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Development of an electrospinning jet control technique for manufacturing vascular grafts

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Abstract: Electrospinning is an advanced and versatile additive manufacturing method for the fabrication of small-diameter, nanofibrous scaffolds. However, because of various instabilities, electrospinning leads to unpredictable fiber deposition. Aligned and oriented nanofibers are required to mimic the mechanical anisotropy of soft tissue. With an adapted electrospinning setup the jet was focused or deflected between two auxiliary electrodes and thereby aligned. Tubular grafts with different fiber orientations were manufactured and evaluated in ultimate tensile tests. Fiber orientation affected the maximum tensile force and the compliance in the circumferential direction.

I. Introduction

Vascular grafts, especially in the small diameter range are needed for the surgical treatment of cardiovascular diseases, including coronary artery and peripheral vascular pathologies. Currently used synthetic materials, like expanded polytetrafluorethylene or polyethylene-terephthalate, often lead to vascular occlusion due to their inherent surface thrombogenicity or anastomotic intimal hyperplasia possibly caused by inferior biomechanical properties. Electrospinning is an interesting method to fabricate fibrous non-woven scaffolds able to mimic the complex structure of the native extracellular matrix. During conventional electrospinning, fibers are formed and deposited in an unpredictable fashion (Fig.1). Increased control of the fiber deposition is beneficial to manufacture grafts, which can mimic the complex structure and the biomechanical behavior of the host vessel.

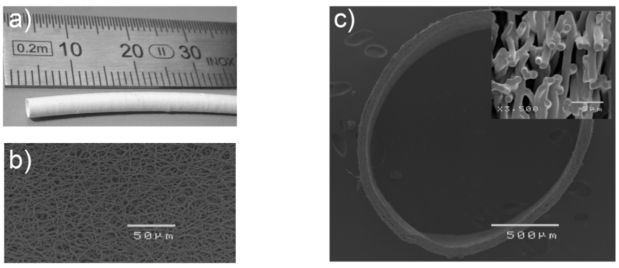


Figure 1: conventional electrospun graft; a) macroscopic view, b) luminal view and c) x-section of the wall

II. Material and methods

Since the electrospinning jet is electrically charged, it was attempted to steer it by means of an additional electric field.[1,2] This was done by introducing two plate-like auxiliary high-voltage electrodes, which were applied with a time-varying square wave potential generated by a newly developed electrical switch based on Reed-Relays (Fig.2).

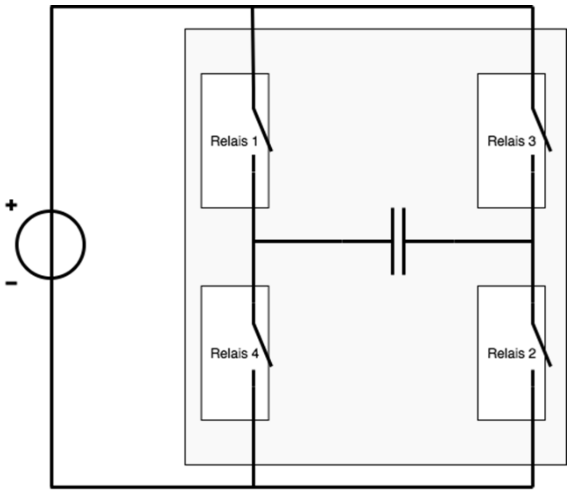
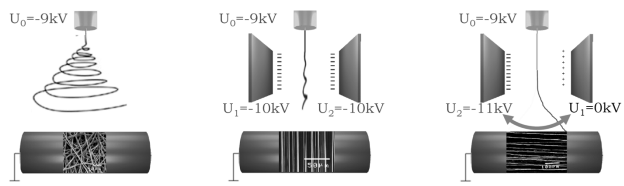


Figure 2: H-bridge made up of 4 reed relays, of which one of the relay pairs (1 and 2 or 3 and 4) is always closed alternately. The two auxiliary electrodes are shown as a capacitor.

The adapted electrospinning setup is depicted in Fig. 3. The electrospinning jet is charged with U_0 and deflected by the potential of the auxiliary electrodes U_1 and U_2. In the "focus mode" the potentials of U_1 and U_2 are equal. In the "switching mode" the high voltage potentials U_1 and U_2 are switched between the two auxiliary electrodes.



a) spiraling jet b) focused jet c) deflected jet

Figure 3: a) conventional electrospinning, b) focus mode, const. potential at aux. electrodes, c) deflection mode, switching potentials between aux. electrodes

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Three types of tubular vascular grafts with different fiber orientations were electrospun: lengthwise fiber orientation in the "switching mode", random fiber orientation with conventional electrospinning and circumferentially fiber orientation in the "focus mode". The grafts were spun on steel wires with a diameter of 2mm and 10cm length from 5% (w/w) polyurethane (Pellethane® 2363-80A; Lubrizol, Cleveland, OH, USA) in 1,1,1,3,3,3-hexafluoro2-propanol and subsequently tested for their biomechanical properties. A quasistatic uniaxial tensile test was performed on ring segments of the tubular grafts, and the force/elongation curves were recorded.

III. Results and discussion

With the electrical switch, high voltage potentials up to 18kV were successfully switched at frequencies from 5 up to 150Hz between the two auxiliary electrodes. At a constant deflection voltage, the deflection of the electrospinning jet decreases exponentially with increasing switching frequencies (Fig. 4).

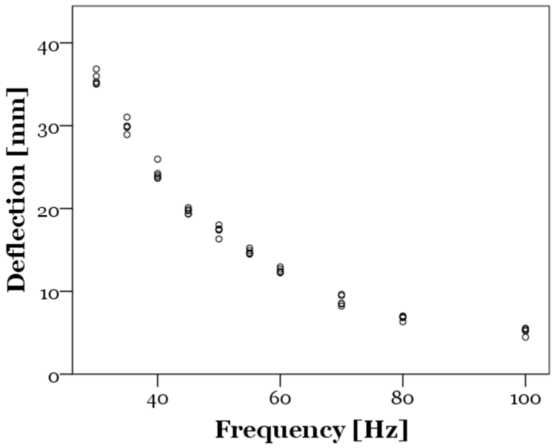

Figure 4: Frequency dependence of the deflection at a deflection voltage of 10 kV

The extent of the jet deflection is linearly dependent on the deflection voltage (Fig. 5).

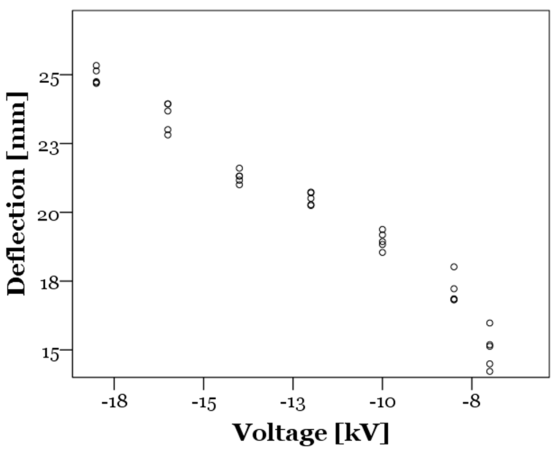

Figure 5: Voltage dependence of the deflection at a frequency of 45 Hz

Three grafts of each fiber orientation were electrospun and five ring samples from each graft were used for tensile test. The tensile tests showed that the fiber orientation affects the maximum tensile force (Fig. 6). The compliance, which is the diameter change of the graft in the physiological blood pressure range (80/120 mmHg) was highest in lengthwise electrospun grafts with 10.1±1.09 [%/100mmHg], followed by randomly oriented grafts 9.1±3.26 [%/100mmHg] and circumferentially spun grafts with 5.6±1.27 [%/100mmHg].

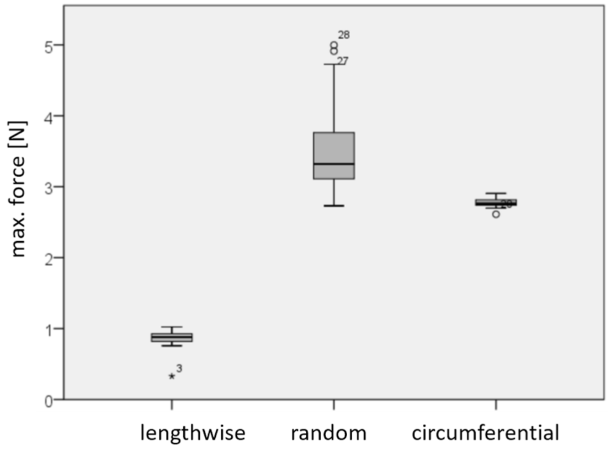

Figure 6: Ultimate tensile force in electrospun grafts with various fiber orientations

IV. Conclusions

The electrospinning jet and its path can be controlled by an auxiliary electric field. Fibers can be aligned by alternating deflection between the two plate-like electrodes. With the developed fiber control apparatus based on Reed Relays voltages up to 18 kV can be switched in a large frequency range. The achieved fiber orientations influence the biomechanical behavior of the electrospun grafts

AUTHOR'S STATEMENT

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