Journal of Dentistry and Dental Practices
ISSN: 2689-5994

Academic Strive
Researcher's perception is our reality

Review Article *Volume 7 Issue 1*

Emerging Role of Electrospun Nanofibers in the Treatment of Periodontitis

Mahmood Arifa[1]* and Sawai MA[2]

[1]Department of Prosthodontics, Government Dental College and Hospital, Hyderabad, India
[2]Department of Periodontology, Faculty of Dentistry, Jamia Millia Islamia, New Delhi, India

***Corresponding author:** Arifa Mahmood Husain, PG student, Department of Prosthodontics, Government Dental College and Hospital, Afzalgunj, Hyderabad, Telangana, 500012, India; Email: arifamahmood774@gmail.com

Received Date: January 06, 2025; **Published Date:** January 20, 2025

Abstract

Periodontitis is a major oral health condition affecting populations worldwide. While the microbial colonization remains an unequivocal etiology, modalities aiming to eliminate/reduce the microbial load form a part of mainstream treatment. This includes meticulous scaling and root planing and sometimes surgical procedures. Nevertheless, the need for anti-microbial therapy was advocated by many researchers that led to a quest to search for a suitable drug delivery system. Local drugs in the form of chips, fibers, gels, etc. have been used in periodontitis. However, these systems fall short of delivering the drug adequately due to limited accessibility and poor release. Electrospun nanofibers can carry drugs that can be used to control local sources of infection, as in periodontitis. These fibers exhibit a large surface area allowing them to carry large doses of drug. They can also withstand high masticatory forces due to their high tensile strength, eliminating the need for their periodic replacement that can ensure a better patient compliance. Various studies have been in place characterizing the morphological and biological characteristics of these fibers. This review aims to highlight the potential of drug loaded nanofibers produced by electro spinning, as a means of local drug delivery in periodontitis.

Keywords: Nanofibers; Periodontitis; Drug Delivery; Electrospinning; Local drugs

Abbreviations

SRP: Scaling and Root Planing; LDD: Local Drug Delivery; LDDS: Local Drug Delivery Systems; DOX: Doxycycline; TXC: Tetracycline; METRO: Metronidazole; AMOX: Amoxicillin; PCL: Polycaprolactone; HA: Hyaluronic Acid; PVA: Poly Vinyl Acid; PLGA: Poly Lactic Glycolic Acid; COAX: Coaxial; HDD: Homogenously Distributed Drug; MTT: 3-(4, -dimethylthiazol-2-yl)-2,5 diphenyl tetrazolium bromide assay; PI: Plaque Index; GI: Gingival Index; PD: Pocket Depth.

Introduction

Periodontal diseases cover a wide spectrum of abnormalities affecting the supporting structure of teeth. Progressing from a reversible tissue inflammation called gingivitis to destruction of alveolar bone and loss of clinical attachment of periodontal ligament, which then is called periodontitis. The colonization of periodontal sulcus by microbes leads to tissue destruction causing a pathological pocket formation which traverses along the root surface apically to disturb the harmony of attachment apparatus leading to periodontitis. The clinical picture ranges from bleeding on probing to tooth mobility and pathological migration. There is loss of attachment with deep probing depths and radiological evidence of bone loss [1] Due to the chronic nature of disease, the treatment implicates a life-long determination by the patient to maintain a visibly good oral hygiene along with a clinician's ability to counter the etiological agent and improving the clinical condition. Minimization of microbial colonization, acute symptoms, restoration of a healthy periodontium all queue up in the itinerary of a successful treatment [2].

A home care routine involving active removal of biofilm by the patient is a prerequisite before proceeding to clinical management of the disease [2]. Scaling and root planing is then advocated in the treatment. It involves mechanical removal of the biofilm and calculus deposits in areas inaccessible to manual cleaning by the patients such as deep sub-gingival areas. It may involve use of hand instruments like scalers and curettes or piezoelectric/sonic/ultrasonic driven instruments [3].

In addition to this, drug therapy has been recommended by many clinicians and researchers for the management of periodontitis. This involves systemic as well as local delivery of the drugs [4]. Available literature supports the superiority of administration of antibiotics as an adjunct to SRP mainly amoxicillin and metronidazole when administered systemically [5-7].

Teeth with poor expected results to non-surgical therapy; only, are then considered for a surgical evaluation. This includes resective and regenerative osseous therapy. The resective osseous surgery aims to remove the defect by lowering the level of alveolar bone to the level of defect while the regenerative therapy intends to re-establish the lost areas of the periodontium [3].

Regardless of the modality of treatment, a better understanding of the disease processes has allowed the clinicians to advocate host modulation therapy as an adjunct to surgical and non-surgical therapies [8]. This involves the administration of local drugs in areas of inflammation.

The Local drug delivery systems (LDDS) have been developed to ensure a sustained release of the drug, providing comfort to the patient, thus improving patient compliance. The challenge to access deep pockets has also revolutionized the discovery of various LDDS. These local drugs are available in the form of microspheres, membranes, fibers, chips; strips etc [9,10].

The limited access to the sub-gingival area and early exhaustion of the drug leading to poor microbial killing, poor patient compliance, and biocompatibility are some of the major challenges that need to be countered before developing LDDS. Needless to highlight the importance of drugs as an adjunct treatment to SRP, new modalities need to be developed to overcome these shortcomings.

Nanodentistry is a term that implicates an amalgamation of nanotechnology with oral health in various aspects spanning diagnosis and management of oral diseases with combined use of a nanomaterial [11]. One such nanomaterial identified is a nanofiber. These are porous and biocompatible fibers comprising of diameter of about 100 nm that can carry within them various classes of antibiotics/drugs that make them a valuable addition to infection control in Dentistry [5,12]. Nanofibers appear as an option for periodontal treatment as they can be used as LDDS.

Microfibers have been used for LDD in periodontitis. They however had a few disadvantages. Their placement was not found convenient by the clinicians and patients displayed discomfort during the same. These fibers often reported dislodgement which required frequent exchanging/ replacement with new fibers [13].

Nanofibers have challenged these shortcomings of microfibers routinely used for LDD. These are available in the form of biodegradable fibers, with high tensile strength that can resist frequent dislodgement and provide a sustained release of the drug [1,2,12].

This review aims to discuss the application of electrospun nanofibers as LDDS in periodontitis.

Electrospinning

The process of spinning fibers with the help of electrostatic forces is known as electro spinning. This is a direct and continuous preparation of nanofibers by a "bottom-up" method.

This method was proposed by William Morton and John Cooley in 1902 [14]. It is the most popular method of producing nanofibers due to its cost effectiveness and minimal apparatus requirements [15,16].

Darrell Reneker and Gregory Rutledge reinvented this technique to be popularized as the term electrospinning in the early 1990s [17].

Electrospinning can be done by melt method or a more popular solution method.

Solution electrospinning: In this method, the solvent is allowed to evaporate quickly as a jet of a polymer solution is stretched, elongated, and thinned by whipping instability. As the jet solidifies, there occurs the deposition of nanofiber at the collector.

Melt electrospinning: This method is mainly used for the polymers for which solutions are difficult to obtain. A heating device is added at the spinneret, as the molten jet cools, it solidifies to form the fibers.

There are other proposed methods of electrospinning based on various parameters such as:
Number of needles: multiple needle or needless electrospinning. Distance between the spinneret and the collector: near or far field electrospinning.

Spinneret type: Hollow Spinneret versus Solid Spinneret type of electrospinning.
Collector type: Conductive Solid Collector versus Liquid Bath Collector.

It can also be based on Simple Needle versus Coaxial Spinneret.

Manufacturing of Nanofibers Via Electro Spinning Technology

The process consists of three stages which are as follow: (Figure 1)

- A working fluid (suitable polymer solution) is introduced into the syringe which regulates its flow and formation of droplets at spinneret's tip takes place. This in turn controls the structure of the nanofiber.

- Under the influence of an electric field provided by a high voltage DC Generator, these droplets form a Taylor cone that are acted upon by three forces namely gravitational, electrostatic and surface tension. With increase in the voltage, the magnitude of electrostatic repulsion rises higher than the surface tension that leads to formation of a straight jet at the tip of cone, which is maintained for a short period of time.

- This jet is pulled down by gravity causing whipping and swinging. The fibers thus produced are collected on the receiving device while the solvent ultimately evaporates.

Properties of Nanofibers

Electrospun fibers produced using suitable polymers that possess small pore size of about 100-500 nm in diameter [18] and high surface area, tensile strength that makes them a suitable carrier for drug delivery. Due to the unique composition of espun fibres they can mimic extracellular matrix [19].

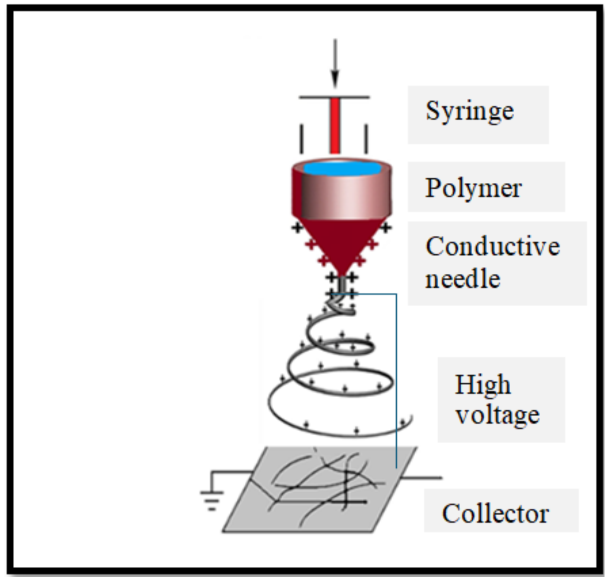

Figure 1: Electrospinning technique for nanofiber production.

Author	Year	Study Design	Drug Used	Electrospinning Material/ Polymer
T.P. Chaturvedi, et al. [22]	2013	Clinical Trial	DOX	Polycaprolactone (PCL)
Ariba et al. [23]	2015	In vitro	PIROXICAM	Chitosan, HA, PVA
Marziyeh et al. [24]	2016	In vitro	TXC	-
Alexa et al. [4]	2019	In vitro	TXC	Polylactic glycolic acid (PLGA)
Ming Hua et al. [25]	2021	In vitro+ vivo	AMOX	PCL
Shahla et al. [5]	2021	In vitro+ vivo	METRO+ AMOX	Poly-DL-Lactic acid
Mohamad et al. [26]	2022	Clinical+ Lab	TXC	PLGA and PCL
Markus, et al. [27]	2023	In vitro comparative (COAX vs. HDD)	METRO	PCL

Table 1: A detailed description of the study protocol.

Nanofibers exhibit a higher surface to volume ratio with which more cell attachment is ensured in comparison to the regular fibres. Their high porosity scaffolds provide greater space for the cell accommodation and an easy passage for the nutrient intake and metabolic waste exchange. Controlled delivery of drugs at a defined rate over a definite period of treatment is possible with biocompatible delivery matrices of either biodegradable or nonbiodegradable polymers [18,20,21].

A controlled release of drug over a long period of time is required in diseases of chronic nature. Non fibrous drug delivery systems have only ensured a drug release for a small-time frame, (sustained in gcf for about 5 days [22] making them less effective than the Nano fibrous scaffolds [23]. While the drug release in various in vitro and in vivo studies done by authors on nanofibers showed drug release for a longer period such as 19 days [5,22]. The treatment with nanofibers on patients was found to be more convenient, less time consuming and cost effective as compared to gels yielding similar clinical benefits [22].

Applications

Electrospun nanofibers are a versatile group of nanomaterial with suitable characteristics that make them suitable for application in tissue engineering and repair, enzyme immobilization, Nano catalysis, tissue scaffolds, protective clothing, filtration, and optical electronics, etc [13,18].

For this review, the data base was searched for articles on the treatment of nanofibers for periodontitis.

Study Selection

A literature search was carried out by two independent researchers on database including PubMed, Embase, Scopus, Web of Science and Google Scholar for an all-inclusive result. The keywords used were periodontitis, local drugs, nanofibers, etc. The search as carried over a period of 3 months May-July 2023.

Inclusion Criteria

- All articles published between the years 2013-2023, (As Nano dentistry paved its way into research and advancements during the last decade, major research has been carried out in this arena).
- Articles reporting the use of electrospun nanofibers as LDD in periodontitis.
- Randomized controlled trials or observational study designs including cross-sectional, case-control, and cohort.
- Studies done on animals were included.
- In vitro studies were also included

Exclusion criteria

- Reviews, book chapters, personal opinions, letter to the editor and conference proceedings.
- Studies reporting use of fibres for other oral health conditions apart from periodontitis.

Results

The various properties of nanofibers produced using the electro spinning technology has been discussed in these studies. These include:

Fiber Morphology

The electrospun nanofibers have been evaluated for their physical characteristics under the Scanning Electron Microscope (SEM) by various authors. The micrographs have revealed a smooth, Beadless morphology with a random distribution of the fibers [5,22-26]. In one study, however it was observed that after heat treatment the smooth texture was lost after the fibers were heat-treated [23], however the addition of drug did not have any effect on the fiber morphology [25]. The smooth structure of the fibers along with their high surface area facilitates holding of a large amount of drug for a prolonged release [18].

Mechanical Properties

These fibers possess excellent mechanical properties including high tensile strength that can be placed inside the patient's mouth under high masticatory load [18]. This has been demonstrated by various studies. The uniaxial tensile machine [24], tensiometer [5] have been used to evaluate the tensile strength of the fibers. The nanofibers exhibit the high tensile strength in both dry and hydrated conditions and loading of drug does not have any significant difference in this property of the fiber. This ensures their insertion in the periodontal pockets with sufficient rigidity, thus improving patient compliance [24].

Biocompatibility

One of the biggest challenges while introducing a newer modality of treatment remains patient compliance and body's reaction to the same. Various studies done on nanofibers have revealed that they are biocompatible in nature. Although, human studies are lacking to strengthen this fact, many animal trials results have indicated high biocompatibility. This has been proven in rat and rabbit models [5] whereby absence of an inflammatory reaction [25] after 3 weeks of implantation under light microscopy [5] was observed. Human studies as well, have revealed that these fibers are biocompatible making them safe for use in periodontitis patients [22].

Cytotoxicity

MTT test has been performed using in mouse L929 fibroblast cell lines [4] to identify the cytotoxic behavior of electrospun nanofibers [4-5]. The test results showed a good cytocompatibility, cell viability with introduction of these fibers to be used as a drug delivery system for periodontitis.

Drug Release

The maximum drug release was observed on the first day after implantation in rat models whereby subcutaneous implantation of drug loaded fibers was done. This was followed by a sustained slow release over the next two weeks [5]. This initial burst release of drug [2,3] is explained by the diffusion phenomenon. This property makes these fibers a very important substitute for the intra oral drug release systems as periodic/ weekly introduction of drug in the pockets can be avoided, this in turn improves patient acceptance.

Antibacterial Effect

The nanofibers loaded with antibiotics show a sustained slow release with an initial burst of drug release that highlights their high antibacterial property. They are active against both Gram positive and Gram negative bacteria [5].The nanofibers loaded with antibiotics, have proven to inhibit the key pathogens responsible for periodontitis, including S. sanguinis [25].

Clinical Evaluation

Studies have aimed to evaluate the clinical aspects of nanofiber drug delivery systems. In these, the patients seeking periodontal treatment were placed in groups undergoing SRP alone and the others with drug release nanofibers systems incorporating at the end of trial, the periodontitis patients in groups receiving drug delivery showed improved clinical results as compared to the controls [22,27]. The baseline scores for PI, GI, PD were evaluated, which significantly improved in the patients undergoing therapy with drug loaded nanofibers.

The method of production of nanofibers also affects the morphology and the properties of the nanofibers produced as demonstrated by Markus, et al. [26].

Coaxial electrospinning produces continuous core–sheath and hollow nanofibers [17]. The fibers produced with coaxial spinning show a retarded drug release as compared to the conventional fibers. The cell viability, biocompatibility and anti-bacterial properties are also improved in the former group [26].

Discussion

Periodontitis is a chronic oral health disorder that affects the supporting alveolar bone of the tooth thus leading to loosening or loss of teeth. Finding a suitable treatment option to restore periodontal health has posed many challenges to the researchers and the clinicians. Traditionally, scaling and root planing have been considered as an essential method in treatment of periodontitis. It is, however, only effective in the mechanical removal of deposits that harbor the periodontal pathogens. Nevertheless, the limited access to sub gingival area, realization of necessity for the removal of microbial cause and the inflammatory nature of the underlying disease alarmed the use of drugs as an adjuvant to SRP [14]. With better understanding of disease processes, the need to alter host responses or immunomodulation was felt.

The systemic administration of drugs especially antibiotics; however, for the treatment of chronic condition was not acceptable due to the adverse drug reactions and poor redistribution to the target site. The therapy is also questioned as to whether to be able to eliminate the bacteria inside the periodontal pockets due to insignificant levels of drug found in the GCF following this route of administration [22]. In the wake of the search for a promising method of drug delivery, several methods have been tried and tested.

In this light, the administration of local drugs emerged on the foot front. The advantages of the same include an increased patient compliance, a better distribution of medicament to the target site along with sustained release of the drug and improved therapeutic efficiency.

Numerous investigations have been in order to incorporate various drugs in the polymeric carriers to develop a suitable LDDS [24]. These are now available in the form of fibers, gels, films, strips, chips, nanoparticles, to name a few; with each system having its own benefits and limitations. Clinically the performance of these systems has been evaluated by parameters such as reduction in PD, increased attachment levels and bone filling along with reduction in periodontal pathogens.

Fibers are reservoir type of LDDS [10]. Fibers that were used initially incorporated drugs that waved off early leading to poor substantivity. With advancements they were used with polymers such as alginate, chitosan, collagen for a sustained release. The system faced a backlash due to cumbersome placement and removal by the clinician and discomfort faced by the patient. FDA approved a tetracycline containing fiber Actisite implicated in periodontitis treatment [9,10].

Intra-pocket strips advocated as LDDS are thin matrix bands containing drugs dispersed in the polymer [10]. They adapt to pocket anatomy promoting easy placement and are now made with biodegradable polymers that do not require removal post placement. Periochip containing chlorhexidine has been widely used and is US FDA approved [10].

Gels gained popularity due to ease of their application and a controlled release of drug at the desired site. Gels containing various drugs such as doxycycline, minocycline and others in chitosan/xanthan etc. based polymers have been formulated that are widely accepted by the patients. Their obvious disadvantage is the rapid release of the drug. Researches have tried various formulations of gels to provide a longer release of the drug. Ex: Atridox is a US FDA approved two-syringe mix system consisting of doxycycline. Minocycline containing Periocline is also available [10].

With the emergence of Nano sized, microsized particles, a diversified LDDS are available such as that in the form of microspheres. These are polymeric spheres incorporating drugs allowing a controlled drug release, increased bioavailability of the drug and possess a bactericidal effect. Arestin is a minocycline loaded microsphere approved by US FDA [10].

Similarly, nanoparticles have been tested in vitro and in vivo for the treatment of periodontitis. These systems have been associated with significant tissue and bone regeneration and have proven to be biocompatible along with the capacity to eliminate the microbes associated with the disease.

A recent advance in the field of nanotechnology has allowed the fabrication of nanofibers that mimic the morphological and structural characteristics of extracellular matrix [24]. In dentistry, electro spinning is mainly used for the construction of these fibers. With this method, drugs can be incorporated by means of single fluid drug loading systems, multiple or co-axial loading. These fibers are biocompatible, biodegradable and have good mechanical properties to withstand oral environment. Nanofibers have the potential to carry antibiotics and other substances.

In this review, various articles that studied the behavior of these nanofibers were explored. The results of various studies showed that the beadless morphology of the nanofibers obtained by the electrospinning method provided a higher surface area that can allow the incorporation of large dose of drugs.

These fibers under in vitro and in vivo conditions did not cause any cellular damage showing their excellent cytocompatibility. Although sufficient human studies are lacking to support this, no significant adverse reactions were seen in experimental animals after the introduction of fibers which indicates that the fibers are potentially biocompatible. The fibers are suitable for use under high masticatory forces as they exhibit high tensile strength under both dry and wet conditions. The drug release mechanics reveals a prolonged release that ensures a drug concentration sufficient for the killing of microbes in the deep pockets. These fibers have proven antibacterial efficacy when loaded with antibiotics, against the microbes implicated in periodontitis. Clinical studies on human subjects have shown superior clinical parameters obtained at the end of therapy.

The results of these studies showed that the nanofibers exhibit properties that make them an excellent carrier of drug for LDDS. Thus, these systems can be used as a newer substitute in treatment of periodontitis.

The limitation of the review is that most of the studies involving the use of nanofibers are in vitro/lab studies or those including animal trials.

Conclusion

A shift in paradigm following the introduction of Nano particles in dentistry was observed and the research associated with maximizing their use has been on an incline. A lot of newer dental materials are being identified and structured utilizing these nanoparticles. Similarly, nanofibers using various methods and polymers have been fabricated. Various studies have characterized the advantages of nanofibers and highlighted their potential as LDDS in periodontitis patients. In this review, we found that the various morphological, mechanical and biological properties exhibited by the nanofibers make them an excellent candidate to replace the older methods of drug delivery. Nevertheless, the characterization of these materials will open new portals for finding more such biomaterials; lack of clinical studies is a major drawback. More clinical trials and human studies are recommended that utilize electrospun nanofibers as drug release system to establish them as a major treatment option in periodontitis patients.

Conflict of Interest

There are no Conflicts of Interest.

References

1. Page RC, Eke PI (2007) Case Definitions for Use in Population-Based Surveillance of Periodontitis. J Periodontol 78(7S): 1387-1399.

2. Graziani F, Karapetsa D, Alonso B, Herrera D (2000) Nonsurgical and surgical treatment of periodontitis: how many options for one disease?. Periodontol 75(1): 152-188.

3. Kwon TH, Lamster IB, Levin L (2021) Current Concepts in the Management of Periodontitis. Int Dent J 71(6): 462-476.

4. Dias AF (2019) Polycaprolactone nanofibers loaded

oxytetracycline hydrochloride and zinc oxide for treatment of periodontal disease. Materials Science and Engineering: C 103: 109798.

5. Mirzaeei S, Mansurian M, Asare-Addo K, Nokhodchi A (2021) Metronidazole-and amoxicillin-loaded PLGA and PCL nanofibers as potential drug delivery systems for the treatment of periodontitis: in vitro and in vivo evaluations. Biomedicines 9(8): 975.
6. Cosgarea R, Juncar R, Heumann C (2016) Non-surgical periodontal treatment in conjunction with 3 or 7 days systemic administration of amoxicillin and metronidazole in severe chronic periodontitis patients. A placebo-controlled randomized clinical study. J Clin Periodontol 43(9): 767-777.
7. Sgolastra F, Gatto R, Petrucci A, Monaco A (2012) Effectiveness of systemic amoxicillin/metronidazole as adjunctive therapy to scaling and root planing in the treatment of chronic periodontitis: A systematic review and. Wiley Online LibraryF Sgolastra, R Gatto, A Petrucci, A MonacoJournal of periodontology. Wiley Online Library 83(10): 1257-1269.
8. Shinwari MS, Tanwir F, Hyder PR, Bin Saeed MH (2014) Host modulation therapeutics in periodontics: role as an adjunctive periodontal therapy. J Coll Physicians Surg Pak 24(9): 676-684.
9. Szulc M, Zakrzewska A, Zborowski J (2018) Local drug delivery in periodontitis treatment: A review of contemporary literature. Dental and medical problems 55(3): 333-342.
10. Wei Y, Deng Y, Ma S, Ran M, Jia Y, et al. (2021) Local drug delivery systems as therapeutic strategies against periodontitis: A systematic review. Journal of Controlled Release 333: 269-282.
11. AlKahtani RN (2018) The implications and applications of nanotechnology in dentistry: A review. The Saudi dental journal 30(2): 107-116.
12. Sousa MGC, Maximiano MR, Costa RA, Rezende TMB, Franco OL (2020) Nanofibers as drug-delivery systems for infection control in dentistry. Expert Opin Drug Deliv 17(7): 919-930.
13. Joshi D, Garg T, Goyal A (2016) Advanced drug delivery approaches against periodontitis. Taylor & Francis 23(2): 363-377.
14. Garg S (2015) Local Drug Delivery Systems as an Adjunct to Cure Periodontitis-The Novel Dental Applicant. Pharmaceutical Methods 6(1).
15. Zhao P, Chen W, Feng Z, Liu Y, Liu P, et al. (2022) Electrospun nanofibers for periodontal treatment: A recent progress. International Journal of Nanomedicine 1: 4137-4162.
16. Li Y, Zhu J, Cheng H (2021) Developments of Advanced Electrospinning Techniques: A Critical Review. Adv Mater Technol 6(11).
17. Xue J, Wu T, Dai Y, Xia Y (2019) Electrospinning and electrospun nanofibers: Methods, materials, and applications. Chem Rev 119(8): 5298-5415.
18. Subbiah T, Bhat GS, Tock RW, Parameswaran S, Ramkumar SS (2005) Electrospinning of nanofibers. J Appl Polym Sci 96(2): 557-569.
19. Xie SH, Liu YY, Li JY (2012) Synthesis, microstructures, and magnetoelectric couplings of electrospun multiferroic nanofibers. Front Phys (Beijing) 7(4): 399-407.
20. Li WJ, Laurencin CT, Caterson EJ, Tuan RS, Ko FK (2002) Electrospun nanofibrous structure: A novel scaffold for tissue engineering. J Biomed Mater Res 60(4): 613-621.
21. Torres-Giner S, Pérez-Masiá R, Lagaron JM (2016) A review on electrospun polymer nanostructures as advanced bioactive platforms. Polym Eng Sci 56(5): 500-527.
22. Chaturvedi TP, Srivastava R, Srivastava AK, Gupta V, Verma PK (2013) Doxycycline poly e-caprolactone nanofibers in patients with chronic periodontitis–a clinical evaluation. Journal of Clinical and Diagnostic Research: JCDR 7(10): 2339.
23. Farooq A, Yar M, Khan AS, Shahzadi L, Siddiqi SA, et al. (2015) Synthesis of piroxicam loaded novel electrospun biodegradable nanocomposite scaffolds for periodontal regeneration. Materials Science and Engineering: C 56: 104-113.
24. Ranjbar-Mohammadi M, Zamani M, Prabhakaran MP, Bahrami SH, Ramakrishna S (2016) lectrospinning of PLGA/gum tragacanth nanofibers containing tetracycline hydrochloride for periodontal regeneration. Materials Science and Engineering: C 58: 521-531.
25. Ho MH, Claudia JC, Tai WC (2021) The treatment response of barrier membrane with amoxicillin-loaded nanofibers in experimental periodontitis. J Periodontol 92(6): 886-895.
26. Alkayali MF, Badria FA, ElBaiomy AA, Youssef JM (2022) Effect of polycaprolactone nanofibers loaded with oxytetracycline hydrochloride and zinc oxide as an

adjunct to SRP on GCF lipocalin-2 levels in periodontitis patients: A clinical and laboratory study. Journal of Advanced Periodontology & Implant Dentistry 14(2): 76.

27. Reise M, Kranz S, Guellmar A, Wyrwa R, Rosenbaum T, et al. (2023) Coaxial electrospun nanofibers as drug delivery system for local treatment of periodontitis. Dental Materials 39(1): 132-139.