Electrospun nonwovens for non-invasive transcutaneous piezoelectric muscle stimulation

J. Drexler[1], L. Tilch[1], D. Obed[2], M. Oelerich[2], I. Morales[3], M. Mueller[1], N. Krezdorn[2,4], B. Glasmacher[1]

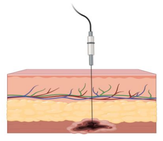
[1] Institute for Multiphase Processes, Leibniz University Hannover
[2] Department of Plastic, Aesthetic, Hand and Reconstructive Surgery, Hannover Medical School
[3] Institute for Inorganic Chemistry, Leibniz University Hannover
[4] Department of Plastic and Breast Surgery, Zealand University Hospital

Leibniz Universität Hannover

1 Motivation



Functional electrical stimulation is necessary for preventing muscle atrophy in patients with traumatic nerve injuries.

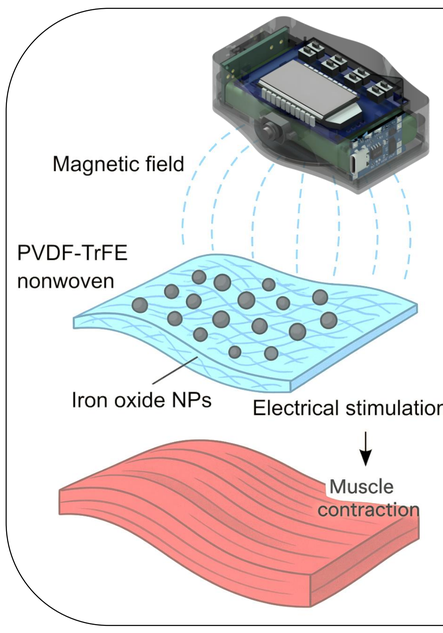


The existing technologies are constrained to superficial muscles (surface electrodes) or carry the risk of infection and tissue damage (invasive stimulation).



We intend to use an electrospun, piezoelectric nonwoven with embedded magnetic nanoparticles (NPs) for stimulation by an external magnetic field.

2 Stimulation concept

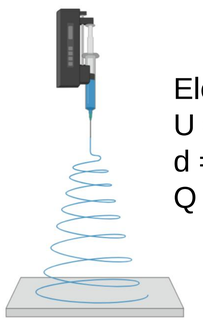


Wearable stimulator for generation of an oscillating magnetic field.



16-20% PVDF-TrFE
1.6-2% Fe(III)-oxide
DMF/acetone

Piezoelectric electrospun nonwoven with embedded magnetic NPs converts deformation into voltage.

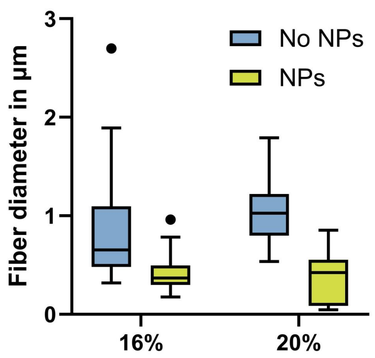


Electrospinning
U = 23 kV
d = 20 cm
Q = 3 ml/h

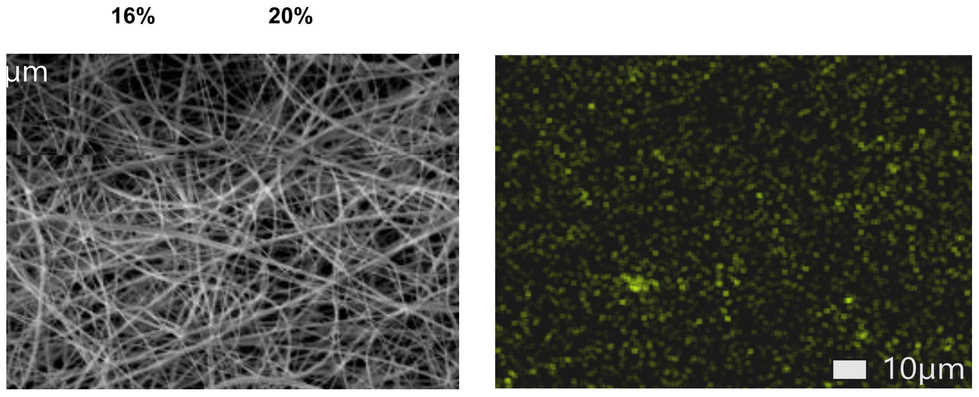
The voltage generated by the nonwoven wrapped around the muscle triggers muscle contraction.

3 Characterization

Morphology and nanoparticle dispersion

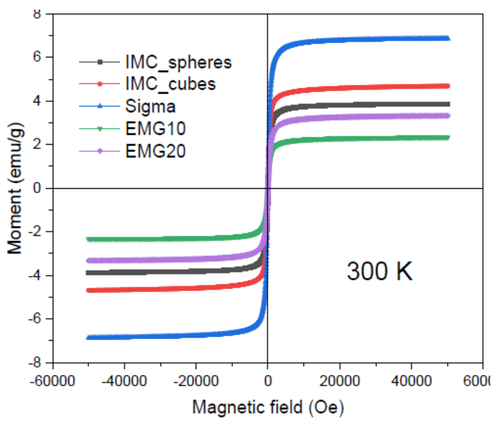


The presence of Fe(III)-oxide nanoparticles decreases fiber diameter in solution of 16w.-% and 20w.-% PVDF-TrFE. The increased charge carrier density causes increased bending instabilities and polymer jet stretching during electrospinning. The process stability was unaffected by the presence of NPs.

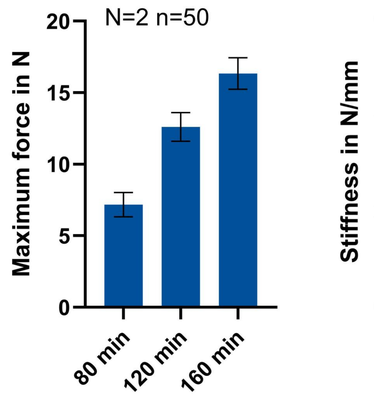


Ultrasonication was employed prior to the electrospinning process to disperse the agglomerates of NPs in the PVDF-TrFE solution. EDX for iron (green, right side) confirmed homogenous distribution of Fe(III)-oxide NPs in electrospun nonwovens.

Magnetic and mechanical properties

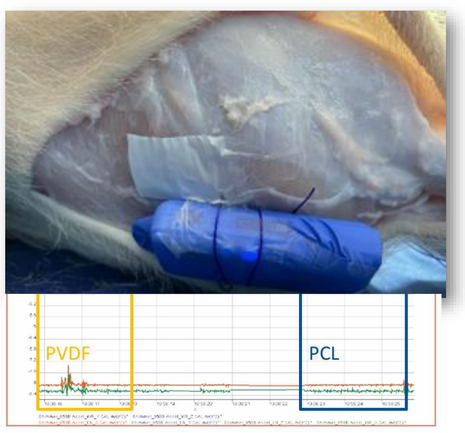


Various shapes and sizes of iron(III) oxide NPs were tested based on their magnetic properties and processability. Of all the NPs evaluated, iron(III) oxide nanopowder (Sigma) exhibited the lowest tendency to agglomerate and the highest magnetic moment.



Nonwovens of various thicknesses, corresponding to different spinning durations, were produced. The produced nonwovens were analyzed using a dynamic tensile test with a sinusoidal displacement over 50 cycles. The maximum forces measured increased with the spinning duration. Initially, the stiffness of the nonwovens increased as well, but decreased for a spinning duration of 160 minutes. Increased delamination of the individual layers of the nonwovens was observed for the highest spinning duration.

Proof of concept



The fundamental functionality of the approach was validated in a porcine cadaver model. A measurable voltage was generated in the muscle using a magnet, whereas no voltage was measurable for the non-piezoelectric PCL control fiber mesh.



Implantation and stitching was evaluated for various spinning durations in a murine cadaver model (M. gastrocnemius). The optimal surgical handling was attained for nonwovens with a 120-minute spinning duration, which demonstrated resistance to tearing and suitability for stitching.

4 Conclusions and Outlook

Conclusions

Successful manufacturing of piezoelectric, magnetically deformable nonwoven by electrospinning.

Magnetite NPs are integrable into electrospun nonwovens, resulting in a uniform distribution with few agglomerates.

The proof of concept was successful in demonstrating implantability and function in murine and porcine cadaver models.

Outlook

Measurement of generated voltage under given deformation.

Investigate influence of electrospinning parameters on piezoelectric properties.

Developing a method to measure muscle activity in cadaver studies.

Contact:
Jan Drexler, M.Sc.
Institute for Multiphase Processes
Leibniz University Hannover
An der Universität 1 | D-30823 Garbsen | Germany
Email: drexler@imp.uni-hannover.de
Web: http://www.imp.uni-hannover.de



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