Preparation and Characterization of an Oral Vaccine Formulation Using Electrosprayed Chitosan Microparticles

Chitosan particles loaded with the antigen ovalbumin (OVA) and the adjuvant Quil-A were produced by electrospray, using mixtures of water/ethanol/acetic acid as a solvent. Three different chitosans designed as HMC+70, HMC+85, and HMC+90 (called as 705010, 855010, and 905010) were tested and its efficacy to be used in oral vaccine delivery applications was investigated. The morphology, size, and zeta potential of the produced particles were investigated, together with the encapsulation efficiency and release of OVA from the three chitosan formulations. Moreover, the mucoadhesion and cytotoxicity of the chitosan microparticles was examined. All the three formulations with OVA and Quil-A were in the micrometer size range and had a positive zeta potential between 46 and 75 mV. Furthermore, all the three formulations displayed encapsulation efficiencies above 80% and the release of OVA over a period of 80 h was observed to be between 38 and 47%. None of the developed formulations exhibited high mucoadhesive properties, either cytotoxicity. The formulation prepared with HMC+70, OVA, and Quil-A had the highest stability within 2 h in buffer solution, as measured by dynamic light scattering. The electrosprayed formulation consisting of HMC+70 with OVA and Quil-A showed to be the most promising as an oral vaccine system.
Development of electrosprayed mucoadhesive chitosan microparticles

The efficacy of chitosan (CS) to be used as drug delivery carrier has previously been reported. However, limited work has been pursued to produce stable and mucoadhesive CS electrosprayed particles for oral drug delivery, which is the aim of this study. Various CS types with different molecular weight (MW), degree of deacetylation (DD), and degree of polymerization (DP) were assessed. In addition, the effect of the solvent composition was also investigated. Results showed that stable CS electrosprayed particles can be produced by dissolving 3% w/v of low MW CS in mixtures of aqueous acetic acid and ethanol (50/50% v/v). The stable CS particles displayed diameters of approximately 1 μm as determined by dynamic light scattering. The zeta potential of these particles was found to be approximately 40 mV confirming the mucoadhesion properties of these CS electrosprayed particles and its potential to be used as drug delivery carrier.

General information

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Organisations: National Food Institute, Research Group for Nano-Bio Science, Department of Micro- and Nanotechnology, Nanoprobes, University of Münster
Contributors: Moreno, J. A. S., Mendes, A. C., Stephansen, K., Engwer, C., Goycoolea, F. M., Boisen, A., Nielsen, L. H., Chronakis, I. S.
Pages: 240-247
Publication date: 2018
Peer-reviewed: Yes
Development of carbohydrate-based nano-microstructures loaded with fish oil by using electrohydrodynamic processing

The encapsulation of fish oil in carbohydrate-based nanomicrostructures obtained by electrohydrodynamic processing was investigated. Solutions of pullulan 200 kDa (15 wt%) and dextran 70 kDa (25 wt%) presented appropriate properties (viscosity, surface tension and conductivity) to allow the formation of nano-microfibers and nano-microcapsules, respectively. Although dextran 70 kDa exhibited antioxidant properties in solution, their capsules produced at lab and pilot-plant scales showed a low oxidative stability both with emulsified and neat oil. Phase separation of solution and opened capsules indicated a poor interaction between dextran and fish oil, which suggested that further optimization of the electrospaying solution is necessary. On the contrary, pullulan solutions were optimized to work even at pilot-plant scale. In this case, in spite of the prooxidant effect of pullulan in solution, oxidatively stable pullulan fibers (PV = 12.3 ± 0.9 meq O2/kg and 15.5 ± 5.1 ng/g of 1-penten-3-ol) were obtained when oil was incorporated as neat oil and when producing batches during short time (30 or 10 min). This superior oxidative stability when compared to fibers with emulsified oil is mainly attributed to a higher fish oil entrapment and to the location of the oil in large bead-structures with a reduced specific surface area. These results indicated the feasibility of producing omega-3 nanodelivery systems by encapsulating fish oil in pullulan nano-microfibers using electrospinning processing.

General information

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Organisations: National Food Institute, Research Group for Bioactives – Analysis and Application, Research Group for Nano-Bio Science, Center for Electron Nanoscopy, Technical University of Denmark, CSIC
Contributors: García Moreno, P. J., Özdemir, N., Boutrup Stephansen, K., Mateiu, R. V., Echegoyend, Y., Lagaron, J., Chronakis, I. S., Jacobsen, C.
Pages: 273-285
Publication date: 2017
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Electrospinning of food proteins and polysaccharides

Nano-microfibrinous structures of biopolymers with a wide range of compositions, morphologies, mechanical properties and bioactivities could be developed using electrospinning technology. This review focuses on the processing, properties, functionalization and potential applications of electrospun biopolymers. Biopolymers include proteins (gelatin, collagen, elastin, silk, soy zein, gliadin, hordein, amaranth, casein, wheat, whey, marine sources proteins), and polysaccharides (chitosan, starch, alginate, cellulose and cellulose derivatives, pullulan, dextran, cyclodextrins).

General information

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Contributors: Mendes, A. C. L., Boutrup Stephansen, K., Chronakis, I. S.
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Innovative Methods and Applications in Mucoadhesion Research

The present review is aimed at elucidating relatively new aspects of mucoadhesion/mucus interaction and related phenomena that emerged from a Mucoadhesion workshop held in Munster on 2–3 September 2015 as a satellite event of the ICCC 13th—EUCHIS 12th. After a brief outline of the new issues, the focus is on mucus description, purification, and mucus/mucin characterization, all steps that are pivotal to the understanding of mucus related phenomena and the choice of the correct mucosal model for in vitro and ex vivo experiments, alternative bio/mucomimetic materials are also presented. Then a selection of preparative techniques and testing methods are described (at molecular as well as micro and macroscale) that may support the pharmaceutical development of mucus interactive systems and assist formulators in the scale-up and industrialization steps. Recent applications of mucoadhesive systems (including medical devices) intended for different routes of administration (oral, gastrointestinal, vaginal, nasal, ocular, and intravesical) and for the treatment of difficult to treat pathologies or the alleviation of symptoms are described.

General information
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Organisations: Department of Mechanical Engineering, Materials and Surface Engineering, Research Group for Nano-Bio Science, National Food Institute, University of Leeds, Friedrich-Alexander University Erlangen-Nürnberg, University of Pavia, University of Oslo, S.I.I.T. S.r.l Pharmaceutical & Health Food Supplements, University of Copenhagen
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Web of Science (2016): Impact factor 3.238
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Scopus rating (2015): CiteScore 3.8 SJR 1.198 SNIP 0.89
Web of Science (2015): Impact factor 3.68
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.87 SJR 1.316 SNIP 0.974
Web of Science (2014): Impact factor 3.851
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Scopus rating (2013): CiteScore 4.05 SJR 1.393 SNIP 1.006
Web of Science (2013): Impact factor 3.65
ISI indexed (2013): ISI indexed yes
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Electrospraying Chitosan Particles for Oral Vaccine Delivery

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Electrospraying particles for loading into microcontainers for drug delivery

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Organisations: National Food Institute, Research Group for Nano-Bio Science, Department of Micro- and Nanotechnology, Nanoprobes
Contributors: Sevilla Moreno, J. A., Boutrup Stephansen, K., Nielsen, L. H., Chronakis, I. S., Boisen, A.
Publication date: 2016
Encapsulation of fish oil in nanofibers by emulsion electrospinning: Physical characterization and oxidative stability

The encapsulation of fish oil in poly(vinyl alcohol) (PVA) nanofibers by emulsion electrospinning was investigated. Independently of the emulsifier used, whey protein isolate (WPI) or fish protein hydrolysate (FPH), PVA concentration had a high influence on fiber morphology. Fibers without bead defects were only produced for solutions with 10.5% (w/w) PVA, which presented sufficient number of polymer chain entanglements. On the other hand, increasing oil load from 1.5 to 3% (w/w) resulted in fibers with larger diameters containing spindle-like enlargements interspersed. High omega-3 encapsulation efficiency (92.4 ± 2.3%) was obtained for fibers produced from 10.5% (w/w) PVA-5% (w/w) emulsion blend stabilized with WPI, resulting in an oil load capacity of 11.3 ± 0.3%. Moreover, the encapsulated oil was randomly distributed as small droplets inside the fibers. However, the electrospun fibers presented a higher content of hydroperoxides and secondary oxidation products (e.g. 1-penten-3-ol, hexanal, octanal and nonanal) compared to emulsified and unprotected fish oil.
Interactions between Surfactants in Solution and Electrospun Protein Fibers: Effects on Release Behavior and Fiber Properties

Intermolecular interaction phenomena occurring between endogenous compounds, such as proteins and bile salts, and electrospun compounds are so far unreported, despite the exposure of fibers to such biorelevant compounds when applied for biomedical purposes, e.g., tissue engineering, wound healing, and drug delivery. In the present study, we present a systematic investigation of how surfactants and proteins, as physiologically relevant components, interact with insulin-loaded fish sarcoplasmic protein (FSP) electrospun fibers (FSP-Ins fibers) in solution and thereby affect fiber properties such as accessible surface hydrophilicity, physical stability, and release characteristics of an encapsulated drug. Interactions between insulin-loaded protein fibers and five anionic surfactants (sodium taurocholate, sodium taurodeoxycholate, sodium glycocholate, sodium glycodeoxycholate, and sodium dodecyl sulfate), a cationic surfactant (benzalkonium chloride), and a neutral surfactant (Triton X-100) were studied. The anionic surfactants increased the insulin release in a concentration-dependent manner, whereas the neutral surfactant had no significant effect on the release. Interestingly, only minute amounts of insulin were released from the fibers when benzalkonium chloride was present. The FSP-Ins fibers appeared dense after incubation with this cationic surfactant, whereas high fiber porosity was observed after incubation with anionic or neutral surfactants. Contact angle measurements and staining with the hydrophobic dye 8-anilino-1-naphthalenesulfonic acid indicated that the FSP-Ins fibers were hydrophobic, and showed that the fiber surface properties were affected differently by the surfactants. Bovine serum albumin also affected insulin release in vitro, indicating that also proteins may affect the fiber performance in an in vivo setting.

General information
Electrohydrodynamic processing is a straightforward and versatile encapsulation technique suitable for the production of nano-microstructures (NMS) (e.g. fibers and capsules) containing bioactive compounds. The process is very gentle and does not require the use of heat, avoiding deterioration of thermolabile active compounds such as fish oil. Moreover, encapsulates produced present a decreased size, which allows their incorporation into food systems without affecting product sensory qualities.

In this work, electrohydrodynamic processing and oxidative stability of NMS containing fish oil were investigated. For that purpose, three different biopolymers namely pullulan, dextran and whey protein concentrate (WPC) were evaluated as encapsulating materials. First, the influence of biopolymer concentration on the physical properties (e.g. viscosity, conductivity and surface tension) of the biopolymer solutions and on the morphology of NMS was assayed. Secondly, the oxidative stability of the biopolymer solutions containing emulsified fish oil during storage (14 days at 40 °C) and of NMS loaded with fish oil (e.g. pullulan fibers and dextran and WPC capsules) was determined. Finally, to improve the oxidative status of the NMS, pullulan fibers, dextran capsules and WPC capsules were produced by adding neat fish oil instead of emulsified fish oil to the biopolymer solutions. These latter NMS presented a higher oxidative stability, which may be due to a better entrapment of the fish oil into biopolymer encapsulates.

Solution-blowing was adopted to form nanofibers from fish sarcoplasmic proteins (FSPs). Nanofiber mats containing different weight ratios (up to 90/10) of FSP in the FSP/nylon 6 blended nanofibers were formed from formic acid solutions, and compared to electrospun fibers made from the same solutions. The nanofiber mats produced by the two methods were characterized in terms of FSP content, fiber diameter distribution, fiber mat porosity, and mass of the fibers collected. The mechanical strength of the solution-blown fibers was also measured. Overall, fibers made by the two techniques were similar, but with some exceptions. The fiber diameter of the electrospun fibers was slightly smaller than those made using solution-blowing, however in both cases the fiber diameter increased with increasing FSP content. Interestingly, for uniform fibers the stretchability of the fibers increased with increasing FSP content, indicated by an increased strain at rupture. Moreover, the mechanical tests showed that up to 50% of nylon 6 could be replaced with FSP without compromising the mechanical properties, compared to pure nylon 6 nanofibers. Comparison of the yield showed that the production rate of solution-blowing was increased 30-fold in relation to electrospinning. Overall, this study reveals FSP as an interesting biopolymeric alternative to synthetic polymers, and the introduction of FSP to nylon 6 provides a composite with controlled properties.
Bioactive protein-based nanofibers interact with intestinal biological components resulting in transepithelial permeation of a therapeutic protein

Proteins originating from natural sources may constitute a novel type of material for use in drug delivery. However, thorough understanding of the behavior and effects of such a material when processed into a matrix together with a drug is crucial prior to further development into a drug product. In the present study the potential of using bioactive electrospun fish sarcoplasmic proteins (FSP) as a carrier matrix for small therapeutic proteins was demonstrated in relation to the interactions with biological components of the intestinal tract. The inherent structural and chemical properties of FSP as a biomaterial facilitated interactions with cells and enzymes found in the gastrointestinal tract and displayed excellent biocompatibility. More specifically, insulin was efficiently encapsulated into FSP fibers maintaining its conformation, and subsequent controlled release was obtained in simulated intestinal fluid. The encapsulation of insulin into FSP fibers provided protection against chymotrypsin degradation, and resulted in an increase in insulin transport to around 12% without compromising the cellular viability. This increased transport was driven by interactions upon contact between the nanofibers and the Caco-2 cell monolayer leading to the opening of the tight junction proteins. Overall, electrospun FSP may constitute a novel material for oral delivery of biopharmaceuticals.
Design and characterization of self-assembled fish sarcoplasmic protein-alginate nanocomplexes

Macrostructures based on natural polymers are subject to large attention, as the application range is wide within the food and pharmaceutical industries. In this study we present nanocomplexes (NCXs) made from electrostatic self-assembly
between negatively charged alginate and positively charged fish sarcoplasmic proteins (FSP), prepared by bulk mixing. A concentration screening revealed that there was a range of alginate and FSP concentrations where stable NCXs with similar properties were formed, rather than two exact concentrations. The size of the NCXs was 293 +/- 3 nm, and the zeta potential was -42 +/- 0.3 mV. The NCXs were stable in water, gastric buffer, intestinal buffer and HEPES buffered glycoside, and at all pH values from 2 to 9 except pH 3, where they aggregated. When proteolytic enzymes were present in the buffer, the NCXs were degraded. Only at high concentrations the NCXs caused a decreased viability in HeLa and U2OS cell lines. The simple processing procedure and the high stability of the NCXs, makes them excellent candidates for use in the food and pharmaceutical industry. (C) 2015 Elsevier B.V. All rights reserved.
Development and characterization of nano-micro structures as carrier for bioactive compounds

New biopolymers are in high demand due to their excellent biocompatibility, biodegradability, and natural origin. In this PhD project, water soluble fish sarcoplasmic proteins (FSPs) from the North Atlantic cod (Gadus morhua) have been studied as a potential new biopolymer for development of nano-micro structures. Two kinds of nano-micro structures have been explored: electrospun fibers (Paper I, Paper II, and Paper III) and self-assembled nanocomplexes (NCXs) (Paper IV). FSP was observed to be highly suitable for electrospinning. The fiber morphology varied significantly with FSP concentration, from beads to fibers. Moreover, the morphology within one FSP concentration was very diverse, as evident from the fiber diameter ranging from nanosized to micronsized (Paper I). The size distribution of the fiber diameter was decreased by removal of low molecular weight compounds (< 8 kDa). Despite the water-soluble nature of FSP, the fibers were insoluble in aquatic media (except at high sodium dodecyl sulfate concentrations) (Paper I, Paper II, and Paper III). Contact angle measurements indicated that the FSP fibers were hydrophobic, and incubation with the hydrophobic dye 8-anilino-1-naphthalenesulfonic acid (ANS), confirmed the presence of hydrophobic pockets inside or at the surface of the fibers (Paper III). Interestingly, the physical properties of the fibers significantly changed after incubation with surfactants as well as with the surfactant type; the FSP fibers were dense after incubation with cationic surfactant, whereas inner porosity of the fibers was observed after incubation with anionic or neutral surfactants. Moreover, the contact angle changed from being large for anionic surfactants, to being small for neutral and cationic surfactants. Lastly, the cationic and neutral surfactants decreased the amount of hydrophobic pockets available for dye interaction (Paper III). The inherent property of FSP as consumed food made the fibers degradable by proteolytic enzymes, and the degradation products were observed to inhibit the diabetes related enzyme dipeptidyl peptidase-4 (Paper I). The FSP fibers showed potential as carrier system for delivery of drugs, bioactive agents, and nutraceuticals. The dipeptide Ala-Trp, rhodamine B, or insulin was encapsulated into the fibers, and the release was studied in biorelevant media (Paper I, Paper II, and Paper III). Release of Ala-Trp was slightly decreased in gastric environments compared to pH 6.8, whereas release of insulin was independent of pH. Instead, insulin release was affected by the presence of biorelevant compounds, i.e. surfactants and proteins encountered in the intestinal system. Anionic surfactants increased the release of insulin from FSP fibers in a dose-dependent manner, neutral surfactants had no effect, and cationic surfactants decreased the insulin release to negligible amounts (Paper III). Encapsulation of insulin into the FSP fibers provided protection against chymotrypsin degradation, and interactions between the fibers and epithelial cells led to opening of the tight junction, which promoted an increased transepithelial transport of insulin without compromising cellular viability (Paper II). The FSPs were also suitable for development of self-assembled NCXs. By gentle bulk mixing of FSP and alginate, stable NCXs were formed (Paper IV). The NCXs were 293 ± 3 nm and anionic (zeta potential was −42 ± 0.3 mV). The zeta potential as a function of pH revealed that the NCX surface was dominated by alginate. The NCXs were stable in biorelevant media, and at pH values from 2 to 9, except at pH 3 where the NCXs aggregated. Proteolytic enzymes were capable of degrading the NCXs. The viability of HeLa and U2OS cell lines was only decreased by high concentrations of NCXs (Paper IV). It was concluded
that FSP is highly suitable for the production of functional nano-micro structures for food and biomedical applications qua the ability of the FSPs to form electrospun fibers and self-assembled NCXs. The inherent properties of FSP of being biocompatible, biodegradable, and bioactive further promote the use of FSP as a biopolymer.

**General information**

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Organisations: National Food Institute, Research Group for Food Production Engineering, Research Group for Nano-Bio Science
Contributors: Boutrup Stephansen, K., Jessen, F., Chronakis, I. S.
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**Interactions between electrospun fibers and the surrounding biological environment; cells and small molecules**

**General information**

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Organisations: National Food Institute, Research Group for Nano-Bio Science, Research Group for Food Production Engineering, University of Copenhagen
Contributors: Stephansen, K., García-Díaz, M., Jessen, F., Nielsen, H. M., Chronakis, I. S.
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**Oxidative stability of electrospun nanofibers loaded with fish oil**

**General information**

State: Published
Organisations: National Food Institute, Research Group for Bioactives – Analysis and Application, Research Group for Nano-Bio Science, University of Granada
Contributors: García Moreno, P. J., Boutrup Stephansen, K., Guadix, A., Guadix, E. M., Chronakis, I. S., Jacobsen, C.
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Production of omega-3 nanodelivery systems by emulsion electrospinning

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Contributors: García Moreno, P. J., van der Kruijs, J., Boutrup Stephansen, K., Chronakis, I. S., Jacobsen, C.
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Research output: Research - peer-review › Conference abstract in proceedings – Annual report year: 2016

Bioactive electrospun fish sarcoplasmic proteins as a drug delivery system
Nano-microfibers were made from cod (Gadus morhua) sarcoplasmic proteins (FSP) (Mw< 200 kDa) using the electrospinning technique. The FSP fibers were studied by scanning electron microscopy, and the fiber morphology was found to be strongly dependent on FSP concentration. Interestingly, the FSP fibers were insoluble in water. However, when exposed to proteolytic enzymes, the fibers were degraded. The degradation products of the FSP fibers proved to be inhibitors of the diabetes-related enzyme DPP-IV. The FSP fibers may have biomedical applications, among others as a delivery system. To demonstrate this, adipeptide (Ala-Trp) was encapsulated into the FSP fibers, and the release properties were investigated in gastric buffer and in intestinal buffer. The release profile showed an initial burst release, where 30% of the compound was released within the first minute, after which an additional 40% was released (still exponential) within the next 30 min (gastric buffer) or 15 min (intestinal buffer). The remaining 30% was not released in the timespan of the experiment.© 2014 Elsevier B.V. All rights reserved.

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Contributors: Stephansen, K., Chronakis, I. S., Jessen, F.
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Web of Science (2015): Indexed yes
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Scopus rating (2014): CiteScore 4.53 SJR 1.21 SNIP 1.56
Web of Science (2014): Impact factor 4.152
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Electrospun fish protein fibers as a biopolymer-based carrier – implications for oral protein delivery

Purpose: Protein-based electrospun fibers have emerged as novel nanostructured materials for tissue engineering and drug delivery due to their unique structural characteristics, biocompatibility and biodegradability. The aim of this study was to explore the use of electrospun fibers based on fish sarcoplasmic proteins as an oral delivery platform for biopharmaceuticals, using insulin as a model protein. Methods: Fish sarcoplasmic proteins (FSP) were isolated from fresh cod and electrospun into nanomicrofibers using insulin as a model payload. The morphology of FSP fibers was characterized using scanning electron microscopy (SEM), and the conformational stability of insulin was confirmed by circular dichroism (CD). The in vitro release and enzymatic degradation of encapsulated insulin was measured in different buffers and quantified using RP-HPLC. The permeability of released insulin across differentiated Caco-2 cell monolayers was followed by RP-HPLC and ELISA, and the transepithelial electrical resistance (TEER) was measured before and after the experiment. Cell viability was assessed by the MTS/PMS assay. Results: Insulin was encapsulated in the electrospun FSP fibers with high efficiency, high loading and without any effect on fiber morphology. Release of insulin in vitro was 75% after 3 h in simulated intestinal fluid. The secondary structure of insulin was preserved after release, and insulin functionality was confirmed by ELISA. Insulin permeability across Caco-2 cell monolayers was significantly enhanced when administered encapsulated in FSP fibers. The TEER was decreased after 4 h incubation, and no negative effect on
cell viability was observed at any time. Conclusion: In this work we present electrospun FSP fibers as a novel oral drug delivery system for biopharmaceuticals. The electrospinning process did not affect the functionality of the encapsulated insulin and it provided controlled release kinetics. The epithelial permeability enhancing effect and biocompatibility of the FSP fibers provide evidence for further investigating protein-based electrospun nanofibers for delivery of proteins and peptides.

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Contributors: Boutrup Stephansen, K., García-Díaz, M., Jessen, F., Chronakis, I. S., Nielsen, H. M.
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Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Research output: Research - peer-review; Conference abstract in proceedings – Annual report year: 2014

Identification of catechols as histone-lysine demethylase inhibitors
Identification of inhibitors of histone-lysine demethylase (HDM) enzymes is important because of their involvement in the development of cancer. An ELISA-based assay was developed for identification of inhibitors of the HDM KDM4C in a natural products library. Based on one of the hits with affinity in the low μM range (1, a catechol), a subset of structurally related compounds was selected and tested against a panel of HDMs. In this subset, two inhibitors (2 and 10) had comparable affinities towards KDM4C and KDM6A but no effect on PHF8. One inhibitor restored H3K9me3 levels in KDM4C transfected U2-OS cells.

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Scopus rating (2016): CiteScore 3.48 SJR 1.967 SNIP 0.89
Web of Science (2016): Impact factor 3.623
Web of Science (2016): Indexed yes
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Scopus rating (2015): CiteScore 3.49 SJR 2.022 SNIP 0.923
Web of Science (2015): Impact factor 3.519
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.19 SJR 1.859 SNIP 0.87
Web of Science (2014): Impact factor 3.169
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.71 SJR 2.356 SNIP 0.982
Preparing poly (caprolactone) micro-particles through solvent-induced phase separation

Poly (caprolactone) (PCL) particles with the size distribution from 1 to 100 μm were prepared through solvent-induced phase separation, in which polyvinyl-alcohol (PVA) was used as the matrix-forming polymer to stabilize PCL particles. The cloud point data of PCL-acetone-water was determined by the titration method. PCL-acetone and PVA-water solutions, PCL-PVA gel, and PCL particles suspension were recorded by a digital camera. The morphology of PCL-PVA suspension and PCL particles were observed by optical microscopy and scanning electron microscopy, respectively. The size distribution of PCL particles was investigated by a particle size analyzer. Results from differential scanning calorimeter indicated that the main interaction between PCL and PVA were mediated through hydrogen bonding.

General information
Development and characterization of nano-microstructures as carrier for bioactive compounds
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Jessen, F., Main Supervisor, National Food Institute
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Sarmento, B., Examiner
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Award relations: Development and characterization of nano-microstructures as carrier for bioactive compounds
Project: PhD

FENAMI: Functional Electrospun Nanostructures and Microstructures for Food and Bioengineering Applications
The objectives of this project is to generate the scientific and technological basis to: (i) develop new nano-microcarrier systems for bioactive compounds using electrospun nano-microstructures for their immobilization, (ii) develop new nano-microdelivery systems utilizing enzyme functionality and molecular imprinted polymers for controlled delivery/release of bioactives, (iii) study the structural and functional properties of nano-microstructures (NMS) as novel components of food and bioengineered products, (iv) evaluate their bioavailability and degradation/digestion in-vitro and in-vivo. The overall aim is to create new functional systems that have a potential usage in foods/healthy foods, as nutritional supplements, as pharmaceutical products and for a range of other bioengineering applications. The project’s ambition is also to contribute to research training in research institutes and industrial companies as well as education of industrial employees. We expect that the obtained knowledge will strengthen the Danish industry's potential to emerging nano-microtechnologies and technologies of bioactives.
Chronakis, I. S., Project Manager, National Food Institute, Division of Industrial Food Research
Meyer, A. S., Project Participant, Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering
Qvortrup, K., Project Participant, University of Copenhagen, Biomedical Institute
Ye, L., Project Participant, University of Lund, Pure and Applied Biochemistry
Goycoolea, F., Project Participant, Westphalian Wilhelm's University of Münster, Institute for Plant Biology and Biotechnology
Nielsen, K. A., Project Participant, Fertin A/S
Jessen, F., Project Participant, National Food Institute, Division of Industrial Food Research
Boutrup Stephansen, K., Project Participant, National Food Institute, Division of Industrial Food Research
Jørgensen, L., Project Participant, National Food Institute, Division of Industrial Food Research
Mendes, A. C. L., Project Participant, National Food Institute, Division of Industrial Food Research
Danish Research Council/Programme Commission for "Sundhed, Fædevær og Velfærd": DKK14,866,637.00
01/05/2011 → 31/10/2015
Collaborators: Westphalian Wilhelm's University of Münster, Institute for Plant Biology and Biotechnology, University of Lund, Pure and Applied Biochemistry, University of Copenhagen, Biomedical Institute, Fertin A/S
Award relations: Functional Electrospun Nanostructures and Microstructures for Food and Bioengineering Applications
Project: Research
Activities:

**Mucoadhesion: Principles, Testing Methods and Applications**  
*Period: 2 Sep 2015 → 3 Sep 2015*  
Karen Boutrup Stephansen (Invited speaker)  
National Food Institute  
Research Group for Nano-Bio Science

**Related event**  
**Mucoadhesion: Principles, Testing Methods and Applications**  
*02/09/2015 → 03/09/2015*  
Münster, Germany  
Activity: Talks and presentations › Conference presentations

**International Conference of the European Chitin Society**  
*Period: 30 Aug 2015 → 2 Sep 2015*  
Karen Boutrup Stephansen (Participant)  
National Food Institute  
Research Group for Nano-Bio Science

**Related event**  
**International Conference of the European Chitin Society**  
*30/08/2015 → 02/09/2015*  
Münster, Germany  
Activity: Attending an event › Participating in or organising a conference

**2015 Controlled Release Society Annual Meeting**  
*Period: 26 Jul 2015 → 29 Jul 2015*  
Karen Boutrup Stephansen (Participant)  
National Food Institute  
Research Group for Nano-Bio Science

**Related event**  
**2015 Controlled Release Society Annual Meeting**  
*26/07/2015 → 29/07/2015*  
Edinburgh, United Kingdom  
Activity: Attending an event › Participating in or organising a conference

**Annual Meeting of the Controlled Release Society - Nordic**  
*Period: 25 Jul 2015*  
Karen Boutrup Stephansen (Speaker)  
National Food Institute  
Research Group for Nano-Bio Science

**Related event**  
**Annual Meeting of the Controlled Release Society - Nordic**  
*25/07/2015 → 25/07/2015*  
Edinburgh, Denmark  
Activity: Talks and presentations › Conference presentations

**Composite, nanofabrication, food and pharma related application and packaging, controlled release**  
*Period: 25 Mar 2015 → 27 Mar 2015*
Karen Boutrup Stephansen (Speaker)
National Food Institute
Research Group for Nano-Bio Science

Related event

Composite, nanofabrication, food and pharma related application and packaging, controlled release
25/03/2009 → 27/03/2015
Novi Sad, Serbia
Activity: Talks and presentations › Conference presentations

2014 AAPS Annual Meeting and Exposition
Period: 1 Nov 2014 → 6 Nov 2014
Karen Boutrup Stephansen (Participant)
National Food Institute
Division of Industrial Food Research

Description
Presentation of poster

Related event

2014 AAPS Annual Meeting and Exposition
02/11/2014 → 06/11/2014
San Diego, CA, United States
Activity: Attending an event › Participating in or organising a conference

Electrospinning: Exploiting Electrohydrodynamics and Rheology for the Control of Nanofiber Structural and Physical Properties
Period: 1 Sep 2014
Karen Boutrup Stephansen (Participant)
National Food Institute

Description
Electrospinning: Exploiting Electrohydrodynamics and Rheology for the Control of Nanofiber Structural and Physical Properties

Related event

Electrospinning: Exploiting Electrohydrodynamics and Rheology for the Control of Nanofiber Structural and Physical Properties
01/09/2014 → 05/09/2014
Udine, Italy
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

3rd International Conference on Electrospinning
Karen Boutrup Stephansen (Participant)
National Food Institute

Description
Presentation of a poster

Related event

3rd International Conference on Electrospinning
04/08/2014 → 07/08/2014
San Francisco, CA, United States
Activity: Attending an event › Participating in or organising a conference
5th International Conference on Advanced Nano Materials  
**Period:** 2 Jul 2014 → 4 Jul 2014  
Karen Boutrup Stephansen (Speaker)  
National Food Institute

**Description**  
Oral presentation at "International Conference on Advanced Nano Materials"

**Related event**

5th International Conference on Advanced Nano Materials  
**Period:** 02/07/2014 → 04/07/2014  
Aveniro, Portugal  
Activity: Talks and presentations › Conference presentations

Electrospinning, Principles, Possibilities and Practice 2013  
**Period:** 5 Dec 2013 → 6 Dec 2013  
Karen Boutrup Stephansen (Speaker)  
National Food Institute

**Description**  
Presentation of the paper: Bioactive electrospun fish sarcoplasmic proteins as a drug delivery system  
Oral presentation at "Electrospinning: Principles, Possibilities and Practice" in London, UK

**Related event**

Electrospinning, Principles, Possibilities and Practice 2013  
**Period:** 05/12/2013 → 06/12/2013  
London, United Kingdom  
Activity: Talks and presentations › Conference presentations