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Electrospun Azido-PCL Nanofibers for Enhanced Surface Functionalization by Click Chemistry

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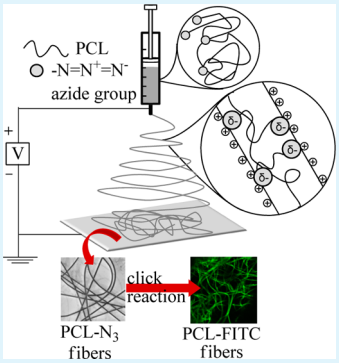
Supporting Information

ABSTRACT: This paper reports highly surface functionalized and "clickable" α,ω-azido-poly(ε-caprolactone) fibers (f-PCL-N_3), obtained by classical electrospinning setup. Azide-functionalized PCL was obtained from a commercially available α,ω-poly(ε-caprolactone)-diol, PCL_2, and electrospun with a nonderivative high-molecular-weight PCL. Successful chemical modifications of PCL_2 were confirmed by NMR, FTIR and MALDI-TOF mass spectroscopy. The high content of surface azides, as a response to the high electric field applied, was characterized using a colorimetric assay. In addition, azide reduction to amines revealed a nondestructive route for highly amine-functionalized fibers. Fluorescence labeling of f-PCL-N_3 fibers with FITC-alkyne fluorophore proved that the azide groups are mainly surface-localized as well as highly available for click-chemistry coupling.



KEYWORDS: *electrospinning, nanofibers, polycaprolactone, azides, click chemistry, surface functionalization*

INTRODUCTION

Nanofibers with a high specific surface area are of the outmost importance in the field of biomaterials science and bioengineering.[1,2] Particularly, polyesters have been often employed as a material of choice for biomedical applications.[3] To prepare biomaterials with enhanced properties, their practice has been frequently followed by additional functionalization and/or surface modifications.[4,5] Several works reported on chemical functionalization, notably wet chemical methods[6] and plasma treatment.[7] Although these methods are simple and easy to use, they induce changes in surface morphology and degradation of a material. Azide−alkyne cycloaddition is a valuable technique for introducing broad functional moieties owing to its versatility and high yields. It was for the first time reported by Huisgen[8,9] under high temperatures and in organic solvents. Sharpless et al.[10] discovered that copper(I)-catalyzed azide−alkyne cycloadditions (CuAAc), popularized as click chemistry, could be performed at ambient temperature and in aqueous phase. Soon, click chemistry concept becomes a simple solution for long known challenges − synthesis of complex polymer structures as co-polymers and dendrimers,[11] bioconjugation[12] and surface functionalization.[13] The combination of electrospinning, a nanofiber-producing process described further, and click chemistry resulted in a number of interesting studies.[14−16] However, these reports reveal complex preparation of a desired polymer from a previously modified monomer[17] and usually low surface-functionalization rate. Thus, it is of significant importance to investigate a new, simple, and nonaggressive path for obtaining highly decorated surface as well as biocompatible nanofibers, able to immobilize various bioactive molecules by means of click chemistry.

Among all the existing processes, electrospinning is a straight forward route for obtaining nanofibrous materials with a high surface-to-volume ratio.[18] The process consists of drawing continuous fibers of micro- and nano-diameters from electrically charged jet of a polymer solution or a melt.[19] A high electric field causes the polymer drop to distort into a Taylor Cone from which an electrically charged jet is emitted. Accumulated charges will result in bending instability and acceleration of the jet towards the collector where solid fibers will be deposited.[20]

Nanofibers based on poly(ε-caprolactone) (PCL) are known as a promising material for biomedical applications because of their biodegradability and biocompatibility.[21] However, the absence of functional groups has put forward many studies about PCL surface modifications where functionalization of the fiber meshes is followed by polymer degradation and surface erosion.[22−24] In the present work, blends of two PCL, with a high-molecular-weight, PCL_{80} ($M_n \approx 80\,000$ g mol^{-1}) and low-molecular-weight PCL-N_3 ($M_n \approx 2300$ g mol^{-1}) were used in different ratios in the electrospinning process. PCL_{80} provides optimal electrospinning conditions and good mechanical

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properties of the fibers while PCL-N_3 is used to functionalize nanofibers. Using standard electrospinning setup, we obtained surface-decorated azido fibers, f-PCL-N_3. We exposed a promising and efficient way of obtaining clickable nanofibrous scaffolds from commercially available poly(ε-caprolactone)s, with functionalized groups localized mainly on the surface and accessible for the CuAAc coupling. The versatility of tuning the fiber's surface with a desired biomolecule (peptides, carbohydrates, etc.) gives access of these scaffolds to a potential use in regenerative medicine, drug delivery, or tissue engineering.

EXPERIMENTAL SECTION

Materials. Poly(ε-caprolactone) (PCL_{80}) M_n 70 000−90 000 g mol^{-1}, triethylamine TEA, sodium chloride- saturated (NaCl), sodium azide (NaN_3), sodium sulphate (Na_2SO_4), hydrochloric acid (HCl), 18-crown-6, *p*-toluenesulfonyl chloride (TsCl), triphenylphosphine (PPh_3), ninhydrin, hydrindantine, fluorescein isothiocyanate (FITC), propargyl amine, copper(II) sulfate pentahydrate ($CuSO_4{\cdot}5H_2O$), sodium ascorbate, and all organic solvents were purchased from Sigma Aldrich and used without further purification. α,ω-poly(ε-caprolactone)-diol (PCL_2), M_n 2000 g mol^{-1} (Sigma), was recrystallized from diethyl ether prior to use.

Synthesys of α,ω-Azide-poly(ε-caprolactone). Modifications of the PCL_2 took place at the chain ends, having as an objective to replace the hydroxyl with azido groups.[25] PCL_2 (2 g, 1 mmol) was dissolved in 30 mL of dichloromethane in a 100 mL round-bottom-flask and stirred until dissolution. Then, triethylamine (6 eq, 0.607 g) and TsCl (6 eq, 1.14 g) dissolved in 20 mL of DCM were added dropwise into the polymer solution. After 28 h at room temperature, the reaction mixture was then washed with saturated NaCl, 1 M HCl, and H_2O. The organic phase was dried over Na_2SO_4 and concentrated. The crude product was dissolved in the minimum of CH_2Cl_2 and then precipitated in cold (4 °C) diethyl ether (10 mL) to give α,ω-p-toluenesulfonyl-poly(ε-caprolactone) (PCL-OTs) intermediate (1.21 g, 54% yield). PCL-OTs (1 g, 0.4332 mmol) was then dissolved in the minimum of DMF (5 mL). When the polymer was dissolved, NaN_3 (6 equiv., 0.169 g) was added with 1−2 crystals of 18-crown-6 and the reaction was stirred for 24 h at 50 °C under argon gas. After precipitation in cold water (20 mL), 0.875 g of the final product α,ω-azido-poly(ε-caprolactone) (PCL-N_3) was isolated (98% yield).

Preparation of Electrospun f-PCL-N_3 Fibers. All polymer solutions for electrospinning were prepared in dichoromethane/methanol (DCM:MeOH 4:1) solvent mixture at room temperature. A high-molecular-weight PCL_{80} and PCL-N_3 were blended in different ratios (20, 40, and 60 wt % of PCL-N_3) to give a final concentration of 10, 16, and 23 wt % polymer in DCM/MeOH solvent mixture, respectively. Polymer content in electrospinning solution is calculated as a mass of the polymer divided by the total mass of both polymer and solvent mixture using the following equation

$$\text{wt \%} = \frac{(\text{mass of polymer})}{(\text{mass of polymer} + \text{mass of solvent})} \times 100\%$$

Preparation of Polymer Film. PCL_{80} and PCL-N_3 (60 wt % PCL-N_3 in the blend) were dissolved in DCM:MeOH (volume ratio 4:1) solvent mixture to a final concentration of 23 wt %. Polymer cast film was obtained from the solution deposited onto a glass slide that was kept in a vacuum oven at 60 °C for 20 minutes.

Synthesis of Propargyl-fluorescein Isothiocyanate. Fluorescein isothiocyanate (FITC) (10 mg, 0.0128 mmol) and propargyl amine (90 μL, 0.703 mmol) were dissolved in 110 μL of DMF in a microcentrifuge tube and stirred in dark for 24 h at room temperature.[26] DMF and excess of propargyl amine were then evaporated and crude product was dissolved in stock solution mixture of acetonitrile/water (1:1).

Surface Modification of f-PCL-N_3 Fibrous Scaffolds. Click reaction between propargyl-FITC and azido-fibers in heterogeneous phase is described on the f-PCL-N_3-60 fibers as example. Prior to use, 0.1 M solutions of $CuSO_4$ and of sodium ascorbate, as well as FITC solution in acetonitrile/water, were filtered through PTFE (0.2 μm) filter in order to eliminate possible undissolved crystals that could aggregate on the fibers. f-PCL-N_3-60 fibers (2 mg) were put in the microcentrifuge tube containing 500 μL of acetonitrile, and then 56 μL (10 equiv. per azide group on the surface, as estimated by the ninhydrin assay) of a solution (6.42 mmol/L) of FITC-alkyne in acetonitrile/water (1:1) along with 500 μL of distilled water, 7 μL of $CuSO_4{\cdot}5H_2O$ in distilled water (0.1 M, 6 equiv.), and 7 μL of sodium ascorbate in distilled water (0.1 M, 6 equiv.) were added. Reaction mixture was stirred in the dark for 24 h at room temperature and then fibers were thoroughly washed with acetonitrile/water (1:1). f-PCL-N_3-40 and f-PCL-N_3-20 were prepared using the same procedure by keeping the same molar ratio. Resulting f-PCL-N_3-20-FITC, f-PCL-N_3-40-FITC, and f-PCL-N_3-60-FITC fibers were kept in acetonitrile/water (1:1) stock solution until observation.

Methods. Electrospinning process was performed with a horizontal setup − a 5 mL syringe was filled with appropriate polymer solution and placed on the syringe pump with the blunt 21-gauge needle attached. Flow rate was controlled by a syringe pump (KD Scientific series 200, USA) in the range from 0.01 to 0.02 mL/min. A rotating cylinder (113.5 mm diameter, 250 mm length, and rotating speed of 420 rpm) was used as a collector. The distance between needle tip and collector was fixed at 15 cm. Applied voltage (dual high voltage power supply, ±30 kV, iseq GMBH Germany) ranges from 11 to 15 kV. All experiments were done at room temperature. The relative humidity noted was between 30 and 55%.

FTIR spectra were recorded in the transmission mode using a Perkin-Elmer 1720X FTIR instrument.

^1H and ^{13}C NMR spectra were obtained with a Bruker AVANCE 400 MHz with 5 mm QNP probe at 298 K.

Matrix-assisted laser desorption/ionization−time-of-flight mass spectroscopy (MALDI-TOF MS) analyses were done in the ionization mode with Autoflex Bruker instrument.

Quantification of azide groups: Ninhydrin test was adapted for the detection and quantification of the azide (−N═N^+═N^-) groups on PCL fibers. f-PCL-N_3 fibers (10 mg) were dropped in 10 g/L PPh_3 solution in ethanol (2 mL) for 15 min in order to reduce the azide to amine groups. Reduced f-PCL-N_3 fibers were washed in ethanol and then dissolved in 1,4-dioxane (500 μL). Solution mixture of ninhydrin (2 g) and hydrindantin (0.3 g) in 75 mL DMSO and sodium acetate buffer (25 mL) was prepared under argon and added (500 μL) to the solution of fibers in 1,4-dioxane (1/1 v/v) in the screw-capped test tubes, then heated at 100 °C for 15 min and finally cooled in an ice bath. At the end, 3 mL of 1,4-dioxane was added into each tube, thoroughly mixed with a Vortex mixer and absorbance at 570 nm was measured with UVIKON 810 UV-vis spectrophotometer. The calibration curve of PCL-N_3 polymer powder was obtained following the same procedure as described for f-PCL-N_3 fibers (see Figure S1 in the Supporting Information).

Viscosity measurements were done using MCR301 and MARS III controlled-stress rheometers equipped with cone−plate geometry: 60 mm titan cone, having 1° angle and 29 μm and 53 μm gap, respectively.

A field-emission−scanning electron microscope (FESEM ZEISS ULTRA55) was used for observing the morphology of the fibers at 1 kV accelerating voltage, 5 mm of working distance, and magnifications of 500, 1000, and 2000 times using an In-Lens detection system. All samples were sputter-coated with Pt of 1 nm thickness. Average fiber diameters of the electrospun fibers were obtained as a mean value of 150 different diameters measured by ImageJ software.

Fluorescence intensity of the fibers was monitored using Leica TCS SP2 AOBS (Acoustico Optical Beam Splitter) confocal laser scanning system and an inverted fluorescence microscope equipped with an oil-immersion objective lens 40×. Fibrous samples were put in between two lamellae and covered with 4 μL of stock solution (acetonitrile/water). FITC-labeled fibers were visualized by excitation of the fluorophore with a 488 nm Ar−Kr laser and the emitted fluorescence was collected between 508 and 533 nm, precisely defined by the AOBS.

RESULTS AND DISCUSSION

Chemical transformations of the hydroxyl groups into tosyle and azido moieties were proved by ^{1}H NMR as represented in the Figure 1. Efficiency of the tosylation reaction was evidenced

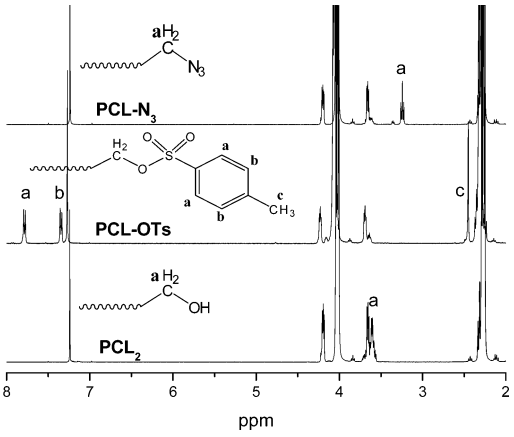

Figure 1. ^{1}H NMR (400 Hz) superposed spectra of the PCL_2, PCL-OTs, and PCL-N_3 polymers in $CDCl_3$.

by the presence of characteristic signals of both the aromatic and methyl group at 7.77−7.31 ppm and 2.42 ppm, respectively. Final substitution of the tosyl group into the azide functions was represented with the characteristic triplet at 3.26−3.23 ppm. Additional analyses by FT-IR and MALDI-TOF mass spectrometry unambiguously confirmed the structure of the PCL-N_3 polymer (see the Supporting Information).

During the electrospinning process, in order to obtain a continuous polymer jet, it is important to know at which concentration chain entanglements occur.[27] For that purpose, zero-shear viscosity in function of PCL_{80} concentration in dichloromethane/methanol (4:1) solvent mixture was traced using controlled-stress rheometer and a critical (c*) concentration was determined (see Figure S7 in the Supporting Information). Assuring high-molecular-weight chain entanglements, polymer solutions of both homopolymer PCL_{80} and polymer blends PCL_{80}/PCL-N_3 were prepared in such a way that individual PCL_{80} concentration was always kept above its c^* concentration (see Table 1).[28,29]

The synthesized PCL-N_3 polymer was blended with PCL_{80} at different ratios, and electrospun fibers were marked as f-PCL-N_3-20, f-PCL-N_3-40, f-PCL-N_3-60, corresponding to 20, 40, and 60 wt % PCL-N_3 respectively, where 60 wt % functionalized PCL-N_3 was the upper limit for obtaining the uniform beadless fibers with submicrometer diameters. All fibrous scaffolds were observed using FESEM microscopy and their average fiber diameter was obtained as a mean value of 150 measurements. FESEM images (Figure 2A−D) show that the presence of azide-functionalized PCL_2 does not significantly modify the size and morphology of the fibers. The statistical analysis of all fiber diameters measured show rather constant value of about 600 nm (Table 1) and a slender fiber-diameter distribution under dry air atmosphere. It is interesting to notice that keeping the PCL_{80} concentration nearly constant while increasing the concentration of PCL-N_3 didn't influence the fiber diameter. The effect of azide groups and the presence of low molecular weight PCL chains on polymer blends have been evaluated through rheological investigations (see Figure S8 in the Supporting Informatiom). In the presence of low-molecular-weight PCL, the viscosity curve of blends is slightly shifted towards higher values, due to increase in concentration, but not sufficiently to increase the fiber diameter. Consequently, the fiber diameter appears to be directed by high-molecular-weight polymer chains. Moreover, viscosity curves of functionalized PCL_{80}/PCL-N_3 and nonfunctionalized PCL_{80}/PCL_2 blends are nearly superimposed, showing that no significant associative interactions between azide groups and PCL chains occur in this blend. Indeed, the density of azide groups is low and the solvent mixture is mostly nonpolar, restricting intra- and intermolecular associations through hydrogen bonding. These results could explain the constant diameter of the electrospun fibers observed by FESEM.

Quantification of azide groups available at the surface of electrospun f-PCL-N_3 fibrous scaffolds was further assessed by a colorimetric assay. Surface azides were reduced with triphenylphosphine (PPh_3) in a solid-liquid phase (fibers-ethanol), the resulting amino-fibers were dissolved in 1,4-dioxane, and finally quantified by the Keiser-ninhydrin method.[30−32] Without the PPh_3 reducing agent, these fibers showed no specific coloration under ninhydrin assay, proving that the azide groups were intact during the electrospinning process.

The results of the ninhydrin assay are shown on Figure 3. Weight percentage of PCL-N_3 on the surface represents an experimentally found mass of PCL-N_3 per total mass of the sample, and it is expressed as experimental value (in grey), whereas initial concentration of PCL-N_3 in the electrospinning solution is represented in white. Total amount of azides (Figure 3, white columns) is the amount of PCL-N_3 initially present in the solution (Table 1). The difference between gray and white column stands for a nonaccessible PCL-N_3 mass per cent inside the fibers or the film. Concentrations of the PCL-N_3 on the surface were calculated from the PCL-N_3 calibration curve (see the Supporting Information, Figure S1). Figure 3 clearly points out that, for the electrospun fibers, about 80% of functionalized azide groups are located on the fiber's surface.

Colorimetric results, defining azide concentration on the surface of the fibers, suggest a surface aggregation of the azide groups. Might this be due to a spontaneous aggregation of azide groups to the solution/air interface or simply induced by the

Table 1. Electrospinning Parameters for Nonderivative PCL_{80} and Azide-Functionalized Fibers: f-PCL-N_3 -20, -40, and -60 and Their Mean Diameter

electrospun fibers	total polymer (wt %)	PCL_{80} (wt %)	PCL-N_3 (wt %)	flow rate mL/min	voltage (kV)	RH[a] (%)	fiber diameter[b] (nm)
PCL_{80}	8	8	0	0,01	13	55	591 ± 283
f-PCL-N_3 -20	10	8	2	0,015	14	49	567 ± 301
f-PCL-N_3-40	16	9,6	6,4	0,015	14	30	547 ± 68
f-PCL-N_3-60	23	9,2	13,8	0,02	13	36	694 ± 149

[a]Relative humidity. [b]Average fiber diameter ± standard deviation.

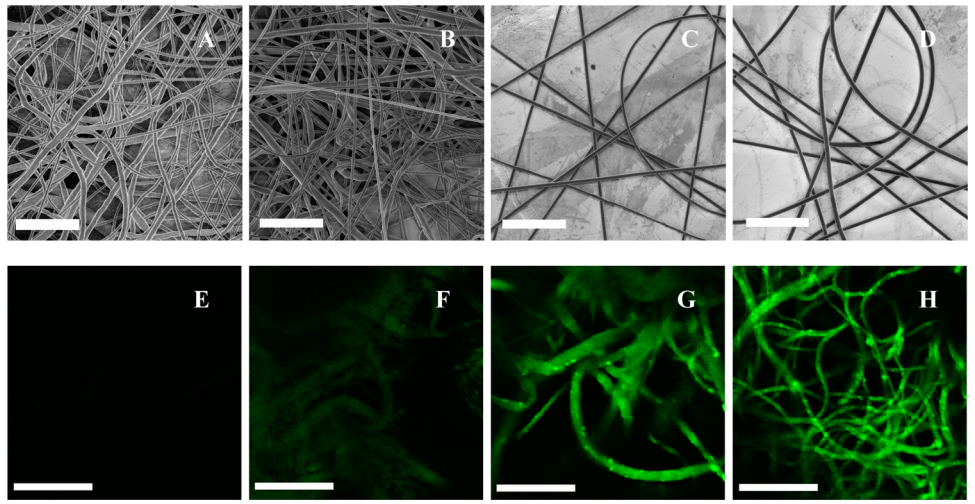

Figure 2. (A–D) FESEM images and (E–H) fluorescent images of f-PCL_{80} fibers containing:(A, E) 0, (B, F) 20, (C, G) 40, and (D, H) 60 wt % PCL-N_3. For fluorescence microscopy, prior observation, all samples were incubated with FITC-alkyne fluorophore and catalysts. Scale bar (A–D) 10 μm and (E–H) 20 μm.

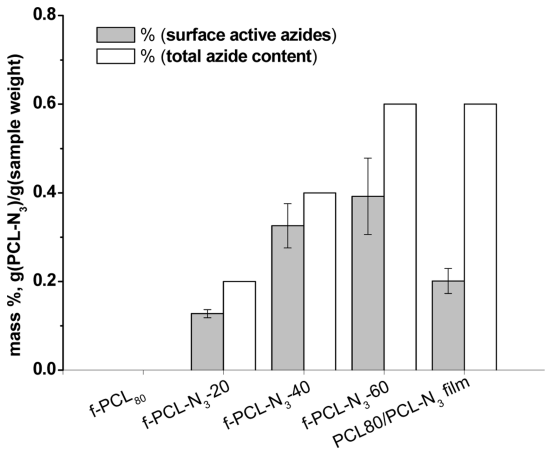

Figure 3. Quantification of azide groups on the surface of the f-PCL_{80}, f-PCL-N_3-20, f-PCL-N_3-40, and f-PCL-N_3-60 fibers and PCL_{80}/PCL-N_3 cast film that contain 0, 20, 40, 60, and 60 mass % of the functionalized PCL-N_3, respectively.

electric field? As observed by S. J. Hardman and coworkers,[33] the addition of even small quantities of fluorocarbon (CF)-functionalized polymer additives to polystyrene solution results in their surface segregation during electrospinning. However, they remind that the segregation of CF groups occurs even without the action of the electric field.[34] In addition, Stachewitz and Barber[35,36] indicated on the chemical group orientation at the surface of electrospun fibers due to polar contribution of polyamide chains. Also, they observed a similar behavior in a cast film after mechanical drawing above the glass-transition temperature. As clearly demonstrated by Fu et al.,[37] for PS bearing polar alkyl-bromide group (C–Br), such segregation can be significantly enhanced by the polarization of chemical groups induced by the electric field. Indeed, positive charges of polymer jet drive alkyl bromide groups to the surface by electrostatic interactions, whereas for the nanofibers electrospun with an anode positioned at spinneret, unpolarized C–Br groups remain in the bulk. X.-Y. Sun et al.[38] showed that the electric field used in electrospinning could promote surface segregation of not only small chemical groups but also large peptide segments. It is known that azide groups can be polarized and bear partially negative charges (δ-).[39] In our case, PCL_{80}/PCL-N_3 fibers have been obtained by using a cathode on the spinneret (Figure 4). Consequently, it is reasonable to

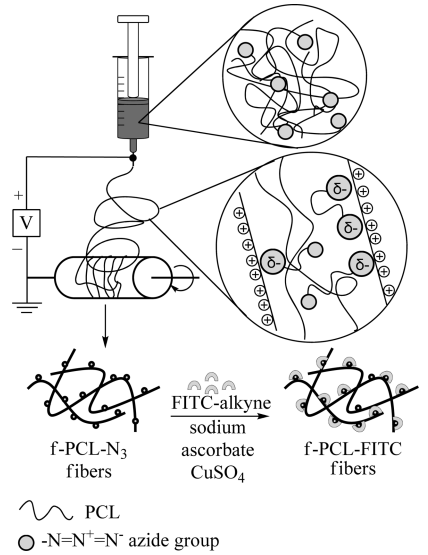

Figure 4. Schematic representation of the electrospinning setup with illustrated electrostatic attractions between negatively polarized azides (δ-) and positively charged surface during the electrospinning, as well as click reaction of f-PCL-N_3 fibers with FITC-alkyne with the resulting f-PCL-FITC fluorescent fibers.

consider that azide group migration at fiber surface could be induced principally by electric field even if the spontaneous migration of azide groups towards the air/liquid interface cannot be excluded. Quantification of azide groups was performed on a cast polymer film from the PCL_{80}/PCL-N_3 blend (mass ratio 2/3) in DCM/MeOH (volume ratio 4:1) solvent mixture to investigate the possible spontaneous migration of azides at the polymer/air interface. With slow evaporation kinetics of few minutes for the cast film, the polymer chains as well as chemical groups have the ability to find spontaneously a preferable conformation. However, the colorimetric measurements performed on the cast film showed

only 20% of the azides on the surface. This result has to be compared with the extremely fast evaporation kinetics of about few milliseconds for the electrospun fibers where about 80% of azide groups were located on the fiber surface. The evaporation process of volatile solvents is extremely fast during electrospinning and this spontaneous migration, hindered by the sharp increase of the solution viscosity, is only partial. Consequently, surface segregation of azide groups is likely due to electrically-induced polarization rather than spontaneous interface attraction. This interpretation has been confirmed by the colorimetric quantification experiments, where azide concentrations on the surface of the polymer cast film decreased for more than double than the one of electrospun fibers (Figure 3). Additionally, increase in the PCL-N_3 concentration in the electrospinning solution increased the concentration of azides on the surface of the fibers.

Fluorescent labeling of f-PCL-N_3 fibers with FITC-alkyne fluorophore using click chemistry enabled us to investigate the accessibility and reactivity of the surface azides (Figure 2E−H). f-PCL_{80}, f-PCL-N_3 -20, -40, and -60 fibrous scaffolds were incubated with the FITC-alkyne dissolved in acetonitrile-water (1:1) solvent mixture, with and without copper(I)/sodium ascorbate catalysts. Without the catalysts, all tested samples exhibited no fiber coloration, demonstrating that there is no nonspecific adsorption of the FITC fluorophore on the PCL (see the Supporting Information, Figure S9). By adding the catalysts, f-PCL_{80} remained noncolored, whereas azide-containing fibers f-PCL-N_3-20, -40, and -60 showed strong fluorescence at 520 nm and uniform coloration on the surface (Figure 2E−H) testifying the accessibility and reactivity of the surface azides. A gradual increase of color intensity, clearly visible to the naked eye, from f-PCL-N_3-20 to f-PCL-N_3-60 corresponds to a degree of FITC fluorophore implemented onto the fibers (Figure 5). This macroscopical observation correlates accurately with the results obtained using confocal microscopy. The fluorescent labeling confirmed that surface-azides could be easily accessed and coupled by heterogeneous click chemistry.

Figure 5. Image (from left to right) of PCL_{80}, f-PCL-N_3-20, f-PCL-N_3-40, and f-PCL-N_3-60 fibers after incubation with FITC-alkyne, with (top line) and without catalysts (bottom line), demonstrates successful attachment of the FITC fluorophore by click chemistry and macroscopically visible differences in the grafting ratio.

Our results show that by electrospinning commercially available unfunctionalized PCL and PCL-N_3 polymers, it is possible to obtain highly surface decorated clickable nanofibers. We demonstrated that azides suffer no change during the electrospinning and could be easily accessed for click conjugation.

Additionally, it is interesting to notice that a chemical reduction of azides to amines using PPh_3 could serve as a simple route for obtaining highly amine-functionalized PCL fibers. Amino fibers of biocompatible PCL could further react by means of peptide coupling with versatile proteins, thus serve as an important precursor to advanced biomaterials for biological and cell culture applications.

CONCLUSION

In this paper, we reported a noninvasive approach of fiber's surface functionalization. Azide-functionalized PCL of low molecular weight was efficiently electrospun together with a nonderivative PCL of high molecular weight to provide clickable fibers. Unlike saponification or aminolysis, which are commonly used method for functionalization of PCL fibers, the methodology reported here is high-yielding and nondestructive. Colorimetric results showed that because of the electrostatic attraction forces during the electrospinning process, about 80% of all implemented azides are present on the fiber's surface. Reduction of azides to amines by using PPh_3 revealed a potential of these fibers to offer highly amine-functionalized surfaces as well. Furthermore, incorporation of the FITC fluorophore highlighted the availability of azide groups for click chemistry reaction. We could summarize that, either in form of azides or amines, these scaffolds can be involved in versatile reactions, click chemistry, or peptide coupling, tailoring the bioactive and reinforced surfaces.

ASSOCIATED CONTENT

Supporting Information

Additional information about ninhydrin test calibration curve, NMR, FTIR, and MALDI-TOF mass spectroscopy of end-functionalized PCL as well as shear viscosity measurements and fluorescence imaging. This material is available free of charge via the Internet at http://pubs.acs.org

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Author Contributions

All authors have given approval to the final version of the manuscript.

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Notes

The authors declare no competing financial interest.

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ABBREVIATIONS

PCL_{80}, poly(ε-caprolactone) M_n 80 000 g/mol; PCL_2, α,ω-diol-poly(ε-caprolactone) M_n 2 000 g/mol; PCL-OTs, α,ω-p-toluenesulfonyl-poly(ε-caprolactone); PCL-N_3, α,ω-azido-poly-(ε-caprolactone); FITC, fluorescein isothiocyanate; f-PCL-FITC, fluorescein isothiocyanate-modified PCL fibers; f-PCL_{80}, poly(ε-caprolactone) fibers; f-PCL-N_3-20, fibers containing 20 wt % PCL-N_3 and 80 wt % nonderivative poly(ε-caprolactone); f-PCL-N_3-40, fibers containing 40 wt % PCL-N_3 and 60 wt % nonderivative poly(ε-caprolactone); f-PCL-N_3-60, fibers containing 60 wt % PCL-N_3 and 40 wt % nonderivative poly(ε-caprolactone); FT-IR, Fourier transform infrared spectroscopy; NMR, nuclear magnetic resonance; MALDI-TOF MS, matrix-assisted laser desorption/ionization—time-of-flight mass spectroscopy; FESEM, field-emission scanning electron microscopy; CuAAc, copper-catalyzed azide alkyne cycloaddition

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