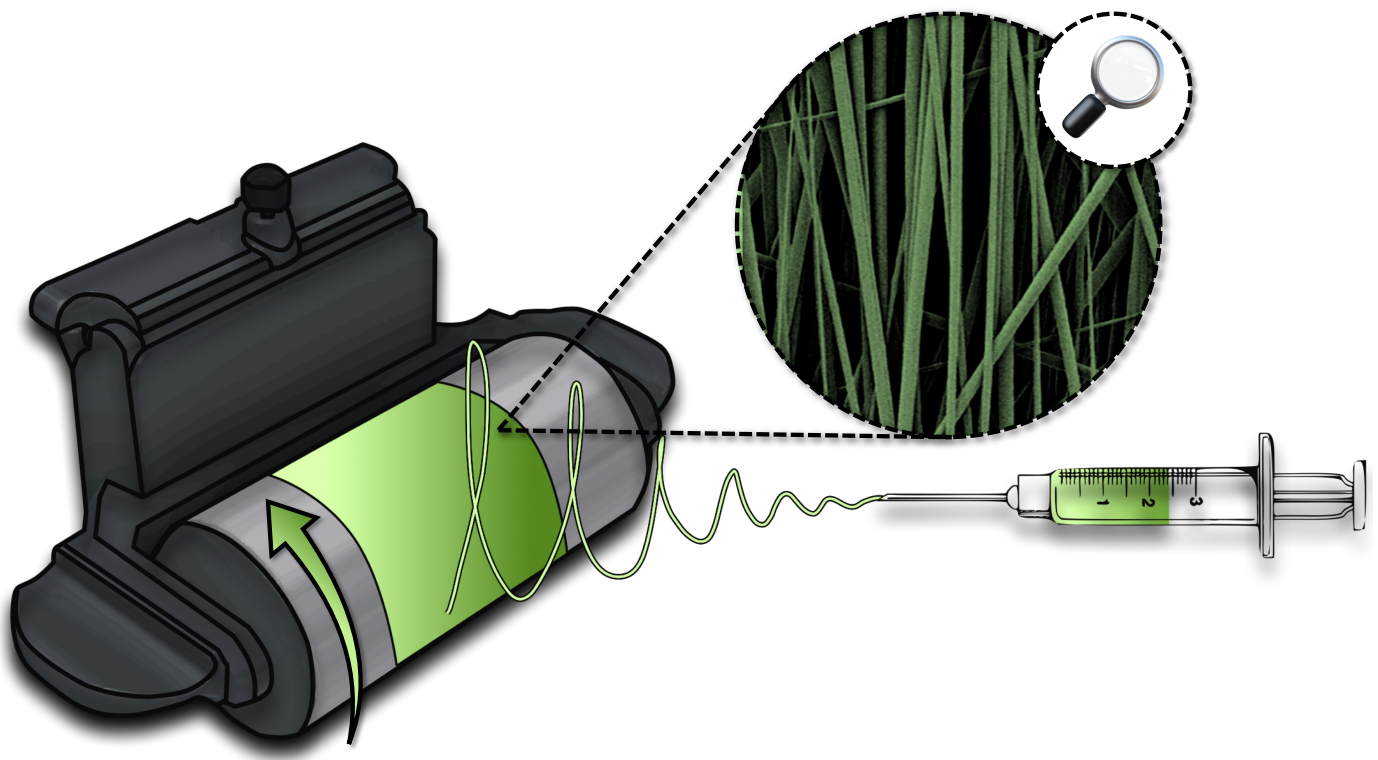


An introduction to:

Oriented fiber formation



1 The origins of oriented electrospinning

The origin of electrospinning technique dates back to the 1600s when the deformation of liquids due to an electrostatic force resulting in a cone was first described. In 1898 John William Strutt physisits, aka III. Lord Rayleigh (known for the Rayleigh-scattering), noted that, when the electrostatic repulsive force equilibrates the surface tension, a liquid jet erupted from the droplet. Then the term of electrospinning was founded and first introduced by John Francis Cooley in 1902, then Sir Geoffrey Ingram Taylor produced the beginnings of a theoretical underpinning of electrospinning describing a mathematical model for Taylor-cone formation between 1964 and 1969. Since then, the technique itself and the application of nanofibrous materials frequently gained more and more attention.

Typically, electrospun nanofibers deposit randomly on collectors and create so-called non-woven mats. Up until now, producing aligned nanofibrous products has proven to be difficult due to unstable and intervening polymer jets. As a result, managing the fibers' orientation on the collector surface and organizing them into the correct alignment is of great interest and has proven to provide a wide range of application possibilities. To aid with oriented fiber alignment, rotating collectors (**Figure 1**) or those with a combination of various distinct configurations such as parallel, planar, and auxiliary electrode are widely utilized. .

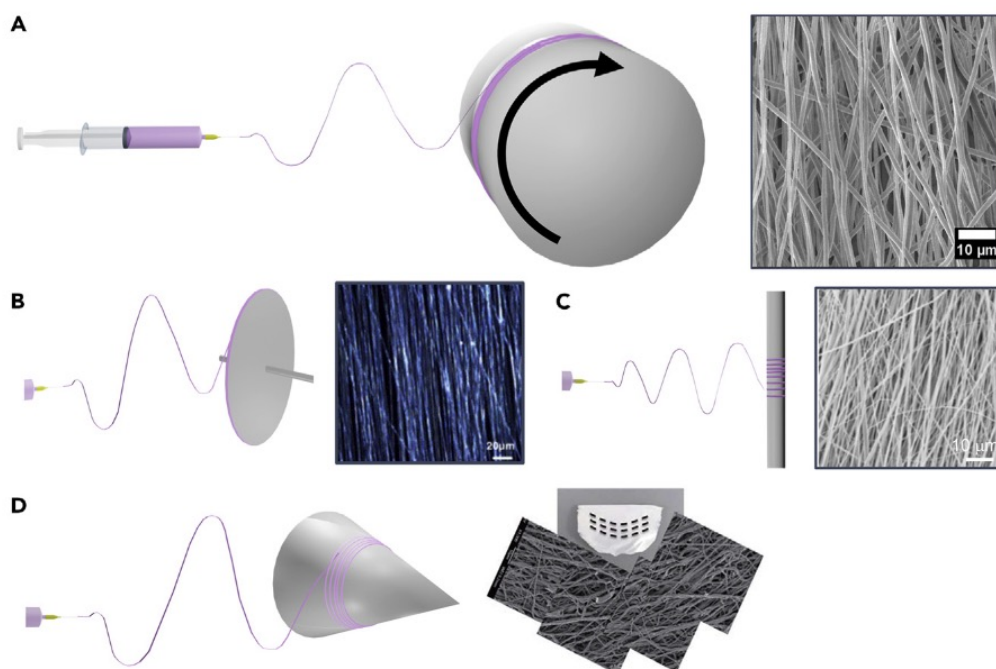


Figure 1: The most commonly used rotating collectors (**A:** cylinder drum, **B:** disc, **C:** rod, **D:** conical mandrel) for the production of aligned nanofibers by electrospinning

These specific requirements may be found in sectors including biomedicine, tissue engineering, filtration membranes, and composite reinforcement. The production of aligned or oriented deposited nanofibers were first described in the preparation of aligned poly(ethylene-oxide) (PEO) nanofibers and poly(glycolic acid) (PGA) scaffolds with the application of a rotational drum collector in 2001.

2 Benefits of using randomly oriented nanofiber meshes

Because electrospun nanofibers deposit randomly on static plate collectors and produce non-woven mats, a moving collector is required to fabricate orientated fibers. Aligned nanofibers have enhanced properties – physico-chemical, optical, mechanical or intracellular-mimicking – which can be beneficial in various applications. Li et al demonstrated the enhanced mechanical properties of aligned PA-6

(polyamide-6) nanofibrous mats. To note, the tensile strength of the maximally aligned nanofibers was more than twofold higher than that of the PA-6 nanofibrous mats with the lowest alignment (**Figure 2A**). The determined Young-modulus follows the same trend. (**Figure 2B**).

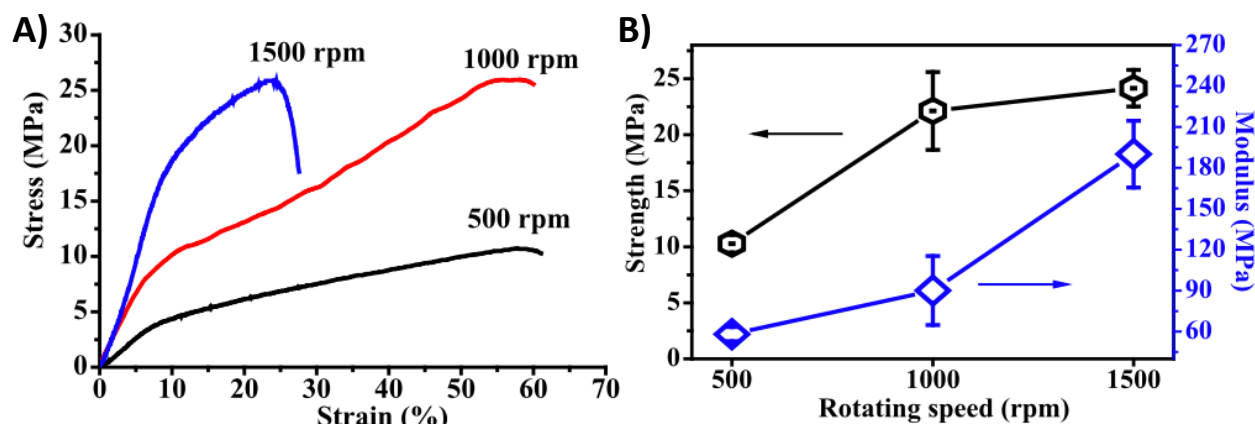


Figure 2: The tensile stress-strain curves and the modulus of of PA-6 nanofibrous meshes (based on the work Biyun Li et al)

In another industry, the through thickness fiber alignment is critical in the development of proton exchange membranes (PEMs) inserted into fuel cells. Zhang et al fabricated aligned sulfonated poly(phthalazinone ether sulfone ketone) copolymer (SPPEsk) nanofibers by electrospinning with the application of a rotational drum collector for this purpose.

The further advantages of aligned fibrous structures can be realized in medical applications such as tissue engineering as a support for cell proliferation and other therapeutic use. Zhao et al fabricated aligned surface modified poly(lactic acid) PLA nanofibers with the application of a rotational collector for capturing of tumor cells. Both the random and aligned nanofibers display uniform morphology and similar fiber diameter distribution with no significant differences. To mention the efficiency, with the aligned structure highest capture yield can be reached comparing the random structure (**Figure 3**).

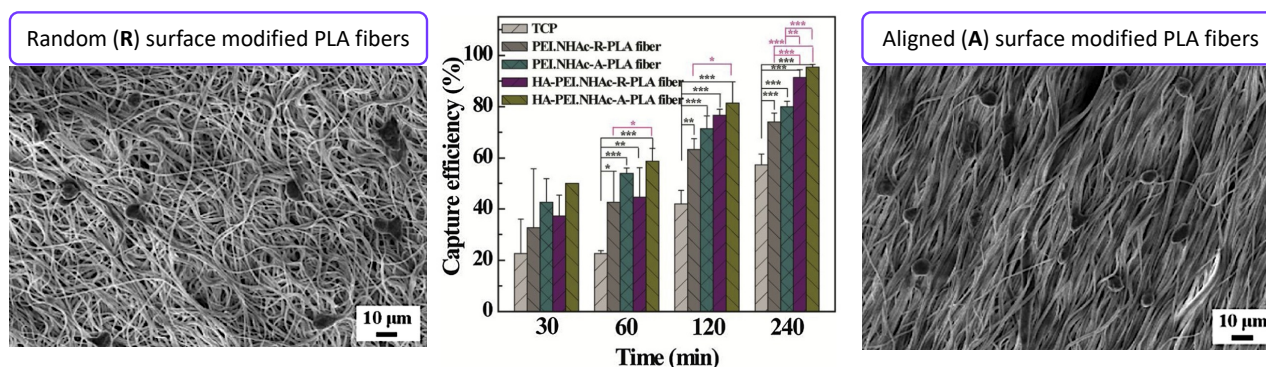


Figure 3: SEM images and the of cell captured on random (R) and aligned (A) surface modified PLA nanofibers and their capture efficiency as the function of incubation time (based on the work of Zhao et al)

Chen et al observed a synergistic impact of aligned nanofibrous PLA structures on cell proliferation and differentiation.. Moreover, Andalib et al claims that mesenchymal stem cells (MSCs) – responsible for repairing bone tissue – exhibited a preference for orientation to the axis of nanofiber alignment. **Table 1** lists some further applications for various polymeric oriented nanofibers.

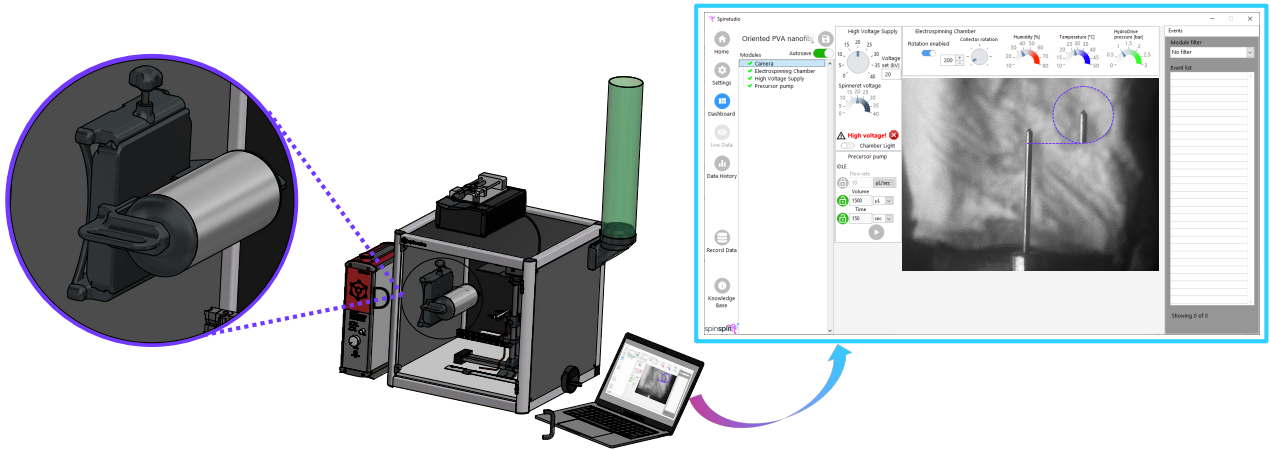
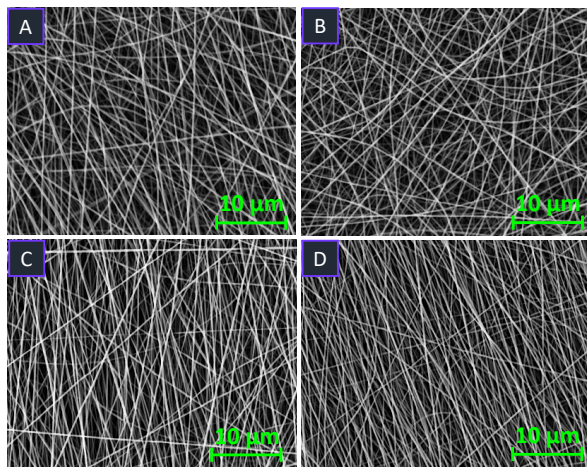
Table 1: Some of the commonly used polymers to prepare aligned nanofibrous systems

Polymer	Collector type	Application field
PCL	cylinder drum	scaffold for vascular endothelial cell culture
PCL-diol-PU	cylinder drum	core-shell nanofibers for controlled release of anticancer API Temozolomide
PLA	cylinder drum	scaffold for primary motor neurons and C2C12 cells
PCNU	conical mandrel	antimicrobial mats in tissue engineering
PVDF	cylinder drum	electrode coating in skin interactive piezoelectric sensor

(PCL: poly(ϵ -caprolactone); PU: polyurethane; PCNU: poly(carbonate urethane); PVDF: poly(vinylidene fluoride))

3 How to prepare aligned nanofibrous mats

In this section the production of aligned nanofibrous mats by electrospinning is explained. Among all of the collector types previously discussed, the cylinder drum is the simplest and most frequently utilized to achieve oriented fiber deposition. The electrospinning chamber of the **spincube** can be upgraded for this purpose by implementing a rotating cylinder drum collector (**Figure 4**).

**Figure 4:** Scheme of **spincube** electrospinning chamber equipped with a cylinder drum collector**Figure 5:** Scanning electron microscope images shows the effect at different surface speed of the drum collector (**A**: random nanofibers ($0 \text{ m} \times \text{sec}^{-1}$), **B**: $3.75 \text{ m} \times \text{sec}^{-1}$, **C**: $7.5 \text{ m} \times \text{sec}^{-1}$, **D**: $15 \text{ m} \times \text{sec}^{-1}$)

After filling the precursor solution in the desired syringe and setting up the electrospinning parameters – the high voltage, flow rate of the precursor solution and the surface speed of the collector – on the dashboard of **spinstudio** (**Figure 6**) the instrument is ready for the aligned fiber formation.

In order to demonstrate the production of aligned nanofiber mats 10 *w/w*% PVA (Mowiol® 18-88) precursor is used, and the electrospinning is performed with the application of different surface speeds of the cylinder drum collector at 3.75, 7.5 and 15 *m/s* respectively (**Figure 5**).

In conclusion, the influence of surface speed determines the degree of alignment of nanofibers once the electrospinning parameters are adjusted. Based on the prepared nanofibrous mats beyond 7.5 *m/s* of surface speed shows satisfactory oriented deposition of nanofibers.

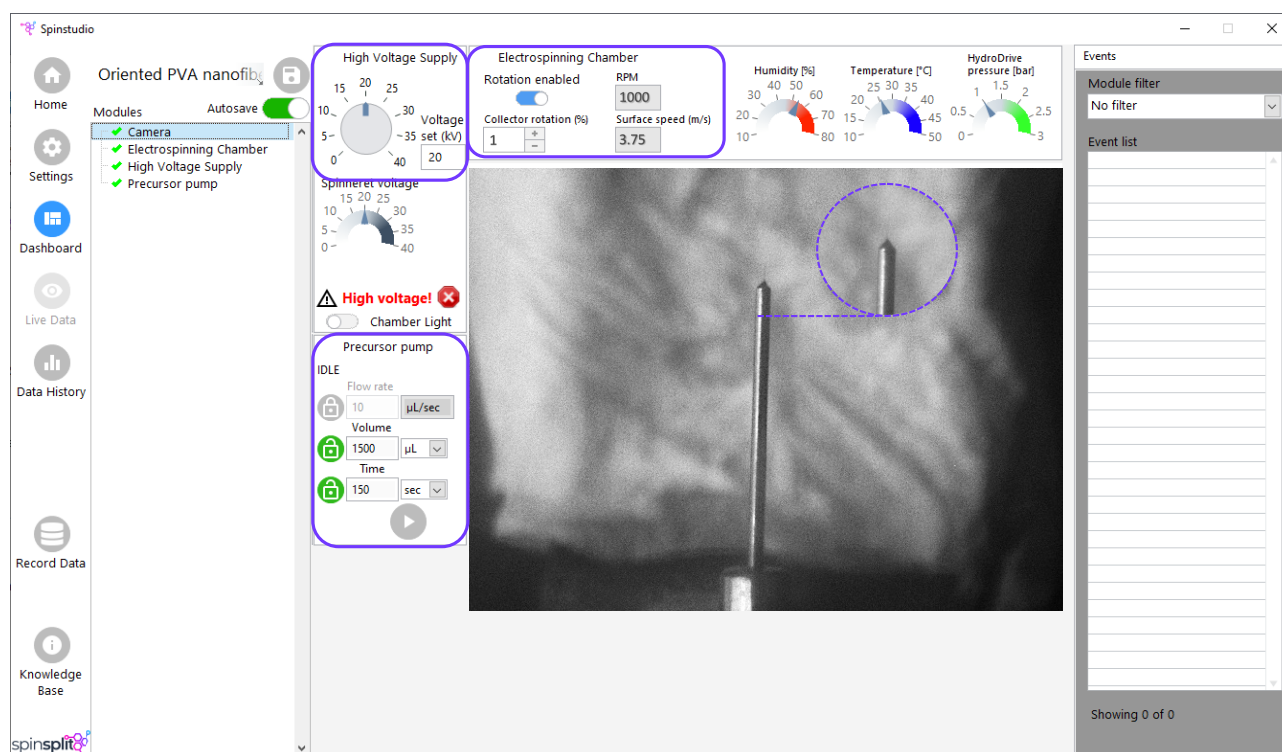


Figure 6: Setting up electrospinning parameters for aligned fiber deposition on the dashboard in spinstudio software

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