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Research Article

Application of Electrospun Nanofiber in Wound Healing: Trends And Recent Patents Analysis

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Abstract: A full-thickness open wound with loss of residual cells for regeneration does not heal spontaneously and takes a long duration for complete healing. Sometimes, this results in scarring of the skin and significant disability. A scaffold that provides a 3D framework for cell signalling, attachment, and proliferation is essential for the rapid closure of a full-thickness wound. Nowadays, the electrospun nanofiber is the most widely employed formulation in wound healing. The current study analyzed a patent trend analysis of electrospun nanofiber's application in tissue regeneration. The patent search was conducted using open-source patent databases like The Lens and Patentscope. Two hundred thirty-one patent records were found with the keywords and exported from the database for January 1, 2010, and December 31, 2021. After the initial screening, 24 patent documents were shortlisted for in-depth analysis. China, the USA, European Countries, Korea, and Australia lead this patent filing field. The top applicants are either private companies or academic institutions. The last ten years of patent were analyzed in terms of Patent-Applicant, Patent-Inventors, Patent-Owners, patent filed, published, and granted. In the top ten Assignee, Marine Essence Bioscience Corp (US) topped the list. The most-recorded IPC class is A61L15/44, a subgroup of A61L15, and it is related to the chemical aspects of, or use of materials for, bandages, dressings or absorbent pads. In the end, some relevant patent was analyzed based on their citation by other patents and non-patent literature. From patent trend analysis, it was observed that the electrospun nanofiber would provide an attractive area for research in tissue regeneration.

Keywords: Electrospun Nanofiber, Patent Trend Analysis, Skin, Drug Delivery, Wound Healing, Tissue Regeneration

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1. INTRODUCTION

The skin is the largest organ in the human body. It interacts with the outside world and protects inside organs from heat, chemical, and bacterial damage. It keeps infections out of the body while preserving homeostasis.[1-3] Any injury to human skin due to violence, accident, or surgery is categorized as a wound. Depending on how long it takes to heal, the damage might be acute or chronic.[4,5] Depending upon the depth of the skin layer, a wound may be restricted to the epidermis or the dermis layer. A full-thickness wound (FTW) that extends beyond the two layers of skin (epidermis and dermis) does not heal spontaneously due to the loss of residual skin stem cells for regeneration except at the wound's periphery.[6-9] As a result, complete re-epithelialization takes longer and is sometimes exacerbated by scarring of the base and considerable disability.[10-11] Hence it requires the use of a skin regeneration product for quick wound healing.[12] For wound healing, a variety of options are available. Plain gauze is the most commonly utilized material due to its affordable and frequent accessibility. However, it has several drawbacks, including non-biodegradability, the necessity to replace it every day, and the inability to prevent microbial infiltration, which has prompted the development of alternative techniques such as hydrogels, foams, films, hydrocolloids, and biologic dressings.[13,14] However, only limited exudates can be absorbed with modest success by conventional foams and hydrogel dressings. Similarly, biological dressings have high cost and availability drawbacks. For example, traditional antibacterial ointments must be reapplied frequently to keep the skin moist. [15,16] There has been a tremendous surge in demand and development of novel skin regeneration products using current materials over the last decade, owing to the limitation of traditional wound healing options. Because of structural similarities to the natural extracellular matrix (ECM), nanofibers have emerged as a possible alternative for skin regeneration products.[17] Among various techniques available for nanofibers fabrication, electrospinning is the most extensively employed technique. Because of its simplicity, flexibility in producing biomimetic nanofibers from a wide range of polymers (like synthetic, natural, and inorganic materials), and cost-effective set-up, electrospinning provides massive commercial & academic interest.[18,19] In the current study, patent trend analysis of electrospun nanofibers' application in wound healing was analyzed for healing that had been patented between January 2010 and December 2021. In addition, detailed charts based on jurisdiction, patent applicant, patent inventors, patent owners, and patent classification are analyzed. Finally, a few relevant patents were analyzed to demonstrate the invention and advancement of the application of electrospun nanofiber in wound healing.

2. MATERIALS AND METHODS

2.1 Resources and Research Methods

The updated patent search was completed on 31st December 2021. The keywords/combination of keywords with the terms 'wound healing', 'tissue repair', 'wound repair', 'wound regeneration' 'nanofiber', and 'electrospun nanofiber' was used for the search of patent records on the World Intellectual Property Organization's Patentscope web-based search service and Cambia Institute's The Lens patent data set.[20,21] The appearance of the selected keywords was inspected in the title, abstract, and claims of the patent records, considering patents written in the English language. The data were sorted to include only patent documents published between January 1, 2010, and December 31, 2021.

2.2 Analysis of the Patentability of Electrospun Nanofiber Membrane

After going through the data, 231 patent applications were retrieved. Of these, 177 patents are grouped into Simple Family, and 173 are grouped into Extended Family. The patent records were further grouped according to their applicant, inventor and owners. Finally, the document types of patent records were categorized as patent application, granted, and limited patent. The patent record is also found in CPC Classification Code, IPCR Classification Code, and US Classification Code.

3. RESULTS AND DISCUSSION

3.1 Geographical Distribution

A patent jurisdiction might be a location where a patent applicant generally resides, holds citizenship, works, or from which the invention usually originates. In most cases, a patent can be filed in different countries or jurisdictions in the form of an extended family. In the present study, the top 10 jurisdictions that have applied nanofiber-based scaffolds for wound healing have been presented in Figure 1.

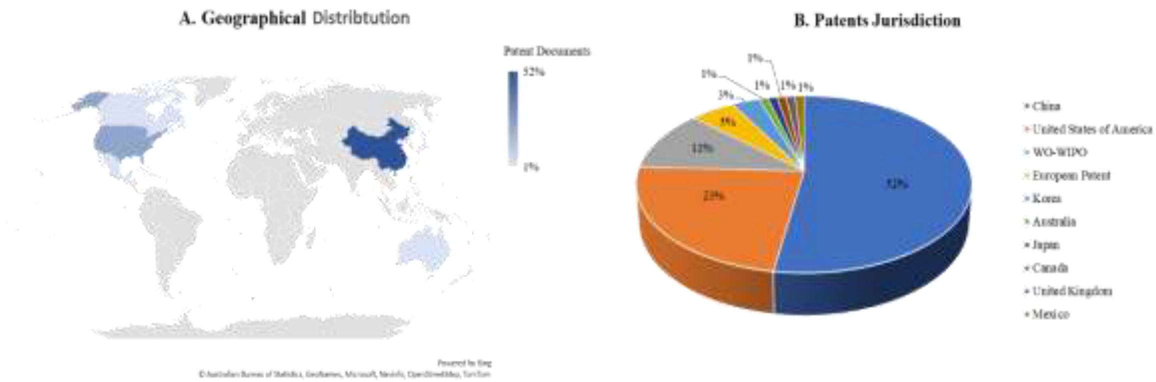

Fig 1: A. Geographic distribution by nationalities of patent inventors. The colour intensity denotes the frequency of patent families; B. 3-D Pie Chart showing the percentage contribution of various jurisdiction in filing the patent

The people's Republic of China has topped the list with 52% of patents filed through the China National Intellectual Property Administration (CNIPA). This contributes to 120 patents out of 231 patents. USA scored top 2nd position in filing the patent through United States Patent and Trademark Office (USPTO), with a 23% patent contribution. The Patent Cooperation Treaty (PCT), which WIPO oversees, is a global body for processing patent claims that include 26 patent papers with an average patent contribution of 11%. The European Patent Office (EPO), by which regional (European) patent applications are filed, includes 12 patents, accounting for 5% of the overall patent contribution. Finally, the Korean Intellectual Property Office (KIPO) submitted eight patent filings, accounting for 3% of total patent contributions.

3.2 Patent Applicants

In the case of a patent filing, an applicant could be either an individual or a legal organization that has submitted the patent application.[22] However, in this study, all top ten applicants are legal entities. Concerning the application of nanofibers in wound healing, the top 10 applicants between January 2010 and December 2021 in terms of the number of patent families are shown in Figure 2 and Table 1. Most of the top applicants come from the United States and China, which shows that market protection is more important in these two countries. The top applicants come from private companies and academic and government bodies. All top ten applicants are legal entities, i.e. a company, an organization, a university etc. Marine Essence Biosciences Corp of USA topped the list with a maximum number of Patent Records (#10). Leonardino S R L and Donghua University secured the top 2nd position with seven patents filed by each. Johns Hopkins University secured the top 3rd position with six patents filed. Council of Scientific & Industrial Research, Government of India, Graphenano Medical Care, South China University of Technology, and Xi'an Polytechnic University filed five patents each.

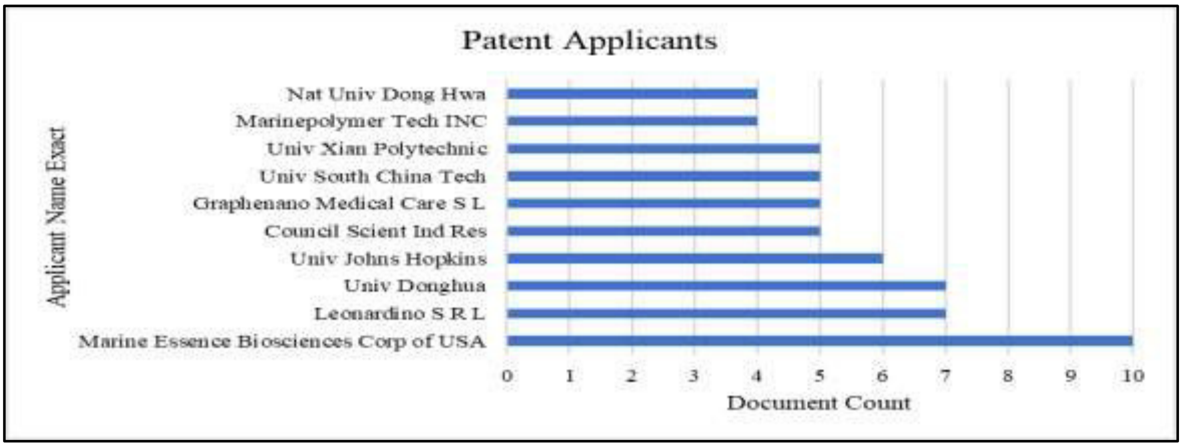

Fig 2: Bar Chart displaying the top 10 Applicant Name versus the number of Documents filed for their innovation

Table 1. Top assignees of electrospun nanofibers.

Rank	Assignee	Patent Documents	Patent Family	Average Number of Patents per family	Assignee Type
1	Marine Essence Bioscience Corp (US)	10	6	1.7	C
2	Leonardino SRL (Italy)	7	4	1.8	C
3	University of Donghua (China)	7	5	1.4	A&G
4	University of John Hopkins (US)	6	2	3.0	A&G
5	Council of Scientific and Industrial Research (India)	5	3	1.7	A&G
6	Graphenano Medical Care SL (Spain)	5	3	1.7	I
7	South China University of Technology (China)	5	4	1.3	A&G
8	Xi'an Polytechnic University (China)	5	4	1.3	A&G
9	Marine Polymer Technologies, Inc (US)	4	3	1.3	I
10	National Dong Hwa University (China)	4	3	1.3	A&G

Abbreviations: C: Company; A&G: Academia and Government; PPP: Public-Private Partnership. Average number of patents per family = the number of patent documents / the number of patent families

3.3 Patent Inventors

A patent inventor is an individual or a group of individuals who contribute to an invention as described by the claims in a patent application. Organizations and companies cannot be an inventor.[23] Top ten inventors who filed their innovation on nanofiber's application in wound closure are shown in Figure 3. From the results, we can see that from January 2010 to December 2021, all inventors have filed the same number of innovations for patentability.

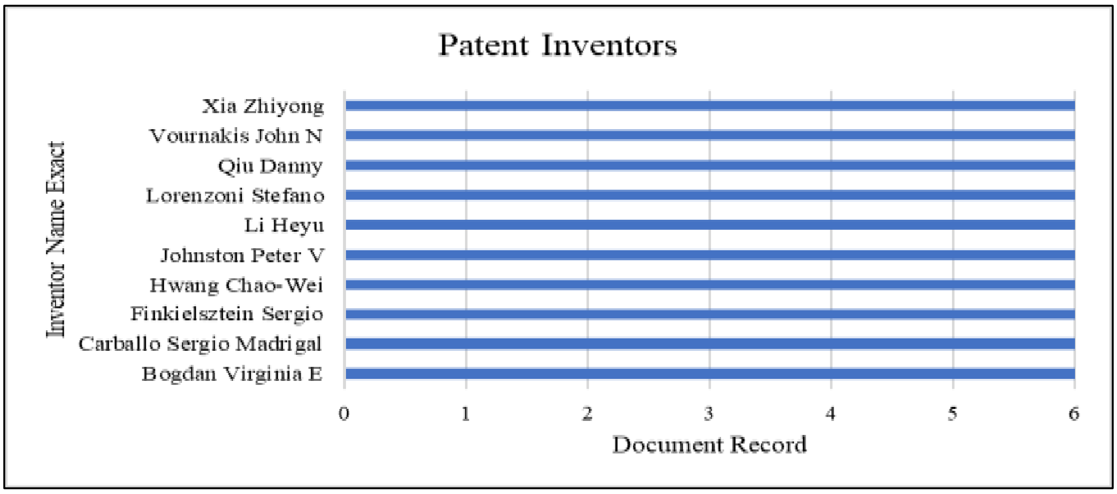

Fig 3: Bar Chart displaying the top 10 Inventors' Name versus the number of Documents filed for their innovation on the application of nanofiber in wound healing from January 2010 to December 2021.

3.4 Patent Owners

Until a specific assignment is done or the innovators are under an obligation to assign the invention, like a contract of employment, the claimed invention is owned by the inventors.[24] In the United States, a patent or patent application is believed to belong to the inventor. There may be several owners if more than one inventor is involved. Transferring or reassigning ownership is possible.[25] The top ten proprietors of nanofiber-based wound healing scaffolds from January 2010 to December 2021 are shown in Figure 4. Marine Essence Biosciences, a high-tech organization, focusing on marine biotechnology research and development, topped this list with four patents filed. The Johns Hopkins University and Washington University got placed in the top 2nd organization with three patents each.

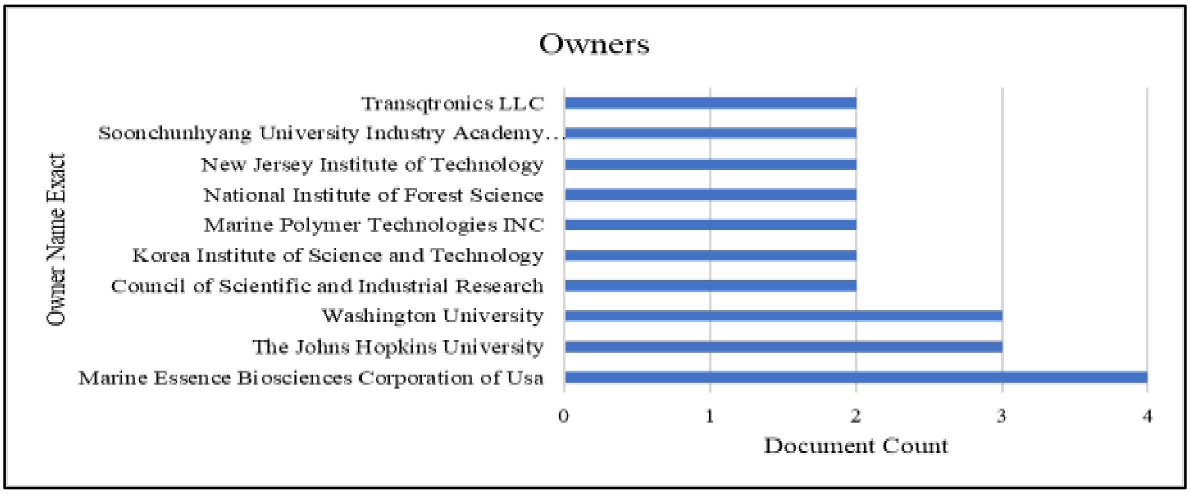

Fig 4: Owners of patent on the application of nanofiber in wound healing during January 2010 to December 2021.

3.5 Patent Document Classification by Filed, Published and Granted

The process of filing a patent application to the relevant local or foreign patent office or authority for proper invention registration is known as patent filing. After that, the patent application is published and granted. A patent application is not necessarily granted only because it is published. Patent applications are made public so that the general public knows what is protected by a patent. Figure 5 shows the number of patents filed, published, and granted annually. The data shows that the number of filed, published and granted patents is increasing continuously. The maximum number of patents filed was in 2019 (#45). At the same time, the maximum number of patents published and granted was in 2021, with 53 and 26 numbers, respectively.

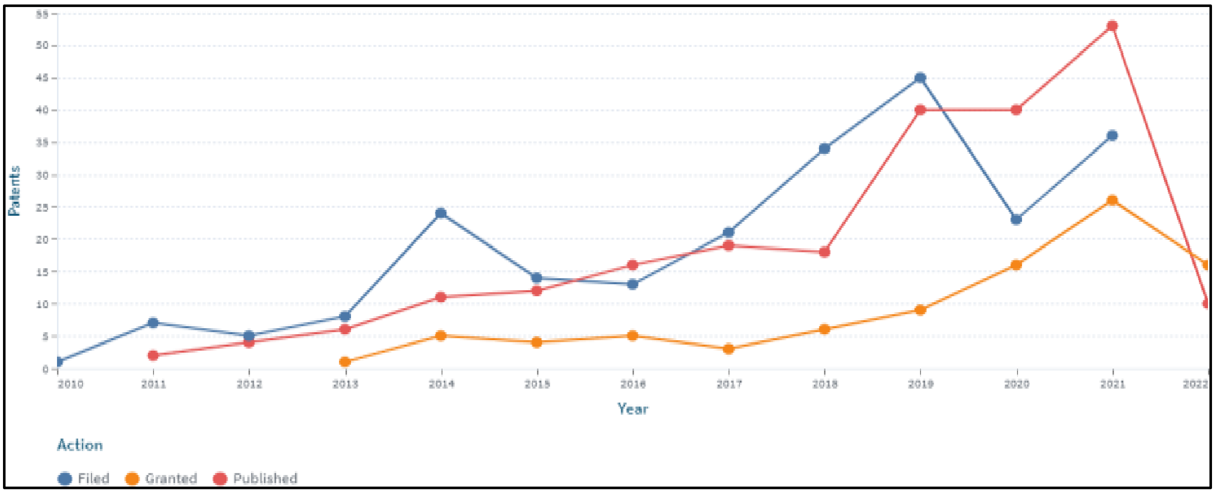

Fig 5: Multiline curve depicting the number of a patent filed, published and granted yearly.

3.6 IPC Classifications to Highlight the Technological Characteristics

The International Patent Classification (IPC) system divides patents into sections, classes, subclasses, groups, and sub-groups. It is an international taxonomy system that provides standardized information for categorizing innovations and establishing their technological uniqueness.[26,27] The top ten IPC codes for the use of nanofiber in wound healing from January 2010 to May 2022 are displayed in Figure 6. The more frequently recorded IPC code during this period corresponds to A61L15/44 (Medicaments), a subgroup of A61L15 (Chemical aspects of, or use of materials for, bandages, dressings or absorbent pads). Sixty-four patents document were filed under this group alone. A61L15/28 is the second most commonly recorded IPC code, described as chemical aspects of, or use of materials for, bandages, dressings or absorbent pads containing polysaccharides or their derivatives. This group has 55 recorded patent documents. For more details concerning these top 10, a description of each IPC code is shown in Table 2.

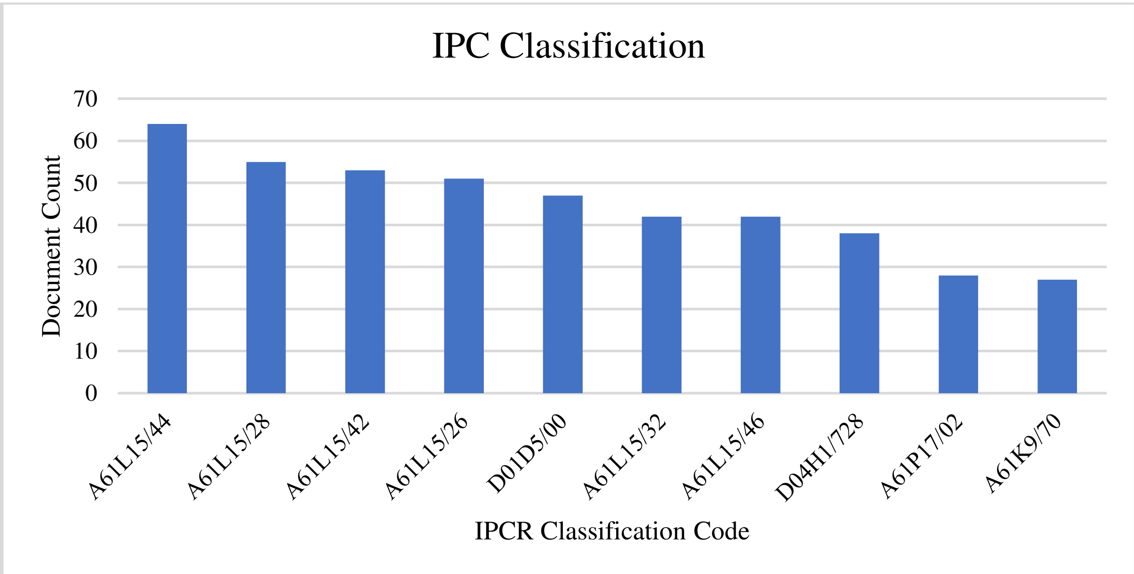

Fig 6: Bar Chart displaying the number of patent documents filed under the top ten sub-categories of the IPC classification system from January 2010 to December 2021.

Table 2. Description of top ten IPC codes obtained from patent records.

S. No.	IPC Codes	Description
1.	A61L15/44	Chemical aspects of, or use of materials for, bandages, dressings or absorbent pads containing medicaments
2.	A61L15/28	Chemical aspects of, or use of materials for, bandages, dressings or absorbent pads containing polysaccharides or their derivatives
3.	A61L15/42	Chemical aspects of, or use of materials for, bandages, dressings or absorbent pads characterized by their function or physical properties
4.	A61L15/26	Macromolecular compounds obtained otherwise than by reactions only involving carbon-to-carbon unsaturated bonds; Derivatives thereof

5.	D01D5/00	Formation of filaments, threads, or the like
6.	A61L15/32	Chemical aspects of, or use of materials for, bandages, dressings or absorbent pads containing proteins, polypeptides; Degradation products or derivatives thereof, e.g. albumin, collagen, fibrin, gelatin
7.	A61L15/46	Chemical aspects of, or use of materials for, bandages, dressings or absorbent pads containing deodorants or malodour counteractants, e.g. to inhibit the formation of ammonia or bacteria
8.	D04H1/728	Non-woven fabrics formed wholly or mainly of staple fibres or relatively short fibres by electrospinning.
9.	A61P17/02	Drugs for dermatological disorders for treating wounds, ulcers, burns, scars, keloids, or the like
10.	A61K9/70	Medicinal preparations characterized by special physical form Web, sheet or filament bases

Note: All descriptions of IPC code were extracted from 'https://www.wipo.int/classifications/ ipc/ipcpub' accessed on 20 March 2022.

3.7 Scientific Implication

An injury to the human body caused by violence, an accident, or surgery is classified as a wound when it results in damage to muscles, tendons, nerves, arteries, parenchymal organs, or even bone. Wounds often involve cutting or tearing the skin and frequently extend into subcutaneous tissue. According to a retrospective analysis from 2018, Medicare found 8.2 million people who had at least one type of wound, with or without infections. Treatment for acute and chronic wounds is expected to cost between $28.1 billion to $96.8 billion. The cost of treating a chronic or hard-to-heal wound can be reduced by applying a 3D scaffold (e.g. Electrospun nanofibers) at the wound site, which would accelerate tissue regeneration by promoting cell signalling, attachment, and proliferation. In this patent landscape study, we have analyzed the patents filed in the last decade on developing electrospun nanofibers loaded with various molecule categories for rapid wound healing. The current study also revealed where further research could be done to get more healing products. Market-wise, this study also shows the geography which can be tapped for pharma field growth.

3.8 Analysis of Relevant Patent

Using nanofiber film to regenerate tissue or wound healing is an innovative concept in topical application. Various combination of natural and synthetic polymers loaded with a series of therapeutic agents was studied.[28] The relevant and most cited patents are listed in Table 3. In the following section, relevant patents based on their citation by other patent and non-patent literature (NPL) were discussed in detail. Aizenberg J. et al.,[29] developed a self-healing, scratch-resistant slippery surface that successfully repels biological materials like blood and prevents, reduces, or delays coagulation and surface-mediated clot formation. The patent also broadly discloses the application of the material as wound dressing devices, as an absorbent for wound exudate fluid. Macewan M.R. et at.,[30] had a multi-laminar electrospun nanofiber scaffold for early wound healing. The first layer of the fabricated scaffold consists of randomly oriented nanofibers, while 2nd layer consists of radially aligned nanofibers. The inventors have claimed the application of the developed formulation as a biomedical wound scaffold for facilitating wound healing. Delisle S. et al.[31] disclosed silk-based product (SBP) formulations for use in a number of applications in human medicines, veterinary medicine, agriculture, and material science. The inventors also have broadly disclosed the application of silk in nanofiber for wound healing. Mirzaei E et al.,[32] invented a three-layer nanofiber patch for wound healing. The outer layer is hydrophilic in nature and acts as support. The intermediate layer is a cross-linked genipin structure that serves as a *Melilotus officinalis* herbal extract reservoir. The third layer consists of non-cross-linked chitosan. Qiu D. et al.,[33] invented a guided tissue regeneration (GTR) device consisting of mutable collagenous tissue (MCT)-chitosan composite material. MCT can be extracted from sponges, jellyfish, molluscs, and echinoderms, which are invertebrate marine animals. MCT-chitosan composite materials can be used as biofilms, 3D sponges, hydrogels, and more. The inventors also broadly disclosed the application in the fabrication of nanofiber as wound-healing dressing material. Li X. et al.[34] developed a porous complex gel-nanofiber oxygen permeation dressing. It consists of a lower layer of collagen nanofiber and an upper layer of chitosan and alginic acid in sponge form. The scaffold has exceptional oxygen permeability, moisture penetrability, water-absorbing efficiency, water permeability, and high biocompatibility, allowing for maintaining a wet physiological environment on the wound surface. Chen B. et al.,[35] disclosed the process of preparing nanofiber by electrospinning technique utilizing natural and synthetic polymers or a mix of these. Also, this scaffold can be loaded with a series of therapeutic agents. The fabricated scaffold can be employed in air filtration, automobile air purification, fresh air systems, pharmaceutical and medical product, beauty care, and other nanofiber products. Kumar V.A. et al.,[36] had developed a cationic amphiphilic self-assembled peptide (CASPs) based hydrogel, which would self-assemble into a nanofiber platform. These nanofiber platforms would disrupt the bacterial colonies in an open wound. Because of its high terminal charge density, it is highly effective as a bactericidal against *Pseudomonas* biofilms. Hauser C. et al.,[37] invented a novel ultrashort hydrophobic peptide capable of self-assembling into the nanofibrous hydrogel. The self-assembled hydrogel could be employed in regenerative drug delivery, injectable formulation, bioactive drug delivery, wound healing formulation, 2D and 3D scaffolding, biosensor development, biofunctionalized scaffold, and fabrication. Sun F. et al.,[38] had developed a Sodium alginate-based nanofiber with high-water-absorption capacity. The inventors had cross-linked the fabricated sod. Alginate nanofiber with a cross-linker to produce a novel scaffold which has a very water-absorbing capacity. This would help absorb exudates released from an open wound and help in early healing.

Table 3: List of most citation having application of nanofiber in wound healing.

S. No.	Patent Number	Publication Date	Title	Applicants	Inventors	Total Citation
1	US9932484B2	03-04-2018	Slippery liquid-infused porous surfaces and biological applications thereof	Harvard College*	Aizenberg J.; Hatton B.; Ingber D; Super M; Wong T.S.	163
2	US11071617B2	27-07-2021	Biomedical patches with aligned fibres	Washington University	Macewan M. R; Xie J.; Ray Z.; Xia Y.	94
3	WO2020247594A1	10-12-2020	Silk-based products, formulations, and methods of use	Cocoon Biotech Inc	Delisle S.; Santos M.; Easthon L.; Eliott D.; Mitchell P.; Tweed-Kent A.; Gilligan R. T.;Chandler M.	91
4	US20130150763A1	13-06-2013	Electro-spun nanofibrous wound dressing and a method of synthesizing the same	Inventors are also Applicants	Mirzaei E.; Majidi R; Sarkar S.; Rezayat S.M.	50
5	US10912822B2	09-02-2021	Biomaterial devices and topical compositions for guided tissue regeneration	Marine Essence Biosciences Corp Of USA	Qiu D.; Carballo S.M.	35
6	US10758594B2	01-09-2020	Biomaterial devices and topical compositions for the treatment of skin abnormalities	Marine Essence Biosciences Corp of USA	Qiu D.; Carballo S.M.	31
7	CN104491914A	08-04-2015	Porous complex gel-nanofiber oxygen permeation dressing and preparation method thereof	Fourth Military Medical Univ	Li X.; Huang R.; Li J.; Lyu X.; Jiang L.; Li J.	29
8	CN108866820A	23-11-2018	Preparation method and application of electrospinning nanofibers	Shenzhen Ruixiangju Tech Development Co Ltd	Chen B; Wang Y; Lin X.	29
9	US10632172B2	28-04-2020	Injectable self-assembling antibacterial peptide hydrogels	New Jersey Inst Technology	Kumar V.A.; Nguyen P.; Sarkar B.; Jaisinghani S.	23
10	WO2019104316A1	31-05-2019	Compounds, compositions, and methods for treating and preventing periodontal disease	Us Health; Univ Yale*	Somerman M.; Foster B.; Chu E.; Braddock D.; De La C.E.	22
11	WO2015080670A1	04-06-2015	Novel ultrashort hydrophobic peptides that self-assemble into nanofibrous hydrogels and their uses	Agency Science Tech & Res	Hauser C.; Loo Y.	17
12	US9636521B2	02-05-2017	Heat and light treatment device using nanotechnology	Inventors are also Applicants	Isserow J.; Isserow L.	16
13	CN106110371A	16-11-2016	Preparation method of high-water-absorption sodium alginate composite nanofiber wound dressing	Inst of Applied Chemistry Jiangxi Acad of Sciences	Sun F.; Zhang P.; Hu Y.; Wang X.; Zeng G.	14
14	CN103041440A	17-04-2013	Preparation method of recombinant spider silk protein/silver nano biological wound membrane	Univ Fujian	Zhao L.; Li M.; Chen D.; Zhang W.	14

15	US20160325022A1	10-11-2016	Composite synthetic nanofibrous scaffolds and articles thereof	3M Innovative Properties Co	Liu J.; Mcnulty A.K.	13
16	CN106390177A	15-02-2017	Chitosan-based multi-layer nanofiber membrane dressing, as well as preparation method and application thereof	Shenzhen Inst of Adv Tech Cas	Zhao X.; Chen Q.	11
17	CN103536958A	29-01-2014	Modified cellulose nanofiber membrane based on layer-by-layer self-assembly of lysozyme and silk protein-based as well as preparation and application thereof	Wuhan University	Deng H.; Wang X.; Zhan Y.; Xin S.; Du Y.; Shi X.	11
18	CN107233611A	10-10-2017	Multifunctional nanofiber wound repair biological dressing and preparation method thereof.	First Hospital Jilin Univ	Chen X.; Yu J.; Wang X.; Wang C.; Zhao R.; Jin Z.; Gao X.	10
19	US20150335788A1	26-11-2015	Stem cell-impregnated therapeutic patch	Univ Johns Hopkins	Xia Z.; Hwang Chao-Wei;;Calderon-Colon X.; Bogdan V.E.; Johnston P.V.	9
20	US10987501B2	27-04-2021	Cell-impregnated sleeve for paracrine and other factor production	Univ Johns Hopkins	Hwang Chao-Wei; Xia Z.; Bogdan V.E.; Brinker J.A; Gerstenblith G.; Johnston P.V.; Schulman S.P.; Tomaselli G.; Weiss R.G.	9
21	US9775917B2	03-10-2017	Nanofibre and bioactive compositions and related methods	Active Fibres Ltd	Vile G.F.; Hosie I.C.; Feasey S.V.	9
22	CN103225172A	31-07-2013	Chondroitin sulfate nanofiber non-woven fabric and preparation method and medical purposes thereof	Univ Changzhou	Wang K.; Yu Q.	8
23	CN112870432A	01-06-2021	Photorepairable nanofiber hydrogel dressing and preparation method thereof	Univ Donghua	Li X.; Liu X.; Dong Y.; Ding B.; Yu J.	8
24	CN109529123A	29-03-2019	Vascularized full-thickness tissue-engineered skin layer-by-layer assembled by hydrogel, nanofiber scaffolds and skin cells and preparation method thereof	Fourth Military Medical Univ PLA	Li X.; Wang H.; Huang R.; Li Y.; Li J.; Li J.; Xu L.; Bian Y.; Zhao C.; Xu X.	8

Inventors are also the applicant.

Zhao L. et al.,[39] invented a recombinant spider silk protein/silver-bearing PVA-based nanofiber by electrospinning technique. Because of silver nitrate, the scaffold provides antibacterial action against a series of gram-negative and gram-positive bacteria. The application of developed nanofibers significantly reduced the wound healing time compared to medical gauze. Liu J. et al.,[40] invented a composite nanofibrous membrane consisting of collagen and an anti-thrombotic glycan. The inventors further disclosed that the framework would be stable enough to allow fibroblast cell signalling and proliferation. The synthetic scaffold would also disintegrate at a rate that will enable it to be used as a transitory cell support in wound healing. Zhao X and Chen Q.[41] had developed a chitosan-based multi-layer nanofibrous wound healing membrane. The scaffold consisted of three layers, the inner was made of chitosan, and it would stop bleeding and resist bacterial invasion. The middle layer consists of a chitosan-hydrophilic polymer composite, which absorbs wound exudates and maintains the wetness of the wounds. The upper layer consists of a hydrophilic polymer loaded with bioactive nano glass, and it would slowly release the growth factors and hence facilitate wound healing. Deng H. et al.,[42] invented a layer-by-layer modified cellulose nanofiber membrane by electrospinning technique. The invention disclosed that the nanofiber membrane of cellulose initially prepared using lysozyme and silk protein having opposite charges were alternately assembled on the surface of the cellulose nanofiber membrane by adopting a layer-by-layer assembly technique. The invention further disclosed the antibacterial, biocompatible, cell adhesion, and in-vitro wound healing ability of scaffold. Chen X. et al.,[43] invented a multifunctional nanofiber scaffold for early wound healing, anti-scar application, suppressing oedema, inhibiting microbial infiltration, etc. To prepare a multifunctional nanofiber membrane, the inventors developed the scaffold using three needles loaded with three different spinning solutions simultaneously. Xia Z. et al.,[44] developed a therapeutic scaffold consisting of a single layer of nanofiber membrane embedded with a layer of the plurality of stem cells and a plurality of stem cell-derived paracrine factors. The inventors broadly disclose the application of a patch as wound healing dressing material along with the implantable pacemaker, cardioverter-defibrillator, an artificial heart, and an artificial valve. In 2021, Hwang Chao-Wei et al. invented a valuable sleeve device for various pharmaceutical applications. The sleeve device comprised PLGA, PLA, PCL, and other biodegradable polymers. The stem cells are then implanted. Stem cells are programmed to release paracrine substances that aid wound healing.[45] Vile G.F. et al.,[46] disclosed the invention of a nanofibrous membrane loaded with one or more bioactive therapeutics. The nanofibrous scaffold acts as base material and is formed by dissolving a bioactive drug into a biodegradable, biocompatible polymer. The inventors also disclosed the application of scaffold as a wound healing facilitator, antimicrobial film, anti-inflammatory scaffold, cell proliferation enhancing film, etc. Li X. et al.,[47] developed a photo-repairing nanofiber hydrogel dressing material. The nanofibrous hydrogel scaffold was made up of a natural polymer loaded with carboxylated polyethene glycol derivative, which forms a multiple hybrid interpenetrating network-like structure. This composite nanofiber was loaded with a micro-size microsphere of dopamine, polyphenol oxidase and fatty acids.

4. CONCLUSIONS

This research looked at recent trends in patenting electrospun nanofiber in wound healing. A detailed analysis between the periods of January 2010 to December 2021 was done. Although China was ranked the first jurisdiction-wise, with 52% of patents filed in this area, Marine Essence Biosciences Corp of USA secured the first rank in patent applicants with ten patent records filed in this period. Similarly, top inventors of this duration invented the same number of patents, i.e., six each—Marine Essence Biosciences Corp of USA top the list of patent-owners with four patent records. A maximum number of patents were filed in 2019, while the maximum number of records was published and granted in 2021. Based on the IPC codes, the A61L15 class was filed the maximum times. Since an open wound is very prone to microbial infiltration and requires single-time application of a scaffold for prompt wound healing, most inventions employed biodegradable and biocompatible polymer(s) in addition to one or more antimicrobial and antioxidant drugs.

5. ACKNOWLEDGMENTS

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6. AUTHOR CONTRIBUTION STATEMENT

G.A. conceived and planned the study. G.A., N.Y., M.K.K., M.R.I. and M.K.S. were responsible for data collection, model analysis and manuscript writing. G.A. took the lead in writing the manuscript. G.A. and N.Y. were responsible for research design, manuscript revision and project management. All authors provided critical feedback and helped shape the research, analysis and manuscript.

7. CONFLICT OF INTEREST

Conflict of interest declared none.

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