MANUFACTURING OF A PORTABLE ELECTROSPINNING GUN FOR BIOMEDICAL APPLICATIONS

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Electrospun patches have attracted interest in different biomedical fields, including tissue engineering and drug delivery. Portable electrospinning guns promise faster and more practical interventions in these areas. In this article, the design, construction and testing of a portable electrospinning gun are described to produce fiber and particle products. Results were discussed depending on the electrospinning gun's working system and properties of the products. The electrospinning gun system could have a high voltage of up to 30 kV. Also, no heating problems were encountered during high voltage values. Due to the uniformity, reproducibility and tunability of the produced PCL and PMSQ fibers, it can be said that electrospinning gun can be used in nanotechnology, drug delivery systems and wound dressing applications.

Keywords: *Electrospinning, electrospinning gun, fiber, wound dressing, biomedical*

1. Introduction

The biomedical industry is showing a huge interest in advanced techniques producing solid particles and fibers to engineer and commercialise efficient products, such as wound dressing patches [1], drug delivery systems [2], and scaffolds [3]. Because the products are used on humans or animals, they must be non-toxic, biocompatible, mechanically robust, adjustable, and easy to fabricate and sterilise [4]. There are many ways to produce the particles and fibers to obtain these properties. For instance, polymerization [5], dry spraying [6], electrospinning [7], sol-gel [8] etc.

The electrospinning method has recently become the most preferred fiber production technique because it has a low cost and high production rate compared to other methods [9]. This method produces nano-sized fibers from polymer solutions or melts with the help of electrostatic force. Fibers produced by electrospinning have smaller diameters and a larger surface area than fibers produced by conventional spinning methods [10]. Nano/fiber surfaces have an important place in biomedical applications such as artificial organs, wound dressings and drug delivery systems, with their vast surface areas, high porosity resulting from random positioning of fibers, and small pore sizes.

The electrospinning process is carried out at room temperature under atmospheric conditions. By controlling the fiber fineness of the fibers produced by this method, nano-micro fibers with desired properties can be obtained [10]. When the applied voltage reaches a certain critical value, the polymer droplet takes the form of a cone by balancing the electrostatic forces and other forces caused by the electrical charges that cause the droplet to dissipate. This special conical shape is called "Taylor Cone" [11,12]. The tensile strengths of the critical stress value cannot balance the electrostatic forces, and a fine jet is sent from the tip of the Taylor Cone-shaped polymer droplet to the collector. As the applied tension increases, the number of jets emerging from the surface of the Taylor cone-shaped polymer also increases [13].

The maximum charge density is located at the tip of the cone where the jet is formed, and the ejected liquid jet accelerates towards the collector [14,15]. As the polymer jet moves towards the collector, it only follows a steady linear motion for a certain distance and gradually accelerates. During this movement, the jet stretches and becomes thinner by being exposed to stretching, and the jet diameter decreases with the evaporation of the solvent [16]. The jet emerging from the surface of the polymer transforming from the spherical form to the Taylor cone form, first follows a linear path in a stable state for a certain time and then enters an unstable region. In this process, jets can undergo three types of physical instability that affect the size and geometry of the fibers [17,18]. The polymer jet is collected in solid form on the collector plate in favour of the evaporating solvent.

The evaporation rate of the solvent affects the transit time of the jet through the zone of instability. When a solvent with a high evaporation rate is used, the passage of the polymer jet through the zone of instability takes a short time, resulting in thicker nano/fibers [19]. When an ideal nano/fiber is desired to be formed by electrospinning, the objectives to be achieved are; the diameter of the fibers should be appropriate and controllable, the fiber surface must have a flawless structure or defects can be controlled, nano/fibers must be collected in a single structure. However, researchers found that achieving these three goals is difficult [20].

Nano/fibers can also be used as wound dressings in treating wounds and burns on human skin. Therefore, using fibers obtained by the electrospinning method as a wound dressing can produce effective results in many cases. Intervention by direct electrospinning of fine fibers

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on the injured surface helps the wounds to heal and causes no scars after treatment. Cam and his colleagues used a portable electrohydrodynamic gun to produce bacterial cellulose/gelatin nanofibers used in diabetic wounds. Results showed that these nanofibers could be safely applied to wound sites without any cytotoxicity [21]. In another research, Aydogdu et. al also produced polycaprolactone electrospun patches by using a such gun. These patches showed good biocompatibility and allowed different proliferation rates that varied with the composition of the scaffolds [22].

In this study, it is aimed to design and manufacture a portable electrospinning gun based on the basic components of the electrospinning system and also shorten the time of intervention on the injured surface and the healing time of the surface by making the electrospinning device portable. For this purpose, the design, production and performance of the electrospinning gun will be discussed.

2.Experimentals

2.1.Gun Design and Construction

2.1.1. Materials and Components

Polycaprolactone (PCL), polymethylsilsesquioxane (PMSQ) and solvents which are dichloromethane and ethanol were purchased from Yasin Technical Company. The solutions were prepared in a glass baker by dissolving the polymer in the solvent under constant stirring with magnetic stirrers until the polymers had completely dissolved. Bühler Motor brand DC Motor with 24V rated voltage, 0.275A rated current, 200 Ncm rated torque, and 14 rpm rated speed was used in the study in **Figure 1(a)**.

2.1.2. Construction

The electrospinning system consists of a capillary tip, a high voltage power supply and a conductive plate. The electrospinning gun was designed as two separate circuits, in which the high voltage value is adjusted with the help of a potentiometer. This voltage value is transferred to the OLED graphic screen and the electronic mechanism that allows the polymer inside the 0.5 ml syringe pump to exit from the level thanks to the back and forth movement of the DC motor.

2.1.3. Electrical and Electronic Design of Electrospun Gun

In the study, Bühler Motor brand DC Motor with 24V rated voltage, 0.275A rated current, 200 Ncm rated torque, and 14 rpm rated speed was used in the study **Figure 1(a)**. In the study, the electrospinning gun was designed as a network-connected system. Therefore, the MS-6024 model power supply of the MERVESAN Brand, shown in **Figure 1(b)**, was used to convert the 220 VAC voltage drawn from the mains into 24 VDC voltage to be used as the supply of the control card. The features of the power supply are as follows.

AC Voltage Input Range: 100-240 VAC

- DC Output Voltage: 24 V
- Output Current Range: 0-2.5 A
- Output Power: 60 W

Short Circuit / Overload / High Voltage Protected

In the first design of the portable electrospinning gun, Arduino Uno R3 was used as a microcontroller and Easy Driver as a motor driver. A special card was developed due to heating problems. The circuit prepared is shown in **Figure 1(c)**. OLED Graphic Display has been preferred in the design of the portable electrospinning gun. This screen is shown in **Figure 1(d)**. OLED Graphic Display with 128x64 pixel resolution, 0.96 inches (2.5 cm) width, operating voltage between 3V and 5V, with SPI / I2C interface support, and it has features that can print desired text or shapes on the screen by controlling with 6 pins. To create the high electric field required for the electrospinning system, the AHV24V30KV1MAW Model high voltage power supply belonging to the Analog Technologies Company is shown in **Figure 1(e)**, which can output up to a maximum of 30 kV, was used. **Figure 1(f)** shows the connection diagram of the high voltage module. Since the input voltage required by the high voltage power supply is 24 VDC, it was aimed to reduce the 220 VAC voltage drawn from the network to 24 VAC voltage in the study. In addition, since the high voltage power supply creates electrical noise and interference in the supply part, it is desired to provide insulation so that the high voltage power supply does not interfere with the network to which the system is connected. Therefore, a closed type step-down voltage transformer is used. The voltage step-down isolation transformer is shown in **Figure 1(g)**. The 24 VAC voltage obtained at the output of the closed type step-down transformer was converted to DC voltage with the bridge diode connection shown in **Figure 1(h)**, and the DC voltage required for high voltage power supply input was obtained. To control the voltage value at the high voltage power supply output, a double pot of 10 K is used. While the part behind the dual potentiometer shown in **Figure 1(i)** is directly connected with the high voltage power supply, the potent on its front part is used to numerically show the change of high voltage value on the Oled graphic display. LM2596 regulator circuit shown in **Figure 1(j)** was used to prevent fluctuations in the output voltage converted from alternating current to direct current with a bridge diode and to keep it at a constant value of 24 VDC.

2.1.4. Mechanical Design of Electrospinning Gun

Due to the success of using nano/fibers produced by electrospinning as a wound dressing in wide medical applications on wound healing speed, the electrospinning system was designed as

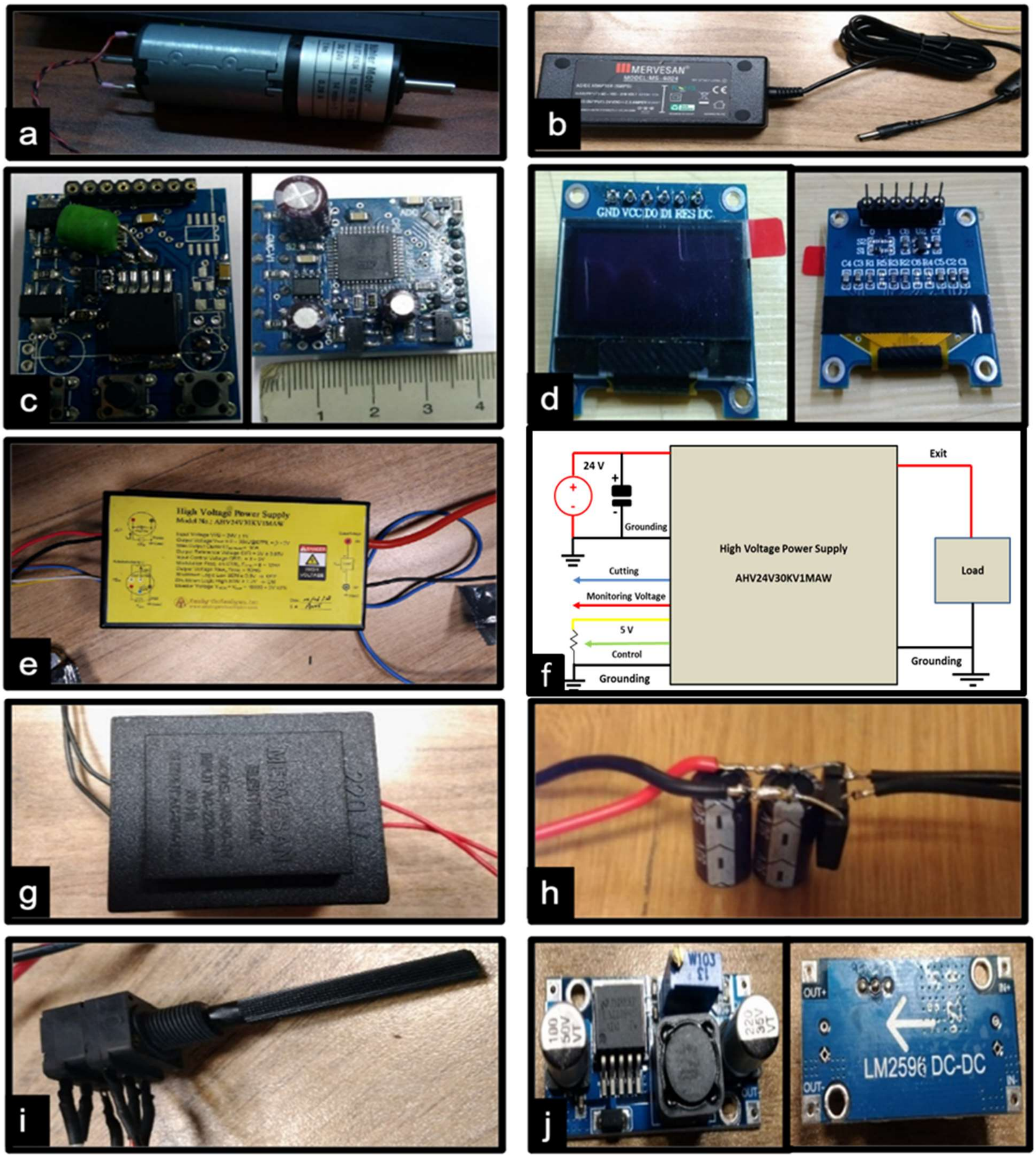


Fig. 1 - **(a)** Bühler Motor brand 24 VDC Motor**, (b)** 24V 2.5A Adapter**, (c)** GEMATE control card front and back**, (d)** OLED graphic screen front and back**, (e)** High voltage power supply with a maximum output of 30 kV**, (f)** Diagram of the HV module**, (g)** Closed type step-down voltage transformer**, (h)** Bridge diode connection**, (i)** Double potentiometer with 10 K value**, (j)** Front and back of LM2596 voltage regulator circuit.

a portable hand-held design and used in emergency medical intervention. The electrospinning gun is designed to accommodate two syringe pumps. The fluids exiting from the syringe pumps were combined at the syringe tip, and their output was provided as a single liquid. Since one of the goals of the electrospinning gun is to release medication, the gun is designed in this way. A uniform polymer fluid was injected into the syringe pumps during the experiments. **Figure 2(a,b)** shows 3D images of the electrospinning gun. **Figure 2(c)** shows the part where the liquid is to be injected, the microchip. **Figure 2(d)** shows the physical components of the electrospinning gun handle. The appearance of the electronic equipment being mounted on the device handle is shown in **Figure 2(e)**.

2.2. System Software

The 8-bit microcontroller ATmega16A was programmed in C language, and the code fragments and explanations used will be included in this section. At the beginning of the program, the

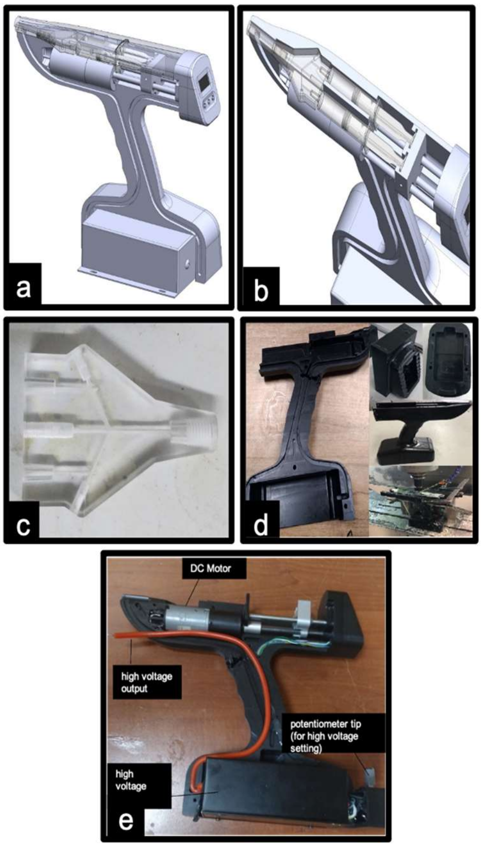
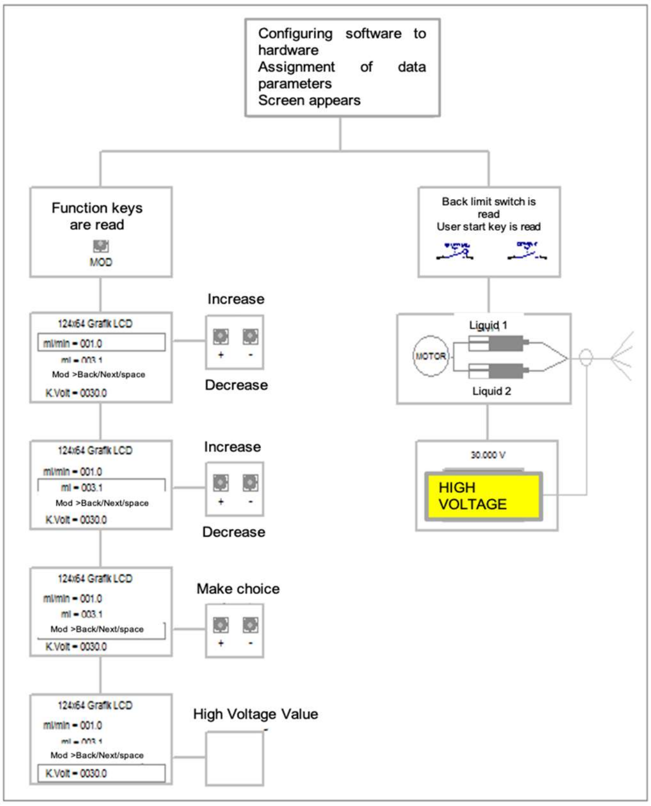


Fig. 2 - (a,b) 3D images of the device, (c) the part where the liquid is to be injected. (the microchip), (d) parts of the device handle, (e) internal view of the device.



Scheme 1 - Diagram showing the operation of the device hardware preload part is defined to automate the right and left parts of the mosfets to change the direction of the motor in the motor driver circuit. In this part, the hardware, circuit diagrams, connection types and software parts were used in portable electrospinning device design. Additionally, the diagram summarising the system is given in **Scheme 1.**

2.3. Electrospun Materials Characterisations

To observe the fiber formation and morphology, obtained fibers were obtained by Scanning Electron Microscopy(SEM), a Zeiss EVO 10 brand/model scanning electron microscope under 15 kV high voltage and with different magnification values. The coverslips were then cut into small pieces and divided into small samples, and it was made ready for SEM imaging by covering them with a Quorum brand gold plating device.

3. Results and Discussion

3.1. Fibers and Particles

The electrospinning process was carried out by drawing 8% wt PCL solution by weight with dichloromethane solvent to two 5 ml syringe pumps. High voltage was kept at 9 kV during the experiment. For comparison, 80% wt PMSQ, which was solved in ethanol, was electrospinning by drawing two 5 ml into two syringe pumps. During the experiment, the high voltage value was kept at 13 kV. Each experiment was repeated 3 times. Parameters are also shown in **Table 1.**

Table 1

Parameters of the electrospinning process

Polymer	Solvent	Voltage (kV)
PCL	Dichlormethane	9
PMSQ	Ethanol	13

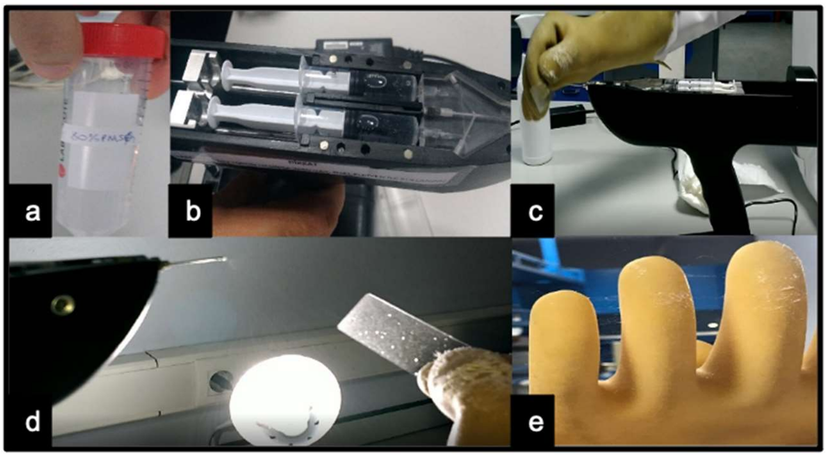


Fig. 3 - Electrospinning process trials a.) 80% wt PMSQ solution b.) Integration of the biopolymer solution into the device c.) Electrospinning process on lamella d.) Electrospinning process displayed by the phone camera e.) Fibers network formed on the glove by the application of electrospinning process.

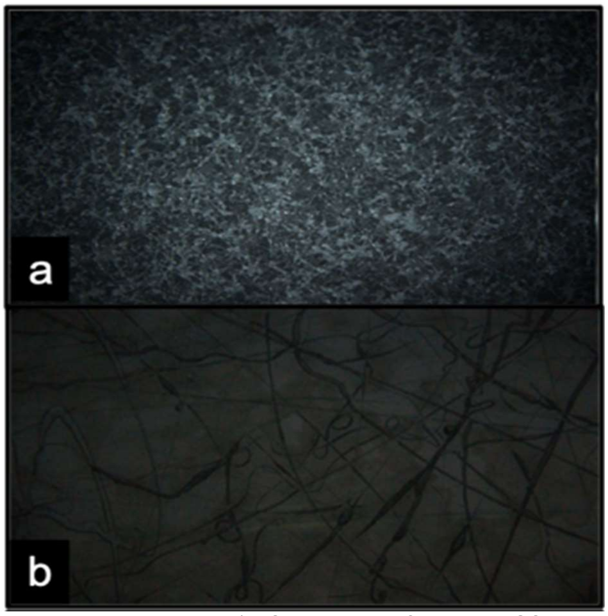


Fig. 4 - Optical microscope images a) PCL beads and fibers b PMSQ beads and fibers

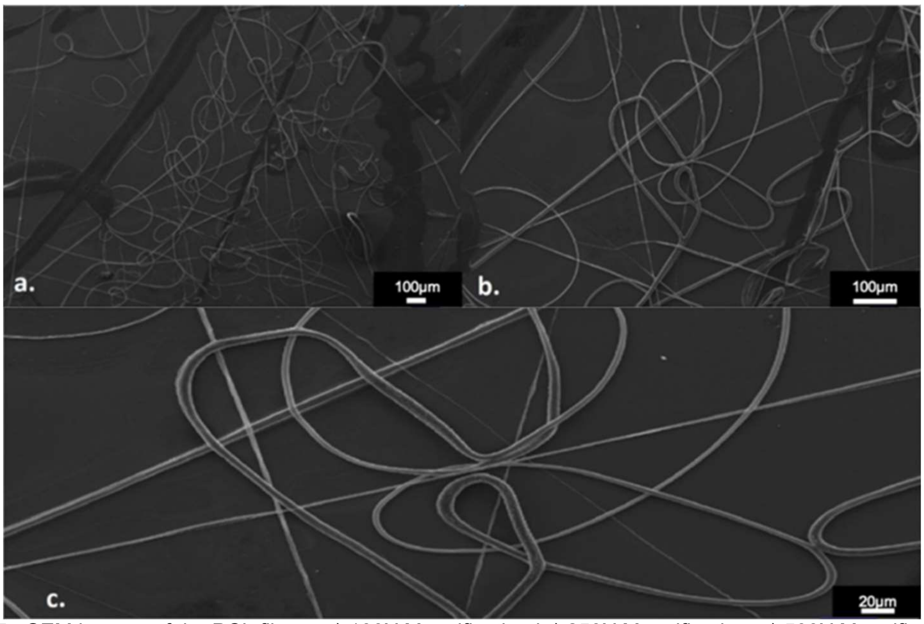


Fig. 5 - SEM images of the PCL fibers a.) 100X Magnification b.) 250X Magnification c.) 500X Magnification.

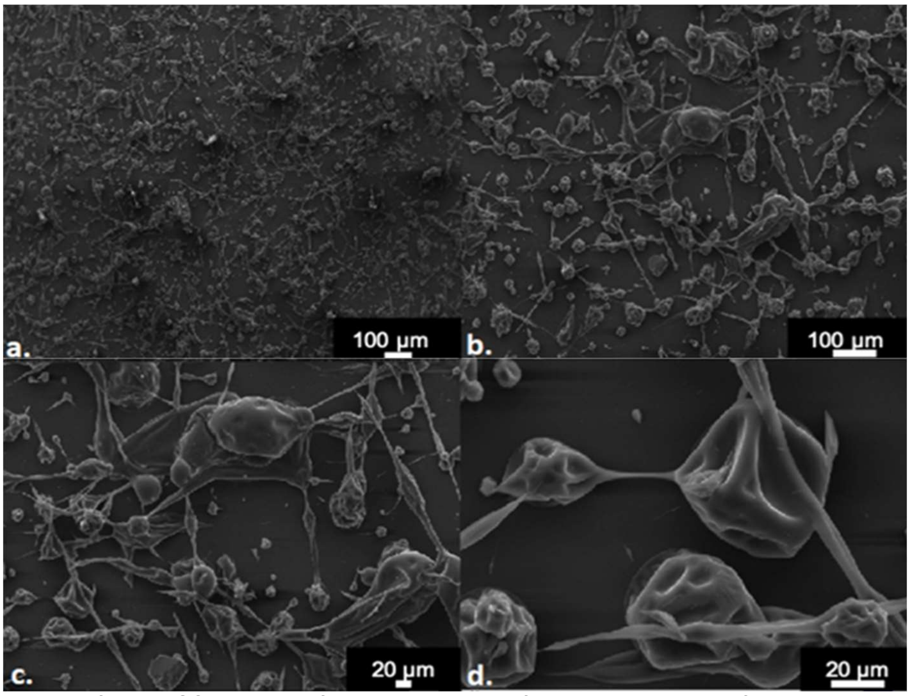


Fig. 6 - SEM images of the PMSQ beads and fibers **a.)** 100X Magnification **b.)** 250X Magnification **c.)** 500X Magnification **d.)** 2000X Magnification.

In the experiments carried out with the produced electrospinning gun, different solutions were used, optical microscope and SEM images of the produced nano/fibers were taken. The accumulation of the nano/fiber surface was observed by electrospinning on coverslips and gloves can be seen in **Figure 3.** Optical microscope images of the beads and fiber surface collected on the lamellae was taken. It can be seen in the **Figure 4.** that both particle and fiber samples can be produced by using a polymer named polymethylsilsesquioxane (PMSQ). Also SEM images of the PCL fibers and PMSQ beads/fibers are shown in **Figure 5.** and **Figure 6.** Based on the produced fibers and beads it can be said that electrospinning gun can be improved by further studies.

4. Conclusion

In this study, the design, production and experiments of a portable electrospinning device designed for biomedical applications are included. The main goal of the study was to design and produce an electrospinning gun that would meet the requirements in its field and in this context, to bring it to tissue engineering. When looking at the different test results, it can be said that the device meets these requirements. The diameters and uniformity of the obtained polymer fibers and particles showed similarity with the ones that were produced in a traditional way. The device has been ergonomically designed to provide the necessity of a portable system and its shape was in the size of a hand drill. The system has the ability to produce high voltage up to 30 kV. The device has been tested at different high voltage values and no heating problems were encountered during the high voltage. In future studies, which aim to create new perspectives in biomedical applications, polymer composite materials can also be produced by the electrospinning method. By adding a laser distance measurement sensor to the device, it can be provided to focus on the surface to be shot and to read comparative data of the amount of liquid used and high voltage values according to the distance. At the same time, the MODBUS RTU protocol can be integrated into the control card for more advanced uses. With this protocol, monitored variables such as operating times, sprayed liquid amounts, and process times can be transferred to external environments like phones and computers.

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