Research Article

Innovative Idea of Making an 8-Piece Collector by Controlling the Electrodes and Improving Texture of Nanofibers in Electrospinning

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Abstract: In this paper, we report the activity of an electrospinning collector that can collect at the same time as controlling the angles and alignment of spun nanofibers. First, electricity is applied to the electrodes to which the electrospinning polyacrylonitrile (PAN) nanofibers are to be absorbed; connected. The new idea for making an 8-electrode collector without rotation is that each of these electrodes works separately with a separate power input wire. This is because the power inside each of the electrodes is connected and disconnected separately so that the input current of the collector can be adjusted with this technique. The main point of success of this method is the use of a collector, consisting of 8 electrodes of a conductive shape, which are separated by cross-section insulation to charge PAN nanofibers, stretch along the gap and form a regular arrangement. Using this method to modify the electrospinning device and better align the nanofibers in regular structures, their performance can be improved to make electrospinning operations easier and more orderly, in controlling the alignment and angles of the nanofibers.

Keywords: Electrospinning, Collector System, Nanofibers, Tissue Engineering, Fiber Alignment.

1.Introduction

The electrospinning process is a well-developed and accepted method for creating continuous fibers at the nanoscale [1]. Electrospinning is a method that uses high voltages to make polyacrylonitrile (PAN) nanofibers with different diameters from 20 nm to 20 μm [2, 3].

In recent decades, researchers have become more interested in studying the unique properties of nanoscale materials. This topic has received more attention in recent years due to its versatility and potential for application in various fields. These notable applications include tissue engineering, biosensors, filtration, wound dressing, and drug delivery [4-7]. The electrospun morphology of nanofibers is significantly affected by parameters such as polymer concentration, viscosity, molecular weight, applied voltage and collector distance, and by controlling these parameters, electrospin nanofiber scaffolds can be easily produced for the desired performance [8, 9]. The effect of an electric field around an electrospinning jet, which has been studied by many researchers, suggests that the existing charges of an electric jet cause it to change direction by an electric field [10]. Electrospun nanofiber textures, characterized by a surface-to-volume ratio, focus on controlling the structure of the fibers at the multilevel scale and the packaging and alignment of the spun nanofibers, which have unique and beneficial properties for various applications [11, 12].

In the study of Chen et al., The structure of nanofibers such as the arrangement of nanofibers parallel to the external electric field and complex internal structures with a simple way to align the nanofibers in a parallel path from a pair of collectors that attract the nanofibers to the edges of the two collectors sit; Has been used [13]. Using a 6-electrode collector with a rotation speed of 75 rpm, Krishnamoorthy et al. achieved significant nanofiber thickness and diameter [14].

Simultaneous collection and alignment control of electrospinning nanofiber bundles, which is a key feature of the collector with a serrated edge through the fission of a part of the collector and is positioned in such a way that it attracts the nanofibers towards it [15]. In the research of Dutivala et al., Using a rotary collector and a rotation speed of more than 1700 rpm, suitable nanofibers and alignment were obtained. The distance between the nanofibers was 10 μm and the nanofibers were well organized using the high rotation speed of the collector [16]. Experiments by Zheng et al. And Kumar et al. Show that spin speed has a significant effect on nanofiber texture. In these studies, a collector with a U-shaped structure and another collector with a rectangular shape are rotated by a motor connected to them, which twisted nanofibers with longer size and higher quality, improved the density of the product [17, 18].

In the study of Zeiss et al., Using a convex and concave collector, porous polycaprolactone (PCL) electrospinning on the metal structure layers of the collector, to produce scaffolds with an average diameter of 15 microns of nanofibers and an average pore size of 250-300 micrometers in The concave state and 20-80 μm were formed in the convex state where the nanofibers interacted in a real 3D environment [19]. Studies by Sun et al. Showed that electrospun nanofibers mainly repair tissue by directly interfering with cell orientation and proliferation and by stimulating cell morphology by interfering with cell differentiation [20]. These scaffolds protect the adaptive environment of the cells for survival and create similar differentiation conditions for the tissue area. Aligned nanofibers cause cell alignment along the nanofiber axis. Because nanofibers are more compatible with cell adhesion than hydrogels, cell growth is easily guided by nanofiber orientation. A hydrogel that acts as a topographic barrier; Allows cells to stay in balance between two barriers. In addition, non-cell adhesion hydrogels promote cell growth and protect those [21-23].

In optimizing for the ideal nanofibers, once a polymer scaffold has been produced, it can be manually applied to cells, which are often the cells used in stem cells; Planting [24,25]. The choice of materials and biocompatibility for scaffolding is as important as it must be mechanical properties such as tensile strength and stiffness for electrospinning nanofibers to be suitable for cell growth [26]. Baker et al. Also believe that the mechanical properties of PCL electrospun polymer depend on the diameter of the nanofibers, and the smaller diameter nanofibers were more resistant but less ductile due to the higher tensile strength applied during the process [27].

In the research of Nataraj et al., Polyacrylonitrile (PAN) has been used as a well-known polymer with good mechanical structure stability. The polymer also has a wide range of applications, including filtration, and is used in many fields of engineering, medicine, and biology [28].

2. Experimental

2.1. Materials and methods: First, a polyacrylonitrile solution in dimethylformamide (DMF) was combined with a concentration of 13% in the laboratory for nanofiber production using electrospinning process. Then, this solution was injected at a feed rate of 0.1 ml/h.

2.2. Equipment: A high-voltage power supply (Hi-V) FC60P2- Glassman Co., USA that provides 17.5 kV power supply. Two syringe pumps, Top5300-Japan, and other, SP 1000 HSM-Iran, were used for flow rate and distance of 15 cm from the needle head to the collector.

2.3. Structure of 8-electrode collector: The design of this collector was analyzed using CAD software and then it was cut from aluminum through CNC laser cutting operation, which is in the desired shape and its map and sizes are shown in Fig. 1 The electrodes of this collector are composed of 8 parts of one shape and all other parts of it can be seen in Fig. 1.

Fig. 1 8-piece collector consisting of eight similar electrodes with various components.

In this collector, several pieces of electrodes of the same shape are designed and cut, and the exact size and numbering of the electrodes (1-8) are specified. These electrodes are spaced apart and have no electrical connection to each other. Because electricity must be applied to each separately and each electrode must do its function separately. These eight electrodes act simultaneously and with the help of each other's power. Fig. 1 shows the location of the power cord connection at the top of each electrode.

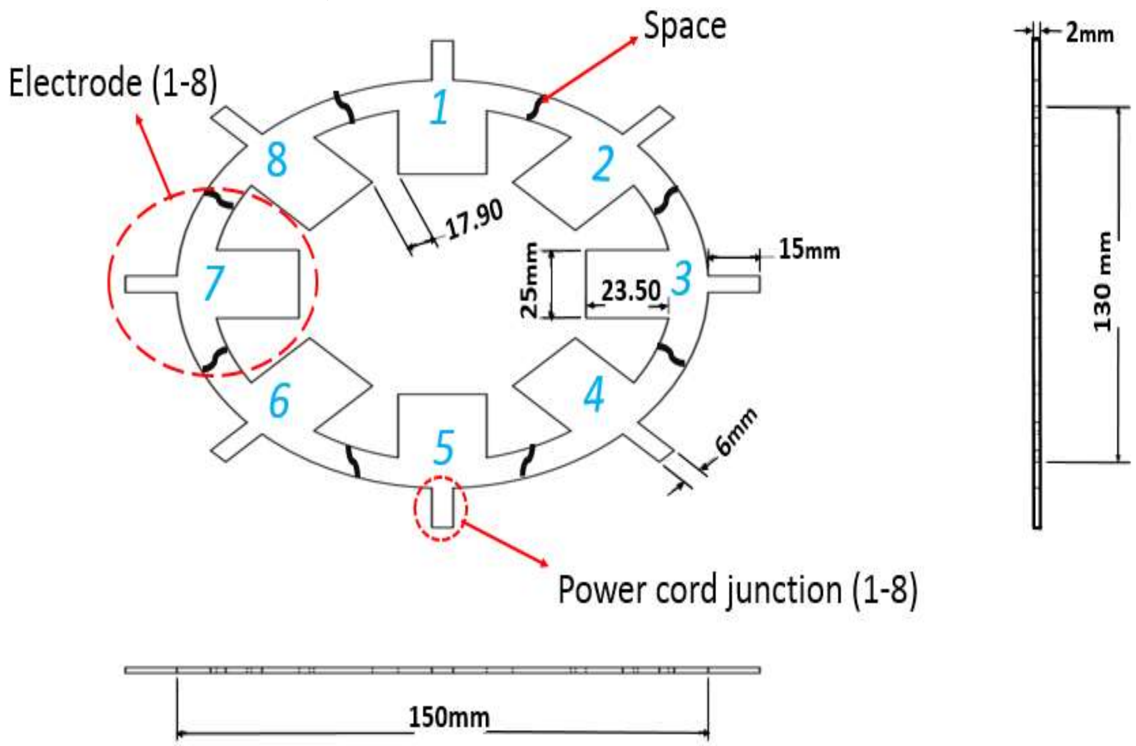
To control the noise and remove unused areas in the collector, two lower and upper guards made of compressed plastic are used to cover the collector. To connect these parts, bolts and nuts were used to fix the collector and the molds of the two lower and upper guards. More details and different parts can be seen in Fig. 2.

According to Fig. 2(a), the 8-piece collector consists of five components as follows:

(1) Connecting screw: Using this nut, a prize is placed inside it and the connection is tightened.

(2) Top protective mold: made of transparent plastic, which is cut using a CNC laser machine, placed on the color and covered.

(3) 8-piece collector: Made of aluminum, the main part that forces the task of absorbing and aligning the nanofibers to work on it.



(4) Bottom protective mold: It is made of plastic, has a floor covering and a color retainer, and has been accurately designed using CAD software and cut and shaped using a CNC milling machine.

(5) Bead: It has a stabilizing role that the complex is inserted and tightened inside to connect different types in this calorie.

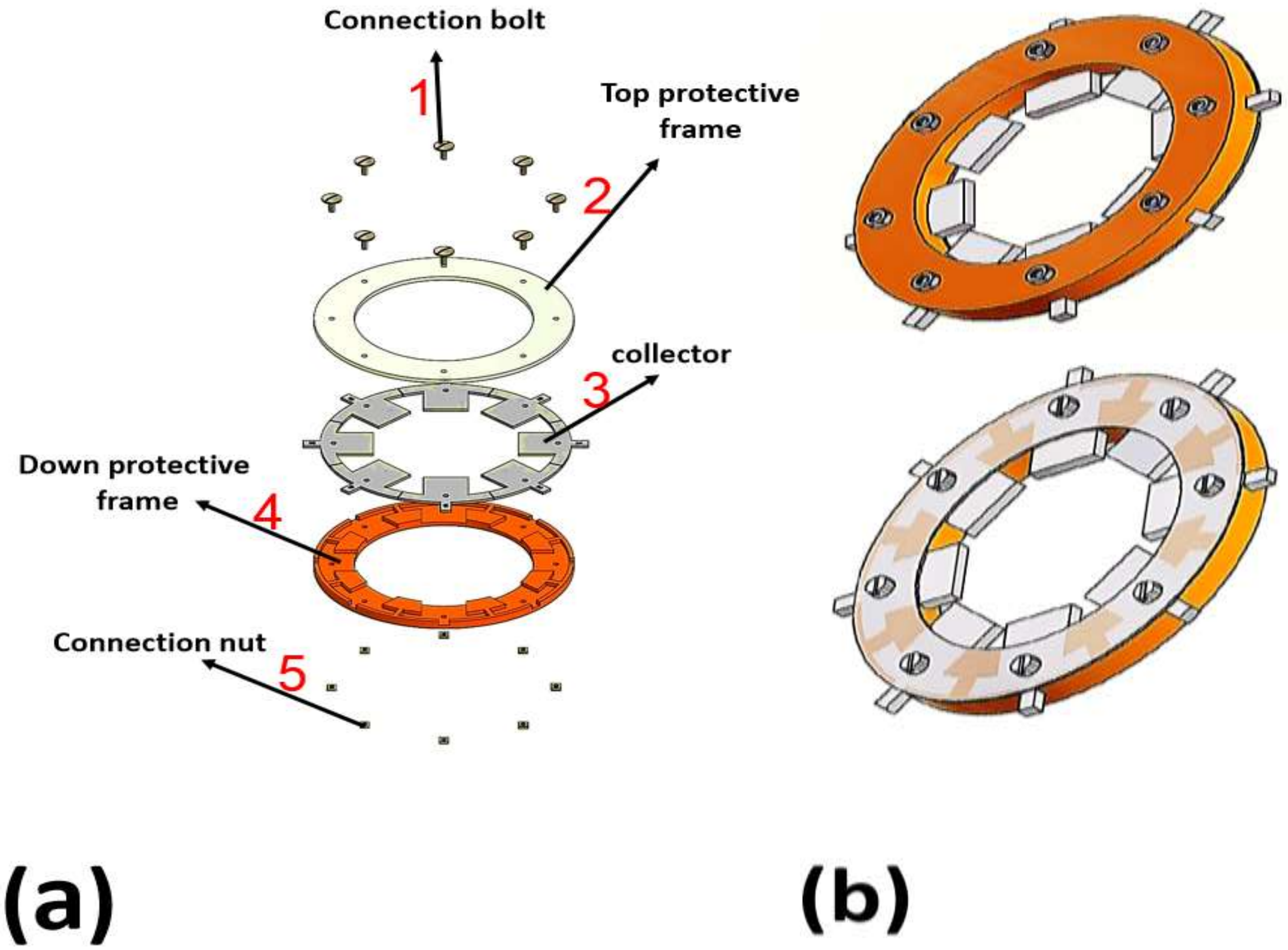


Fig. 2 all the components of the collector

a The unassembled components of the collector

b View from above and below the assembled collector

2.4. Electrospinning method in vitro: This collector uses 8 separate electrodes. The term separate means having 8 electrodes together; but their input power is separate and have no connection to each other. This is because each of the electrodes must operate separately so that when the input current is connected, the spinning nanofibers are mounted on the target electrode and trapped on it by hand.

This is done by using the central switch device, which uses this device to control the current flow to each desired electrode in a completely controlled way. Here, for each electrode, we have a separate power cord that is connected to a central power control device. In total, there are 8 power cords that are connected to the controller on one side and to the electrode on the other. This mode allows us to control each electrode to issue commands. The device is instructed by humans, so that each of the target electrodes to spin the polymer nanofibers receives power at the command of humans. By doing this, the state, type and shape of the nanofiber texture can be adjusted and controlled relatively well. Fig. 3 shows an overview of how this system works. The central switch control device is designed to be able to control the switching on and off of the power supply and also adjust the timer according to the type of activity or operation.

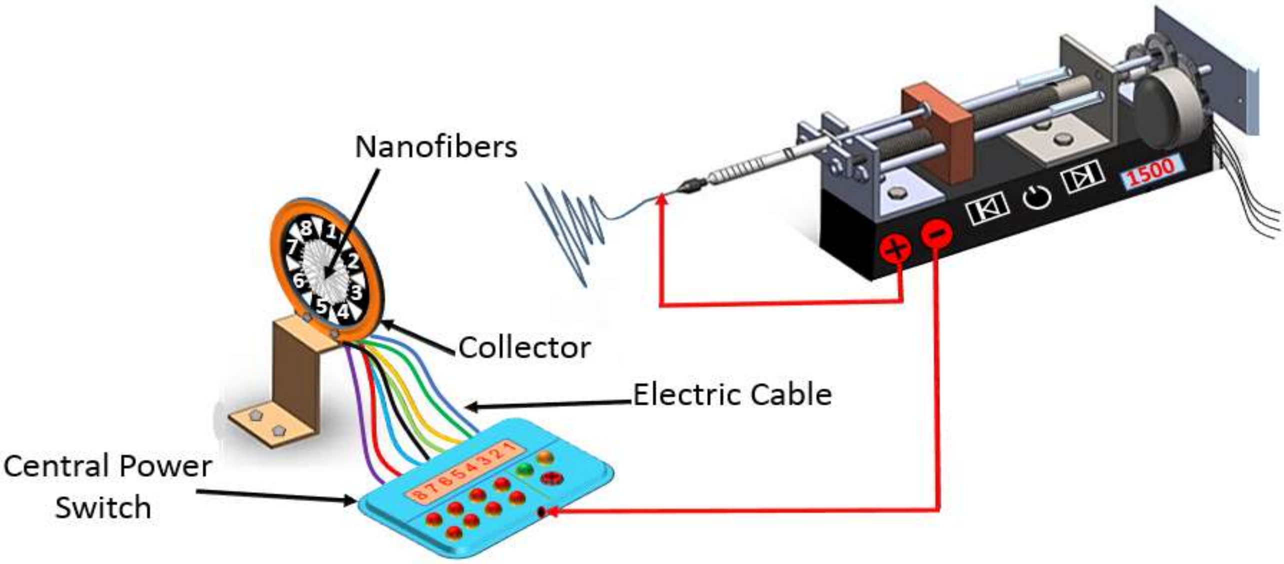


Fig. 3 Overview of the electrospinning system and how the collector and central power control device are located.

3. Results

3.1. Electrostatic field analysis for the prediction of nanofiber alignment

Characteristics of angles of electrospun nanofibers: As shown in Fig. 1; the method of numbering the electrodes is 1-8, which have been performed according to the same numbering. Two different types of electrospinning were performed on this collector, which are reported as follows:

Operation Type A: 8-Piece Collector Electrospinning - As shown in Fig. 4(a), current is connected to all electrodes. Then, electric current was applied to all the corresponding electrodes in order to absorb the nanofibers, in a regular manner and in accordance with the clockwise movement. After 1 minute, the operation was repeated for the next corresponding collectors. This leads to better control and alignment as well as preventing nanofiber dispersion. One of the disadvantages of this operation is the prolongation of electrospinning time; but its advantages include control, alignment, and greater order of the nanofibers adsorbed on the collector. Electric current entered the electrodes using a central electrical device. All wires connected to the electrodes to this device, which is responsible for controlling and regulating the current; are connected. Operation control is achieved when electrodes No. 1 and 5 are charged and have one minute to absorb the nanofibers. The other electrodes are in the neutral state. This device, after one minute and when the electrodes No. 2 and 6 were charged; As soon as current enters the next electrodes, it immediately cuts off the power to the previous electrodes. In the same way, all the corresponding electrodes absorb the nanofibers on a regular basis. This operation was repeated in sequence for 1 hour.

Operation Type B: All electrodes were engaged in clockwise order. All pairs of corresponding electrodes acted together; but with the difference that electrodes No. 2 and 6 had the most time to work together. This operation, shown in Fig. 4(b), was performed to demonstrate the potential for ductility of nanofibers as desired and to prevent scattering during electrospinning. The lower part of Fig. 4(b) shows that the other electrodes also operated simultaneously. All electrodes carry electricity during operation and the operation is performed without changing the electrodes. It was also observed that the operation encountered a minor problem and the nanofibers became complicated and distorted during the operation. In addition, the nanofiber diameters are shown to be slightly thicker than the previous method. The diameter and angle of the nanofibers were controlled and recorded by ImageJ computer program. Because the nanofibers were not properly stretched and aligned during electrospinning; we encountered an increase in the angle and diameter of the nanofibers and could not control it. Fig. 5 compares the changes in nanofiber angles and Fig. 6 compares their diameter changes.

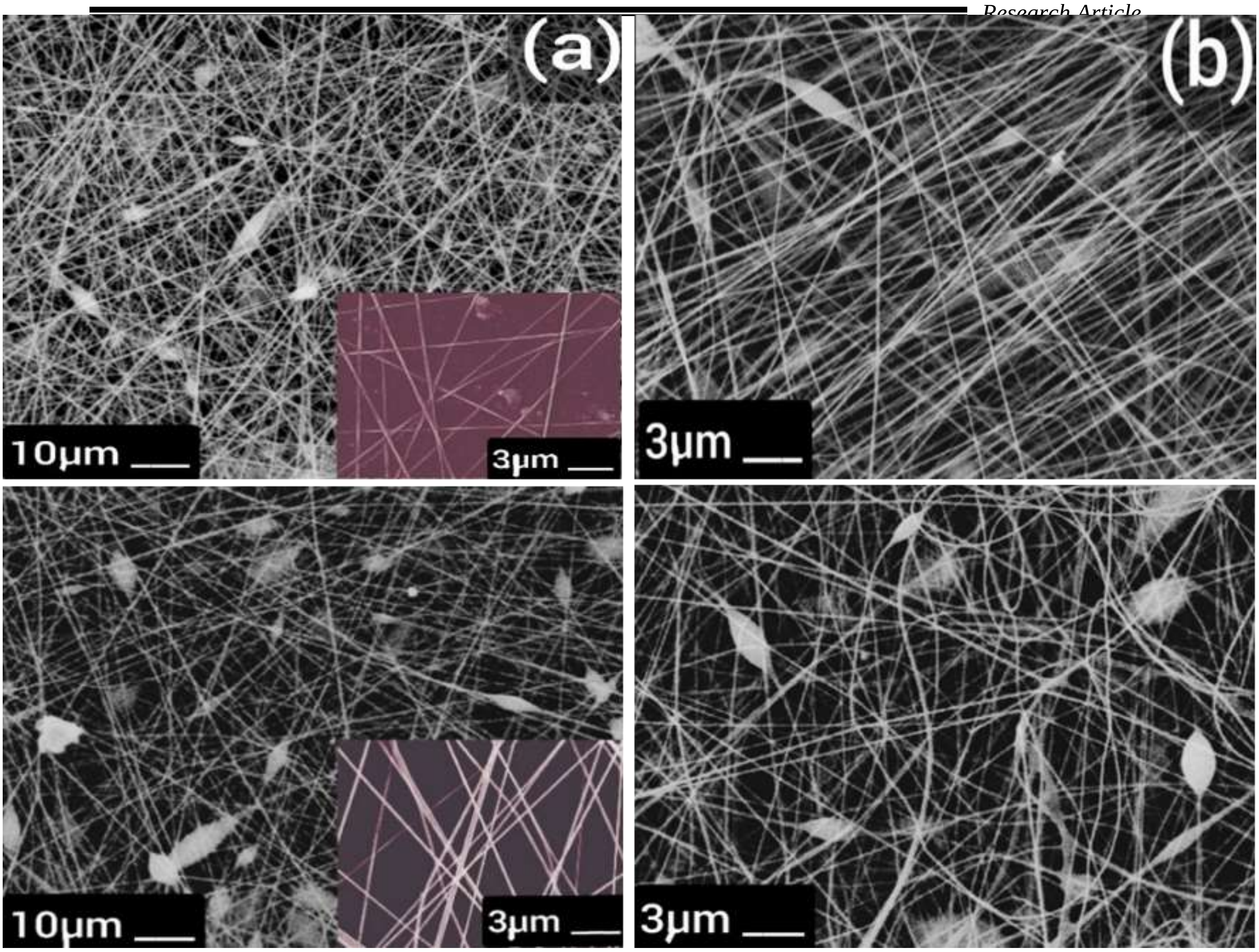


Fig. 4 Arrangement comparison between two experimental samples.

a Regularly and agreeing clockwise

b Maximum cooperation time between electrodes No. 2 and 6

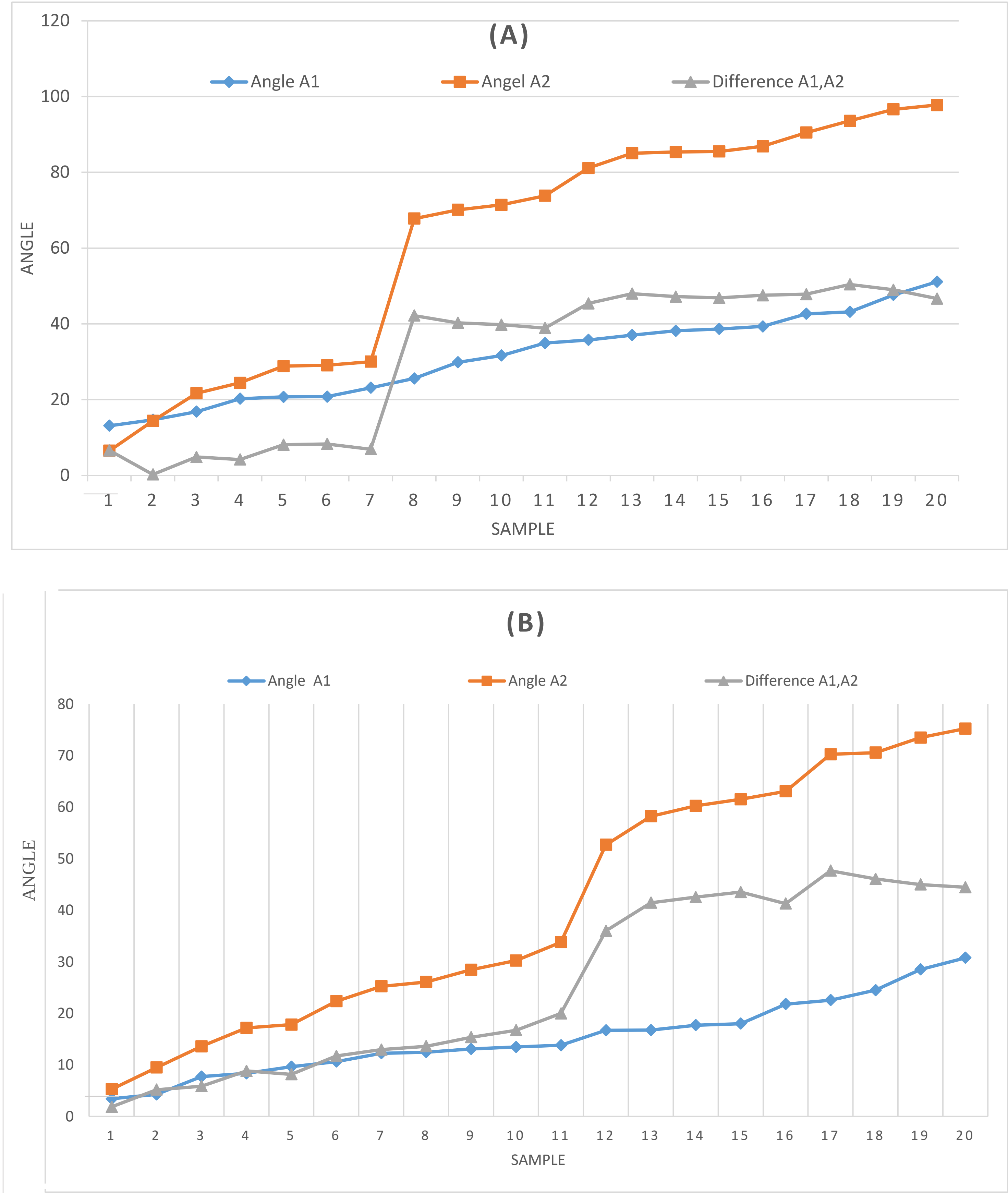
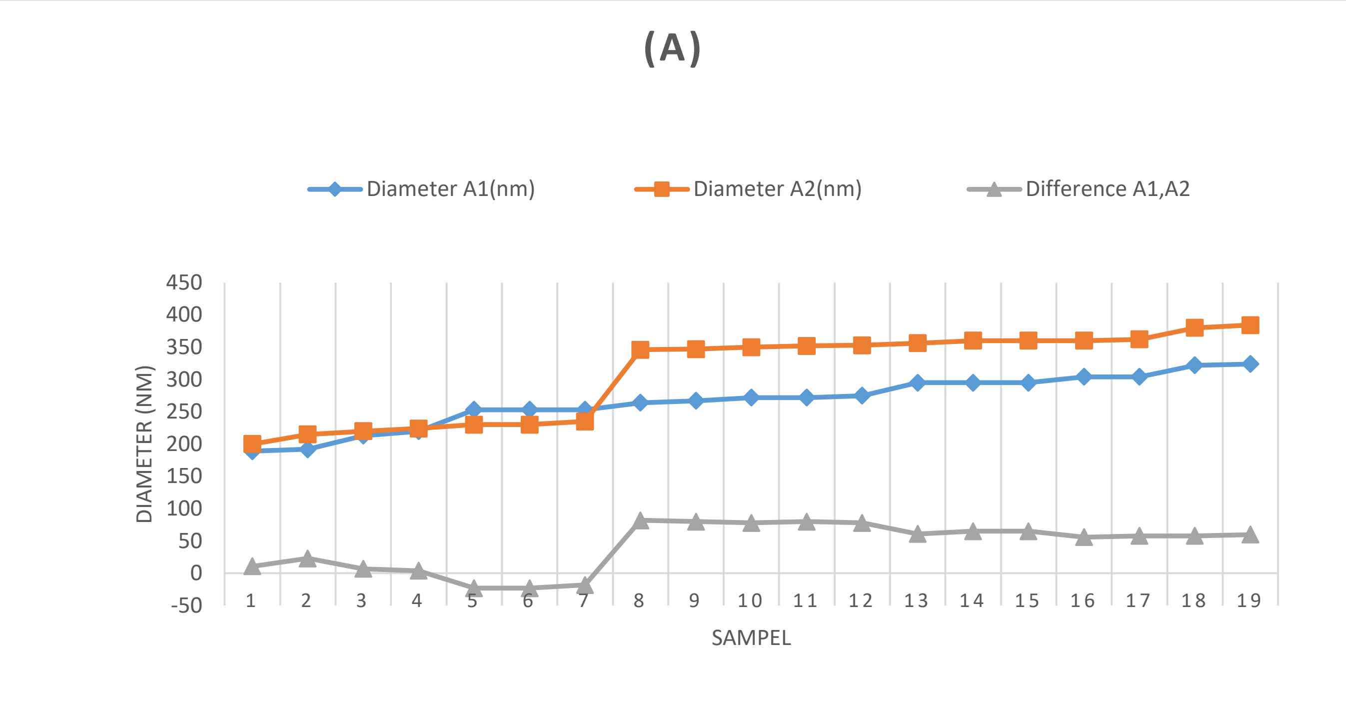


Fig. 5 Calculate the average angle difference between two experimental samples (Healthy nanofibers).

a 14.12%



b 4.19%

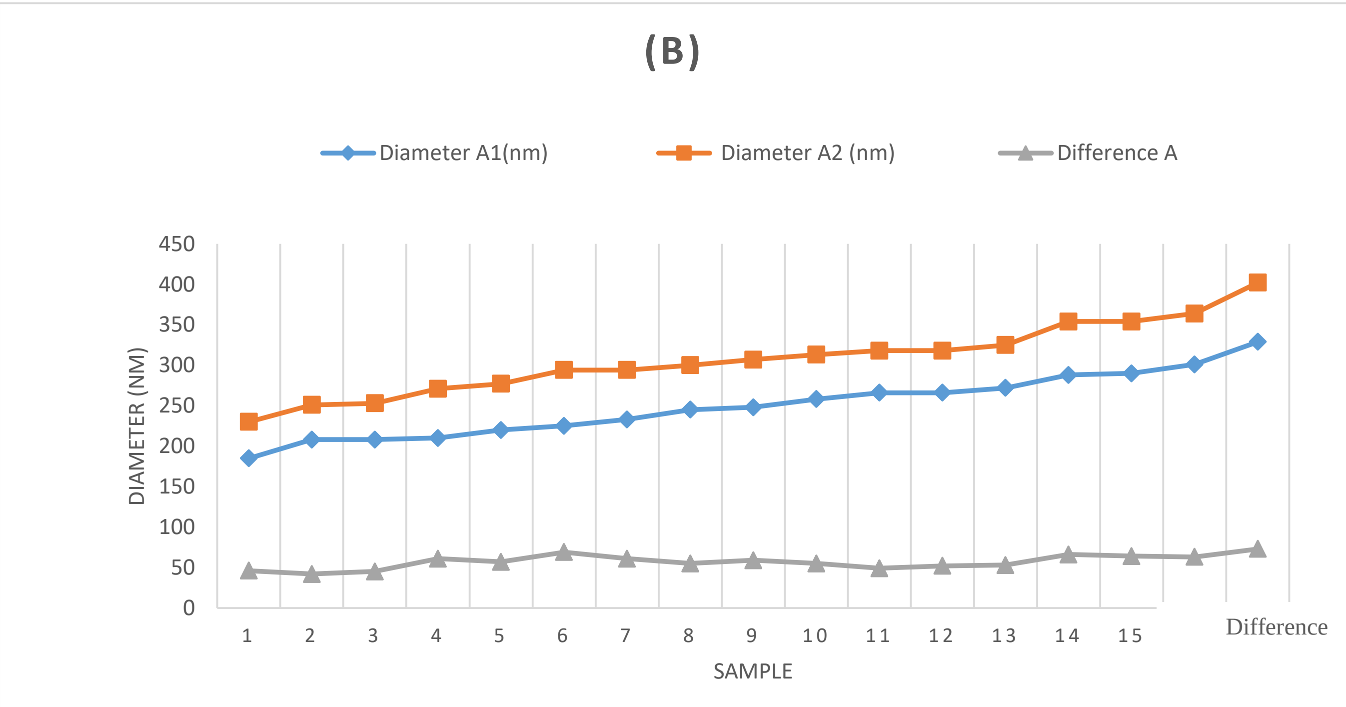


Fig. 6 Comparison of diameter differences between two experimental samples (Unacceptable nanofibers).

a 18%

b 4.74%

It was observed that in operation A, we had a 14% increase in angle and an 18% increase in diameter compared to operation B. The graphs also report that the nanofibers increased in angle by 4% and the diameter by nearly 5%. This means that electrode control operations can interfere with the diameter, angle and even shape of the nanofibers. We conclude that controlling the electrodes can have a positive effect on the nanofiber texture and the process of operation. In addition, we performed electrospinning by connecting two or more collectors to each other and connecting them to the power supply. Fig. 7 shows an overview of the collector and the formation of electrospun nanofibers on its edge.

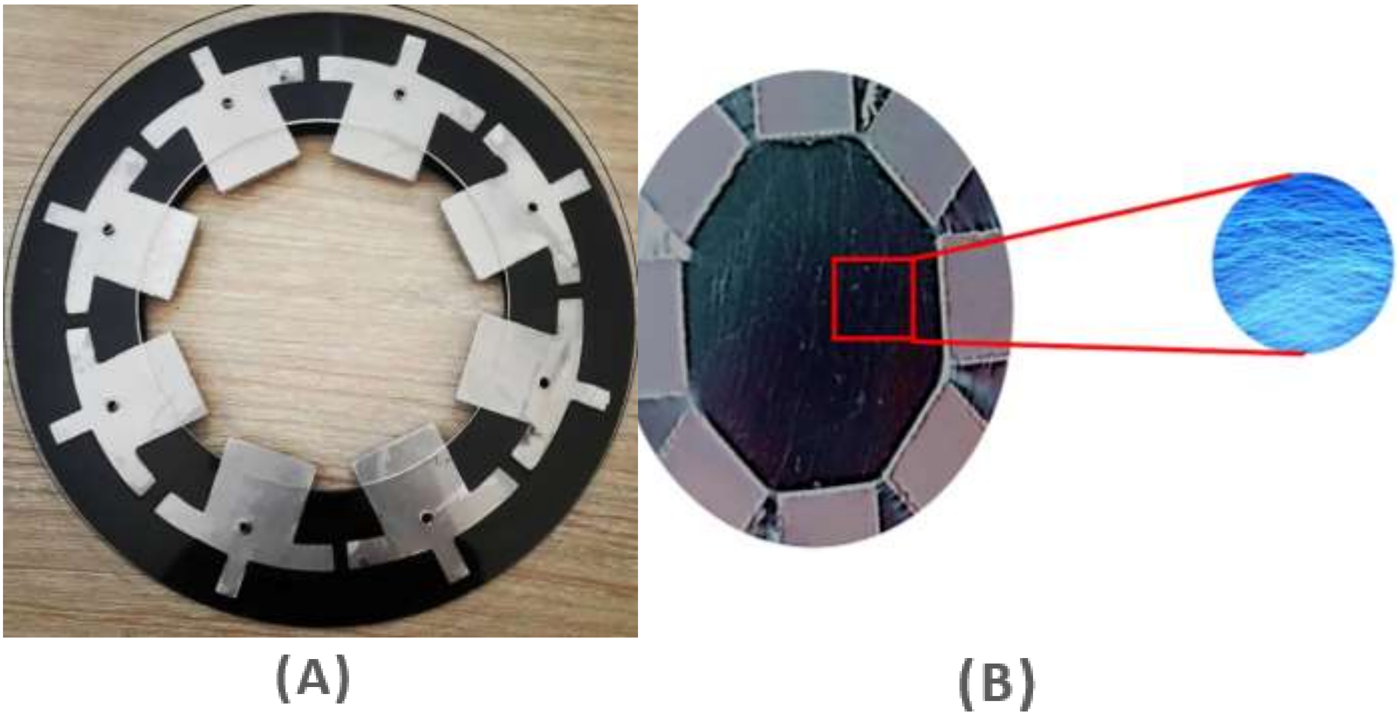


Fig. 7 8-electrode collector
(a) Overview

(b) View of the edges on which the nanofibers are electrospun.

4. Discussion

In this article, we were able to perform electrospinning operations in two different types using a separate 8-piece collector. Finally, we trapped several layers of electrospun nanofibers by manual and command adjustment. Of course, this type of operation depends on the type of activity and application used to plan the state, shape and type of nanofibers. This idea has helped us a lot in controlling and regulating the nanofibers. Using this method, you can have nanofibers with different angles and even layers.

Scanning Electron Microscope (SEM): As shown in Fig. 4; in this type of electrospinning operation, due to the lack of regulation of the incoming current to the electrode, the nanofibers with high dispersion, scattering and lack of electrospinning control. In order to better adsorb the nanofibers on the electrode as well as increase the diameter of the nanofibers and less adsorption of the nanofibers, it was observed and studied by SEM. Fig. 8 shows that nanofibers sit together beautifully, more accurately, and with less damage during electrode control operations. Fig. 8 also shows the health of the nanofibers.

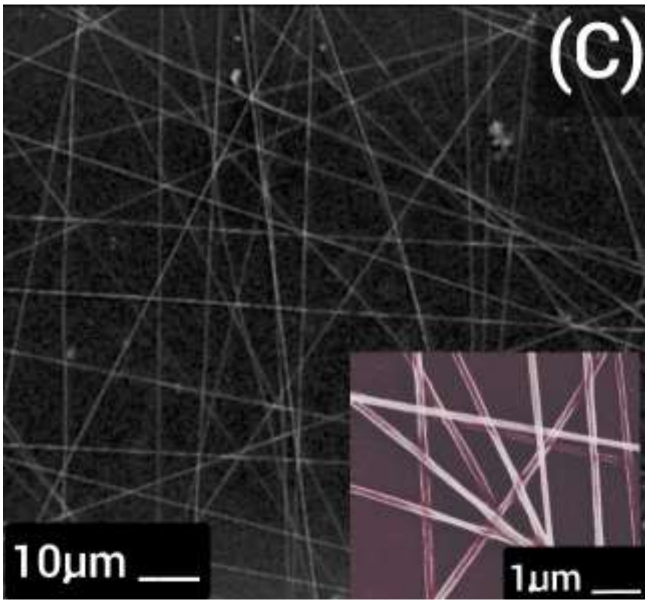


Fig. 8 View of nanofibers sitting on top of each other.

The corresponding electrode pairs were electrospun in order and in accordance with the clockwise movement. This prevents the nanofibers from slipping on top of each other, breaking or damaging them. It is also observed that the nanofibers are seated beautifully and in a certain order. This is because the electrodes are controlled and this causes the nanofibers between the two electrodes to be stretched and truncated and the other nanofibers to sit well on them. If the primary base nanofibers are very well aligned; the nanofibers sit on top of each other until the end of the electrospinning operation. Eventually, we will have regular and even nanofibers.

5. Conclusion

In this paper, a new and easy method of electrospinning collector was reported to simultaneously produce several batches of spun nanofibers with alignment and control capability. The key point of using this collector is that using a central current control device, the input of the collectors was manipulated and connected according to the instructions. We believe that this collector helped us to control and regulate nanofibers. Using this method, the nanofibers were electrospun with better tissue control along with shape and alignment capability. We also tried to greatly reduce the errors of this type of operation and better control the nanofibers. Also, more accurate programming of power input to the electrodes, shorter operation time with alignment, and control of target angles in nanofibers are some of the challenges that should be discussed and resolved in the present approach.

6. Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported this paper.

7. Acknowledgments

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