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Electrospun Nanofibers of Herbal Origin for Effective Wound Healing

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Abstract:

The healing process is a complex tissue regeneration process that the body undergoes in response to a traumatic injury. Recent advances in nanotechnology have enabled the production of electrospun fibers, which have the potential to become the ideal candidate for encapsulation and delivery drugs to the wound site. The selection of using particular polymers in electrospun fibers majorly depends on the type of drug and the current stage of wound so that the healing process can be improved. In this review, we would explore the incorporation of various wound healing herbal drugs into electrospun fibers and their release behaviors for wound healing & their effectiveness to treat the wound. While electrospinning possesses many advantages in drug delivery and tissue engineering, which are beneficial for wound healing, concerns over the use of harsh chemicals (cytotoxicity) may limit its use in pharmaceutical applications for dressing materials. Keeping in view all these factors we expect a better future perspective if using electrospun nanofiblers for effective wound healing.

Keywords **—** Nanofibers, herbal, wound healing, extract, drugs, nanotechnology.

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I. INTRODUCTION

This Wound healing is a complex responsive regeneration process that the body undergoes on wound openings or missing cellular structures caused by various types of traumatic injuries. To promote the healing process and avoiding infection effective wound healing is usually done at the wound site by typically covering the area with a sterile dressing material. In clinical settings usually Gels and creams with a antibiotic drug load of only 5% at the highest are typically applied to the wound site as a treatment method [1]. Constant monitoring /cleaning of the wound site are frequently required for the healing process. In patients with non-healing wounds such as diabetic wounds and venous ulcers, the inefficiency of the therapeutic product coupled with the frequent wound manipulation can often be painful for the patient and often cost- and labor-intensive for the healthcare system. With the current advancement in medical fabrics, a new generation of the dressing materials is expected to be able to carry a higher level of drugs and thus provide sustained release properties that will enhance the wound healing process and reduce the painful repetitive process of frequent changes of dressing materials. Such development in this field can potentially be incorporated into making of multifunctional wound bandages and providing treatment strategies for various types of wounds, locations of the wounds, and conditions of the wounds. Thus the therapeutic wound healing process can be improved by enhancing the quality and rate of wound healing process. Prominent methods that have been studied till now for the fabrication of polymeric fibers are melt blowing, phase separation, self-assembly, and temple synthesis etc. Drug-eluting fibers made by electrospinning are potential candidates for the formulation of medical fabrics for wound healing can be considered the best method amoung these available technologies. The method of Electrospinning is simple and robust to produce drug-containing fibers with diameters ranging from tens of nanometers to several micrometers [2].

Treating patients with herbal remedies has remained an old practice due to extraordinary influence posed by plants in various diseases. A significant percentage of drugs are supposed to be derived from various plants types [3]. Plants can be considered the best option as they have many potential attributes which make them a suitable source of material for nanofiber fabrication. Most of the antimicrobial products are usually phytochemical in nature [4]. Phytochemicals like phenolics, terpenoids and alkaloids are found associated with antimicrobial activity [5]. Encapsulation of plant material, through electrospinning, can accelerate their remedial potential to many folds. This process maximizes the therapeutic potential by improving bioavailability and maintains a steady concentration of drug to the target area [6].

Multiple advantages, associated with using plant material and potential of electrospinning to process them for biomedical applications, has led to an increased focus on research in last decade. The major aim of this review is to compile various researches done on the use of crude plant extracts for wound healing applications through electrospinning and future prospects of this particular area.

II. ELECTROSPINNING NANOFIBERS

Despite the development of nanotechnology various materials for wound dressings are available in the markets which do not fully satisfy the requirements of an ideal wound bandage [46]. Electrospinning (ES) is a technology to obtain nanomaterials formed by the deposition of polymer nanofibers, which results in an interconnected three-dimensional network. Despite their extremely small diameter, these nanofibers show large surface area to volume ratio and high porosity. Taken together, these characteristics show applicability in many different areas, such as high performance, intelligent textiles, biosensors, scaffolds for tissue engineering, and drug delivery systems [7].

The electrospinning apparatus consists of three components: the solution dispensing system, electric field, and collector. The solution dispensing unit consists of a syringe that contains the polymer solution, a pump that precisely controls the rate at which the solution is dispensed and a very fine hypodermic needle, known as the spinneret. The electric field is another critical component of the electrospinning apparatus, because the geometry of the polymer cone (known as the Taylor Cone) is controlled by the ratio of the surface tension of the polymer solution to the applied electric field. Typically the electric field is generated by a high voltage power supply. The final component is the collector. The collector impacts the orientation of the spun nanofibers. For instance, if a stationary collector is chosen, the fibers will be oriented randomly, however by using a spinning collector (such as a rotating wheel or drum) the spun fibers can be aligned [13].

Fibers obtained from electrospinning have gained popularity in the field of drug delivery and are considered as ideal dressing materials for non-healing wounds since the method is versatile and can deliver various biological agents long-term to local tissues at the wound site [8-10]. Not only do they provide physical protection to the wound, but they also have the capacity to be incorporated with a high amount of drugs (up to 40% loading), where the release of which can be adjusted by changing the types and compositions of the materials in the fibers [11]. A large variety of materials can be used to produce electrospun fibers in the pursuit of medical fabrics in wound dressing [8], and these materials can be categorized into natural and synthetic polymers [9,12]. Nanofibers have been widely used in various biomedical applications, including drug delivery [42], tissue engineering [41], stem cell therapy [40], cancer therapy [42], and wound healing [43-45].

III. ELECTROSPUN PLANT EXTRACTS USED FOR WOUND HEALING APPLICATIONS

3.1.Tridax procumbens (coatbuttons or tridax daisy)

It is one of those plants which have been successfully electrospun to prepare nanofibrous mat by Ganesan P and Paradeepa P (2017) blended with Poly vinyl alcohol (PVA). The research showed that they could achieve the maximum pore size upto 2.26μm, a density of 1.37 g/cc for PVA/TP nanofibrous mat and thickness upto 0.03mm. SEM results indicated a uniform and smooth surface nanofibrous mat with diameter ranging from 108-519 nm. They also tested the nanofibrous mat for antimicrobial activity for both Gram positive and Gram negative bacteria. A 45mm zone of inhibition was achieved for Gram positive (*Staphylococcus aureus*) and 36mm against Gram negative (*Escherichia coli*).These results indicate that the natural potential of plants can be successfully transferred to a structure which can be used for medical applications [14].

3.2.Urtica dioica (nettle leaf)

In a study conducted, a bioactive coating was prepared with the help of nanofibers in which extract of *U. dioica* was blended with PCL. The coating not only showed antimicrobial activity but also antioxidant activity. These two potentials helped to increase the shelf life of the fresh fish fillet. As for the characterization of the nanofiber is concerned, a bead-less ultrathin fibers, having mean diameters of 575 ± 130 nm, were produced. The incorporation of plant extract did not affect the morphology of the fibers compared to fibers produced from PCL only. This indicates a healthy sign for future use of plant extracts [15].

3.3.Chamomilla recutita (chamomile)

The natural wound healing ability of chamomile was explored, through electrospinning, by Behrooz Motealleh et al. 2014. In this study, chamomile extract was loaded into PCL/PS through D- optimal design approach. The prepared material was evaluated for its antimicrobial activity, drug release profile, cell culture and in vivo impact. An average diameter of 175 nm was obtained after incorporating 15% chamomile extract. A gradual drug release was achieved for the material PCL/PS throughout the release time which maintained a steady concentration of about 70% drug on wound area which is a positive sign for wound healing. The rat wound model examination indicated that almost complete wound closure was achieved on 14th day of treatment. 15% extract loaded sample of PCL/PS also found to be nontoxic [16].

3.4.Stryphnodendron barbatimao (barbatimão)

Electrospinning not only provides an option to incorporate the plant extracts through blending or encapsulating but also a composite material can be prepared. In a study was conducted a bio-nanocomposite was prepared by using PVA/pineapple nanofibers/ *S. barbatimao* bark extract. After successful preparation, material was characterized for surface morphology and thermal stability. A significant morphological change was observed in bio-nanocomposites compared to PVA nanofibers mat. Similarly, melting behaviour and thermal properties of the PVA are also affected by *S. barbatimao* bark extract [17].

3.5.Lawsonia inermis (henna tree or mignonette tree)

In one of the research an electrospun nanofibers mat was fabricated by using leaf extract of *L. inermis* (Henna), chitosan and polyethylene oxide (PEO) polymers. SEM characterization confirmed a smooth and ultrafine nanofiberous structure. Addition of leaf extract did not affect the morphology of the blended nanofibers mat (CS and PEO) negatively which indicates the successful incorporation of plant extract through ES. It was noted that, by increasing the concentration of extract, the diameter can be reduced. This is beneficial because low diameter will provide more surface volume. Similar behavior was also observed in case of porosity. Nanofiber mat showed a slight increase in swelling rate which is beneficial for medical applications. However, a slight increase in rate of loss of mat was seen in case of leaf extract which can be attributed to high porosity and less diameter associated with leaf extract. A decline in tensile strength, however, has been observed. But still the strength remained within required range for dermal tissue regeneration. An in vivo study indicated that leaf extract, in nanofibers form, showed more wound healing potential than henna ointment. It means that polymers have potential to release bioactive compound in steady rate to target area [18].

3.6.Juniperus chinensis (juniper)

A nanocomposite was fabricated by Jeong H K et al. 2013 by using the extract of *J. chinesis* and PVA. The loading of extract was confirmed by XRD. SEM results indicated the randomly oriented, bead free and smooth surface morphology of the resultant fibers. However, an increase in fibers diameters was observed with increase in concentration of the extract which was attributed to increase in viscosity. The result showed the effect of plant extract on fibers diameters. A disk diffusion test was carried out to observe the antibacterial activity of the nanocomposite fiber. Two bacterial strains; *S. aureus* and *Klebsiella pneumonia* were tested for the purpose. The result indicated the antimicrobial activity of fibers, with plant extract, was much higher than PVA pure nanofiber which showed no antibacterial activity. This can be attributed to specific bioactive compounds present in extract. Antimicrobial activity plays much role in wound healing, so resultant composite fiber can be used as wound dressing [19].

3.7.Annona muricata (Soursop)

Another successful fabrication of antibacterial potential of A. muricata was carried out by Neni M A *et. al*. 2017 in which they prepared a fiber material by using leaf extract and PVA polymer. Ultrafine fibers with diameter 137,132 and 121 nm were obtained when concentration of SLE was kept 8, 12 and 14 (w/w) respectively. This change was attributed to low concentration of PVA with increase in concentration of SLE [20]. The antibacterial activity was observed against *S. aureus* through zone of inhibition. It was observed that increase in concentration of SLE increased the antibacterial activity.

3.8.Beta vulgaris (beetroot)

Simzar H *et al*. 2017 successfully fabricated composite scaffold by using herbal extract of *B. vulgaris* and co culture of mesenchymal stem-cells (MSC) and human keratinocyte (h-Keratino). SEM images confirmed a uniformed, bead free and porous structure with high rate of porosity. Addition of *B. vulgaris* has slightly affected the diameter of the fiber. [21]

3.9.Curcuma longa (Turmeric)

Curcumin has been used as antibacterial and natural wound healer for centuries. However, poor bio availability and stability of curcumin is a major issue while dealing with wounds. ES provides an option for stability of curcumin and its release in controlled rate through blending it with some suitable polymer and converting this potential biologically active compound into a scaffold structure. A successful incorporation of curcumin into a blend of poly lactic acid (PLA) and hyperbranched polyglycerol (HPG) was carried out by Govindraj P et al. 2017. Concentration of curcumin was optimized upto 10% to get smooth and bead free fibers. Concentration of curcumin showed the effect on diameter of the fiber. HPG was stood out to be an important factor who determines the successful incorporation of curcumin by keeping the structure smooth, aligned and bead free. The presence of HPG also enhances the swelling rate, an important feature required for tissue engineering, by making structure more hydrophilic. This higher swelling feature also enhanced the release profile of the curcumin, an important application of a nanofibrous scaffold. As far as the tissue engineering parameters like cell adhesion, cell proliferation and cell viability is concerned, the blended structure PLA/HPG/Cur fiber provide a suitable profile for these features [22].

3.10 **Aloe vera**

Aloe vera is another promising plant offering variety of medical applications being used for centuries. The natural wound healing property of *A. vera* can not only be preserved but accelerated by incorporating it into a scaffold structure with some suitable polymers. A similar effort was done by Itxaso C-A et al. in which they blended AV extract with PLGA and recombinant human epidermal growth factor (rhEGF) to synergize the effect of rhEGF and AV extract. Former is a growth mediator in tissue engineering and later is found associated with stimulation of cell proliferation and activity of fibroblast. SEM characterization indicated both uniform and randomly oriented nanofiber with high degree of porosity ranging above 79%. The diameter of the fibers remained low upto 356.03±112.05 nm in the PLGA/rhEGF/AV compared to other two fibers consisting of PLGA and PLGA/AV. Zone of inhibition test was applied to assess the antibacterial efficacy of AV. The result indicated a remarkable inhibition for the case of PLGA/AV compared to almost no inhibition in case of PLGA alone. A significant increase was also observed in cell proliferation when cells were treated with PLGA/AV/rhEGF compared to control. An in vivo study was carried out to assess the wound healing potential of the PLGA/AV/rhEGF compared to other combinations of material. By calculating the wound area reduction and histological analysis of the wound, it was established that AV bended with PLGA and rhEGF showed remarkable progression in terms of wound healing and reepithelization. These results again confirmed that ES not only preserve the natural potential of the biological material but also increase the efficiency by controlling the release profile and bioavailability of the active compound present [23].

3.11 Centella asiatica (Asiatic pennywort or Gotu kola)

Another fiber mat was fabricated by Orawan S et al. (2008) by using cellulose acetate (CA) and pure substance (PAC) or crude extract of *C. asiatica* (CACE) .SEM images indicated a smooth fabrication of fiber mat with diameter upto 301±64 nm for neat CA fiber and 545±96 nm for CACE. This shows that plant extract have some effects on diameter of the fiber. However, surface remained smooth in all the cases indicating the successful loading of plant extract during ES. The release profile of asiaticoside (AC) was investigated through total immersion and the transdermal diffusion method. Two releasing medium, A/B/M and P/B/M, were used for 32° C and 37° C respectively. The result indicated a release of AC upto~ 24 and~ 10% in A/B/M medium and to~ 26 and~ 12%in P/B/M medium. However, a significant decrease in release profile have been noted when mat was placed on top of the piece of pigskin. The result also indicates that the concentration needs to be optimized to avoid cytotoxicity extended by CACE to human dermal fibroblasts due to the presence of triterpenoid compounds. It can be concluded that, suitable release profile and water retention ability, are the two desirable features presented by the above mentioned fibers mat [24].

3.12 Grape seed

Grape seed extract (GSE) was successfully loaded into SF/ polyethylene oxide (PEO) through electrospinning process. The fabricated material was undergone through SEM characterization, drug release profile, cell viability, anti-oxidation activity etc. Their result revealed no significant morphological change in fiber structure after loading GSE in various concentrations. The fiber diameter remained around 420nm for various concentarions. Cytocompatibility of the nanofibrous mat was assessed in vitro through SEM and MTT assay. The result indicated a healthy proliferation of the cells on mat which improves morewith the increasing concentration of the GSE. However, 3% GSE loaded mat was found to be optimum in this regard. The mechanism through which grape seed extract acts as potential wound healer is its antioxidant activity. The result revealed the significant survival rate of the cells treated with t-BHP and this rate was also concentration dependent and the optimum concentration of GSE remained in between 3 to 5% in this context [25].

3.13 Camellia sinensis (Tea plant)

Another plant extract which has been electrospun is green tea plant which is famous for its antibacterial, antioxidant and anti-inflammatory activities. The natural potential of this plant was successfully incorporated into Chitosan/polyethylene oxide to make an antibacterial wound dressing. Material was morphologically characterized through SEM and further analysed for drug release profile, anti bacterial activity and also undergone through animal model tests. SEM images revealed that both diameter and beading is associated with the concentration of the extract. The diameter of 86.18 nm, with few beads, was achieved by chitosan/PEO/GT (2%) concentration. UV-Vis spectrometry was used to study the release profile of extract from composite fiber. The result revealed a moderate and steady release of drug during 13th day of study. Chitosan/PEO/ GT were also tested for its antibacterial activity against Gram-positive bacteria and Gram-negative bacteria and zone of inhibition remained 6 and 4 mm respectively for both strains [26].

3.14 Garcinia mangostana Linn (Mangosteen)

An antibacterial wound dressing was prepared by Orawan Suwantong and co-worker in which they had used the extracts of *G. mangostanalinn* [i.e., dichloromethane extract (dGM) and acetone extract (aGM)] and PLLA. The material was analysed for its morphology, antimicrobial activity, drug release and cytotoxicity. A smooth fiber structure with a diameter range of 0.77 and 1.14 µm was achieved. The drug release results indicated a correlation between drug amount and release profile. 50% loaded dGM and aGM release concentration was found higher than 30% loaded dGM and aGM. In comparing the release profile of aGM and dGM, aGM showed higher release profile in both A/T/M and S/T/M mediums. Furthermore, all the GM release profile of S/T/M medium was found higher than A/T/M medium. Moreover, both the extracts showed significant antibacterial activity for various strains of bacteria. However, no zone f inhibition could achieve by 30 % aGM-loaded PLLA fiber mats against *E. coli*. The concentration of 10 mg mL-1 for 50% and 30% dGM loaded PLLA was found toxic for human dermal fibroblasts whereas rest of all concentrations of the two extracts were not found toxic to the cells that proves the antibacterial wound dressing ability of the material [27].

3.15 Grewia mollis juss (Grewia gum)

Methanolic extract of Grewia mollis Juss (mGM) was electrospun with poly (D, L-lactide-co-glycolide) (PLGA) by Hanan M and coworkers in 2013. SEM and FE-SEM were used to characterize material for its morphological properties. The material was also undergone through antibacterial tests. SEM result revealed a homogenous distribution of extract over polymer surface which appeared smooth. A diameter range of 1.27-2.03 µm was achieved after extract incorporation compared to 0.65-1.0µm without mGMextarcr. EDX spectra confirmed the successful blending of extract into PLGA. To determine the antibacterial activity, growth curve was assessed under various concentration of (0, 6.2, 12.4, 25, 50, and 100µg/mL) mGM. Both E. coli cells and S. aureus were lagged to 3-4 h, respectively under various concentrations. It was also observed that increase in concentration further delayed lag phase. MIC found for the bacterial strain was 12.5µg/mL whereas 100 µg/mL was found to be more toxic. After incorporation into PLGA, the fibrous mat containing mGM showed significant inhibition indicating that structure is promising for antibacterial wound dressing [28].

3.16 Calendula officinalis (pot marigold)

The extract of calendula officinalis, as natural wound healing and anti-inflammatory agent, was successfully blended with hyperbranched polyglycerol (HPGL) to produce elctrospun nanofibrous structure as active drug delivery system by E.A. Torres vargas and co-worker. The material's morphology was determined by SEM and drug release profile was exhibited by HPLC. They could achieve an ultra-fine fibrous structure with the diameter range of 58-80nm. The structure of HPGL was found to be sensitive to the concentration of C. officinalis. Furthermore, the mechanical property of the fiber was also affected positively by C.

officinalis incorporation which turned out to be more elastic and soft. A rapid release of drug was observed which can be attributed to high degree of swelling rate and large surface area. The biocompatibility evaluation was carried to determine cytotoxicity. The result indicated high cell viability. Invivo testing of the material indicated a fast degree of re-epithelialisation and low inflammatory reaction [29]. All these results confirm that natural potential of plant material can be executed into a biomaterial through electrospinning process.

` 3.17 *Melilotus officinalis (Semelil)*

Mirzaei et.al 2016 incorporated Semelil in electrospun nanofibers to benefit both the advantages of Semelil and electrospun nanofibers for the treatment of wounds. A blend solution of chitosan, polyethylene oxide (PEO) and the herbal extract were electrospun and chitosan-based nanofibers loaded with the herbal extract were fabricated. Uniform and bead-free nanofibrous mats loaded with 10-50 Wt. % extract were successfully fabricated. The FTIR spectrum indicated that the chemical nature of chitosan was not changed in the process of electrospinning. TGA analysis confirms both polymers and extract in electrospun mats. The extract loaded mats showed a high swelling ratio and a burst release of extract after 1h incubation in PBS [30].

3.18 Tecomella undulata (rohida)

Suganya et al. have proposed the use of nanofibres of polycaprolactone (PCL) and PVP embedding crude bark extracts of Tecomella undulata, a medicinal plant from Thar Desert regions of northwest and western India, for the treatment of skin infections [31]. The extract was rapidly released in vitro from the composite mats in the first few hours, followed by a slow release over a prolonged period of time (24 h). The potent antibacterial activity of the bark extracts released from the electrospun mats was evaluated against *P. aeruginosa, S. aureus, and E. coli,* achieving zones of inhibition of 30, 24, and 28 mm in diameter, respectively.

3.19 Cinnamomum zeylanicum Nees (Cinnamon)

The production of electrospun chitosan/PEO nanofibres containing cinnamon EO was demonstrated. Fibres with a diameter in the range of 38–55 nm were produced by electrospinning chitosan and PEO (1:1 ratio) from aqueous solutions containing 5 w/v % of acetic acid and different concentrations of EO (0.5 and 5.0 v/v %). After production, the fibres were cross-linked using glutaraldehyde, in order to increase their chemical stability. The chitosan/PEO nanofibres were tested against P. aeruginosa achieving a rate of bacteria inactivation of 50% and 76% for mats without and with 5% of cinnamon EO, respectively. Moreover, the composite nanofibres were active against E. coli after 30 min of contact with the bacteria and a viability loss higher than 99% was measured after 180 min [32].

3.20 Lithospermum erythrorhizon (shikonin)

Novel electrospun poly(ε-caprolactone) (PCL)/poly(trimethylene carbonate) (PTMC) ultrafine composite fiber mats were prepared and used as drug-carrying materials to encapsulate the herbal medicine shikonin isolated from the plant *Lithospermum erythrorhizon* . The PCL/PTMC blended solutions in various ratios (9:1, 7:3, and 5:5 w/w) containing 1 and 5 wt. % shikonin were studied for electrospinning into nanoscale fiber mats. With good drug stability and high drug-loading efficacy, incorporation of shikonin in the polymer media did not appear to influence the morphology of the resulting fibers, as both the drug-free and the shikonin-loaded composite fibers remained unaltered, microscopically. The average diameter of the composite fibers decreased, and the morphology of the fibers became finer with the increasing content of PTMC. *In vitro* drug release studies demonstrated an initial rapid release of shikonin followed by a plateau after 11 h. It was found that the release behavior could be tailored by the PCL/PTMC blend ratio and drug-loading content. Moreover, the free radical scavenging activity and the antibacterial effects of the shikonin-loaded fiber mats indicated that it could act not only as a drug delivery system but also in the treatment of wound healing or dermal bacterial infections [33].

3.21 Bovine lactoferrin

The work by Padrão J et.al described the production and characterization of a protein-based electrospun fibrous membrane bearing antimicrobial properties. Its composition exclusively comprised of proteins, with fish gelatine as structural matrix and bovine lactoferrin (bLF) as the active antimicrobial agent. The bLF bactericidal effect was determined against clinical isolates of Escherichia coli and Staphylococcus aureus through microdilution assays. Two distinctive methods were used to incorporate bLF into the fish gelatine nanofibres: (i) as a filler in the electrospinning formulation with concentrations of 2, 5 and 10 (wt %), and cross-linked with glutaraldehyde vapour, in order to achieve stability in aqueous solution; and (ii) through adsorption in a solution with 40 mg/mL bLF. Fourier transform infrared spectroscopy analysis showed that the structure of both proteins remained intact through the electrospinning blending and cross-linking procedure. Remarkable antibacterial properties were obtained with membranes containing 5% and 10% bLF with a bacterial reduction of approximately 90% and 100%, respectively [34].

3.22 Honey

Sarhan, et al. 2015 was able to fabricate nanofibers with high honey concentrations (40%) and high chitosan concentrations (5.5%) of the total weight of the fibers using biocompatible solvents (1% acetic acid) [42]. The fabricated nanofibers showed pronounced antibacterial activity against *Staphylococcus aureus* but weak antibacterial activity against *Escherichia coli*. Also, the nanofibers revealed no cytotoxicity effects on cultured fibroblasts. [35]

3.23 Nigella sativa (Thymoquinone)

Novel electrospun mats contained NS oil/polyacrylonitrile as a sustained release nano-bandage was studied to treat rheumatoid arthritis. It was fabricated by one and two-nozzle electrospinning method. To prepare this material, various amount of NS oil as; 8, 10, 12 and 15 wt% was added to the specific polyacrylonitrile (PAN) concentration as the initial spinnable solution. In addition, Tween80 was used as an emulsifier to improve the NS oil release and limit the burst release. The release profiles of the singular and hybrid nanofibers produced by both one- and two-nozzle electrospinning methods were compared and the results showed a desirable controlled release for hybrid nanofibrous mats in 5 days. The inherent difference of PAN solution and NS oil could make quasi core-shell nanofiber with PAN core and NS oil cortex. Core-shell structure could be responsible for the observed burst release. Tween80 may cause some weak bonds between PAN surface and NS oil molecule that limit the burst release and act as an enhancer agent. The tensile modules for these samples were measured and the sample with 8 wt% NS oil was selected as the optimum case. The cytotoxicity results showed the cell viability to PAN nanofiber was almost about 93% [36].

In this review, we explore the incorporation of various wound healing herbal drugs into electrospun fibers and their release behaviors for wound healing & their effectiveness to treat the wound. While electrospinning possesses many advantages in drug delivery and tissue engineering, which are beneficial for wound healing, concerns over the use of harsh chemicals (cytotoxicity) may limit its use in pharmaceutical applications for dressing materials. In such case, exhaustion of the organic solvents under vacuum is required to eliminate residual chemicals that remain in the fibers after electrospinning. This is a costly and time-consuming step. Furthermore, low production rate (e.g., approximately 1~1.5 g/h via uniaxial electrospinning) can be another issue that limits the use of electrospun fibers in clinical aspect. This limitation has been improved by free-surface electrospinning process [37, 38]; whereas the production rates may be 5–10 fold higher than typical uniaxial electrospinning. In general, electrospun fibers demonstrate the ability of sustained release of herbal drugs with effective wound healing capacity. This drug delivery platform is especially ideal for the use of topical dressing materials in wound healing applications [39].

IV. CONCLUSIONS

Recent advances in nanotechnology enable the production of electrospun fibers, which have the potential to become the ideal candidate for encapsulation and delivery drugs to the wound site. In particular, electrospinning accepts most of the polymer and drugs where the interactions between them play in important role in drug release rates. The choice of using particular polymers and architectures in electrospun fibers will depend on the types of drugs and the stage of wound so that the healing process can be improved. Herbal extracts have been considered folklore medicines all over the world. Plants indigenous to particular areas have the advantage of familiarity to the common people and to some extend reliable to them as well. It is a dire need of the hour to explore more natural products as medicines in an era of diseases.

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