Natural Fibers and Innovative Biomaterials for Medical Applications

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Classification of textile fibers

Textile fibers

[Diagram showing categories of textile fibers: Natural fibers, Chemical fibers, Synthetic 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
  - Polyspropylene
Classification of medical textile products

- Healthcare and hygiene
- Non-implantable materials
- Extracorporeal devices
- Implantable materials

Healthcare and hygiene

- 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

Source: Bundesverband Medizintechnologie
Extracorporeal devices

Devices used to support the function of vital organs

- **Artificial kidneys (Dialyzers)**
  - remove waste products from 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

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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
  - Source: B Braun
  - Non-biodegradable: silk, polyester, polypropylene, polyanide, PTFE, polyethylene
  - Source: cp-medical
Implantable materials (2)

- Cardiovascular implants
  
  Vascular grafts: Polyester, PTFE  
  Stent grafts: Polyester, PTFE  
  Artificial heart valves: Polyester mechanical

Source: St. Jude Medical

- Biological

Source: Labcor

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)
- Biodegradable, 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

M. Wöltje  Bremen 2016  Page 11

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

M. Wöltje  Bremen 2016  Page 12
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/

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

Implant

- cells in hydrogel
- fibres
- substrate
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 silkworm *Bombyx mori*
- Silk thread consists of two main proteins: sericin (glue like protein) and fibroin the structural protein
- Fibroin elementary unit: $H_6L_6P_{25}$, MW 2.3 MDa

- Biore sorbable, 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

Adapted 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)

Textile scaffolds for bone regeneration (2)

Artificial 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](image1)
![Smooth nanofibers forming networks](image2)
![Collagen coated chitosan NSN scaffolds](image3)

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