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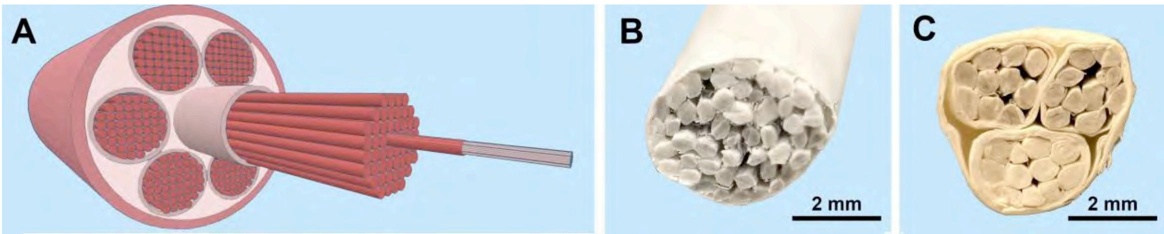
MORPHOLOGICALLY BIO-INSPIRED HIERARCHICAL NYLON 6,6 ELECTROSPUN STRUCTURES FOR SOFT-ROBOTICS APPLICATIONS

ALBERTO SENSINI[1], CARLO GOTTI[1], MARIA LETIZIA FOCARETE[2], CHIARA GUALANDI[2], ALEXANDER KAO[3], GIANLUCA TOZZI[3], LUCA CRISTOFOLINI[1], ANDREA ZUCCHELLI[1]

[1]*Dept. of Industrial Engineering, University of Bologna, 40131, Bologna, (IT) - Email: carlo.gotti2@unibo.it*
[2]*Dept.* of Chemistry 'G. Ciamician', *University of Bologna, 40126, Bologna (IT)*
[3]*Zeiss Global Centre, School of Mechanical and Design Engineering, University of Portsmouth, PO1 3DJ, Portsmouth (UK)*

Abstract

The last decades have seen an increasing attention on a new, ground-breaking field, soft-robotics [1]. Soft-robotics tries to overcome the limits of classical rigid robots, developing bioinspired structures with compliant and soft materials. Skeletal muscle is a biological, hierarchically arranged fibrous structure (Fig A), suitable to inspire innovative soft actuators. The possibility to mimic muscles and soft tissues has been demonstrated through the use of the electrospinning technique [2]. The aim of the present study was to develop and characterize innovative muscle-inspired, hierarchically arranged electrospun structures made of Nylon 6,6 for soft-robotics applications. In order to mimic skeletal muscle myofibrils [3], mats of aligned Nylon 6,6 nanofibers were electrospun on a rotating drum collector. To reproduce skeletal muscle fibers and fascicles morphology [3], the mats were cut in stripes and wrapped up on the drum, producing bundles of axially aligned nanofibers. The bundles were then pulled out from the drum, obtaining ring-shaped bundles. To mimic a whole skeletal muscle with its epimysium membrane [3], 2-levels hierarchical structure was developed (Fig B). Several bundles were aligned and packed together using a nanofibrous sheath produced through an innovative electrospinning setup [4]. Finally, in order to mimic also the skeletal muscle fascicles and perimysium [3], a 3-levels hierarchical structure was obtained by grouping together three 2-levels hierarchical structures, produced as previously described, with an additional electrospun sheath (Fig C).



A morphological investigation of the different electrospun structures was carried out with scanning electron microscopy (SEM) and high-resolution x-ray tomography (XCT). The alignment of the nanofibers of the electrospun sheaths and the internal bundles, was quantified with a previously validated methodology [5]. The bundles and the 2-levels hierarchical structures were also mechanically characterized with a monotonic tensile test. The level of alignment of the nanofibers in the sheaths has proved to be tuneable by modifying the electrospinning parameters. The electrospun sheaths are also capable to tighten the structures wrapped inside, reducing their cross-sectional area and improving the apparent mechanical strength and stiffness. The high-resolution imaging confirmed that the mean diameters of the different hierarchical structures were comparable to the corresponding structures of biological skeletal muscle [3]. The directionality analysis on both bundles and sheaths nanofibers showed comparable levels of alignment with corresponding skeletal muscles fibrous tissues [3]. The mechanical test on the structures revealed a non-linear behaviour typical of soft tissue. The 2- levels hierarchical structures showed mechanical properties roughly proportional to the number of single bundles incorporated (with a possible underestimation of the ultimate strength, due to a stress concentration at the grips). In conclusion, this innovative electrospinning approach to produce hierarchically-arranged structures will be suitable to develop muscle-inspired assemblies. We will explore the possibility of incorporating adequate contracting ability so as to build soft actuators.

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