Processing and Characterization of Porous Scaffolds for Bone Regeneration

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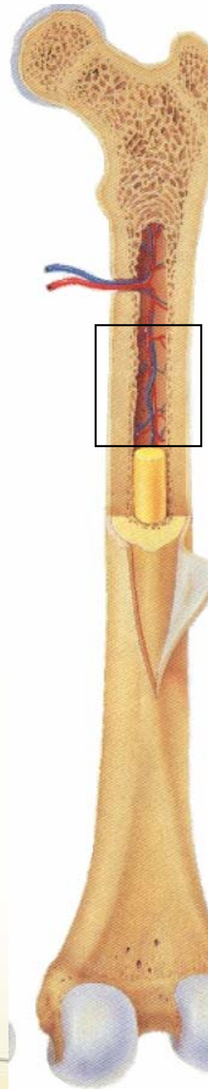
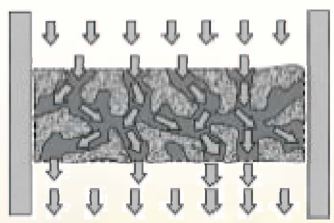
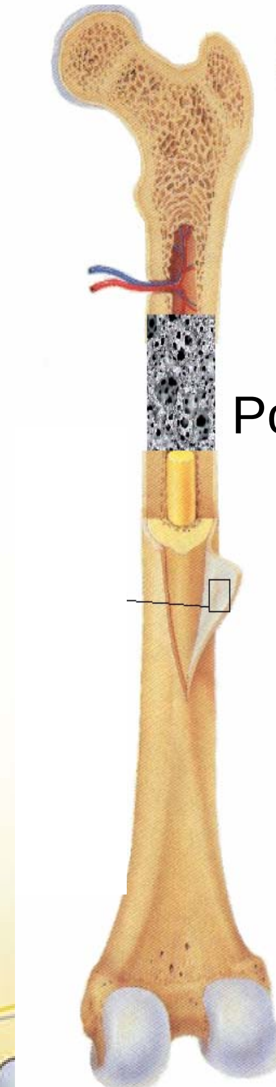
Bone tissue engineering



defect



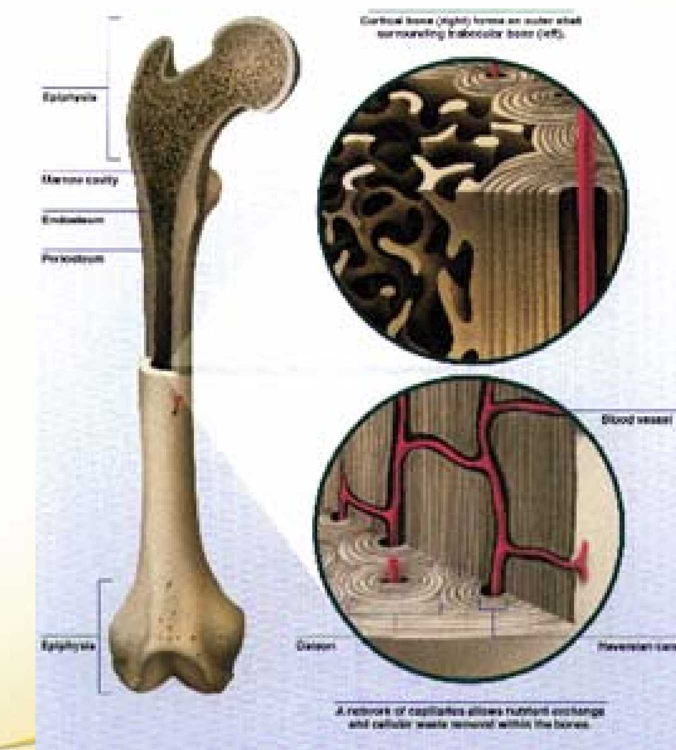
Porous scaffold, seeded in perfusion bioreactor (cells, bmp,...)



Porous scaffold + cells + ...

Bone scaffold requirements

- Biocompatibility: bio-inert or bio-active
  - Bio-inert metals: Ti-6Al-4V, Ti, SS, Ta
  - Bioresorbable ceramics: hydroxyapatite, α- or β-tri calcium phosphate
  - Biodegradable polymers: PGA, PLA, PGLA
- Structural parameters:
  - High porosity
  - Open porosity
    - Allowing osteoprogenitor cell seeding
    - cell attachment/cell migration
    - Mass transport cell nutrition
    - Vascularization
  - Interconnectivity
  - Surface topography
  - Specific surface area
- Adequate mechanical behaviour



Fabrication of porous materials

Replication of polymeric sponge

Infiltration/reaction of porous C-preforms

Infiltration of porous substrate and leaching

Sol gel method

Space holder method (volatile/combustible phase)

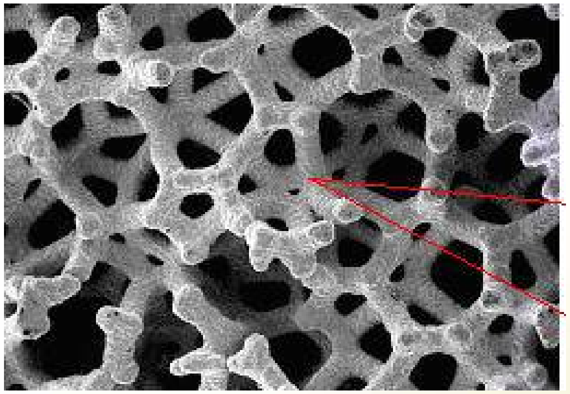
Sintering of hollow spheres

Self propagating high temperature synthesis (SHS)

Gel casting

Rapid Prototyping Technologies

…



Ta-C composite by CVD
Trabecular Metal™ (Zimmer Inc.)

Ryan et al, Biomaterials, 2006

Gelcasting

Procedure

Ceramic/metallic suspension + foaming agent + gelling agents

⬇

Foaming of mixture

⬇

Moulding

⬇

Gelation

⬇

Drying, calcination

⬇

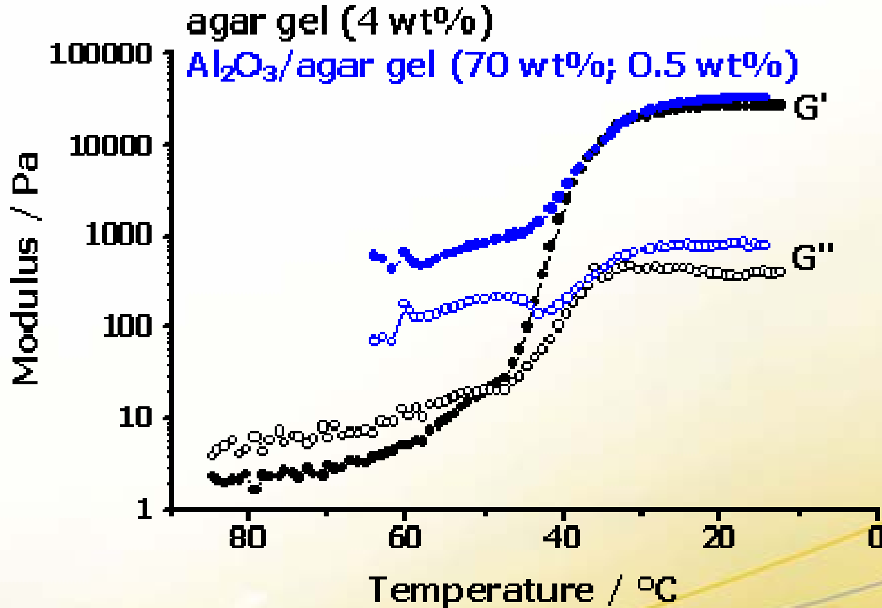
Sintering

⬇

Ceramic or metallic foam structure

Gelation

Liquid foam ⟶ **solid foam**

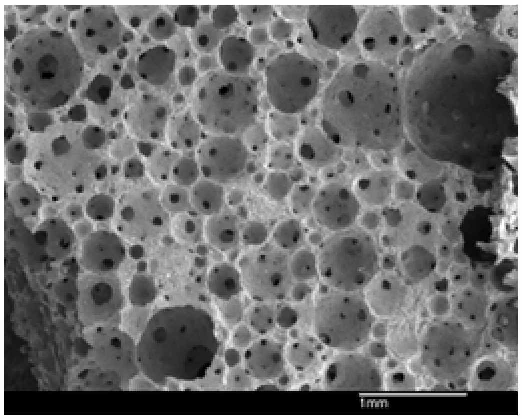


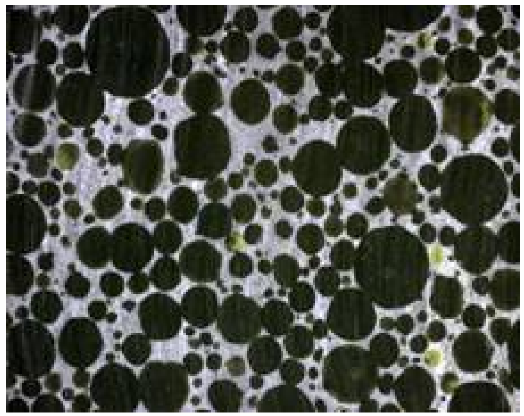
Materials

- Ceramic: Al_2O_3, SiC, hydroxyapatite, β-TCP
- Metallic: Ti, Ti-6Al-4V, SS, CoCr

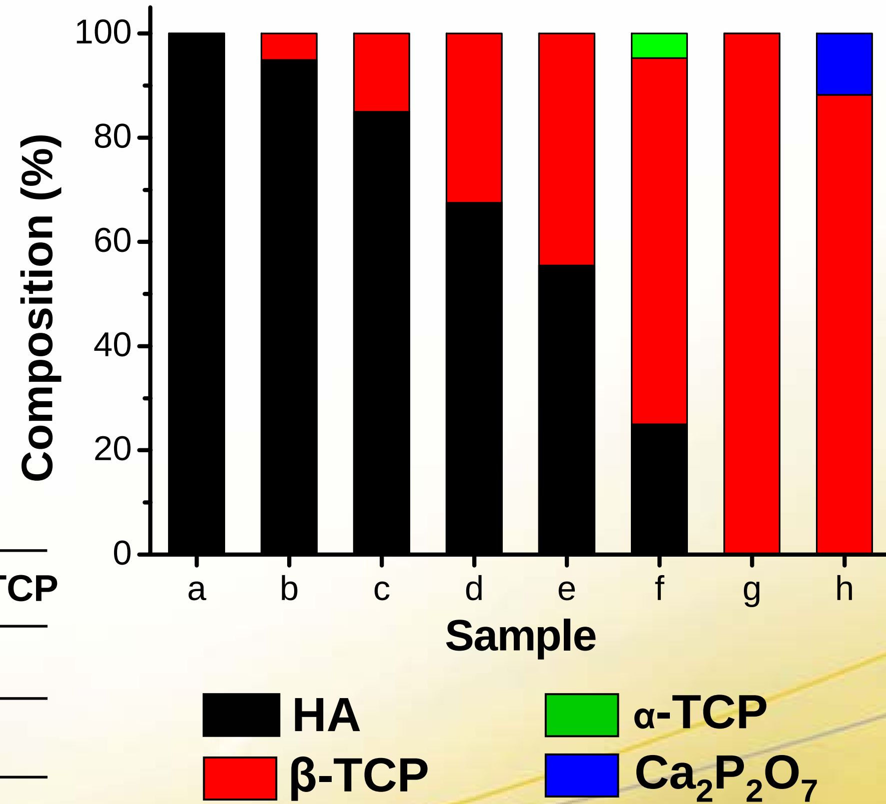
Gelcasting of bioceramics

Microstructure





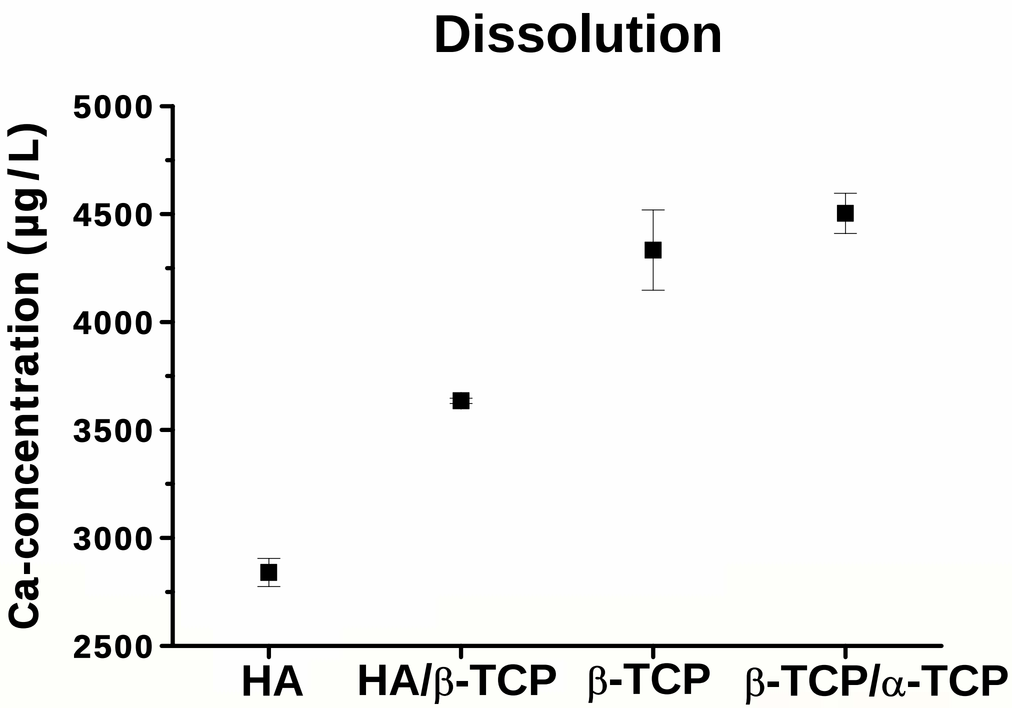
Controllable composition

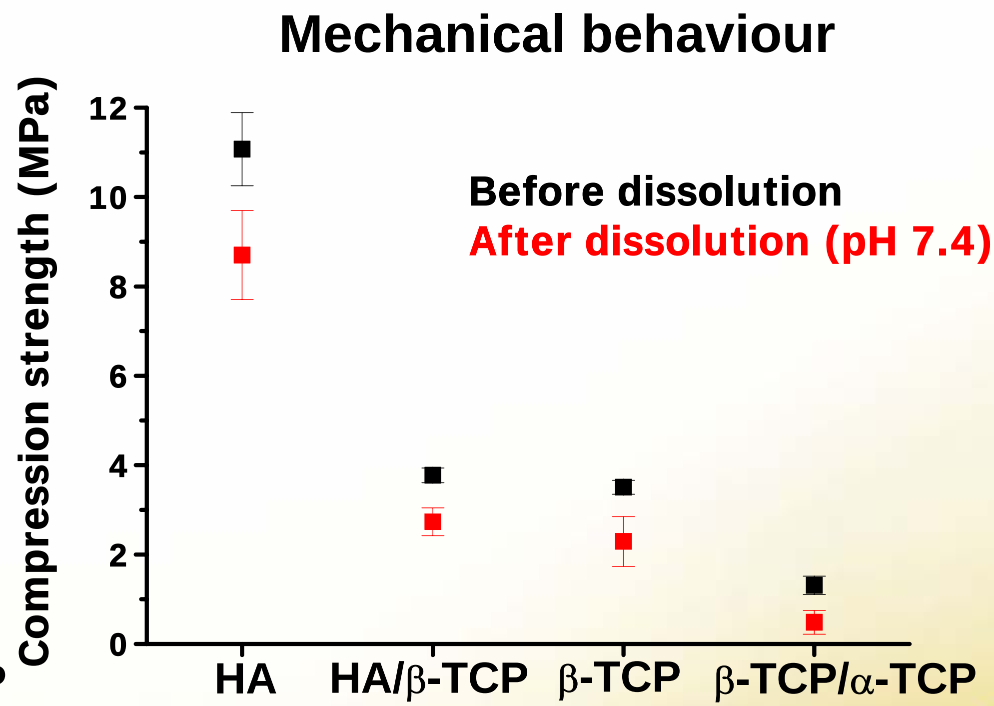


Phase	HA	HA/β-TCP	β-TCP	β-TCP/α-TCP
Phase composition	100	85/15	100	65/35
Porosity (%)	70	80	80	85
Mean pore size (μm)	120	175	150	350
Compression (MPa)	10.1	4.3	2.1	0.4

Gelcasting of bioceramics

In vitro behaviour





Ca^{2+} release promotes bone formation

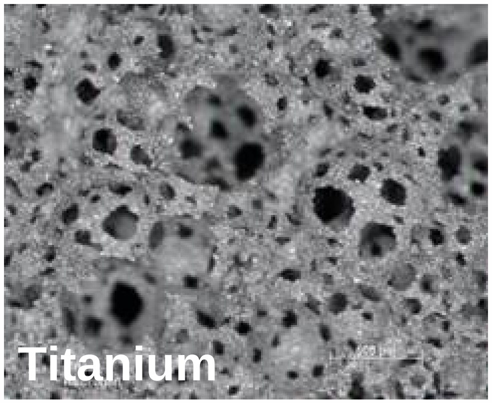
Strength loss varying from -21 % to -61 %

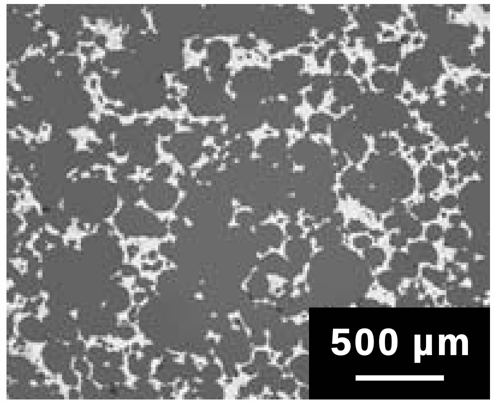
→ Limited to non-load bearing applications

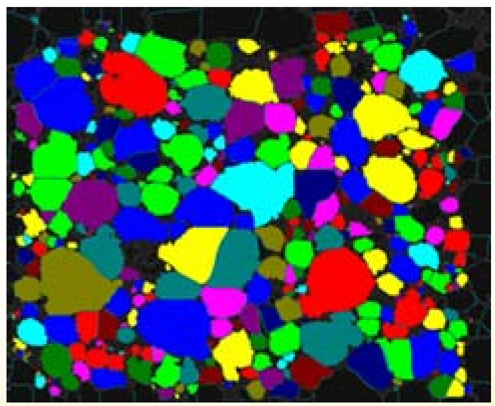
Perfusion; PBS solution; pH =7.4; 11 days; 37 °C

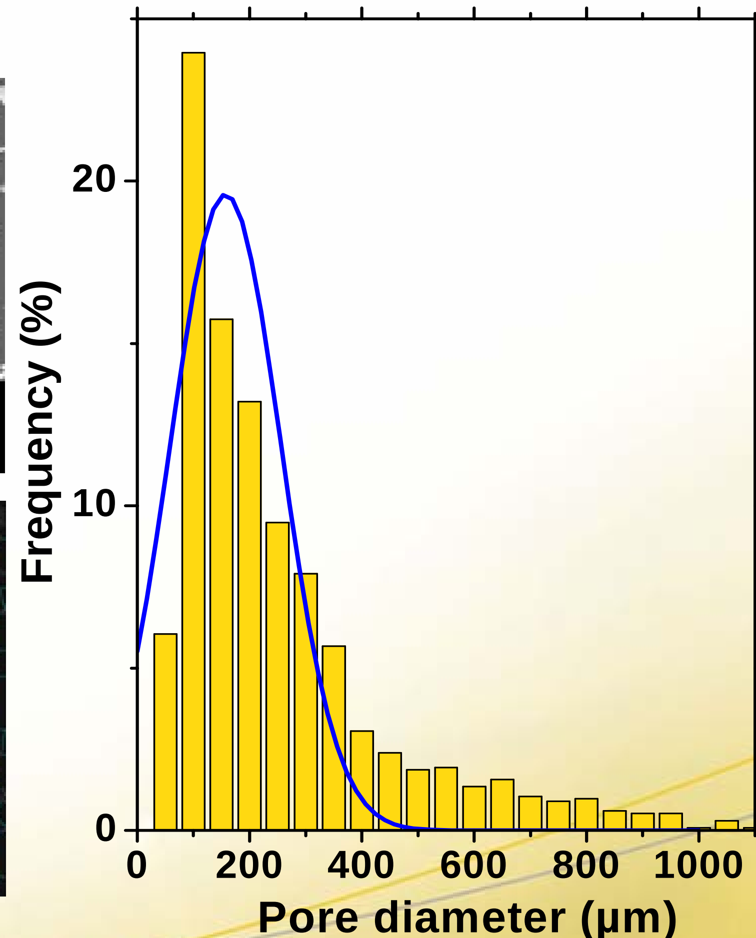
Gelcasting of metals - Vitofoam™

Pore Size Distribution – Image Analysis









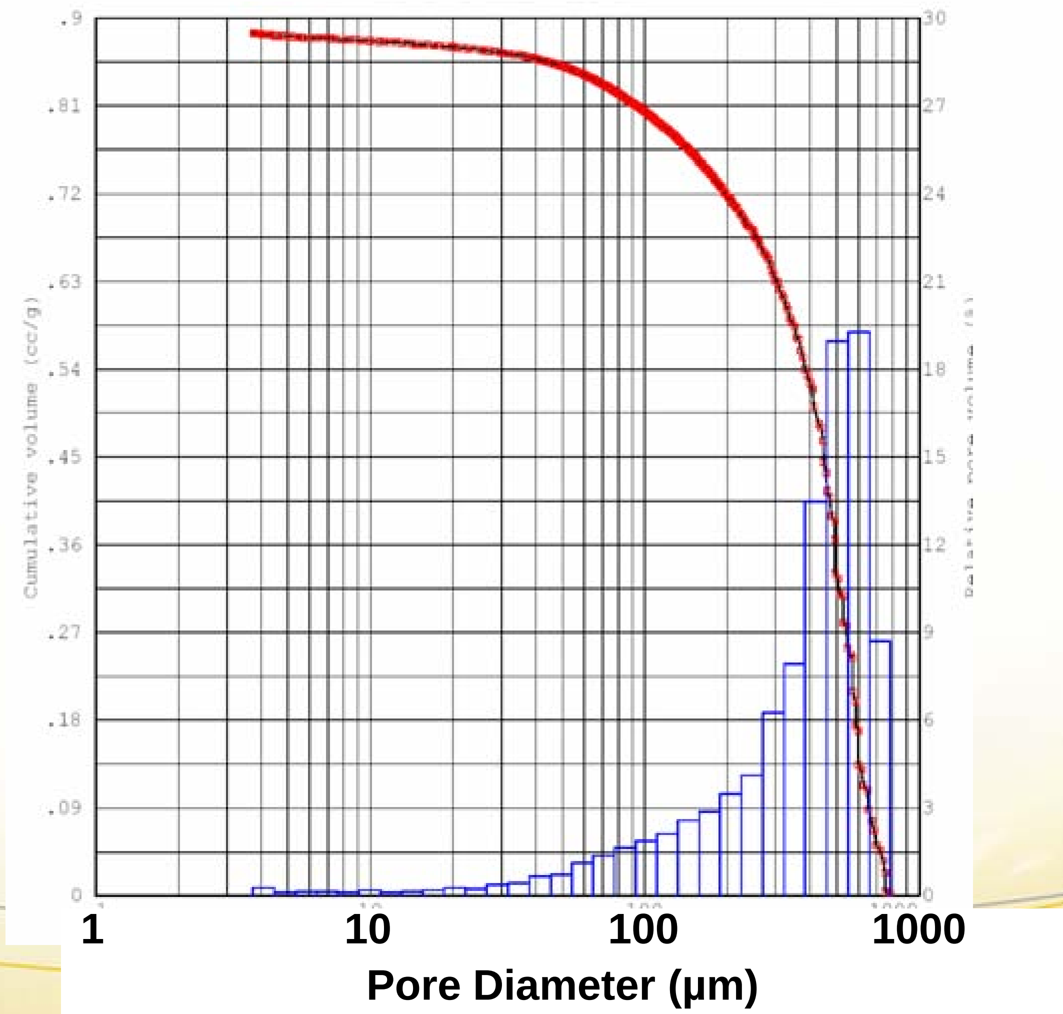
Results

- Mean pore size: 150 µm
- Porosity 80 %

1340 pores analyzed (5 cross section images)
3D-corrected values $D_{3D} = D_{2D} / 0.785$

Gelcasting of metals - Vitofoam™

Interconnectivity – Hg Intrusion Porosimetry

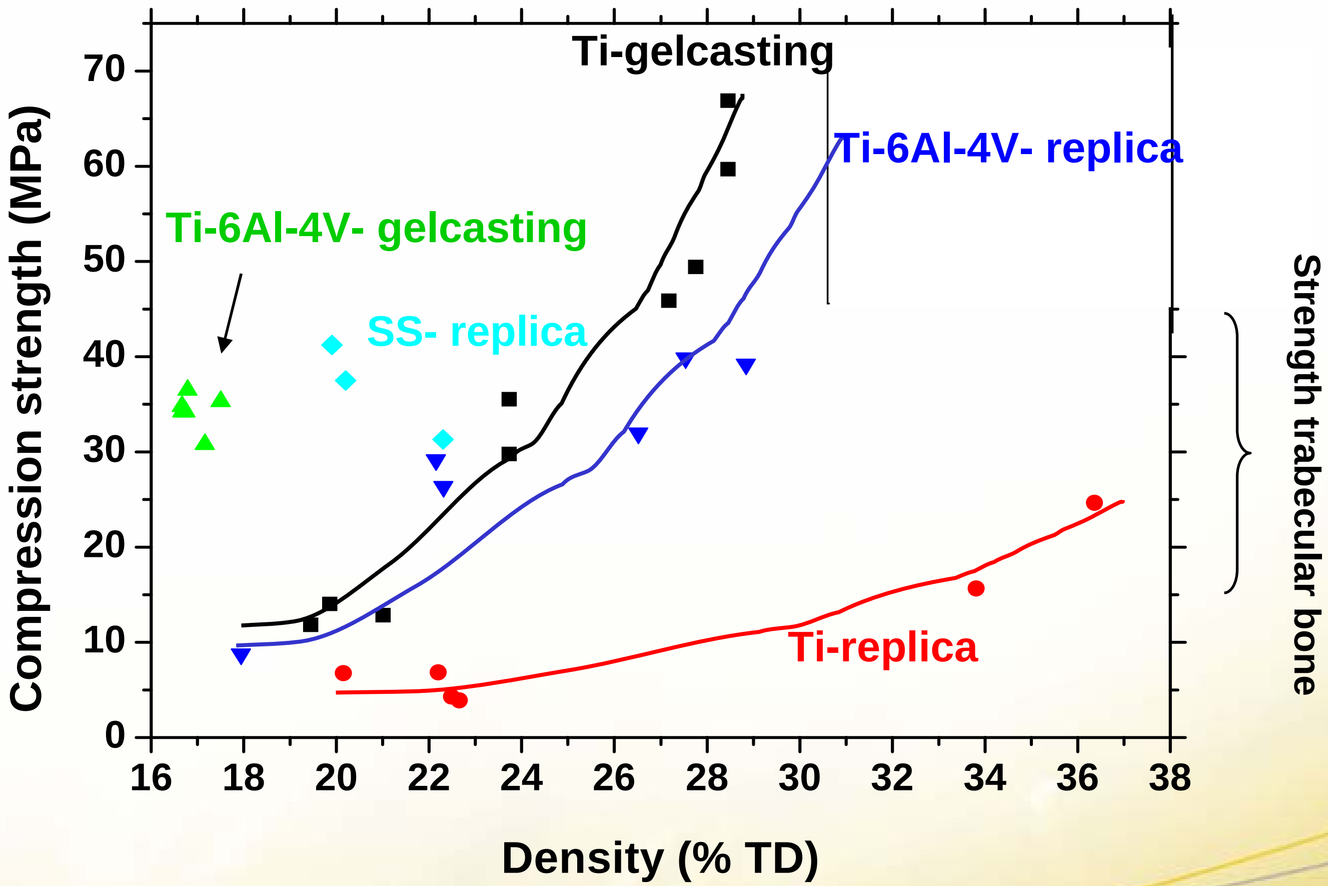


Results:

- 0.836 cm³ pores / g sample
- Average pore diameter : 448 µm

Gelcasting of metals - Vitofoam™

Compression strength

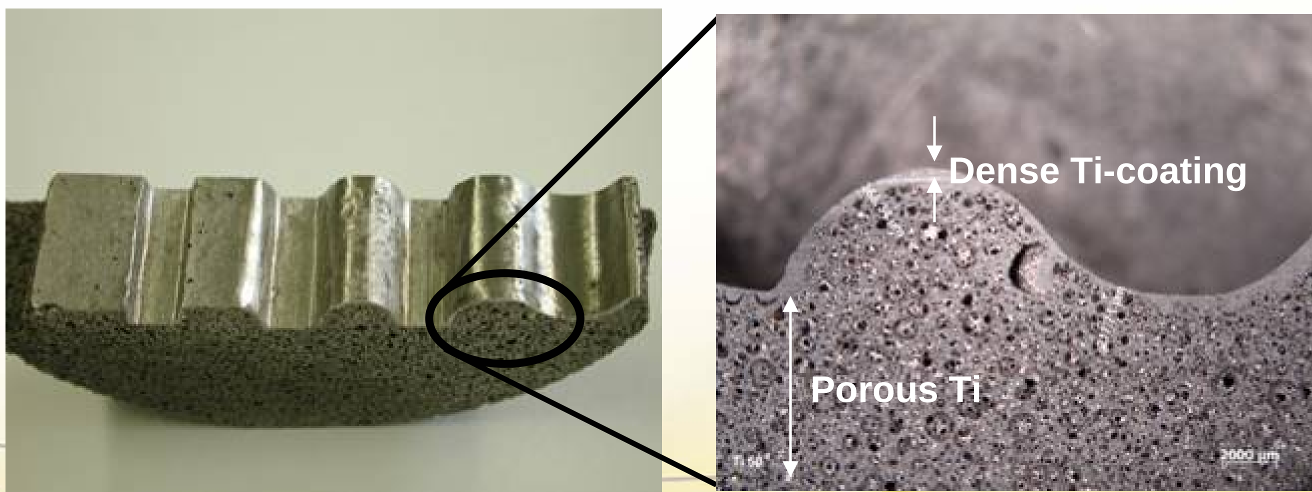


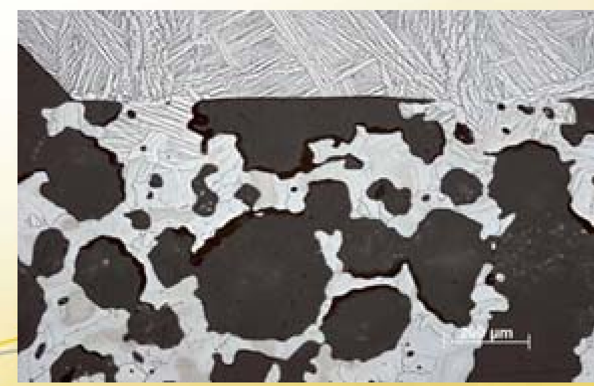
Tunable mechanical strength
High ductility

Gelcasting of metals - Vitofoam^{TM}

Machinability

Combination dense - porous





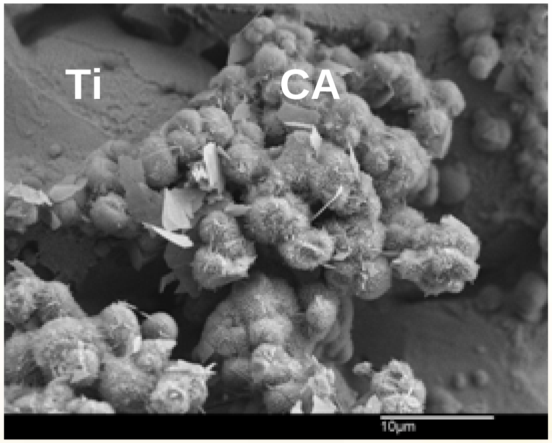
Coatings on porous metals

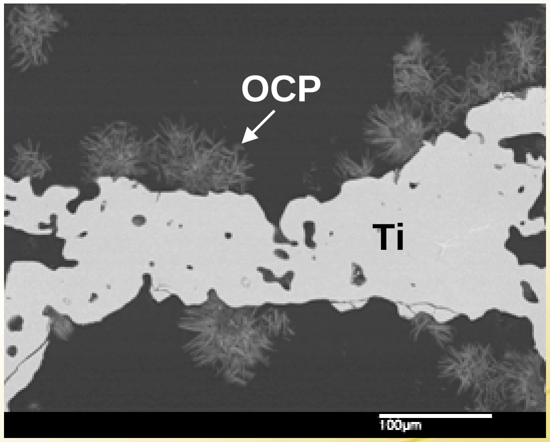
Motivation

- High strength / ductility of porous metals and bio-stimulating surface chemistry of calcium phosphates
- Reservoir for in situ release of bone morphogenic proteins, antibiotics, vascularization aids,…

Technologies

- Sol gel
- Biomimetic coprecipitation





See presentation Ravelinghien et al, Theme 2, Friday 10:40

Scaffolds of the next generation ?

3D- Fiber Deposition (3DFD)

Preparation of highly viscous ceramic/metallic paste

↓

Extrude through thin nozzle

↓

Computer controlled deposition of fibers

↓

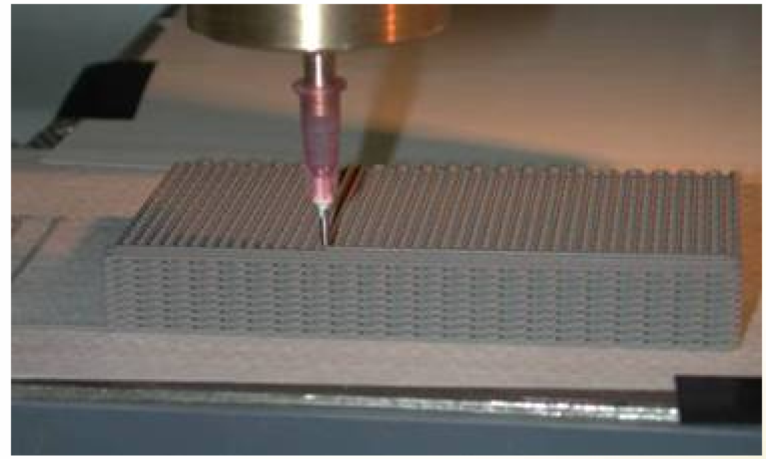
Drying, calcination

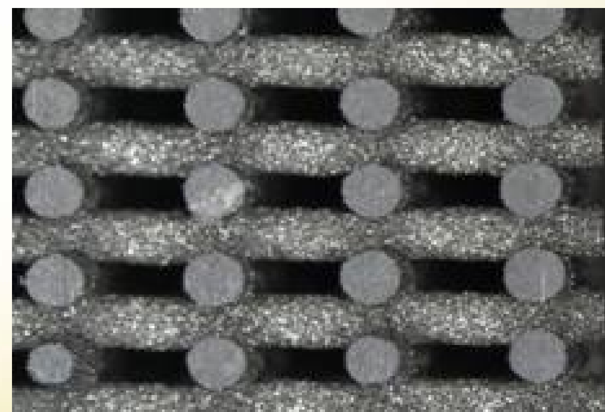
↓

Sintering

↓

Ceramic or metallic porous fiber structure





Parameters

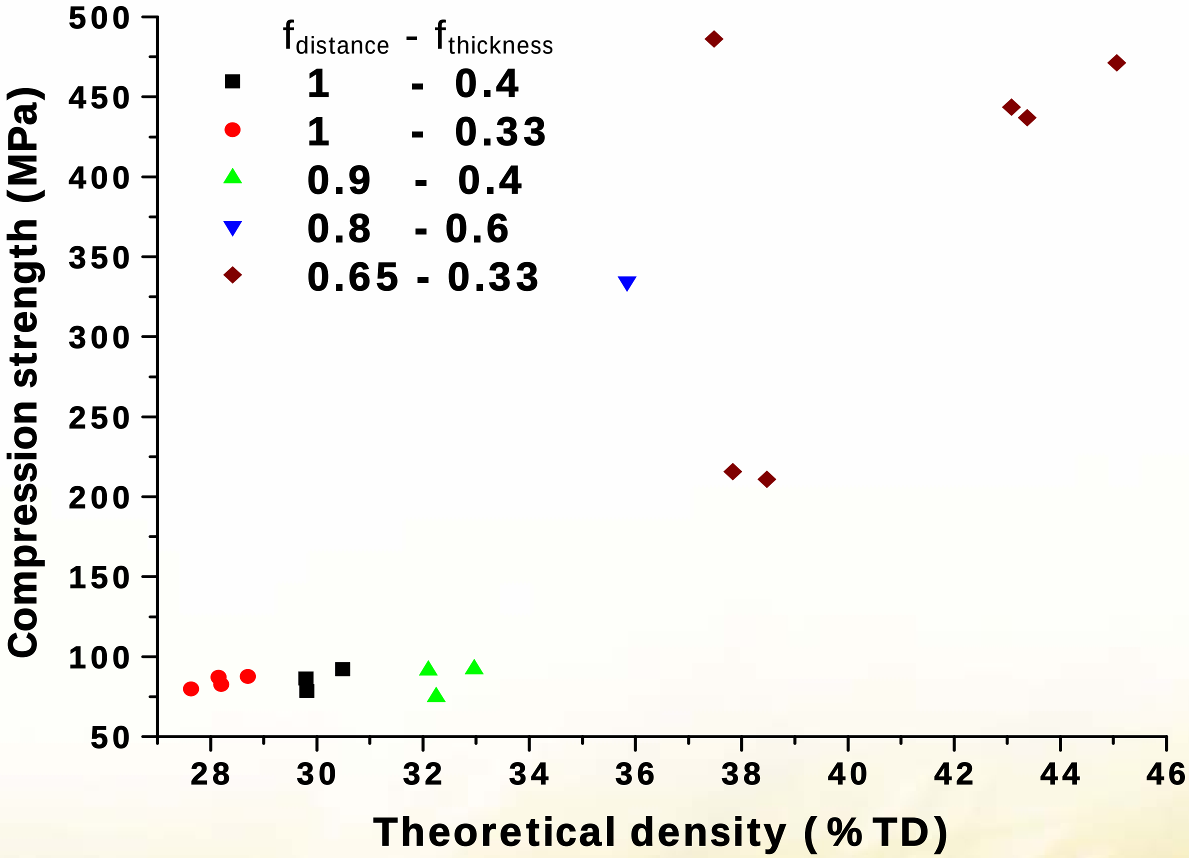
- Yield point of the paste: 150 – 500 Pa
- Nozzle opening: 200 µm – 900 µm
- Total porosity : 40 – 80 %TD

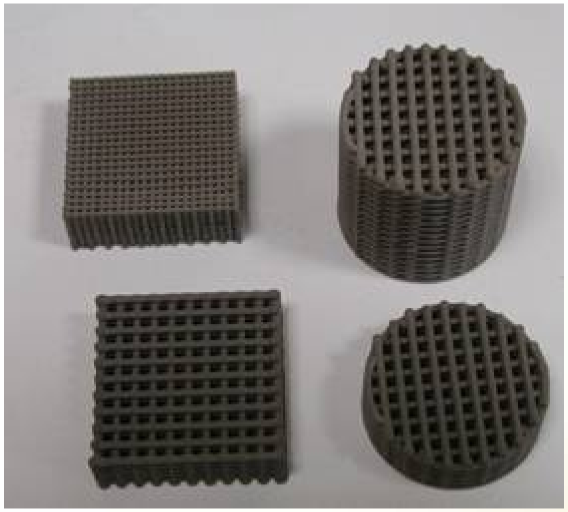
20071022_3DFD.wmv

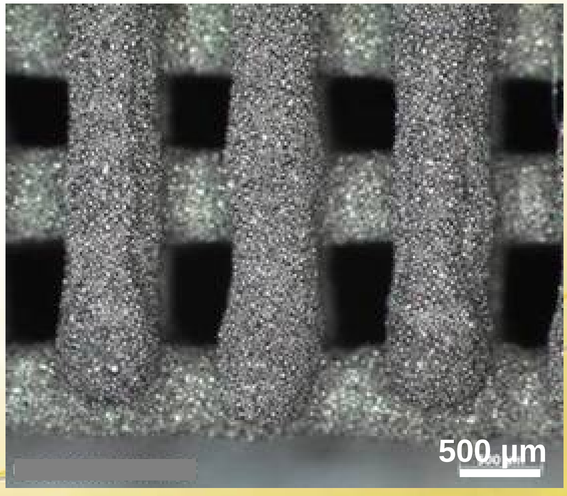
Ceserano et al, Sandia Nat. Lab.
Li et al, Biomaterials, 2006

3D fiber deposition

Compression strength

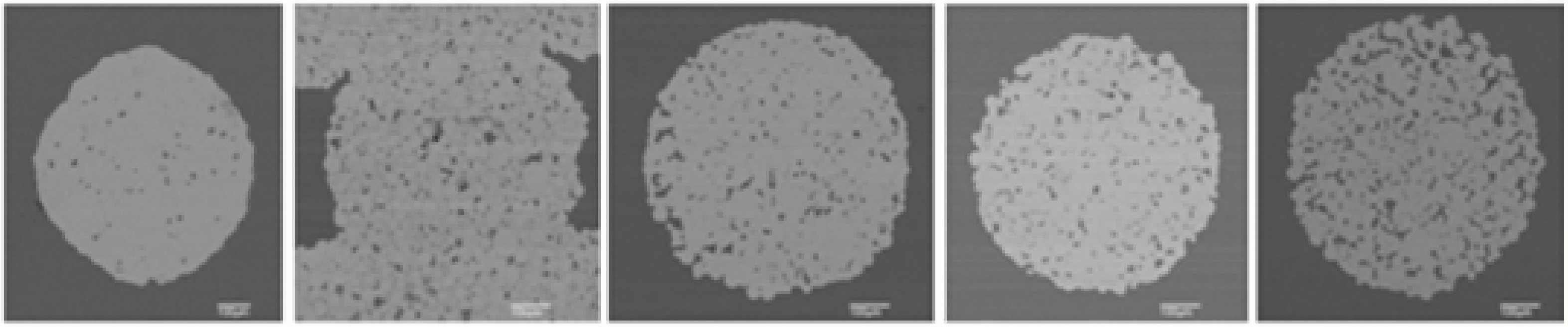


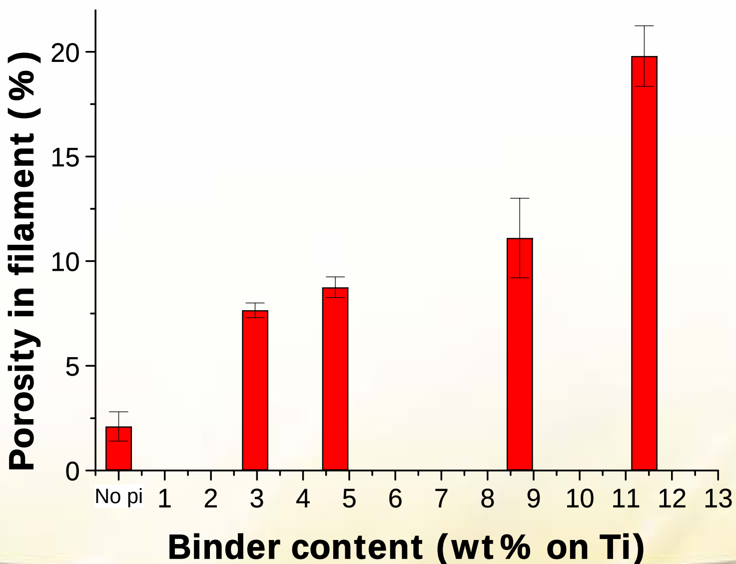


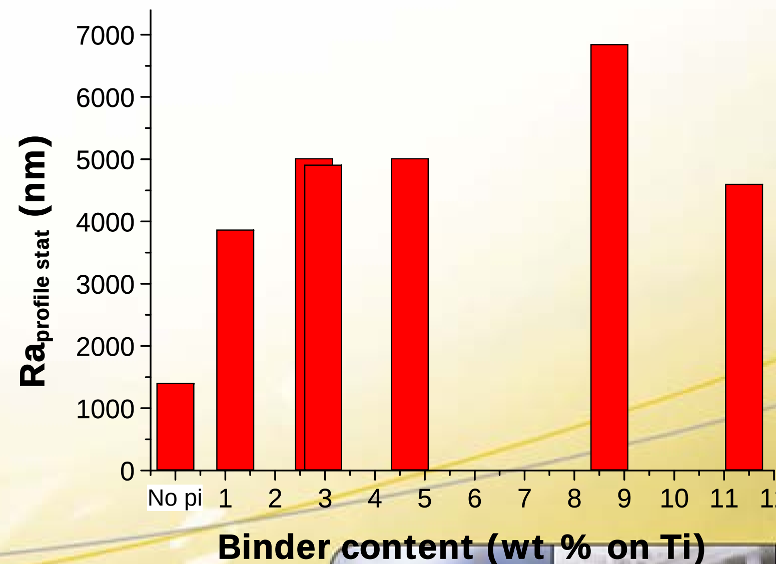


3D fiber deposition

Introduction of microporosity







Conclusions

- Versatile manufacturing routes for porous metals and ceramics, both in materials and applications
- Gelcasting : Biomimetic, bone-like structure - - tunable composition and mechanical properties
- 3DFD: narrow control on porous parameters - - microporosity and surface roughness
- Future: focus on bio-active surfaces and rapid prototyping 3DFD (customized design)

Acknowledgements

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