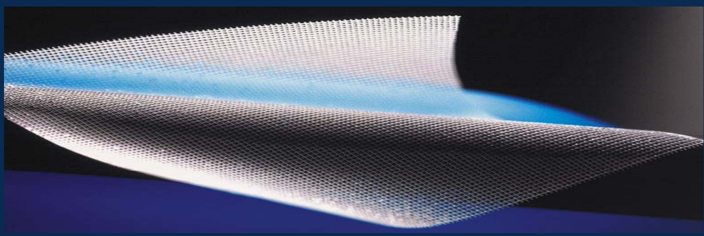
TECHNISCHE UNIVERSITÄT DRESDEN

ITM

Faculty of Mechanical Science and Engineering Institute of Textile Machinery and High Performance Material Technology, Professorship of Textile Technology

Natural Fibers and Innovative Biomaterials for Medical Applications



Dr. Michael Wöltje

33rd International Cotton Conference Bremen, 17.03.2016

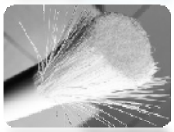
Classification of textile fibers

- **Textile fibers**
  - **Natural fibers**
    - Plant (Cotton, linen etc.)
    - Animal (Wool, silk etc.)
    - Chitin (Chitosan)
    - Mineral (Glass, aramid, asbestos etc.)
  - **Chemical fibers**
    - **Regenerated fibers**
      - Regenerated cellulose (viscose)
      - Regenerated protein (silk, soybean, keratin)
    - **Synthetic fibers**
      - Polyester
      - Polyamide
      - Polyacrylonitrile
      - Polyurethane
      - Polypropylene

Classification of medical textile products

- Healthcare and hygiene

- Non-implantable materials



- Extracorporeal devices

- Implantable materials

Healthcare and hygiene


Source: Bundesverband Medizintechnologie

- Surgical gowns
  Cotton, polyester, viscose rayon, polypropylene
- Caps and masks
  Viscose rayon, polyester
- Surgical covers, drape cloths
  Polyester, polyethylene
- Bedding, blankets, sheets, pillow covers
  Cotton, polyester
- Uniforms, protective clothing
  Cotton, polyester, polypropylene
- Surgical hosiery
  Cotton, polyamide, polyester, elastomeric yarns

Extracorporeal devices

Devices used to support the function of vital organs

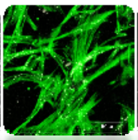
- Artificial kidneys (Dialyzers)
  - remove waste products form patients' blood
  - Synthetic hair-sized hollow fibers (Cellulose or polyester)
- Artificial livers
  - Separate and dispose of patient plasma and supply fresh plasma
  - Cellulose hollow fibers
- Mechanical lungs
  - Remove carbon dioxide from patients' blood and supply fresh oxygen
  - Polypropylene hollow fibers or hollow silicone membrane

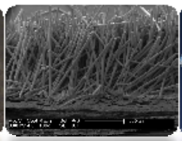
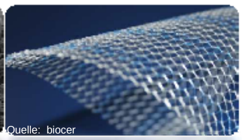
Non-implantable materials

- Absorbent pads, wound contact layer
  - ***Cotton***, viscose, silk, polyamide, polyethylene
- Simple bandages, elastic bandages
  - ***Cotton***, viscose, polyamide, elastomeric fiber and yarn
- Plaster
  - Viscose, polyester, polypropylene, perforated films
- Gauze
  - ***Cotton***, viscose, alginate, chitosan
- Wadding
  - ***Cotton***, viscose, wood-pulp

Implantable materials: Biological requirements

- Suitable artificial surface for adherence and growth of cells.
- Porosity to enable cell ingrowth and encapsulation.
- Non-toxicity of fiber polymers or fabrication techniques.
- Biocompatibility for interaction with the host in a controlled and predictable way.
- Hemocompatibility without damaging blood cells or cause formation of destructive blood clots.
- Biodegradability or bio-stability depending on the application.
- Mechanical requirements must be met according particular application.

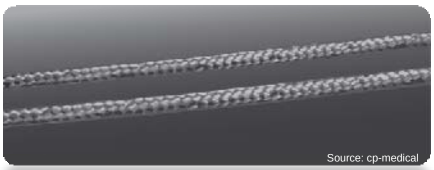



Implantable materials (1)

- Sutures for surgery and wound closure

Biodegradable: polyglycolide, catgut, polylactide

Non-biodegradable: silk, polyester, polypropylene, polyamide, PTFE, polyethylene



Implantable materials (2)

- Cardiovascular implants

Vascular grafts: Polyester, PTFE

Source: B. Braun

Stent grafts: Polyester, PTFE

Source: Jotec

Artificial heard valves: Polyester

mechanical

Source: St. Jude Medical

biological

Source: Labcor

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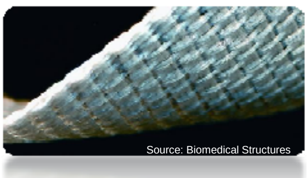
Implantable materials (3)

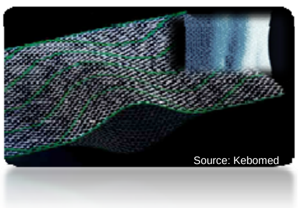
- Soft tissue implants

1. Artificial tendon and ligament: PTFE, PVDF, polyester, polyamide, polyethylene, silk



Source: Biomedical Structures

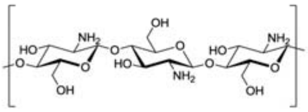
2. Hernia meshes: Polypropylene, polyester, PTFE



Source: Kebomed

Natural fibers from biopolymers (chitosan 1)

Chitosan isolation process

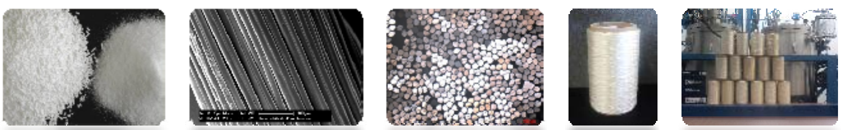


- Source: Arthropods, fungi and algae
- widely available biopolymer (polysaccharide)
- Bioresorbable, non-allergic, bacteria- and mould-repressive
- Process: 1. washing, drying, grinding, sieving
  2. demineralization and deproteinization
  => **chitin** powder
  1. ceacetylation
  2. washing, drying, grinding, sieving
  => **chitosan**

Natural fibers from biopolymers (chitosan 2)

Chitosan wet spinning

- Chitosan powder (deacetylation 90-95%, medical grade)
- Wet spinning using acetic acid, winding, washing, drying and quilling



Chitosan scaffolds for cartilage regeneration (1)

Cartilage defects (knee)

- Aging
- Mechanical stress
- Risk factors (sports, overweight, leg deformities, …)
- Low regeneration capacity of cartilage tissue
- Lack of blood vessels and blood flow

source: https://physione.wordpress.com/2013/12/15/knee-pain/

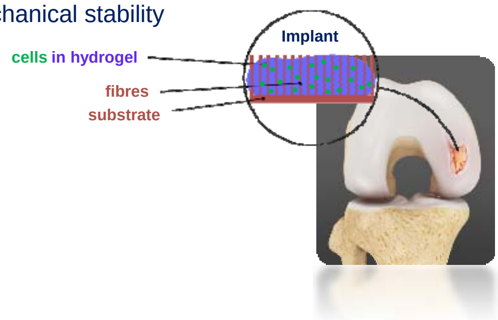
surce: http://www.preserveyourjoints.com/autologous-cartilage-implantation-save-your-joints.html

source: www.mayoclinic.orgmedical-professionals clinical-updatesorthopedic-surgeryinnovations-managing-articular-cartilage-defects-knee

Chitosan scaffolds for cartilage regeneration (2)

Tissue Engineering

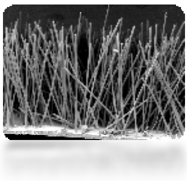
- Goal: Generation of target tissues
- Scaffolds are an essential component to deliver cells to the defect
- Biocompatibility and -degradability
- Adhesion growth and differentiation of stem cells
- Mechanical stability

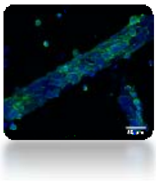


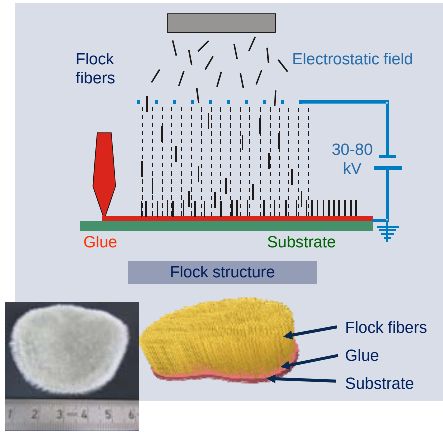
Chitosan scaffolds for cartilage regeneration (3)

Flock process

- Single component system:
- Chitosan:
  - Substrate
  - Glue
  - Short fibers
- Deformation stable
- Biocompatible



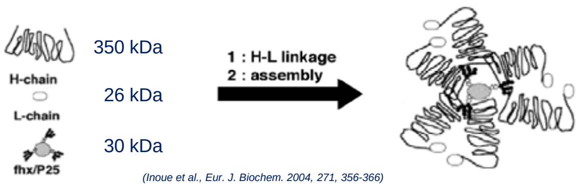




Natural fibers from biopolymers (silk 1)

Silk fibroin

- Source: Cocoons of larvae of the silkmoth *Bombyx mori*
- Silk thread consists of two main proteins: sericin (glue like protein) and fibroin the structural protein
- Fibroin elementary unit: H_6L_6P25, MW 2.3 MDa

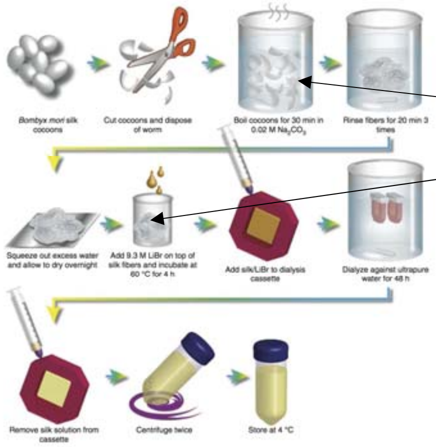


(Inoue et al., Eur. J. Biochem. 2004, 271, 356-366)

- Bioresorbable, non-allergic and biocompatible after complete removal of sericin (degumming)

Natural fibers from biopolymers (silk 2)

Regeneration of silk protein fibroin



Boiling of cocons

Incubation in 9.3 M LiBr

Harsh processing destroys native protein folding structure of silk protein

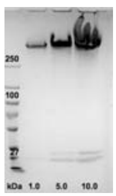
- requires refolding
- reduces quality
- 230kDa silk protein fragments

Adopted from Rockwood et al. 2011 Nature Protocols

Natural fibers from biopolymers (silk 3)

Processing of native silk fibroin

- Isolation of native silk fibroin solution from silk glands of silkworms.
- Pure native silk fibroin has a molecular weight of 2.3 MDa.
- Wet spinning and functionalization (Spintec Engineering GmbH).

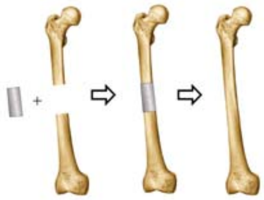


Silk gland dissection → Isolation of native fibroin → Biomimetic spinning and functionalization → Biospun fibers

Textile scaffolds for bone regeneration (1)

Bone defects

- Difficult therapeutic problem in reconstructive surgery
- Reconstructive surgery on the skeletal system needs bone substitutes
- Autologous grafts are the best method for healing bone defects
- Restrictions
  - Limited availability of autologous bone
  - Reasonableness of required additional surgery (comorbidity at donor site)

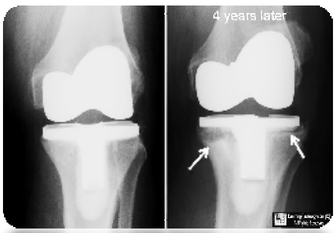


Source: https://www.mech.kuleuven.be/en/bme/research/images/ image_aurelie

Textile scaffolds for bone regeneration (2)

Artifical implants

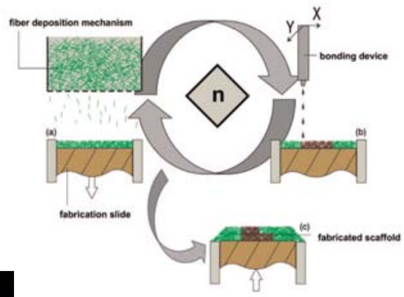
- Implants made of metal alloys have good strength and high long-term stability
- Disadvantages:
  - Lack of regeneration conveying capacity,
  - “Stress shielding"
  - Need to renewal especially in younger patients due to growth.

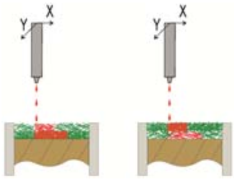


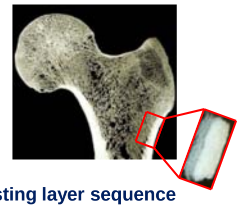
Generation of textile scaffolds by NSN Technology (1)

Net-Shape Nonwoven Technology (NSN)

- Additive manufacturing technology
- Short fiber layers
- Selective adhesive application and
- Layer-by-layer 3D construction
- Porosity of each layer can be adjusted by fiber length and fiber diameter
- **Any desirable geometry possible**





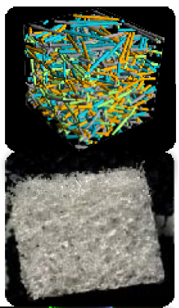


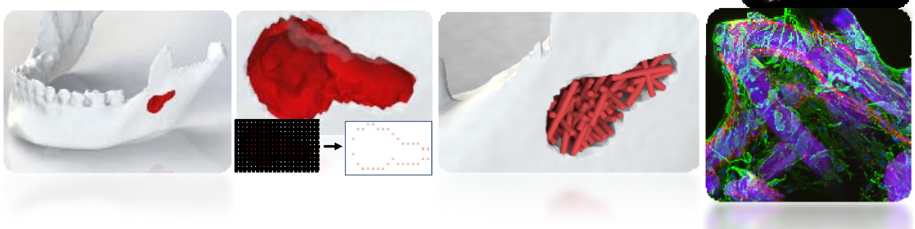
Pore-size gradients by adjusting layer sequence

NSN scaffolds for bone tissue regeneration (2)

Manufacturing patient specific implants

- Scanning patients' bone defect and modeling the scaffold geometry
- Slicing the CAD-file
- Generating machine tool paths via CAM
- Modelling NSN scaffold using GeoDict software

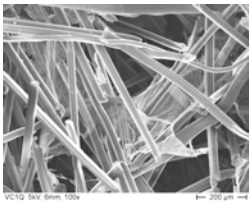


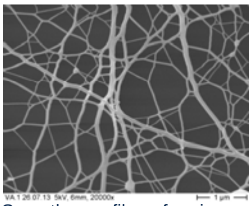


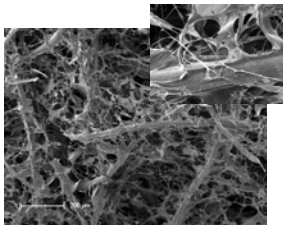
Additional functionalization of NSN scaffolds

Collagen coating using electrospinning

- Single component scaffold system is used (Chitosan)
- Process-integrated electrospinning is established
- Continuous functionalization with Nanofibers was achieved
- Degradation properties and immune responses remain unchanged

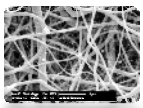

Continuous nanofiber functionalization

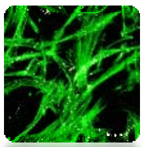

Smooth nanofibers forming networks


Collagen coated chitosan NSN scaffolds

Conclusion & Outlook

- Textile implants can be generated via multiple textile technologies, e.g.
  - Flock technology
  - NSN-technology
- The presented technologies allow generating textile implants with
  - Interconnected pores
  - Adjustable mechanical stability
  - Excellent cell reaction
  - Suitable degradation behavior
- Further research is focused on
  - Process automation
  - Adaption to other natural fibers and biomaterials
  - Conducting multiple tests on cell behavior and cell response





Many thanks for your kind attention