Electrospinning of Nanofiber-Based Materials and Application of the Technology to Lower Extremity Joint Exercise Rehabilitation

Jingmiao Ma¹ and Seung-Soo Baek²

¹Department of Physical Education, Sang Myung University, Jongnogu, 03016 Seoul, Republic of Korea
²Exercise Rehabilitation Research Institute, Sang Myung University, Jongnogu, 03016 Seoul, Republic of Korea

Correspondence should be addressed to Seung-Soo Baek; 18409472@masu.edu.cn

Received 12 March 2022; Revised 22 April 2022; Accepted 30 April 2022; Published 17 May 2022

Academic Editor: Awais Ahmed

This study mainly explores the electrospinning of nanofiber-based materials and the application of the technology to lower extremity joint exercise rehabilitation. In response to people’s concerns, this study mainly discusses electrospinning technology from the aspects of the safety of nanomaterials prepared by electrospinning technology and the application of nanomaterials prepared by electrospinning technology in lower limb joints. In the safety study of nanomaterials, six groups of experiments were set up to measure the joints of nanomaterials prepared by electrospinning technology under pressures of 500 N, 510 N, 520 N, 530 N, 540 N, and 550 N. For compression resistance, when the pressure is 540 N, the compressive performance of the nanomaterial is preferably 96%. In terms of the application of nanomaterials, 100 patients with lower extremity sprains in the Affiliated Hospital of Sun Yat-sen University were divided into 5 groups and then divided into 6 groups. Patient recovery rate when the device is applied to the patient’s lower extremity joint. Patients had the best recovery rate of 92% when the immobilization device was used for 6 days. The use of arthrodesis did not affect the patient’s other factors. The experimental results show that when the pressure is 540 N and the fixation device is used for 6 days, the nanofiber material prepared by electrospinning technology has the best rehabilitation effect on lower limb joint movement.

1. Introduction

1.1. Background and Significance. Traditional nanofibrous materials are seriously impractical due to their increasing pressure and corrosion resistance. Whether in the field of biology or construction, people are eager to find a technology to improve nanomaterials, so that the safety performance and corrosion resistance of nanomaterials can be improved to a higher level. With the continuous research of relevant experts, the preparation of nanofiber materials based on electrospinning technology is proposed.

Electrospinning technology is widely used in many fields, and the application of nanomaterials can improve various properties of nanomaterials. Nanomaterials are highly concerned by the medical community as an auxiliary rehabilitation material. The application of electrospinning technology to the preparation of nanomaterials can not only increase the yield of nanomaterials but also improve various properties of nanomaterials. Improvements in equipment have helped a lot [1].

1.2. Related Work. In Trejo et al.’s research, nylon 6 nm Monburon cloth and silk yarn and stylish fabrics of Eugansa were combined to construct a complete flying object. This work is the first demonstration that laser cutting and ultrasonic technology are used to process electrospun nanofabrics. The morphology and mechanical properties of the composite cloth are analyzed [2]. Although this study did an experimental comparison, it did not divide in terms of detailed parameters. Cianci et al. believe that epoxy resin (LX) A 4 is a metabolite of aladinic acid (arachidonic acid) produced by epoxy kinase. Its therapeutic effect is fully
standardized on various models of cells, preclinical and clinical. Among them, LXA 4 promotes tissue repair of periodontal disease and can also regulate the function of human periodontal ligament stem cells (hPDLC) [3]. The clinical treatment effect of LXA 4 is obvious, but the study did not discuss it in depth. Jiang et al. believe that nanofibers, as the main component of one-dimensional nanomaterials, have many uses. Electrospinning is a convenient and effective method for constructing nanofibers. However, in the conventional preparation method, since only unoriented nanofibers can be obtained, its applicability is greatly hindered. In recent decades, a lot of effort has been devoted to optimizing preparation methods. By improving the spinning structure, extraction, and separation of nanofibers, successfully aligned nanofibers (ANF) have been successfully obtained. Due to insufficient system evaluation of ANF, their research will outline the application of ANF in electronic spinning-based preparation, tissue engineering regeneration, sensors, reinforcement materials, sensors, and energy machines. ANF’s extensive application in tissue engineering regeneration provides a detailed explanation on this point. In the energy sector, ANF will focus on PEM fuel cells. Finally, we summarize the issues and prospects of ANF development [4]. The research only raised many conceptual questions, and specific experiments need to be further explored. Su et al. prepared multilayered TiO2 nanofibers (TiO2-NF) and nanoparticles (TiO2-NP) by template support method and single solvothermal method, respectively. The decomposition of methylene blue (MB) was used as a reaction model to evaluate the photocatalytic properties of these prepared materials. It is important that TiO2-NF prepared by template-assisted solvent heating has a multilayer structure [5]. The study confirmed that TiO2-NF can improve the photocatalytic rate but did not specifically determine the catalytic effect.

1.3. Innovation and Related Content. The main purpose of this study is to discuss the safety of the nanofiber material prepared by electrospinning technology and the application of the nanomaterial prepared by electrospinning technology in the joints of lower extremities. The joint fixation device uses the recovery of the patient’s lower extremity joint to evaluate the nanofiber material prepared by electrospinning technology. The main contents are as follows:

(1) Discuss the development of electrospinning technology from the perspective of domestic and foreign research. In-depth analysis of the preparation of nanomaterials by electrospinning technology was used to find out the beneficial inspiration for this research

(2) Conduct an in-depth discussion on electrospinning technology to find out the best method for preparing nanomaterials and related formulas that may be used. The preliminary discussion on the preparation method of nanomaterials is helpful for further research of the experiment

(3) Control the variables related to the experiment when conducting the experiment. The experiment of electrospinning technology actually involves the experiment of the solidity of the nanomaterials and deeply grasps the experimental concept to discuss the characteristics and applications of the nanomaterials in the experimental process

(4) The analysis of data after the experiment is based on tables and figures. Through the relevant software, the experiment is processed to draw the best solution and the most practical nanotechnology

2. Electrospinning Technology

2.1. Optimization of Electrospinning Technology. The structure of the mixed nanofiber membrane prepared by electrospinning technology is not outstanding in quality. In water, the reacted nanofiber membrane will partially dissolve and shrink significantly. Moreover, the mechanical properties of the fiber membrane are insufficient and need to be further strengthened, so it is necessary to link the polyvinyl alcohol/chitosan electrospun nanofiber membrane. The fiber membrane is treated with alcohol solution or alcohol vapor. The degree of expansion and shrinkage of the fiber membrane treated with alcohol is reduced, the strength characteristics, quality characteristics, covalent bond expansion, and shrinkage of the nanofiber membrane are improved, and the toughness of the sample is greatly improved, thereby achieving the purpose of cross-linking [6, 7]. At the same time, it is necessary to pay attention to the different conditions of patients in the application of nanomaterials in lower limb joints, so it is necessary to conduct a careful examination of patients before using nanomaterials for rehabilitation treatment [8].

In the field of nanobatteries, due to its excellent conductivity properties, it is a widely used carbon material in the research of lithium-sulfur batteries, which can greatly improve the conductivity of battery anode materials. The carbon-silicon composite material can not only improve the conductivity of the active sulfur of the positive electrode but also effectively inhibit the diffusion of polyurethane to the negative electrode through physical adsorption and ease the volume expansion of the positive electrode. It is an electrode material in the working process of the battery. And sometimes, there is research in the field of machinery. This can improve battery performance, but the capacity is small and the decay is fast. Then, sulfur is coated with a carbon material, and the carbon material is used as a conductive skeleton to realize electron transmission. After the porous carbon fiber is prepared by the electrospinning method, the pores of the carbon fiber are filled with sulfur by the liquid-phase deposition method, which is the best preparation method for the battery. When the current density is 6°C, the initial specific capacity of the battery increases by 800 milliamperes per gram [1, 9, 10]. Liquid-phase deposition belongs to liquid-phase epitaxy technology of the semiconductor growth process.

2.2. Application of Electrospinning Technology in Nanofiber Materials. In the field of nanocatalyst materials, nanometals are an excellent catalyst, combining nanomaterial carriers with
nanocopper and composite catalysts, substitutes for precious metal catalysts such as platinum and gold, many organic reactions have better catalyst characteristics, and high capacitor electrodes. The material and copper oxide have good electrochemical properties. To this end, researchers have been developing nanocomposites with various morphologies, sizes, and characteristics to meet the various applications and needs of today's society. Nanometal is an excellent high-temperature material. The traditional preparation method is mainly based on wet spinning, and the fibers can be obtained in the micron level. At present, there is little research on the preparation of nanometal nanofibers by electrospinning technology. Nanometal can be prepared by electrospinning technology. Nanofibers have good metal tensile properties, so the performance of nanometallic materials can be optimized [11]. By changing the environment of the textile fluid with electric current, the nanoparticles can adapt to the environment in the textile fluid.

The angle of the PAN nanofiber test sample and the droplet formation is one hundred degrees, the material surface has almost no hydrophilic groups, and the hydrophilicity is poor. The average static contact angle of AOPAN nanofibers was reduced to 80 degrees after treatment of PAN nanofibers with amino modification technology. Therefore, a certain number of hydrophilic groups are added to the surface of AOPAN nanofibers modified by amino acids to improve the hydrophilicity. With the further change of ATRP technology of AOPEN nanofibers, the average static contact angle of polymerized nanofibers is reduced to 50 degrees, which can further improve the hydrophilicity of nanofibers. This is because a large number of groups are introduced on the surface of the transplanted nanofibers. In promoting the improvement of hydrophilicity, the carboxyl group plays a very good role, and the hydrophilicity is greatly improved [12]. Electrospinning technology is used to prepare nanometal materials in water, and the manufacturing process of nanometal materials is clearly displayed.

2.3. Research Methods of Nanomaterials by Electrospinning Technology

(1) Polymer research method. During the preparation of the textile solution, the nanomaterials are introduced into the fiber-forming polymer matrix, and then, spinning is performed. This method has a certain influence on the process of electronic spinning; nanoparticles become very easy to aggregate. Therefore, the difficulty of this technology is how to improve the adaptability between nanoparticles and textile liquor. The surface of the nanoparticles can be modified, and the ligand can be rotated in the liquid phase. However, the application of nanosurface modification technology is limited due to its complicated process, and may not be suitable for most nanoparticles and textile solutions [13, 14]. Controlled release of drugs can only be used in the field of biomedicine, wound repair, biological tissue engineering, and other aspects of the fiber filter material in the gas filtration liquid filtration and personal protection and other fields but also can be applied to the shell of ships, the inner wall of oil pipelines, high-rise glass, automobile glass, and so on [15].

(2) Medical research method. Nanomaterials in medical research, first of all, the comparison of the lower limb pretreatment of sEMG and the wavelet transform-based filtering method in the traditional filtering method, are more effective than the wavelet transform method for noise removal processing of signal filtering. Next, using the three types of time-domain feature value changes, the action at the start of sEMG is determined. Next, the eigenvectors of the lower limb sEMG are studied, and finally, the eigenvalues of the time domain and the frequency domain are extracted. The neural network is trained by using the characteristic values of the time domain and frequency domain features and their joint features as the input of the neural network, where the BP neural network classifier classifies the two operation modes of lower limb bending and design will expand the application range [16, 17].

(3) Carbonization treatment method. During the carbonization process, since the graphite ring structure is formed after dehydrogenation, the PAN will not collapse during the carbonization process. The fiber membrane shrinks during the preoxidation process. Therefore, in order to ensure the specific structure of the fiber, during the preoxidation process, a specific mass object can be used to extend the film in the vertical direction to maintain the fiber state. Clamping the nanofiber bundles at both ends of the jar and placing them in a tubular furnace can produce a fixing material with its own high temperature resistance. In order to prepare the aluminum foil for direct oxidation, the orientation structure of the fiber can be maintained during the preliminary oxidation according to the adsorption force between the fiber film and the aluminum foil. In the preoxidation process, the fiber bundle is covered with glass, and the binding force of glass gravity on the fiber bundle maintains the structure of the fiber bundle [18–20].

(4) Electrostatic treatment method. Generally speaking, it includes the following steps. First, the precursor containing the target material and the organic polymer are mixed, and an organic solvent is added to form a viscous yarn solution. Then, the solution is injected into the high-voltage electrospinning yarn with a specific voltage for spinning and collection. The general electronic spinning system is mainly composed of three parts: high-voltage electrostatic electric field power supply, spinning port discharged from nanofibers, and ground plate. The high-voltage power supply is generally a DC power supply, and the voltage range of the AC power supply is generally sixty volts. The output end is connected to the spinning port, and the other end is grounded. The spinning port is usually a metal needle with a specific
diameter, and the diameter of the spinning port affects the diameter of the nanofiber. The solution is usually discharged directly into the cylinder by gravity, and there is also a peristaltic pump connection for controlling the uniform flow of droplets. The power receiving plate for the metal plate usually uses a ground wire to make the potential of the power receiving plate zero. Therefore, the electrospinning of the output voltage of the high-voltage power supply is the spindle voltage. Another type of device, connecting the attraction device to the receiving board, can not only expand the electric field strength but also reduce the output voltage of the high-voltage power supply [21].

(5) Sprinkler method based on nanomaterials. Three hundred times higher than single nozzle electrospinning efficiency. Multinozzle devices can improve production efficiency but can also cause other problems. For example, during the electrospinning process, since the sprinkler heads are charged, if multiple sprinkler heads are used, an electrostatic repulsive force will be generated between different sprinkler heads, affecting the formation of the jet. Therefore, multiple sprinkler devices of different layouts are designed to reduce mutual repulsion between sprinkler heads. The six needle ring configuration device can not only obtain a stable jet aircraft but also avoid the interference of environmental factors such as air flow. Under the premise of ensuring fiber quality, we improve the production efficiency of fibers and contribute to promoting the mass production and practical application of electric field spinning fibers.

2.4. Formulas Used in the Preparation of Nanofiber Materials. In the preparation of nanomaterials by electrospinning technology, it is necessary to conduct a comprehensive study of nanomaterials through performance and actual application. At this time, relevant formulas will be used to explain them.

(1) In the signal recognition of human body, the information transmission function of nanomaterials plays a huge role. The relevant formula is as follows:

\[ m_k(t) = \sum_{i=1}^{N} u_k(t) \times \delta(t - \tau_i) \times g_k(t) \times g(t) \times M \]  \hspace{1cm} (1)

In information transmission, usually the signal transmission requires a certain process, and the transmission time will also be affected by related factors. When using nanomaterials for human body information collection, the time factor and the temperature factor of the nanomaterials need to be considered. The longer the time, the more sensitive the reaction of the nanomaterials, because the nanomaterials need time to continuously activate during the information transmission.

(2) When processing the collected information with special equipment, the information needs to be processed first. The relevant formula is as follows:

\[ u_p(t) = \sum_{k=1}^{M} [u_k(t) \times \delta(t)] = \sum_{k=1}^{M} \delta(t_k - t_k) (t_k + t) \]  \hspace{1cm} (2)

The processing of information is carried out in segments, each segment needs to be refined, and then, the image description of the information. The entire process is carried out in a complete processor, which can be directly filtered from the table when data extraction is performed.

(3) In the conduction information of nanomaterials, the conduction distance and the average power of conduction are very important. The relevant formula is as follows:

\[ vS_1(t) = S_2(t)(1 - \cos \omega \Delta) = 4S_2 \sin^2(\frac{\omega \Delta}{2}) \]  \hspace{1cm} (3)

When the conducted power is constant, the larger the cosine value of the conduction process, the lower the conduction rate of the nanomaterial. The greater the sinusoidal value during conduction, the greater the rate of conduction. In most medical devices, the rate of change in the rate of nanomaterial conduction will be focused on. For the nanomaterials with larger conduction rate, they will be used first.

(4) The stress performance of nanomaterials reflects the bearing capacity of nanomaterials to a certain extent, and the related formula is expressed as follows:

\[ \sigma_m^2 = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_m(\omega)d_\omega = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int |H(\omega)|^2 S_m(\omega)d_\omega \]  \hspace{1cm} (4)

\[ \sigma_r^2(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_r(\omega,d_\omega = \sigma_m^2 \rho^2(t) \]  \hspace{1cm} (5)

The value of the stress change can directly reflect the quality of the nanomaterial. In general, the stress value of nanomaterials with large specific surface area will also increase; of course, this is to exclude the specific surface area under the environment not affected by temperature. Nanomaterials are highly durable materials, and their corresponding stress coefficients will directly determine the lifetime of nanomaterials.
Table 1: Related equipment used before the experiment.

| Equipment name               | Specification                        | Manufacturer                     |
|-----------------------------|--------------------------------------|----------------------------------|
| Constant temperature oil bath device | Temperature-controlled magnetic stirring | Germany                          |
| Infrared spectrometer       | NiN10                                | American Asia Pacific            |
| High temperature power supply | DMP303                               | Hefei Power Supply Company       |
| Precision grouting machine  | LPS-5A                                | Changhe Electric Appliance Company |
| Electron microscope         | PM-80                                 | Sino-American                    |
| Pressure sensor             | MQ-50                                 | Kunshan Instrument Company       |
| Data analyzer               | AM3240C                               | Electronic Technology Research Institute |
| Spectrum analyzer           | TNC-20                                | China to Federal Group           |
| Assembly machine            | 1313                                  | Japan                            |

3. Electrospinning Technology Experiment

3.1. Experimental Equipment. The relevant experimental data needs to be measured before the experiment. The relevant equipment used before the experiment is shown in Table 1. The function of the assembling machine is to systematically assemble the joint fixing device of nanomaterial synthesis during the experiment, which avoids certain errors caused by the experiment in the process of manual assembly. The function of the frequency analyzer is to control the transmission rate and transmission time of the signal during the experiment. The data analyzer is designed to comprehensively collect the data that appears during information processing to prevent the omission of information during the experiment. In addition to controlling the external environment, we also need to control the internal environment reasonably in order to get more accurate results [22]. The data analyzer is controlled by the computer throughout the use. The role of the pressure sensor is equivalent to further data mining of the experiment through the data returned by the pressure sensor when applying pressure to the fixture. The function of the optical instrument is to observe the rehabilitation state of the patient at any time without changing the fixed instrument during the experiment.

3.2. Control of Experiment-Related Factors. We pay attention to controlling related factors during the experiment. When conducting safety experiments, the measurement of the joint fixture must be performed in a safe environment. Each time a measurement is taken, relevant data records are required. The value of pressure is within a reasonable range. During the experiment of the application of the joint fixation device, the joint fixation device needs to be polished to prevent the patient from being scratched during the experiment. During the experiment, the patients had the same degree of sprains, and the patients had the same sprained parts.

3.3. Experimental Process. In the study of the safety of nanomaterials, six groups of experiments were set up to measure the joints of nanomaterials prepared by electrospinning technology under the pressure of 500 N, 510 N, 520 N, 530 N, 540 N, and 550 N and compression resistance.

In terms of application of nanomaterials, 100 patients with sprains of lower extremities who were admitted to the Affiliated Hospital of Sun Yat-sen University were divided into 5 groups, and each group of experimenters was divided into 20 people. A total of 6 groups of days at 1 d, 2 d, 3 d, 4 d, 5 d, and 6 d were used to observe the recovery rate of the patients when the nanomaterial fixation device prepared by electrospinning technology was applied to the patients’ lower limb joints.

4. Analysis of Electrospinning Technology

4.1. Summary of Experimental Data. The compressive performance of the nanomaterial joint fixation device when studying different pressures is shown in Table 2.

The performance of nanomaterials is usually determined by the molecular structure of nanomaterials. In general, the
4.2. *Experimental Data Analysis.* The safety performance of the lower limb joint fixation device under different pressures is shown in Figure 1. In the figure, when the pressure is 500 N, the safety performance of the 6 sets of data is at the lowest state. The measurement time during the experiment was carried out on the same day to avoid different measurement results caused by different time. Through comparison, it is found that the safety performance also increases when the pressure value gradually increases, but when the pressure value reaches a certain range, it will reach a critical value. As the pressure continues to increase, the entire fixing device is in a state of being easily broken. If this limit is exceeded, the safety performance will be affected. The nanomaterials after applying pressure are no longer suitable for the fixation of the patient’s lower limbs.

As the pressure changes, the safety rate of the lower limb joint fixation device is shown in Figure 2. The concept of pressure change is quoted in the figure. The value 1 represents 500 and the value 2 represents 510. When the pressure is 540 N, the compressive performance of the nanomaterials is preferably 96%. When the pressure is 500 N, the maximum value of the measured safety performance is 50%.

The safety performance of the nanomaterial itself has not changed, and the value measured during the experiment represents the actual safety rate under a certain pressure. With the constant change of the pressure value, the highest position is reached when the pressure is 540 N, that is, the safety of the lower limb joint fixing device at this time is the best. Within a certain range, the force sustained by nanomaterials is directly related to safety performance.

With the gradual change of the number of days, the patient’s recovery is shown in Figure 3. At a certain number of days, the overall recovery of group 6 is relatively low. Most of the reasons for this situation are due to the different circumstances of the patients, but the overall recovery shows an upward trend with time. Therefore, the specimens collected during the experiment meet the experimental requirements. The recovery effect of the patients in group 4 was lower than that in group 1 on the first day, but after the use of the lower extremity joint fixation device, the patients showed that the recovery situation surpassed that of group 1. It shows that the joint fixation device with nanomaterial as the main power shows a good trend in the use of patients.

The corresponding change of the patient’s recovery rate with time is shown in Figure 4. When the fixed device was used for 6 days, the recovery rate of the patient was the best, at 92%. Among them, the fixing device is equivalent to auxiliary treatment to prevent the patient from being injured.
The recovery rate of the patients in group 1 is generally low, but when the time changes, the recovery rate shows a rising state. The recovery rate of the patients in group 6 is higher at a certain number of days. In this case, it is more suitable for the rehabilitation of patients. The data in the figure also tends to the sixth group. The recovery level of the patients in group 2, group 2, and group 3 is lower than the recovery rate of normal patients, indicating that the patients in these three situations have poor recovery treatment effects.

5. Conclusion

Starting from the background at home and abroad, this research deeply explores the preparation of electrospun nanofiber materials and its application in the rehabilitation of lower extremity joints, and a series of experiments have made breakthroughs, confirming the safety and reliability of nanomaterials. Rehabilitation treatment effect is good. Open up new ideas for further research on nanomaterials.

As a high-strength material with broad development prospects, nanomaterials have made outstanding contributions in the fields of construction, medicine, aviation, and so on. Especially in recent years, the country has paid attention to and supported high-tech and high-information materials, and nanomaterials have become more and more widely used as a landmark application for many polymer materials.

This study explores the strength of nanomaterials from the safety performance of nanomaterials and explores the effect of nanomaterials on the recovery rate of nanomaterials in medicine from the application of nanomaterials. We analyze the practical properties of nanomaterials from different angles. In a certain pressure range and a certain time, the use of nanomaterials is the best. This study has a very important value for the discussion of nanomaterials.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Exercise Rehabilitation Research Institute, Sang Myung University.

References

[1] R. Ramakrishnan, J. Gim bun, F. Samsuri et al., “Needleless Electrospinning Technology – An Entrepreneurial Perspective,” Indian Journal of Science and Technology, vol. 9, no. 15, pp. 1–11, 2016.
[2] N. K. Trejo, C. G. Reyes, V. Sanchez, D. Zhang, and M. W. Frey, “Developing composite nanofibre fabrics using electrospinning, ultrasonic sewing, and laser cutting technologies,” International Journal of Fashion Design Technology & Education, vol. 9, no. 3, pp. 192–200, 2016.
[3] E. Cianci, O. Trubiani, F. Diomede et al., “Immobilization and delivery of biologically active Lipoxin A4 using electrospinning technology,” International Journal of Pharmaceutics, vol. 515, no. 1-2, pp. 254–261, 2016.
[4] M. Jiang, M. Wang, S. Wei, and Z. Chen, “Aligned electrospun nanofibers based on electrospinning technology,” Progress in Chemistry Beijing, vol. 28, no. 5, pp. 711–726, 2016.
[5] B. Su, J. Xin, J. Li et al., “Comparing the photocatalytic property of TiO$_2$ nanoparticles and structured nanofiber materials,” *Micro & Nano Letters*, vol. 11, no. 6, pp. 323–325, 2016.

[6] E. S. Bokova, G. M. Kovalenko, Y. N. Filatov, and N. V. Evsyukova, “Electrospinning as promising technology for expanding the assortment of fibre-reinforced porous composite materials and coatings,” *Fibre Chemistry*, vol. 49, no. 3, pp. 167–172, 2017.

[7] J. Tian, Q. Ma, W. Yu et al., “Comparison of different electrospinning technologies for the production of arrays with multi-functional properties: fluorescence, conduction and magnetism,” *Journal of Physics D Applied Physics*, vol. 53, no. 15, article 155301, 2020.

[8] P. Wang, S. Wang, X. Zhang et al., “Rational construction of CoO/CoF2 coating on burnt-pot inspired 2D CNs as the battery-like electrode for supercapacitors,” *Journal of Alloys and Compounds*, vol. 819, article 153374, 2020.

[9] F. Afgah, C. Dikyol, M. Altunbek, and B. Yüce, “Biomimicry in bio-manufacturing: developments in melt electrospinning writing technology towards hybrid biomanufacturing,” *Applied Sciences*, vol. 9, no. 17, p. 3540, 2019.

[10] K. I. Lukaniina, T. E. Grigor’ev, T. K. Tenchurin, A. D. Shepelev, and S. N. Chvalun, “Nonwoven materials produced by electrospinning for modern medical technologies (review),” *Fibre Chemistry*, vol. 49, no. 3, pp. 205–216, 2017.

[11] M. Chen, Y. Zhang, H. Li, H. Yan, and W. Yang, “Nanofiber preparation technology by melt differential electrospinning with high efficiency in the absence of a solvent,” *Beijing Hua-gong Daxue Xuebao*, vol. 45, no. 5, pp. 119–128, 2018.

[12] L. Persano, A. Camposeo, and D. Pisignano, “Advancing the science and technology of electrospinning and functional nanofibers,” *Macromolecular Materials & Engineering*, vol. 302, no. 8, article 1700237, 2017.

[13] M. A. Cerqueira, M. J. Fabra, J. L. Castro-Mayorga et al., “Use of electrospinning to develop antimicrobial biodegradable multilayer systems: encapsulation of cinnamaldehyde and their physicochemical characterization,” *Food & Bioprocess Technology*, vol. 9, no. 11, pp. 1874–1884, 2016.

[14] Z. Chen, A. A. Trofinov, L. G. Jacobsohn et al., “Permeation and optical properties of YAG:Er$^3+$ fiber membrane scintillators prepared by novel sol–gel/electrospinning method,” *Science & Technology*, vol. 83, no. 1, pp. 35–43, 2017.

[15] X. Sun, H. Zhang, W. Meng, R. Zhang, K. Li, and T. Peng, “Primary resonance analysis and vibration suppression for the harmonically excited nonlinear suspension system using a pair of symmetric viscoelastic buffers,” *Nonlinear Dynamics*, vol. 94, no. 2, pp. 1243–1265, 2018.

[16] X. L. Zeng, M. R. Kobischka, T. Karwoth, T. Hauet, and U. Hartmann, “Preparation of granular Bi-2212 nanowires by electrospinning,” *Superconductor Science & Technology*, vol. 30, no. 3, article 035014, 2017.

[17] H. Y. Wei, H. Li, Y. Cui et al., “Synthesis of flexible mullite nanofibres by electrospinning based on nonhydrolytic sol–gel method,” *Journal of Sol Gel Science & Technology*, vol. 82, no. 3, pp. 718–727, 2017.

[18] Y. Zhao, J. Jiang, W. Li et al., “Electrospinning jet behaviors under the constraints of a sheath gas,” *AIP Advances*, vol. 6, no. 11, article 115022, 2016.

[19] S. Coppola, G. Nasti, V. Vespini, and P. Ferraro, “Layered 3D printing by tethered pyro-electrospinning,” *Advances in Poly-mer Technology*, vol. 2020, no. 2, Article ID 1252960, 9 pages, 2020.

[20] S. Jang, Y. Kim, S. Lee, and J. H. Oh, “Optimization of electrospinning parameters for electrospun nanofiber-based triboelectric nanogenerators,” *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol. 6, no. 4, pp. 731–739, 2019.

[21] A. Choudhury, J. H. Kim, S. Sinha Mahapatra, K. S. Yang, and D. J. Yang, "Nitrogen-enriched porous carbon nanofiber mat as efficient flexible electrode material for supercapacitors,” *ACS Sustainable Chemistry & Engineering*, vol. 5, no. 3, pp. 2109–2118, 2017.

[22] G. Bo, L. Chang, H. Chenglong et al., “Effect of Mg and RE on the surface properties of hot dipped Zn–23Al–0.3Si coatings,” *Science of Advanced Materials*, vol. 11, no. 4, pp. 580–587, 2019.