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ПРОИЗВОДСТВО МИКРОНАНОСТРУКТУР ПВС С ИСПОЛЬЗОВАНИЕМ ТРАДИЦИОННЫХ МЕТОДОВ ЭЛЕКТРОПРЯДЕНИЯ И ЭЛЕКТРОСПИННИНГА В БЛИЖНЕЙ ЗОНЕ

Аннотация: *Электропрядение использовалось для производства волокнистых каркасов, имитирующих внеклеточный матрикс (ECM) в течение десятилетий. Фиброзные каркасы из электроспряденного материала обеспечивают микроволокнистую структуру с взаимосвязанными порами, которые напоминают структуру внеклеточного матрикса естественной клетки в тканях, и продемонстрировали высокую способность способствовать формированию синтетических функциональных тканей. В этой статье микроструктуры изготавливаются из ПВС с использованием электроспиннинга в ближнем поле и обычной установки для электроспиннинга.*

Ключевые слова: *Электропрядение, Электропрядение в ближнем поле, Строительные леса, Extracellular matrix.*

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PRODUCTION OF PVA MICRO-NANO STRUCTURES USING CONVENTIONAL AND NEAR-FIELD ELECTROSPINNING TECHNIQUES

Annotation: *Electrospinning has been used to manufacture fibrous scaffolds that mimic an extracellular matrix (ECM) for decades. Electrospun fibrous scaffolds provide a micro - nano fibrous structure with interconnected pores that resemble the structure of the extracellular matrix of a nature cell in tissues, and have shown a high ability to facilitate formation of synthetic functional tissues. In this paper, micro - nano structures are produced from PVA using near field electrospinning and conventional electrospinning setup.*

Keywords: *Electrospinning, Near-field electrospinning, Scaffold, Extracellular matrix.*

Introduction:

Tissue engineering is an emerging multidisciplinary field that aims to regenerate damage or loss of tissues / organs in living organisms using a combination of cells and scaffolds [1,C.1780]. These engineering techniques begin with scaffolding that provides a suitable environment for cells and tissues to grow in an orderly manner and become functional in the form of new tissues / organs [2,C.755]. Given the importance of interactions between cells, scaffolds, and peripheral implanted tissues, many efforts have been made to design an extracellular matrix (ECM) for the artificial cell consisting of a complex mixture of fibers. Including glycosaminoglycans, collagen, elastin and retinal fibers [3,C.7].

Electrospinning has been used to manufacture fibrous scaffolds that simulate the extracellular matrix for several decades [4,C.20]. Electrospinning is a technique that uses static electrical forces to produce scaffold fibers from biocompatible polymers. The simple setup of electrospinning makes it a versatile and methodological technology for treating all biocompatible polymers in fibrous scaffolds. Several studies have been conducted to apply tissue engineering by controlling the parameters of the electrospinning process (voltage, flow rate, spinning distance, metal needle diameter) in addition to the solution parameters (concentration, viscosity, and conductivity of the solution) [5,C.210]. Electrospinning can be an appropriate method for producing scaffolds on a large scale due to the possibility of controlling the diameter of the fiber, giving room for manipulation in tissue applications. Electrospun fibrous scaffolds provide the micro - nano fibrous structures with interconnected pores that resemble the structure of the extracellular matrix in tissues, and demonstrate a high ability to facilitate the formation of synthetic functional tissues, Figure (1). For example, the porosity of skin and bone tissues has a large volume in order to facilitate cell migration and transport of nutrients during tissue regeneration [6,C.25]. However, fibrous scaffolds that spun by conventional electrospinning consist entirely of fibers with closed, or very small pores, which provide a surface porous structure, and these porous structures become smaller as the fiber diameters are small. This causes a decrease in the passage of cells in the scaffold leading to the formation of a two-dimensional environment rather than a three-dimensional environment, which further mimics the structure of the extracellular matrix. (Sisson et al) Demonstrated that the small pore size of electrospun scaffolds impedes cellular migration and restricts tissue flow [7,C.1319].

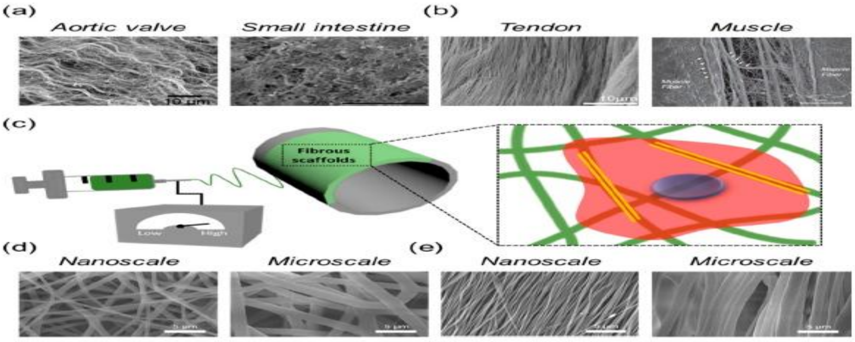

Figure 1. Scanning electron microscope (SEM) images of a natural extracellular matrix (ECM) in distinct types of tissues with (**a**) isotropic direction and (**b**) anisotropic direction; (**c**) Schematic illustration of the electrospinning process; (**d**) Representative SEM images of fibrous scaffolds with a controllable fibrous scale with (**d**) randomly and (**e**) aligned fibrous deposition via electrospinning.

Near-field electrospinning:

Despite extensive studies, it is still not possible to fabricate highly structured fibrous scaffolds with controlled uniformity and structural engineering using conventional electrospinning due to the resulting random fibers. Near-field electrospinning is a relatively new method in the field of electrospinning, and it has been widely applied recently by researchers. It uses a short spinning distance (less than 1 cm) to reduce the bending instability and splitting of the fibers. This method provides stability to the polymer jet zone, thus controlling the positioning of the fibers and enabling the production of 3D structures. Near-field electrospinning was used by Fuh et la. to produce parallel nanofibers from chitosan with a site-specific density by direct writing patterns. In these experiments, the parallelism of chitosan fibers significantly affected the proliferation and morphology of human embryonic kidney (HEK) cells and their successful reconstruction on chitosan fibers[8,C.97]. Due to the easy availability and low cost of direct writing styles, this technique provides a promising method for studying bioengineering research [9,C.8670].

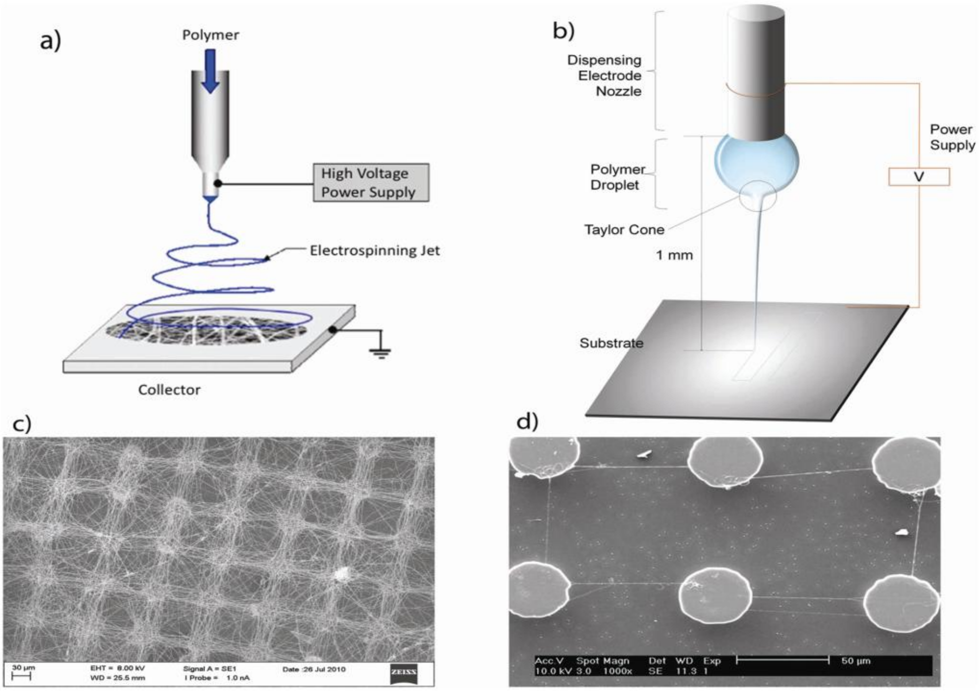

Figure 2. Far-field electrospinning (FFES; **a, c**) compared with low-voltage near-field electrospinning (LV NFES; **b, d**). The fibers are chaotically deposited on carbon 3D posts in FFES (**c**), whereas LV NFES allows more controlled patterning (**d**).

In this study, four layers of microfibers were produced on top of each other with a near-field electrospinning technique, and then a random micro – nano fibrous mesh layer was produced by using conventional electrospinning settings on the same device.

Experiments and Results:

The PVA solution dissolved with water was prepared at a concentration of 6 wt%. The samples were produced on a near-field electrospinning device with 3D printing technique using the following parameters.:

Table1. used parameters for produced on a near-field electrospinning device with 3D printing technique

Experiment number	Polymer	Concentration wt%	transition velocity mm / s	distance cm	voltage V
1	PVA	6	15	1	2600
				4	4000
2	PVA	6	15	1	2500
				4	4000

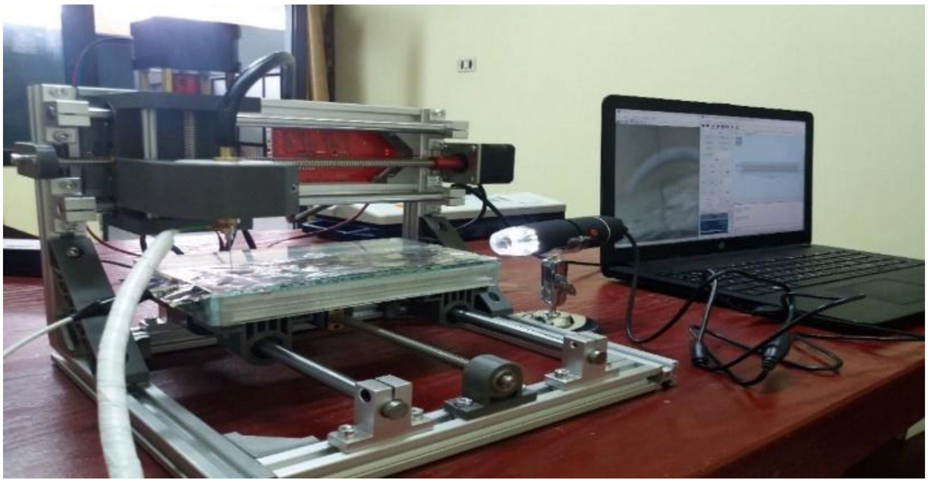

Figure 3. Near-Field Electrospinning Device.

Experiment No. 1:

At first, a single layer was spun with near-field electrospinning setup, and then an upper layer was spun with the traditional electrospinning setup as shown in Table (1).

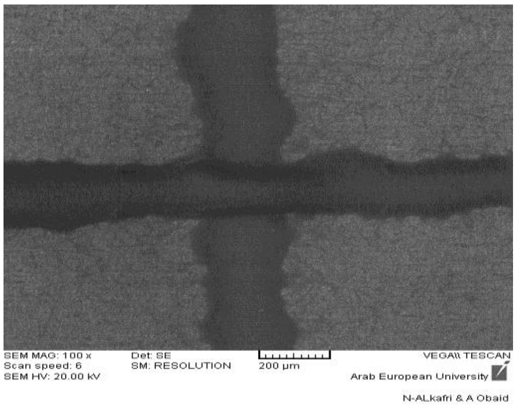

Figure 4. SEM image of sample no 1.

Figure 3. shows the resulting structure, where we note that the resulting polyvinyl alcohol microfibers are branched fibers, and the branched fibers have a diameter of several microns as shown in Figure 4.

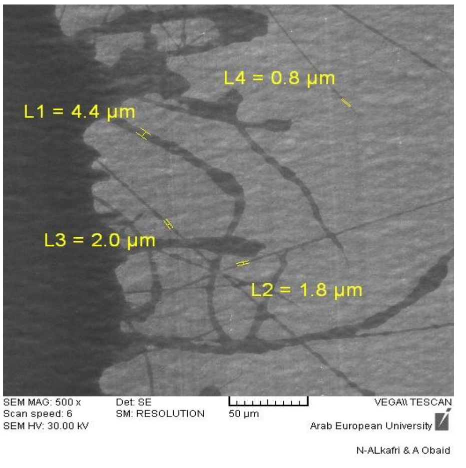

Figure 5. SEM image of branched fibers in sample no 1.

Figure 6. shows below the produced nanostructure, where the fiber diameters reached up to 90 nm.

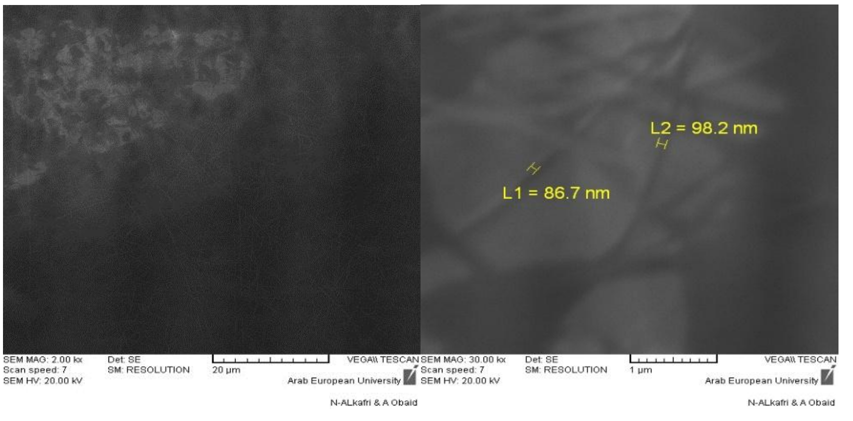

Figure 6. SEM image shows the nanofibers mesh.

This disparity between the fiber diameters shows the potential for producing hierarchical structures by combining electrospinning techniques.

<u>Experiment No. 2:</u>

In this experiment, 4 layers of microfibers were spinning (for the ground layer) and then spinning a nanofibers layer according to the parameters mentioned in Table (1). Figure (5-28) below shows a microscopic scan of the produced sample.

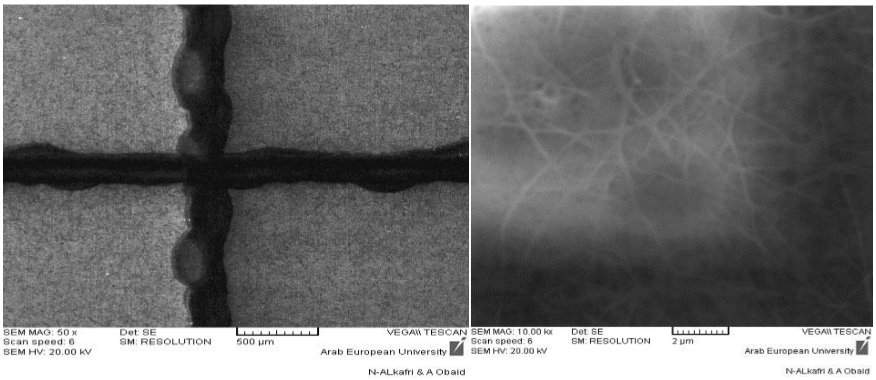

Figure 7. SEM Image of sample no 2 and the nanofibers mesh of the sample.

Discussion:

The combination of traditional electrospinning techniques and near-field electrospinning provided a greater possibility to combine layers of hierarchical scaffolds, as we obtained the features of near-field electrospinning in the micro-layer which is compatible with 3D printing technology and obtaining accurate deposition of the product fiber. In contrast, using conventional electrospinning parameters, we obtained nanofibers up to 90 nm and a high surface area. This disparity in the structure provides a great similarity to the structure of the natural extracellular matrix in tissues to provide a suitable environment for cell culture and control of their growth and thus gives us an opportunity to better study these structures and get a future outlook for scaffold production in bioengineering.

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