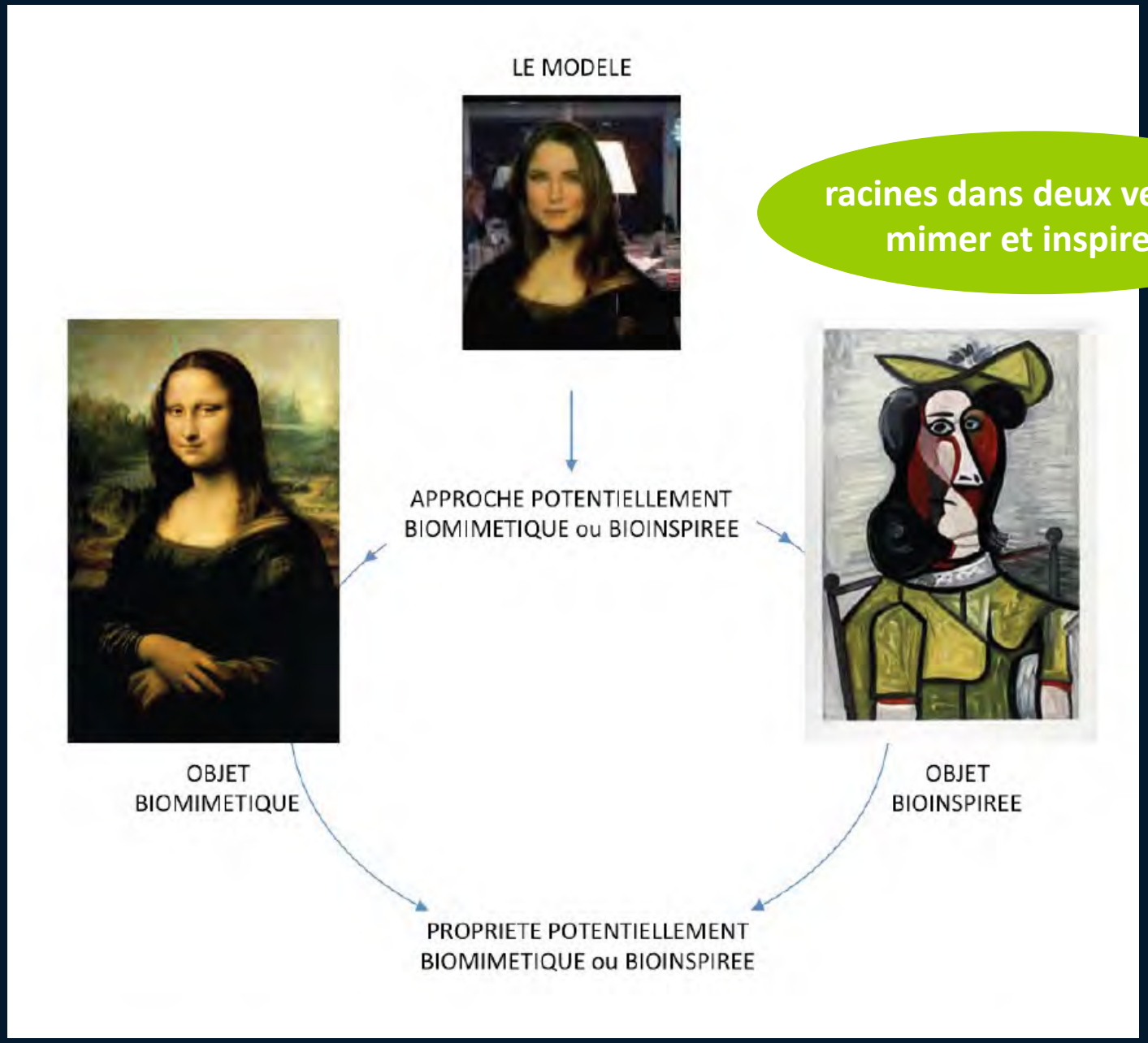
➡ Mais également **nature des ions**

En bref, c’est compliqué !

Il faut donc bien lire le « Matériel et Méthodes »...

Alors comment fait-on pour être biomimétique ?

Biomimetisme & Bioinspiration

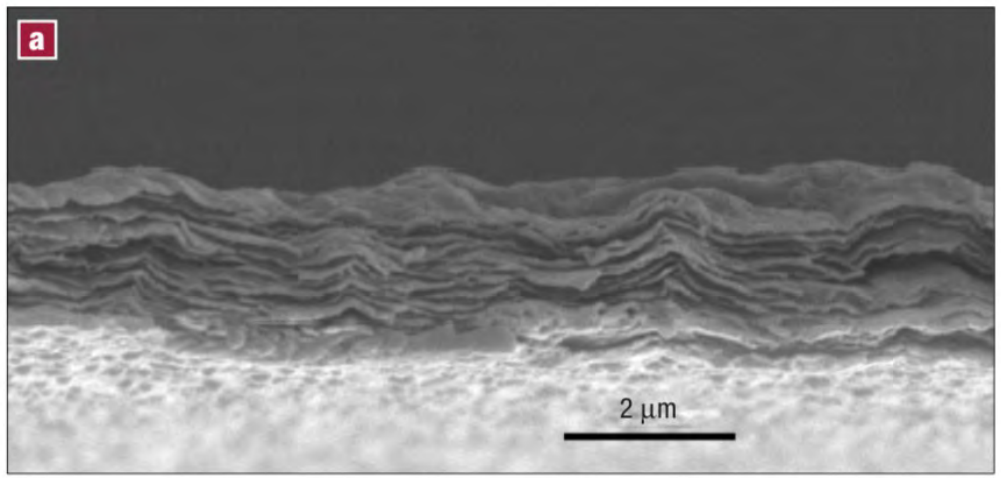


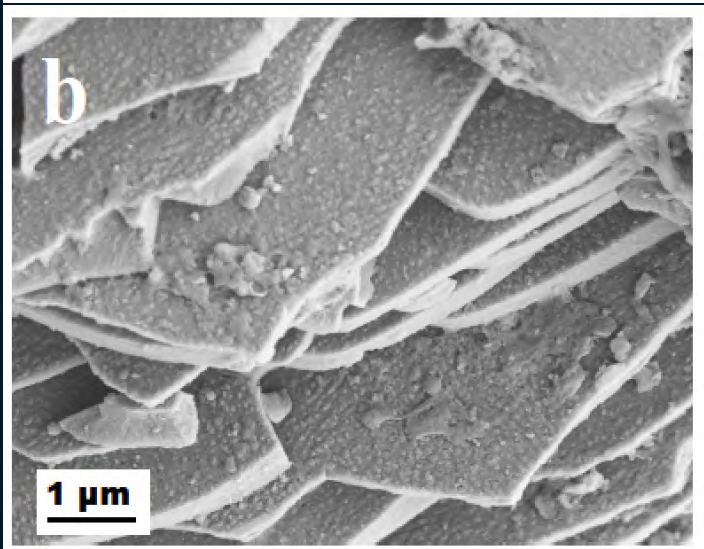
racines dans deux verbes : mimer et inspirer !

inspiré de la thèse de Clémentine Gautier-Martin (2007)

Nanostructured artificial nacre

ZHIYONG TANG[1], NICHOLAS A. KOTOV*[1], SERGEI MAGONOV[2] AND BIROL OZTURK[1]
[1]Department of Chemistry, Oklahoma State University, Stillwater, Oklahoma 74078, USA
[2]Digital Instruments/Veeco, 112 Robin Hill Road Santa Barbara, California 9311, USA
*e-mail: kotov@okstate.edu





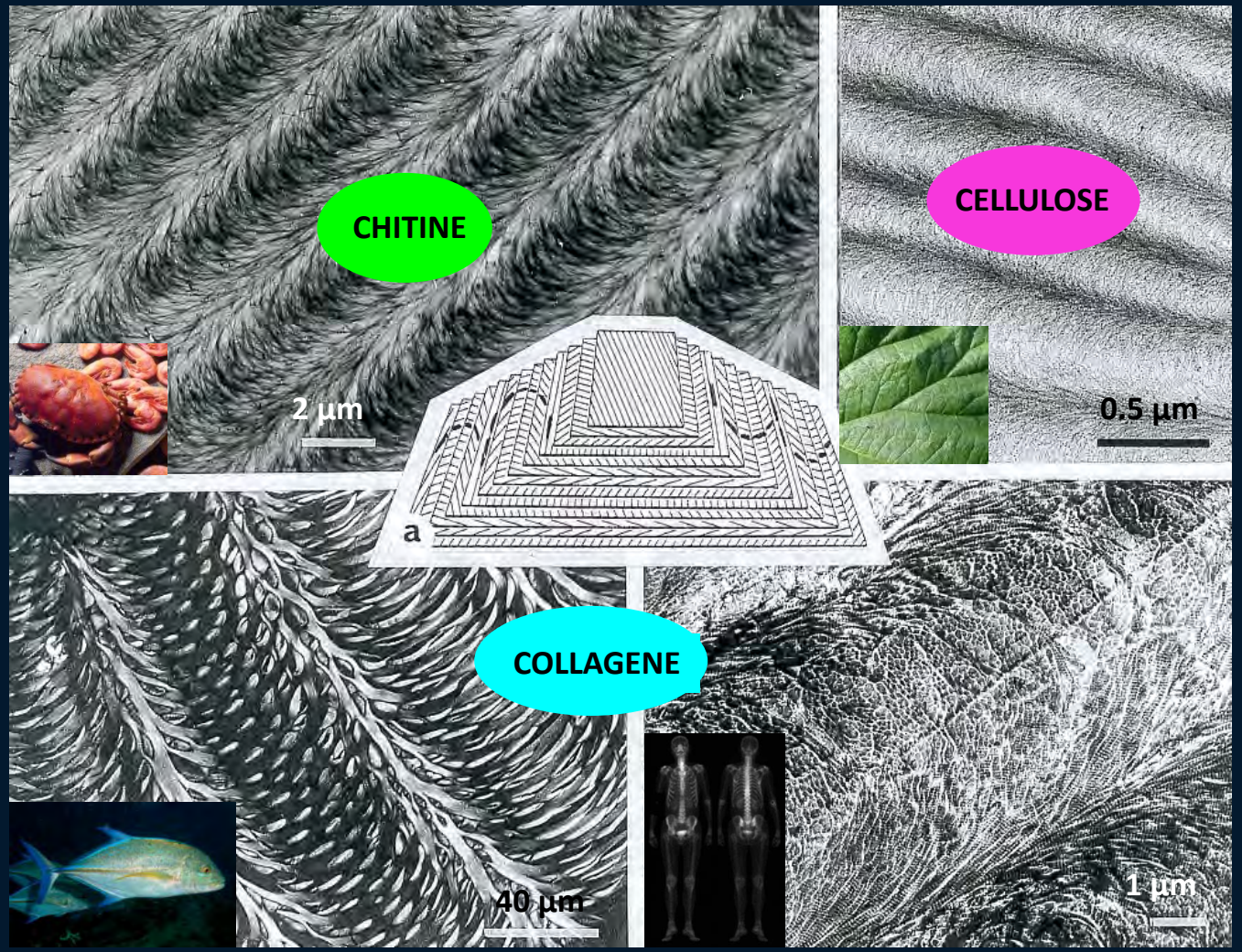
Bioinspiration

Biomimetisme

folded macromolecules is equally important. Here, we demonstrate that both structural features can be reproduced by sequential deposition of polyelectrolytes and clays. This simple process results in a nanoscale version of nacre with alternating organic and inorganic layers. The macromolecular folding effect reveals itself in the unique saw-tooth pattern of differential stretching curves attributed to the gradual breakage of ionic crosslinks in polyelectrolyte chains. The tensile strength of the prepared multilayers approached that of nacre, whereas their ultimate Young modulus was similar to that of lamellar bones. Structural and functional resemblance makes clay–

Analogues biologiques des cristaux-liquides

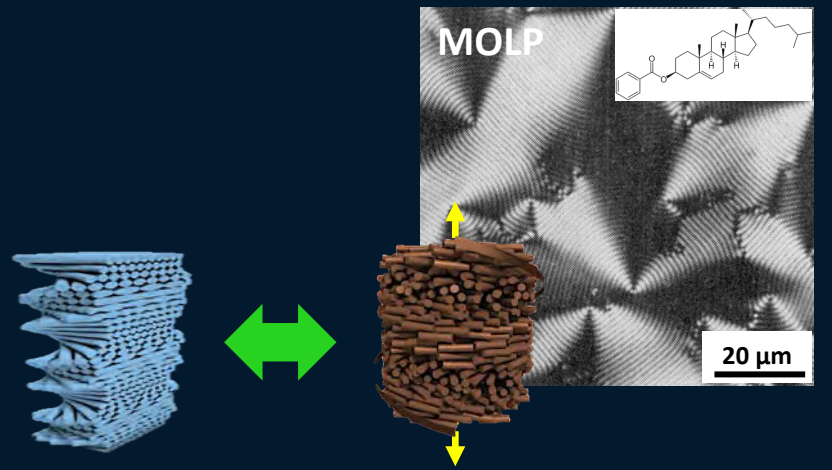
MET (coupes ultrafines)



M.M. Giraud-Guille, Curr. Opin. Solid State Mater. Sci. (1998)

Yves Bouligand
(1935-2011)

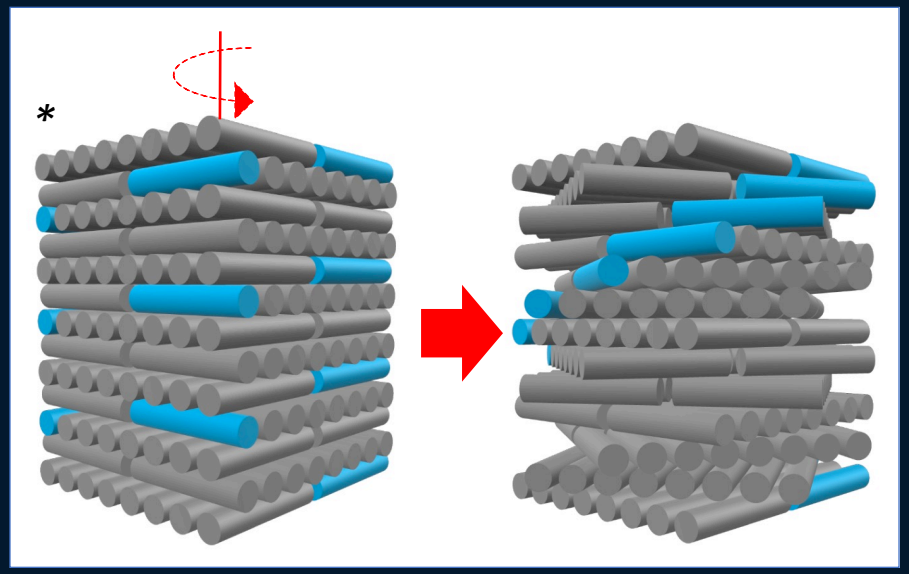
CL cholestérique

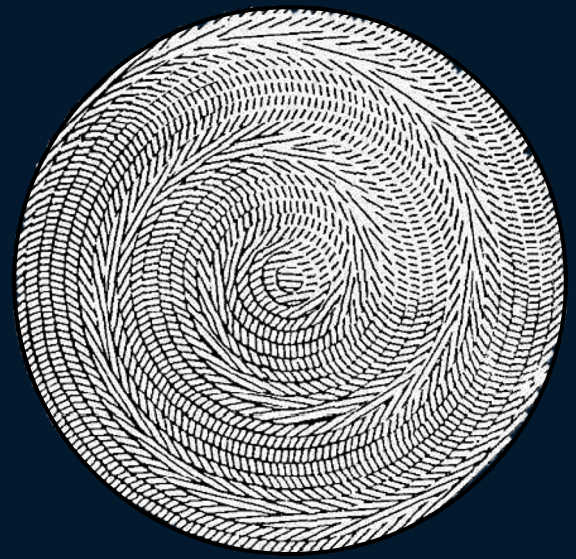


⚠ Géométrie *versus* Etat de la matière

« Modèle du contre-plaque torsadé/hélcoïdal = « twisted plywood »

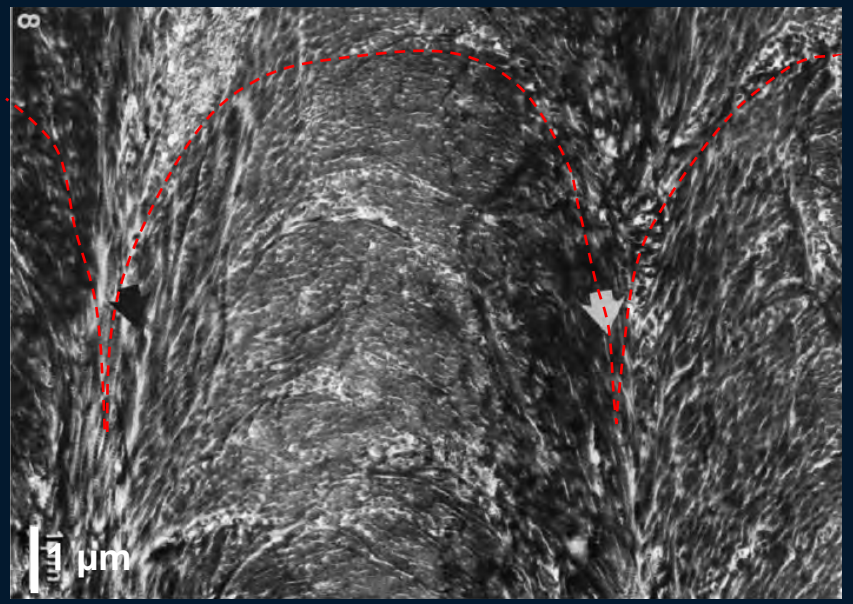
aussi Bouligand structure



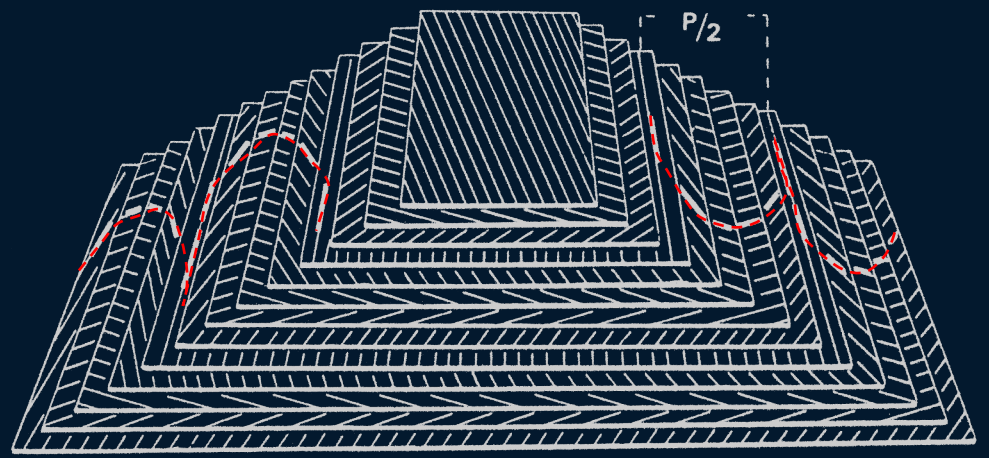


Y. Bouligand, J. Phys. Colloq. (1969)

MET (coupes ultrafines)

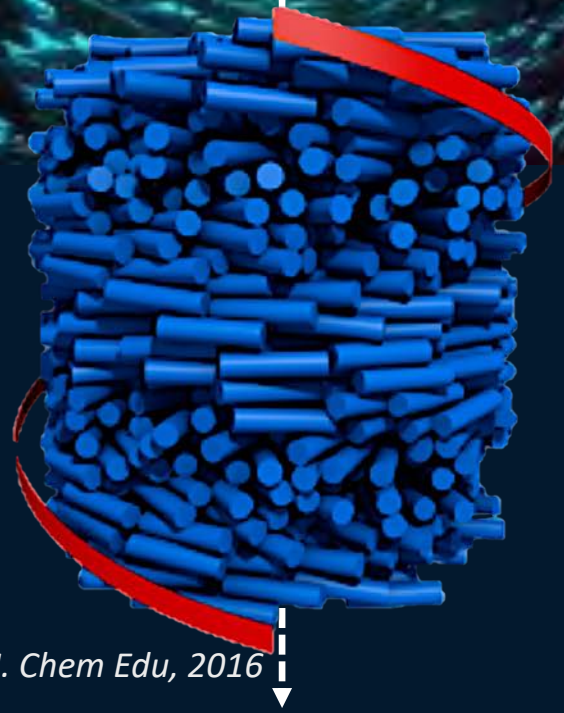


M.M. Giraud-Guille, Microsc. Res. Tech. (1994)



L. Besseau et M.M. Giraud-Guille, J. Mol. Biol. (1995)

Cholesteric axis



Cholesteric axis

Popova *et al., J. Chem Edu, 2016*

Collagène de type I : un cristal-liquide lyotrope

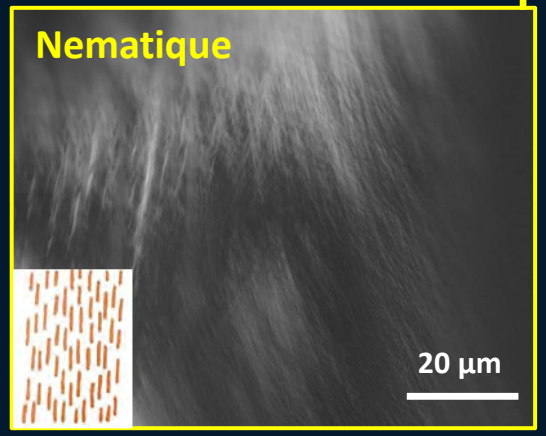
N.S. Murthy, Biopolymers (1984)

M.M. Giraud-Guille

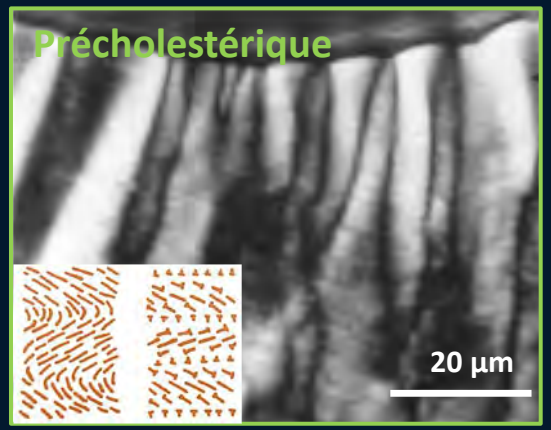
– Isotrope ≲ 40 mg/mL ≲ 75 mg/mL +

concentration

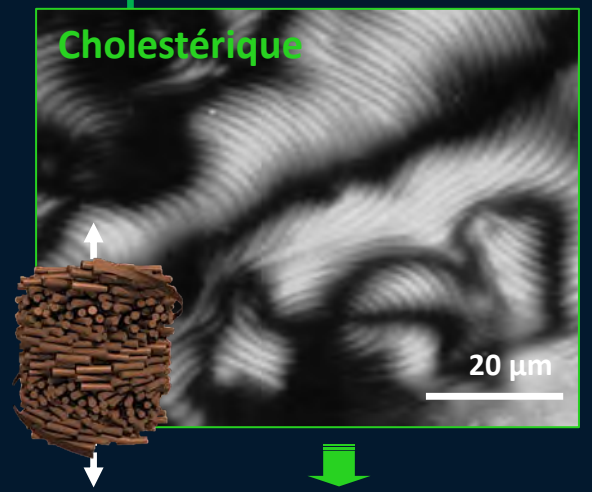
Nematique



Précholestérique



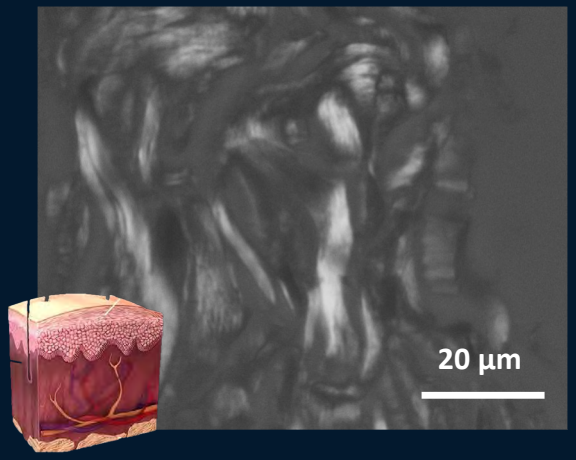
Cholestérique



Microscope à lumière polarisée

P

A



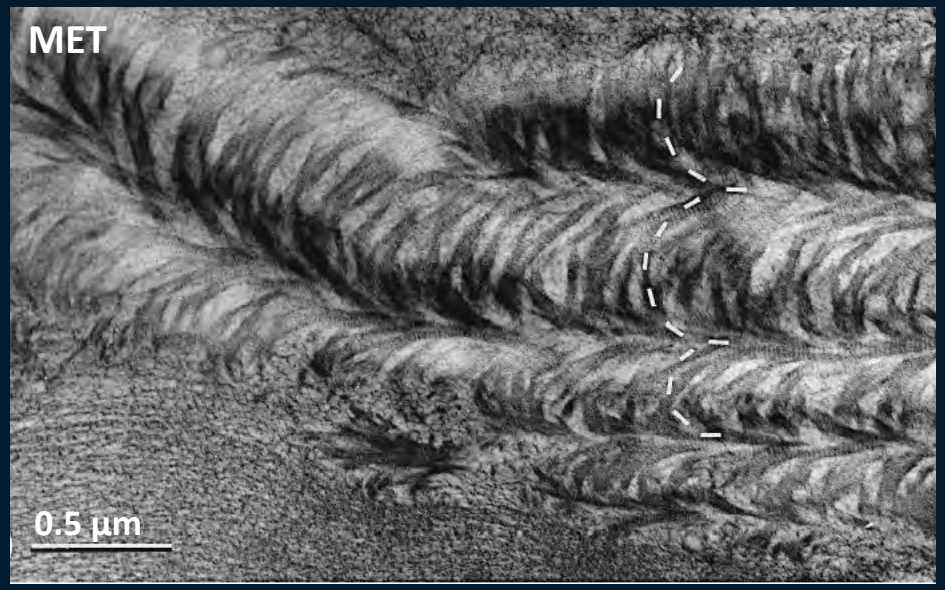
in vitro :
conditions acides

in vivo :
pH physiologique

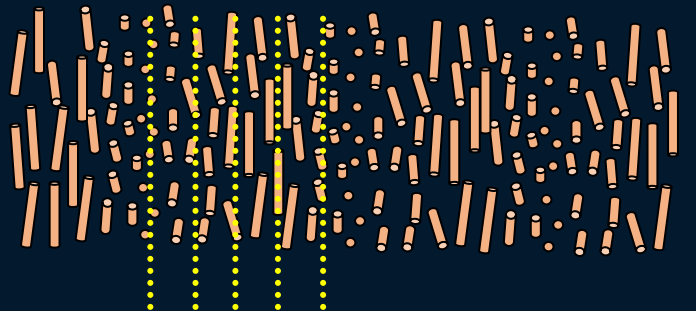
Fibrillogénèse in vitro = Précipitation des fibrilles

~~Fibrillation~~ 

pH ↗

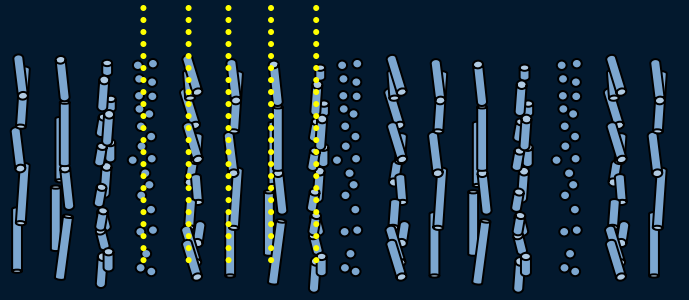


Phase cholesterique (C > 80 mg/mL) :



MOLECULES
Ø = 1,5 nm

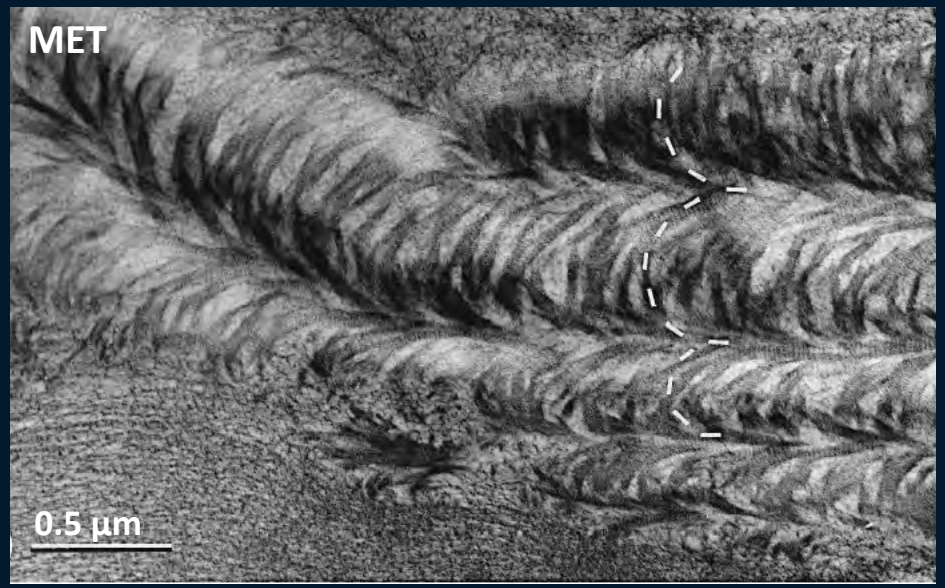
Matrice dense & structurée :



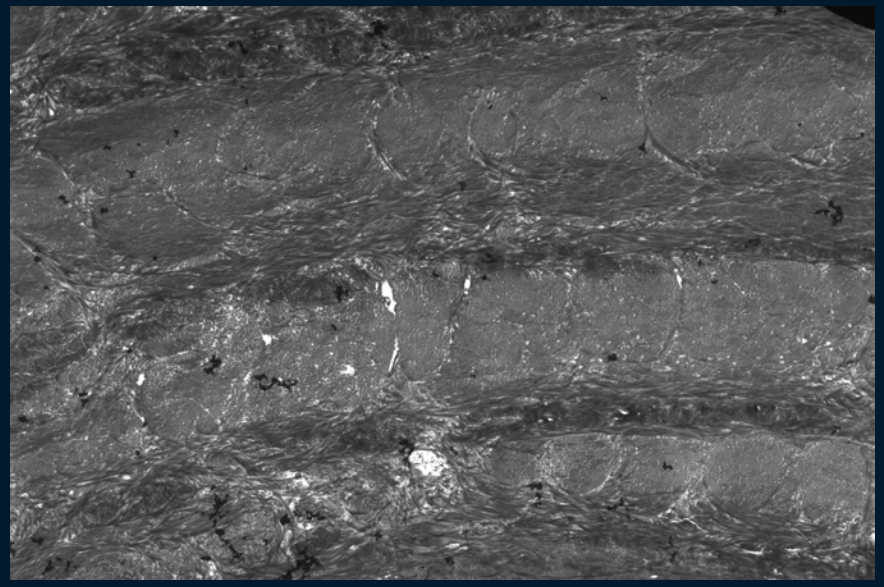
FIBRILLES
Ø = 100 nm !

M. M. Giraud Guille, J. Mol. Biol. (1992)

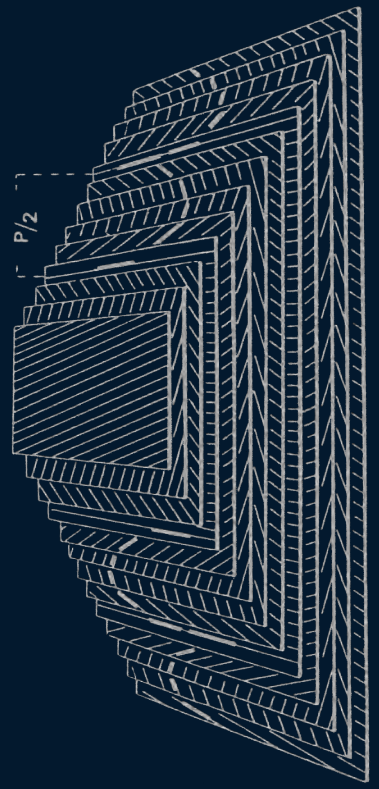
Contreplaqué helicoïdal reproduit *in vitro*



Gel de collagène In vitro



Os compact humain déminéralisé



Preuve ou Coïncidence ?

Biomaterials 97 (2016) 74–84

Contents lists available at ScienceDirect

Biomaterials

journal homepage: www.elsevier.com/locate/biomaterials

Review

Mechanisms of lamellar collagen formation in connective tissues

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[c] Biomaterials Innovation Research Center, Division of Biomedical Engineering, Department of Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA
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[f] Department of Bioindustrial Technologies, College of Animal Bioscience and Technology, Konkuk University, Hwayang-dong, Gwangjin-gu, Seoul, Republic
[g] Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia

« While dense concentrations of collagen show such behavior, there is little evidence that the conditions for liquid crystal phasing are actually met in vivo. »

ARTICLE INFO

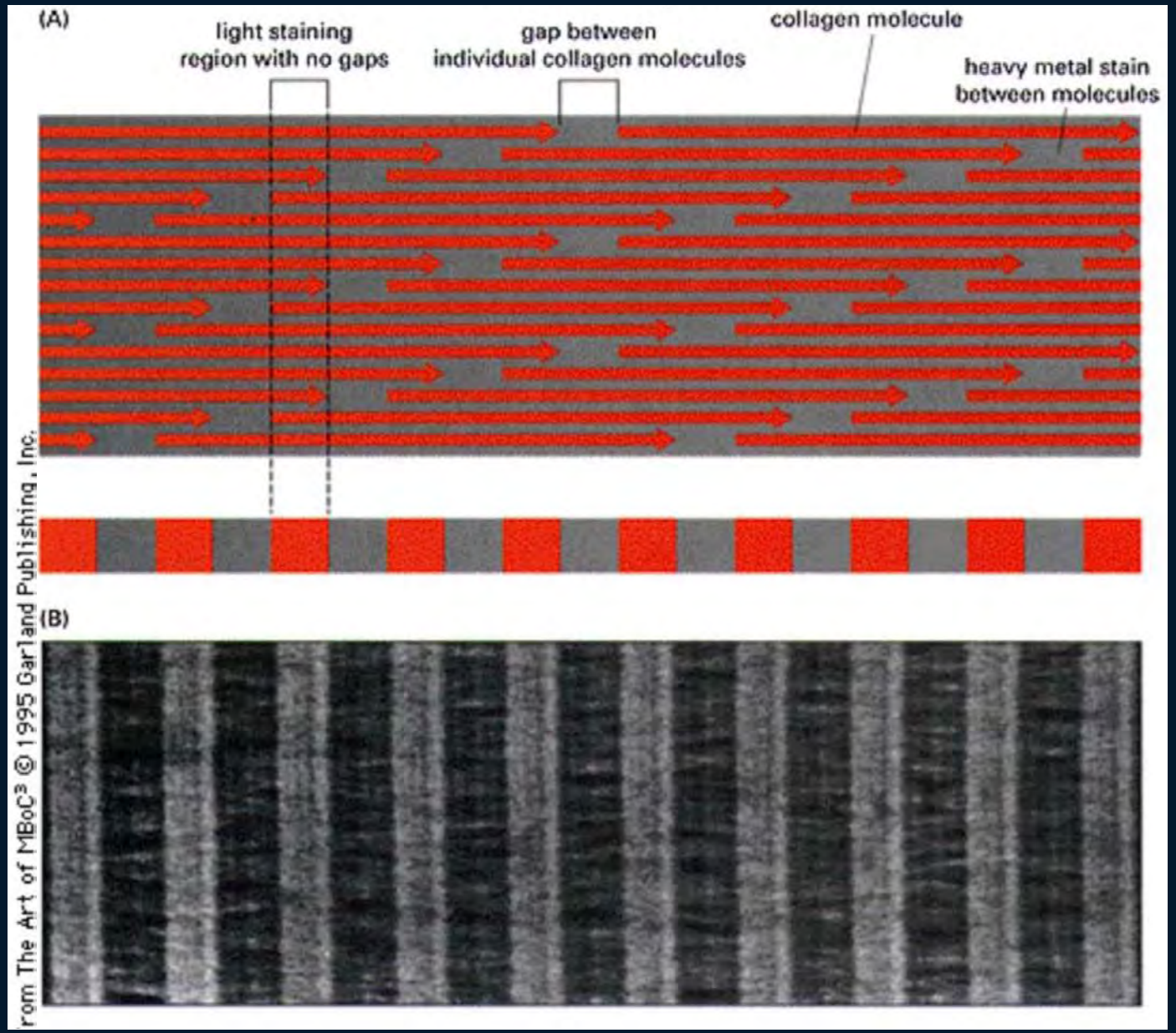
Article history:
Received 29 January 2016
Received in revised form
29 March 2016
Accepted 20 April 2016
Available online 27 April 2016

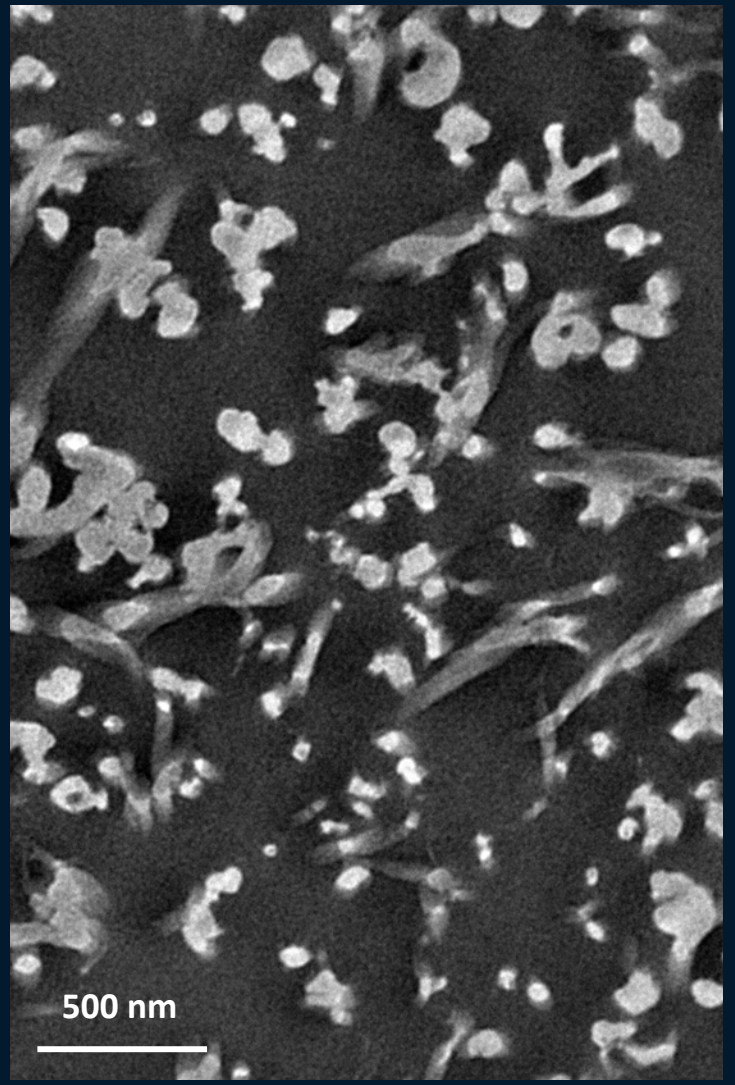
Keywords:
Collagen
Arrangment
Lamellar structure
Liquid crystal behavior
Functional tissue

ABSTRACT

The objective of tissue engineering is to regenerate functional tissues. Engineering functional tissues requires an understanding of the mechanisms that guide the formation and evolution of structure in the extracellular matrix (ECM). In particular, the three-dimensional (3D) collagen fiber arrangement is important as it is the key structural determinant that provides mechanical integrity and biological function. In this review, we survey the current knowledge on collagen organization mechanisms that can be applied to create well-structured functional lamellar tissues and in particular intervertebral disc and cornea. Thus far, the mechanisms behind the formation of cross-aligned collagen fibers in the lamellar structures is not fully understood. We start with cell-induced collagen alignment and strain-stabilization behavior mechanisms which can explain a single anisotropically aligned collagen fiber layer. These mechanisms may explain why there is anisotropy in a single layer in the first place. However, they cannot explain why a consecutive collagen layer is laid down with an alternating alignment. Therefore, we explored another mechanism, called liquid crystal phasing. While dense concentrations of collagen show such behavior, there is little evidence that the conditions for liquid crystal phasing are actually met *in vivo*. Instead, lysyl aldehyde-derived collagen cross-links have been found essential for correct lamellar matrix deposition. Furthermore, we suggest that supra-cellular (tissue-level) shear stress may be instrumental in the alignment of collagen fibers. Understanding the potential mechanisms behind the lamellar collagen structure in connective tissues will lead to further improvement of the regeneration strategies of functional complex lamellar tissues.

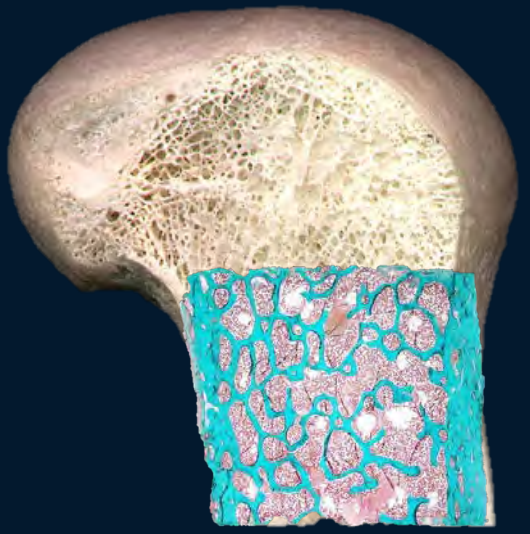
Explication chimique de la striation périodique observée en MET

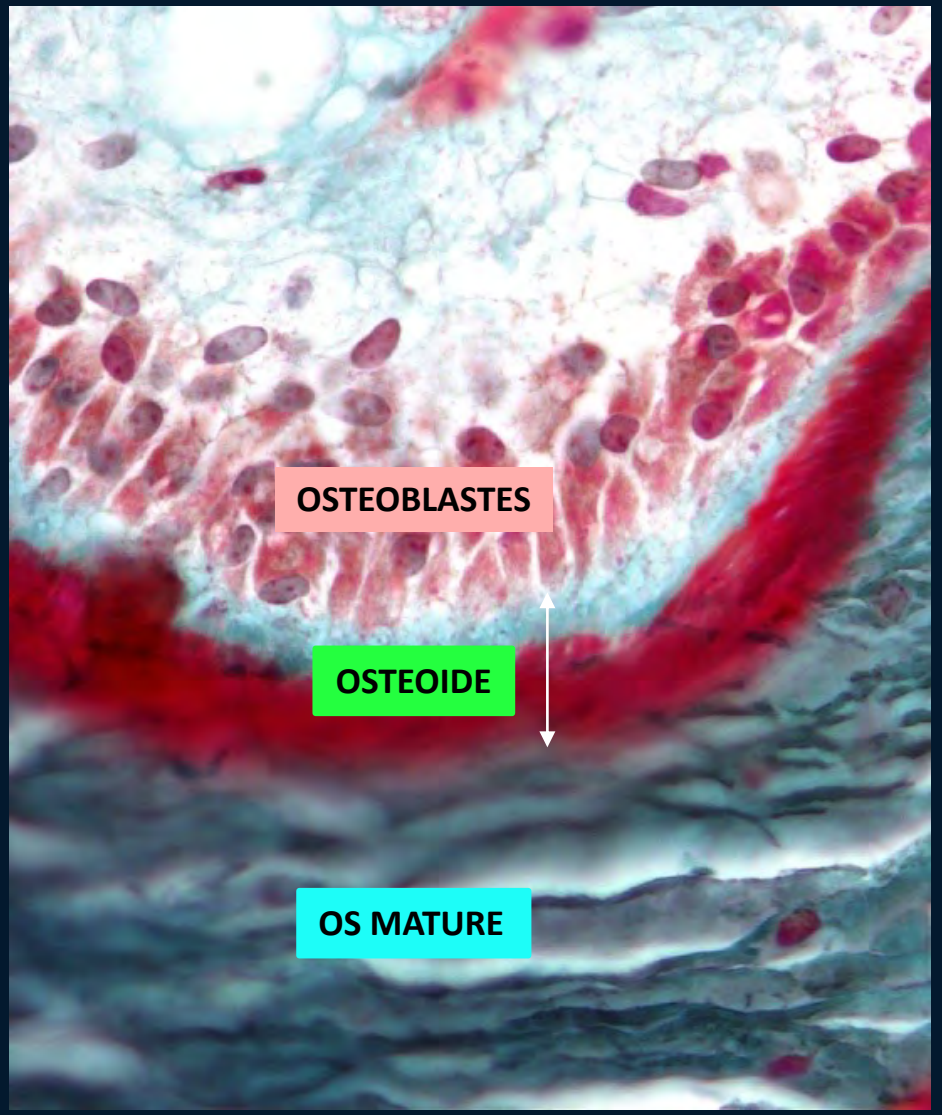




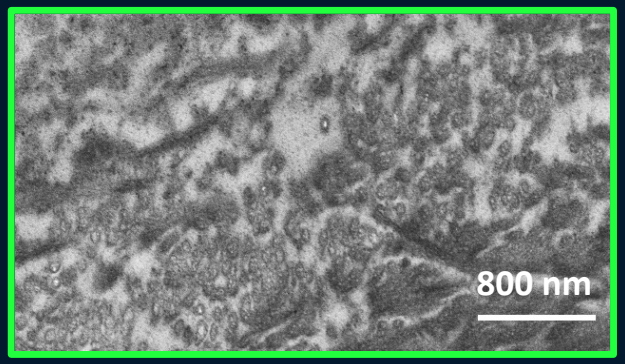
J. Silvent, et al. Biomacromolecules (2021)

Différentes densités et organisations de la MEC

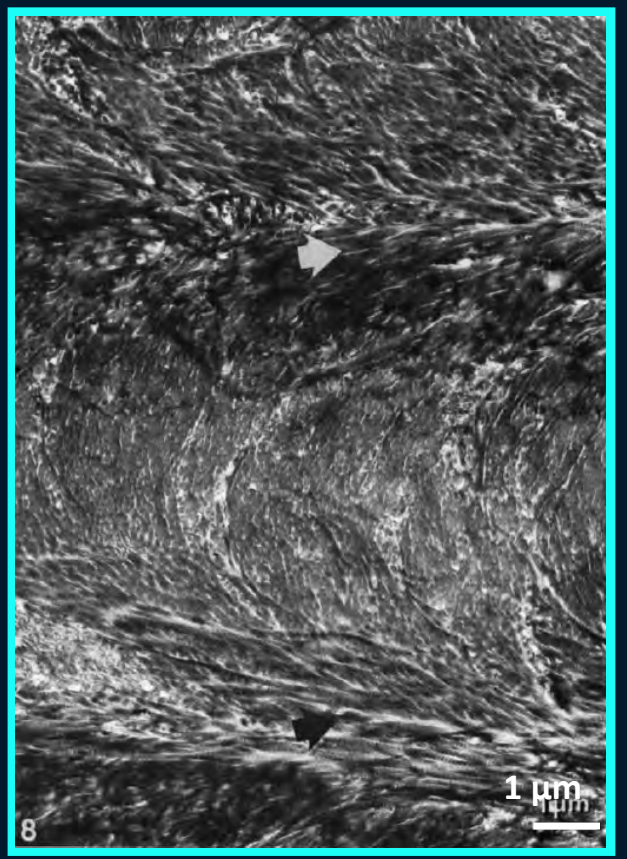




MO (coloration Trichrome de Masson)

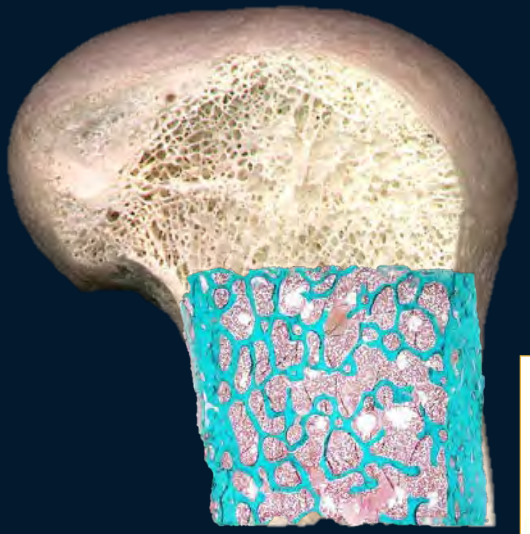


MET
(coupes ultrafines)

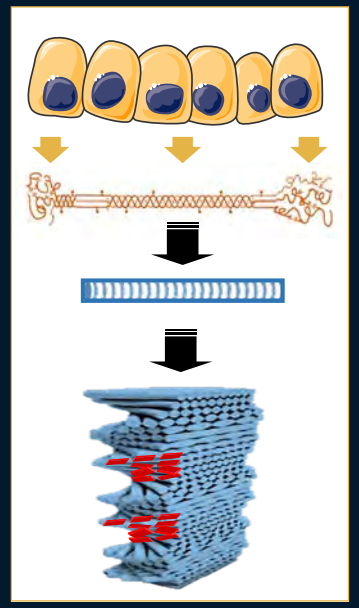


M.M. Giraud-Guille, *Microsc. Res. Tech.* (1994)

Mécanismes proposés *in vivo*



in vivo



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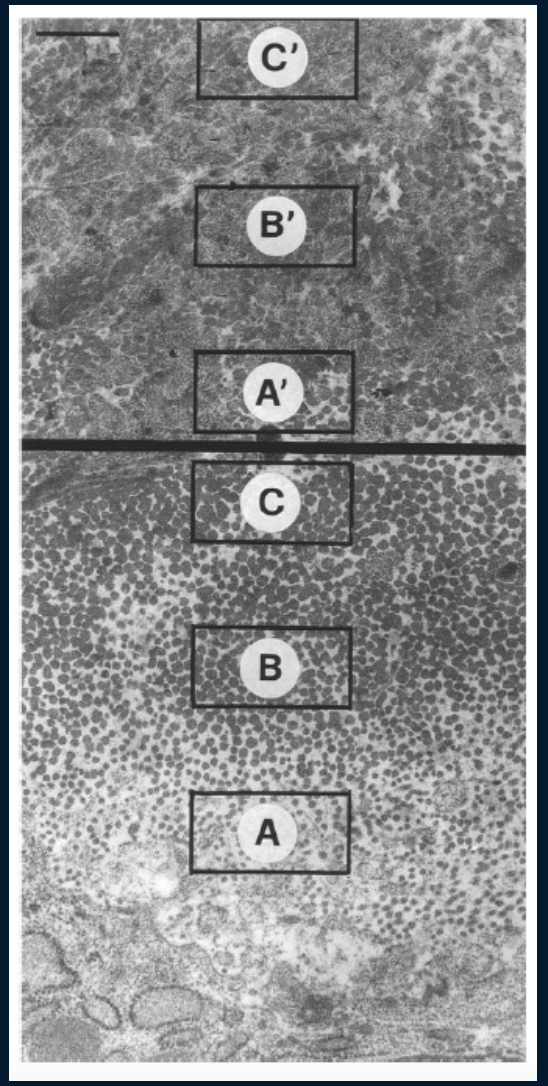
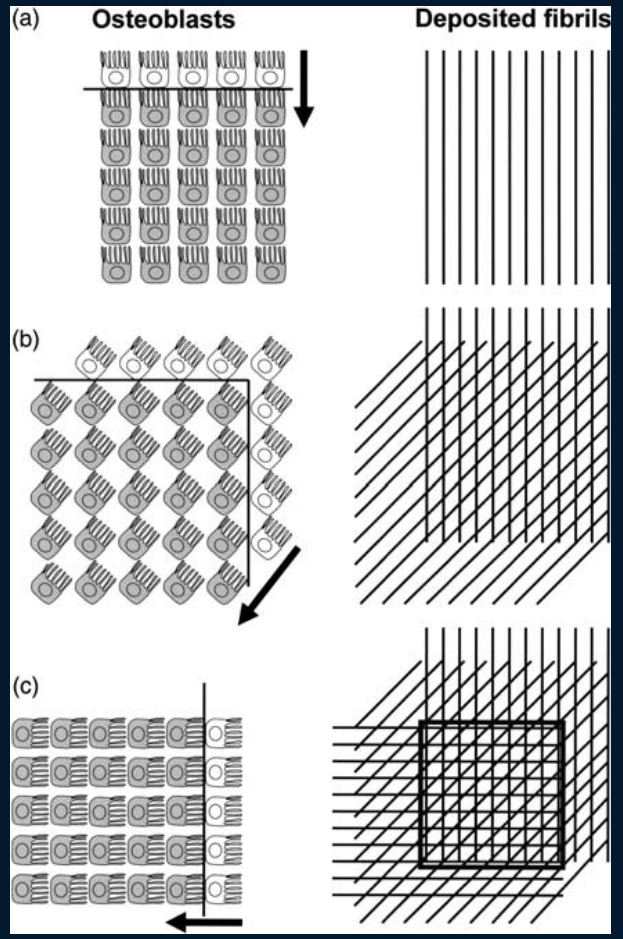


8 semaines

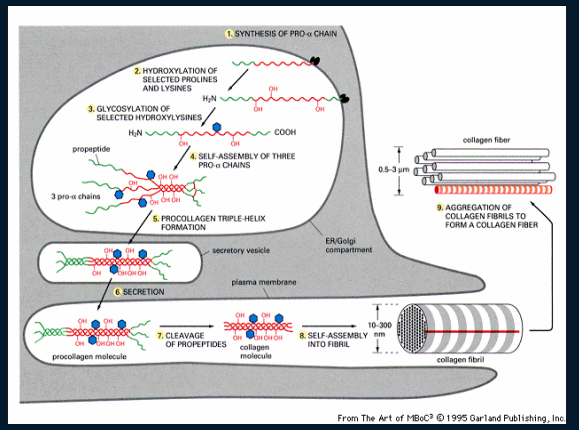


Yamamoto *et al.*, Microscopy **2012**, 61

Palumbo *et al. Anat Embryol* (1995) Yamamoto *et al. J. Electron Microsc. (*2012)

Mécanismes proposés *in vivo*

Existence de mesophase de procollagène intracellulaire ?



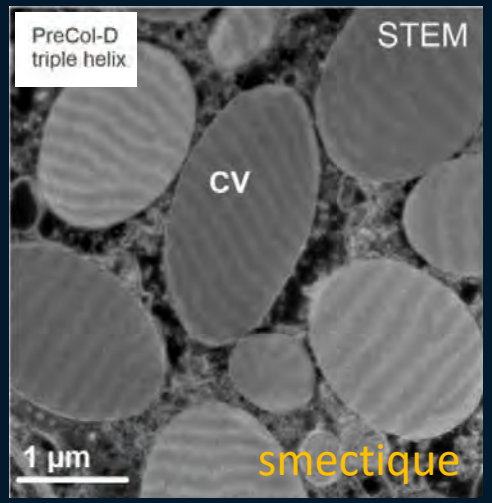
doi:10.1006/jmbi.2000.3855 available online at http://www.idealibrary.com on IDEAL® J. Mol. Biol. (2000) 301, 11–17

JMB

COMMUNICATION

Liquid Crystalline Ordering of Procollagen as a Determinant of Three-dimensional Extracellular Matrix Architecture

Raquel Martin[1], Jean Farjanel[2], Denise Eichenberger[2] Alain Colige[3] Efrat Kessler[4], David J. S. Hulmes[2] and Marie-Madeleine Giraud-Guille[1]*



ACS NANO

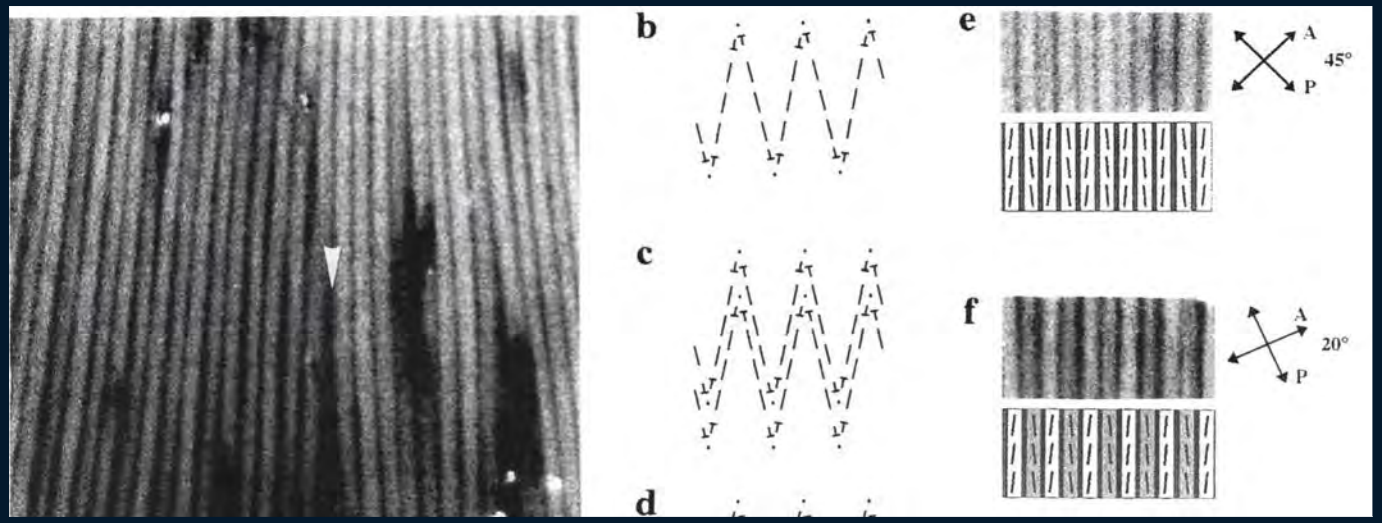
Collagen Pentablock Copolymers Form Smectic Liquid Crystals as Precursors for Mussel Byssus Fabrication

Franziska Jehle, Tobias Priemel, Mike Strauss, Peter Fratzl, Luca Bertinetti,* and Matthew J. Harrington*

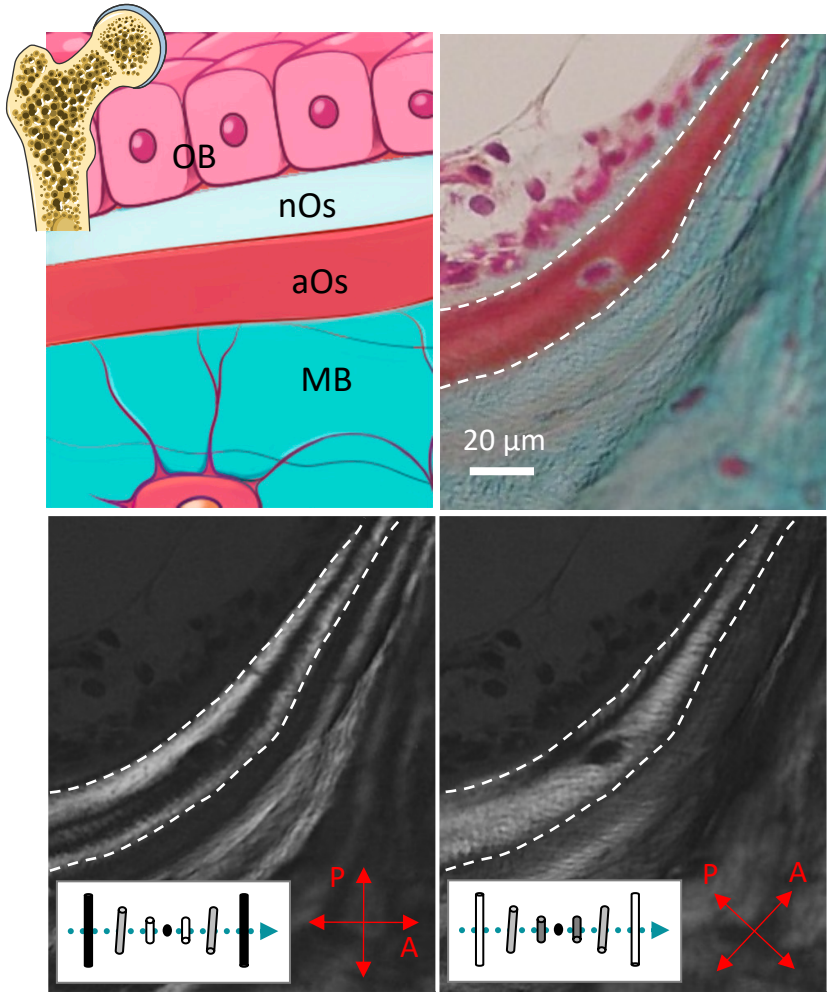
Extraction de ~ mg de protéine issus de fibroblastes de tendon d'embryon de poulet

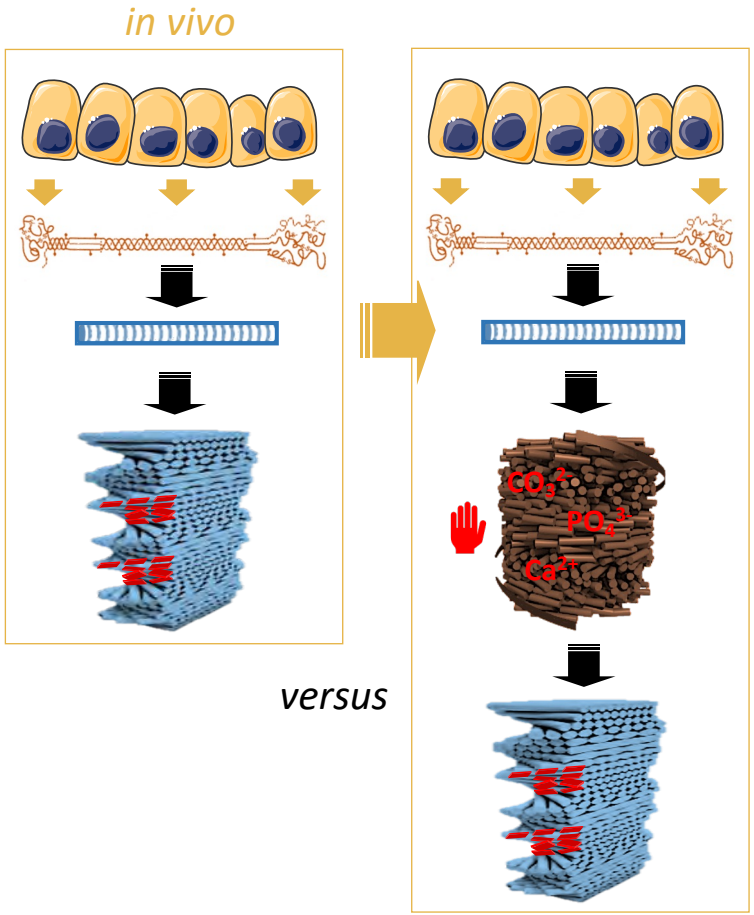
Réseaux ordonnés à 30 mg/ml dans un tampon physiologique

Précholestérique

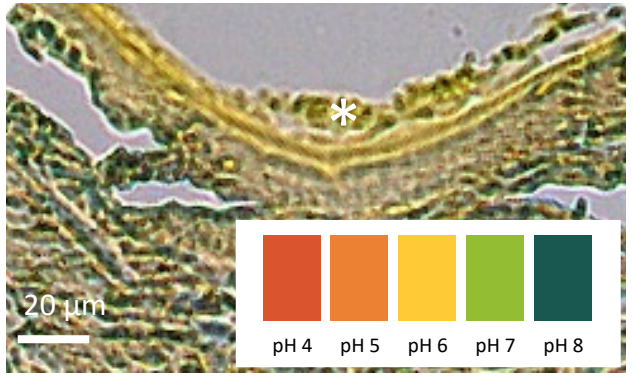


Mésophase de collagène *in vivo*



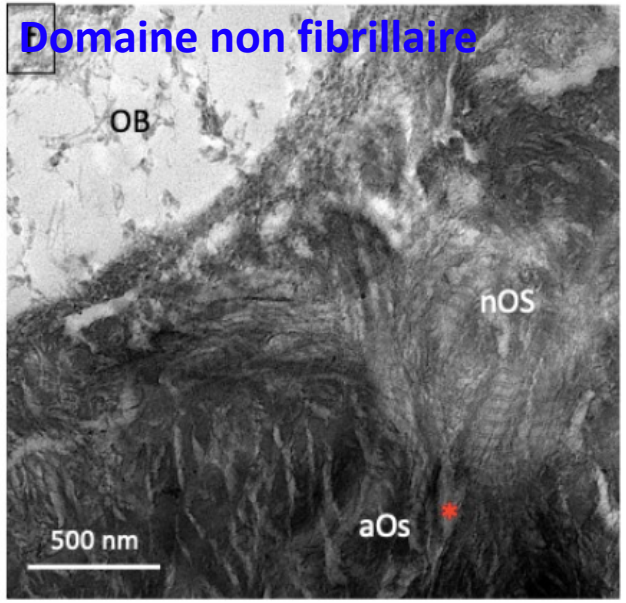


➢ **Domaine acide !**



Thèse
M. ROBIN

➢ **Domaine non fibrillaire**



Thèse
C. CHAREYRON

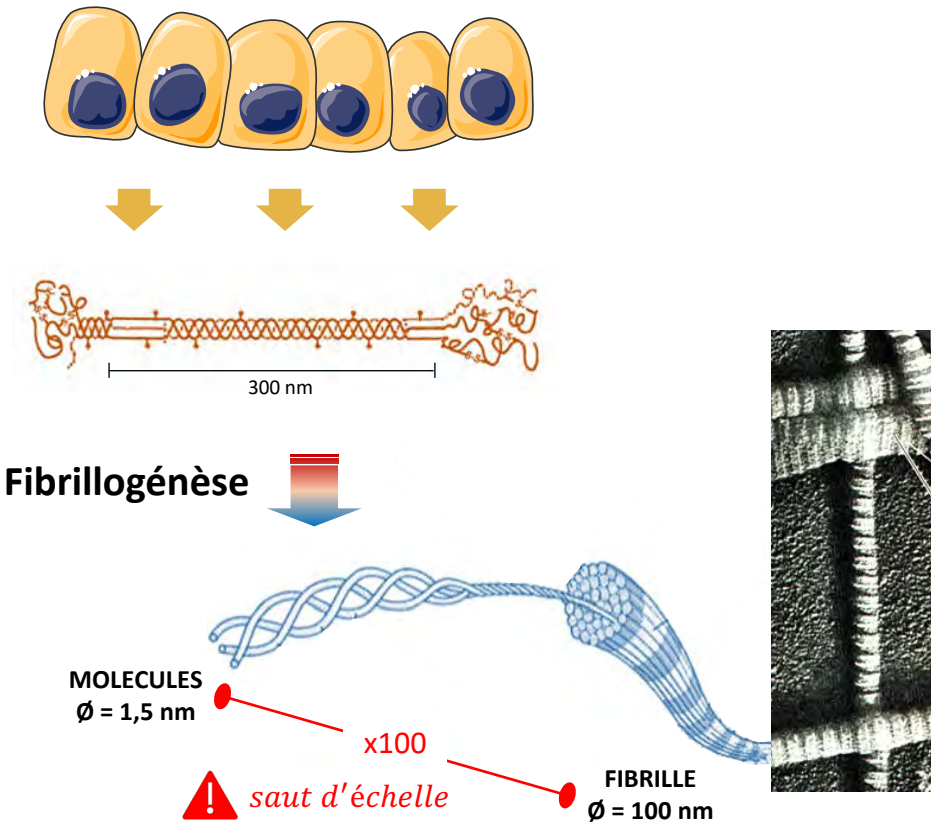
Robin *et al. Adv. Sci.* 2024

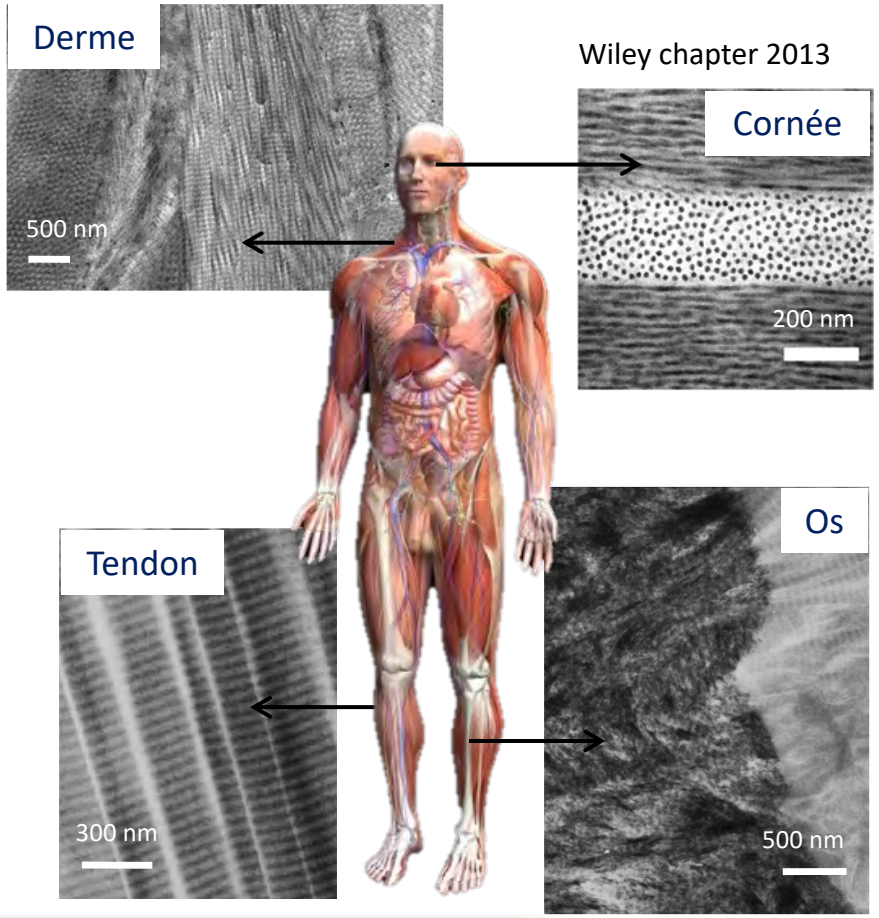
Collaborations : CHARITÉ P. Zaslansky IPR F. Artzner

H. Kerdoujdj

Collagène animal

❖ **3 états** identifiés du **collagène de Type I** dans les **tissus biologiques** :





Molécule → Fibrille → Suprafibrillaire 3D (MEC)

Merci !

Questions ?