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Nanomaterials and Nanofibers As Wound Dressing Mats: An Overview Of The Fundamentals, Properties And Applications

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Abstract

Polymeric nanofibers can simply be fabricated through an electrospinning technique. The electrospinning process is one of the best usually utilized approaches to achieve continuous fibers in the nanosized form. Electrospinning has extended attractiveness because of its ease of use, simplicity and various applications. The electrospun fibers properties could be controlled via adjusting each procedure variables such as solution flow rate, applied voltage, as well as space between charged capillary and collector) or the properties of polymeric solution for example (e.g., molecular weight, concentration, surface tension, surface charge density, viscosity, solvent volatility, and conductivity). Furthermore, the used polymeric solution can be a polymeric melt, aqueous, or an emulsion, which give opportunity to diverse sorts of nanofiber construction. Also, by polarity inversion and by varying the collector design the properties of nanofiber can be improved. Moreover, polymeric fibers can be modified by incorporated through blending, surface modification or emulsion formation. The nanofibers were modified to provide manifold drugs, as well as multilayer polymer coating lets continuous release of the combined active moiety. Electrospun nanofibers fabricated from different polymers are utilized to realize anticancer agents and antibiotic, DNA, RNA, as well as growth factors. The current review delivers a collecting of some work concerning the usage of electrospun fibers in drug delivery with a special emphasis on electrospun nanofibers impregnated with nanoparticles also electrospun nanofibers in biomedical applications such as wound dressings prevents infection and speeds up the healing process.
Keywords: Electrospinning; polymers; nanofibers; nanomaterials, wound dressings

1. Nanotechnology

The nanotechnology branch has experienced tremendous growth during the previous century. And nowadays, nanotechnology is involved in a variety of development projects, either directly or indirectly. Nanotechnology is described as the procedure of creating, manufacturing, evaluating, and applying materials and devices by altering their size and form at the nanoscale. The suffix "nano" is used as a catchphrase in each and every broadcast, as well as in commercial promotion. Apparently, the term "nano" comes from the Greek word "nanos" or the Latin word "nanus," which meaning "dwarf." It combines biosciences, chemistry, solid state, physics, , and materials science. As a result, mastery in a single area will not suffice; knowledge of solid state, physics, biosciences, chemistry, and material science will be obligatory. Nanotechnology is finding applications in nearly every branch of science and technology. Nanotechnology is a fast emerging scientific subject that studies and expands things and materials with unique identifiers of less than 100 nanometers [1].

Nanofibers manufactured from both synthetic and natural polymers have gotten a lot of interest recently because of their simplicity of production and ability to regulate their compositional, structural, and functional characteristics [2, 3]. Although there are a variety of processing techniques for making nanofibers, including template synthesis, drawing, self-assembly, phase separation, and electrospinning. The electrospinning process has been proven to be among the highest efficient, facile, and adaptable ways because of its comparatively easy with cost effective [4, 5]. Polymer nanofibers can be made by applying a high electrical field between a ground target and a polymeric solution pushed from a closed

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chamber thru a tiny capillary aperture in electrospinning. Fibers being collected as a non-woven mesh or membranes on a collector plate that works as such a counter electrode.

The diameter of the fibers is less than 1 thousand nm based on the viscosity, molecular weight, conductivity and surface tension of the whole polymer's solution. The electrospun nanofibers can be formed with a variety of in fibers diameter. Creating fibers with exceptionally small diameters has several advantages, including high a surface area, high porosity, and excellent mechanical efficiency [6]. Furthermore, fiber functions may have been governed by molecules at the fiber's surface, enabling fiber characteristics to be tailored by altering fiber surface composition and morphology. Nanofibers have been used in medical implants, wound healing, dental applications, drug delivery, biosensors, and tissue engineering [7, 8], military protective clothing, filtration media, and other industrial applications as a result of this [9].

2. Fabrication of Nanofibers via Electrospinning

Rayleigh described electrospinning as a manufacturing method in 1897, Zeleny investigated it in further depth in 1914 [10],, and Formhals patented it in 1934 [11].. However, it wasn't until the development of nanotechnology in the 1990s that large-scale industrial use became possible. Since that day, electrospinning has grown in popularity as research has revealed that a wide range of polymers can be electrospun. At the present time, several firms of electrospun nanofibers are effectively create with wholesale significant quantities, and difficulties related to scaling–up process are being resolved. As a result of the minimal energy usage, the method is very cost–effective.

The electrospinning of biopolymers is accompanied by significant challenges considering the fact of biopolymers frequently have dispersed molecular weights or sophisticated chemical structures. Additional studies are required to be able to contribute effectively to the production of effective nanofibers on a wide scale utilizing biopolymers that are ecologically friendly.

Because of their inexpensive cost, great abundance, and broad range of distinct molecular and efficient properties, synthetic polymers are selected for the manufacturing of nanofibers. A solvent suited for producing a polymer solution must be chosen based on the polymer. This selection is vital because the solvent can affect the surface tension, viscosity, and conductivity, all of which are important factors in the electrospinning process. When compared to naturally occurring biopolymer fibers, manufactured, water-insoluble nanofibers exhibit enhanced mechanical characteristics or better preserve structural integrity when exposed to watery conditions [12]. Furthermore, synthetic polymers have more well-defined chemical characteristics allowing enable more consistent electrospinning performance.

Comprehensive reviews have been published on the production of nanofibers from synthetic polymers including such poly-caprolactone (PCL), polyglycolic acid, polylactic acid, polyethylene glycol, polyethylene oxide, and polyvinylacetate. [13]. Biocompatible polymers are of considerable interest in a variety of sectors because they are (a) benign, digestible, and edible, (b) biodegradable, and (c) sustainable and renewable, allowing for a larger use, particularly in biomedical sciences and related disciplines. Furthermore, despite recent improvements in electrospinning and nanofiber manufacturing, Due to a variety of technical challenges, the production of nanofibrous membranes from biopolymers has moderate effectiveness. Firstly, before electrospinning, biologically-derived polymers generally require extensive, complex, and expensive purification procedures. Secondly, due to their comparatively high crystallinity or polarity, biopolymers are far less soluble in very many organic solvents. Thirdly, numerous biopolymers have a proclivity for producing hydrogen bonds that are strong, resulting in forming a solution with high viscous gel. Furthermore, biopolymer fibers' mechanical characteristics and processability are generally poor.

3. Set of Electrospinning process

Figure 1 depicts a schematic diagram of a typical electrospinning process. In this design, a syringe with a blunt-ended stainless-steel capillary is used to pump the dispersed polymer solution. The syringe is inserted into a syringe pump, which allows for exact control and modification of the solution flow rates. However vertical configurations have been documented, the syringe is generally aligned horizontally [14].

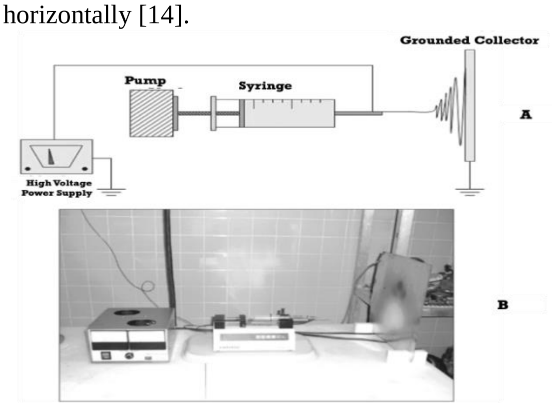

Figure 1: Schematic illustration of (A) photographic picture and (B) laboratory-scale electrospinning apparatus [14].

3.1. Electrospinning mechanism

A definite polymer solution contained in a syringe is subjected to a high electrical field. When pressure force is supplied to the polymer surface at the capillary's end, a drop occurs. The drop surface and shape are preserved in the absence of an electric field via a balance of power that includes gravity and surface tension. The presence of an electrical field in electrospinning brings extra pressures into this complicated scenario, which can result in a number of outcomes. The simultaneous charge repulsion of the polymer and the solvent used results in a force which is precisely in opposition to the surface tension and attracts the board electrode [15]. As a consequence, the solution's hemispherical surface at the capillary's tip is deformed into a conical shape termed as a Taylor cone, as seen in **Figure 2** [16].

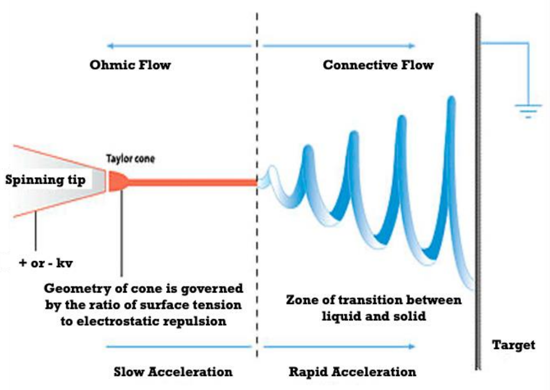

Figure 2: Schematic representation of the Taylor cone formation [16].

A charged polymer solution jet is expelled from the tip of the Taylor cone when the electrical field reaches a critical value, exceeding the shape-maintaining surface forces. The electrical field accelerates this jet towards the grounded collector. Charges collect on the jet's surface as it passes thru the electrical field. The jet may whip or bend as a result of these charges being improperly dispersed. As a consequence, the solvent could evaporate quickly, whereas the polymer chains in the jet expand and spin. The polymer molecules are subsequently placed on the collecting plate [3]. by a narrow jet [16]. It It's worth mentioning that the jet may not stay whole and instead split up into tiny droplets depending on the solution and process circumstances, resulting in particles rather than fibers being dumped on the collection plate.

4. Nanofibers production: advantages and drawbacks

Nanofibers have a significant surface area to volume ratio, almost twice greater than nanoparticles of the same diameter depending on the same quantity of material. Nanofibers offer a number of benefits over nanoparticles in terms of performance. They are more easily separated from the solution medium, allowing it to be reused. Nanofibers can also have tiny diameter size, porosity, connectivity, microscale interstitial space, small interfibrous holes, and greater mechanical characteristics. Most of these properties demonstrate that nanofibers are versatile materials that may be used in a various applications [17, 18]. Nanofibers may be made using a variety of techniques. Nevertheless, it is critical to highlight the method's features in order to determine which of these is best for each material and application, taking into account process variables, manufacturing costs, and production rates.

As a result, new nanofiber manufacturing techniques have evolved, as detailed throughout this topic, and some of them may be better suited to the development of chitosan-based nanofibers. The best method for creating nanofibers is electrospinning (**Figure 3**).

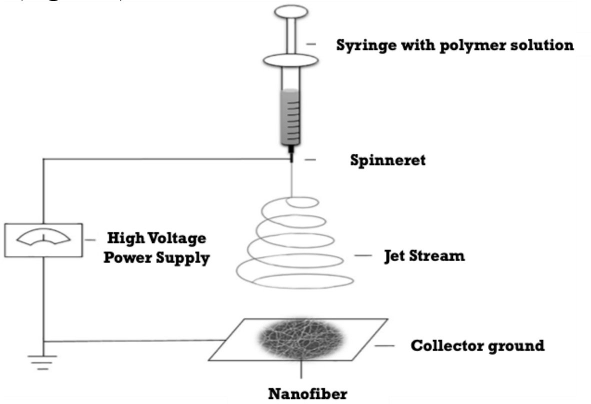

Figure 3: Basic scheme of electrospinning technique [19].

Furthermore, the solution's viscosity should be adequate, since low viscous solutions are unable to withstand the Rayleigh instability and usually break up to droplets, which would be unfavorable. The electrospun fibers' morphology is influenced by a number of variables, including solution characteristics, processing factors, and ambient circumstances. Of these solution characteristics, molecular weight of the polymer, surface tension, conductivity, and viscosity. The electric field intensity used, diameter of spinneret distance between the spinneret and the collecting substrate, and rate of solution feeding are all processing conditions [20–22]. Electrospinning has the benefit of producing nanofibers of diverse materials in a variety of fibrous assembly with thicknesses ranging from 100 nanometers to 5 nanometers [17, 18, 23].

The solution blowing method is a relatively new nanofiber spinning technique (**Figure 4**). The technology was created to eliminate the disadvantages of electrospinning, such as the necessity for high-dielectric-constant solvents or even a huge electric field.

Furthermore, the solution blowing process shares certain characteristics with industrial fiber manufacturing processes, allowing for scale-up [24]. The pressurized gas accelerates the polymer solution, causing it to distort into a conical shape, comparable to the Taylor cone mostly during electrospinning process [25].

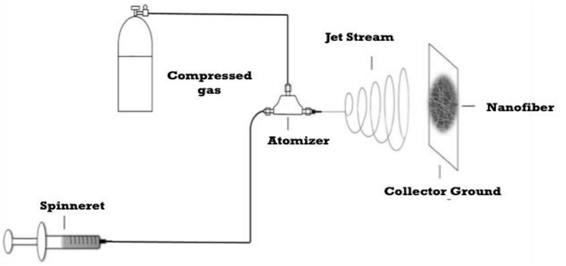

Figure 4: Basic scheme of solution blowing technique [19]

As a result, more research is needed to enhance the spinnability of chitosan. Electrospinning's scale-up difficulty was also addressed using centrifugal jet spinning. When compared to electrospinning, it was intended to produce nanofibers on a bigger scale by increasing the rotating speed to obtain greater efficiency and cheaper costs [26, 27].

By reality, its fiber synthesis is predicted to be around 500 times greater than that of the traditional electrospinning method [28]. Furthermore, centrifugal spinning does not need high voltage, which alleviates safety issues. Optimizing centrifugal force, as well as viscoelastic and mass transfer fluid characteristics, is the basis of the technique.

The technique's basis is the transfer fluid properties. As the jet overcomes the surface tension, the polymer-solvent combination is injected into a spinning spinneret and subsequently expelled (**Figure 5**). polyethylene oxide [29] poly(L-lactic acid) [26], polycaprolactone [30], ethyl cellulose/polyvinyl pyrrolidone [31], and PCL/gelatin [32] are among the polymers utilized in the centrifugal spinning of nanofibers.

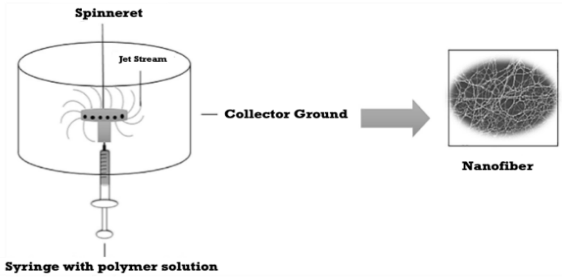

Figure 5: Basic scheme of centrifugal jet spinning technique [28].

5. Polymers used for electrospinning

5.1. Chitosan nanofibers

Chitosan is a copolymer of (1→ 4)-2-amino-2-deoxy—D-glucan and (1→ 4)-2-acetamido-2-deoxy—D-glucan [33] with substantial intra- and intermolecular hydrogen bonds fashioned by deacetylation of chitin. Figure 6 depicts the architectures of chitin and chitosan. Molecular weight, deacetylation degree, acetylation sites dibonsutitri, as well as pH and ionic strength of solution, all influence the properties of chitosan [34]. The charge density is determined by the degree of deacetylation or even the proportion of the monomer units inside this chain, as only the deacetylated amino groups can lose or acquire protons [35]. In acidic solution, chitosan acts as a cationic polyelectrolyte with such a high charge density. Owing to the variation in molecular configurations, it may be very viscous as a polyelectrolyte, depending on polymer concentration, pH and media ionic strength [36].

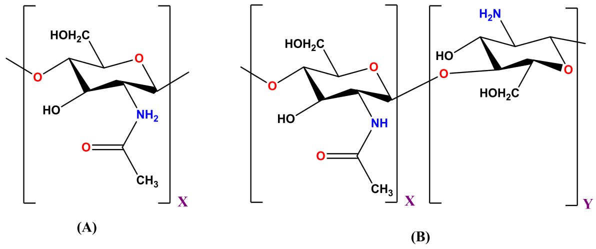

Figure 6: Chemical structures of (A) chitin and (B) chitosan [34].

Nontoxicity, biodegradability, biocompatibility, biofunctionality, metal chelating, and antibacterial capabilities are all attributes of chitosan [37, 38]. It possesses a strong mechanical strength and a strong affinity for proteins. A wide range of possible biomedical uses have been described as a result of its biological activity [39]. Nonetheless, by mixing chitosan with other polymers such as PEO [40] or PVA [41] in acetic, acrylic, or other acids, various research groups have succeeded in producing chitosan-based composite fibers. The co-spinning agent's outstanding fiber forming capabilities are used in this situation. Chitosan also has been effectively combined with some other natural biopolymers that seem to be easier to electrospun, including such collagen [42]. It possesses a strong mechanical strength and a strong affinity for proteins. A broad range of possible uses in biomedical and pharmaceutical sectors were extensively explained as the result of its biological activity [39]. Due to its broad spectrum of antibacterial action against diverse microbiological species, its application as a food preservative is of particular interest [43].

5.2. Cellulose nanofibers

Cellulose is among the most common polysaccharides in nature and is the major structural component of plant cell walls [44–47]. Cellulose is a broadly applied sustainable and renewable basic compound in order to produce biopolymer-derived industries, and the utilization of this derived biopolymer is very affordable due to its broad accessibility. Cellulose is biocompatible and has excellent thermal and mechanical characteristics [48]. Due to its crystallinity and strong hydrogen bonding, cellulose has a limited solubility in common organic and aqueous solvent, making fiber synthesis by electrospinning from the solution problematic. For the electrospinning of cellulose to be effective, the proper solvent must be carefully selected. As a result, only a few experiments have been reported in which cellulose has been effectively electrospun. In order to make completely dissolved cellulose solution of diverse sources varying in (DP ranges from 940 to 140), Frey and coauthors used combinations of ethylenediamine and different thiocyanate salts [49].

5.3. Cellulose acetate nanofibers

Many studies have been performed on the electrospinning of cellulose derivatives including such cellulose acetate [46, 50–59] due to the challenges associated with cellulose as described above [60]. Liu created cellulose acetate nanofibers from cellulose acetate, which were then deacetylated to become cellulose fibers [61]. Electrospinning polymer blends including cellulose derivatives are another method for producing cellulosic nanofibers. Electrospun nanofibers with new characteristics and topologies were created using a binary combination of CA and PEO [62].

5.4. Polyvinyl alcohol (PVA) nanofibers

PVA (polyvinyl alcohol) is a widely used synthetic polymer that is water soluble and can be produced in large quantities economically [45]. Due to its high chemical resistance, physical characteristics, and biodegradability, PVA is one of the most often utilized polymers for ultrafine electrospun fiber manufacturing. Numerous different types of functional composite nanofibers based on PVA have been developed over the last years [63]. Electrospun PVA fibers have a wide range of uses, including such reinforcing materials, filtration, tissue scaffolding, wound dressings, and as a carrier for drugs [64].

However, one of the most significant issues limiting the use of electrospun PVA nanofibers is their strength, which is related to the fact that as-spun fibers are frequently gathered as randomly arranged structures in the form of non-woven mats. Fabricating aligned electrospun PVA nanofibers is a viable and easy way to solve this problem. Producing composite nanofibers is another viable way to increase the strength of electrospun PVA nanofibers. Carbon nanotubes (CNTs) have previously been the subject of several studies as an effective reinforcement for nanocomposites. For many years, CNT/PVA composite fibers have piqued people's curiosity [65, 66].

5.5. Poly (vinyl pyrrolidone) (PVP)

Poly (vinyl pyrrolidone) (PVP) is a common synthetic polymer (**Figure 7**). PVP was chosen because it has a long history of usage as a carrier of pharmacological molecules in drug delivery systems [67]. PVP has also been approved by the FDA in the United States as a safe polymer to be used in the health fields. Numerous studies have extensively done for the production of PVP nanofibers for a variety of applications [67, 68].

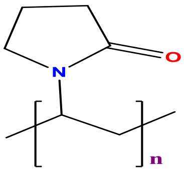

Figure 7: Chemical structure of poly (vinyl pyrrolidone).

The incorporation of GME into PVP nanofibers had no effect on the fiber shape, and relatively homogenous and regular nanofibers were produced. The addition of emodin to PVP fibers up to a concentration of 0.2 % w/v had no effect on the production of regular fibers [67]. As a result, the concentration of the polymer is one of the variables that influence the production of fibers by electrospinning. The polymer concentrations in the electrospinning precursor solution should be high enough to allow polymer chains to bind and produce fibers. **Figure 8** depicts the diameter distribution of nanofibers.

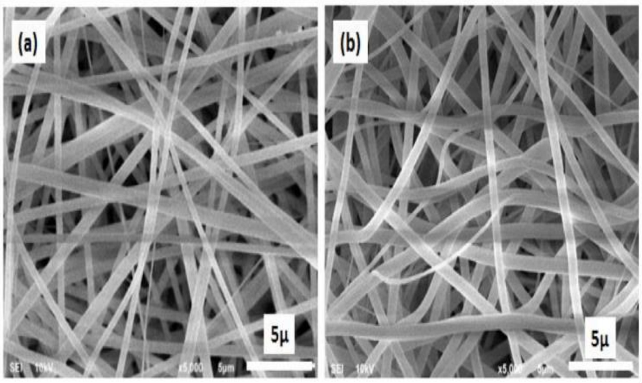

Figure 8: SEM pictures of nanofibers based on (a) PVP and (b) PVP-GME [69].

5.6. Polyurethane nanofibers

Polyurethanes (PU) are a common polymer utilized in wound healing, biomedical, protective clothing, filtration, sensor, composites, and actuator applications [70, 71]. As a result, it's crucial in order to explore at the spinnability and characteristics of the nanofibers based on polyurethane.

There is numerous researches work on the manufacture of polyurethane nanofibers using needle electrospinning, but there has been relatively little research on roller electrospinning. The rheological behavior of thermoplastic polyurethane solutions was studied by Vlad and Oprea. They discovered that when the shear rate increases, the viscosity of polyurethane reduces [72]. Demir et al. investigated the electrospinning of polyurethane (PU) and discovered that viscosity, concentration, and temperature are the most important determinants of fiber shape [73]. According to Khil et al., PU nanofibrous that formed produced by electrospinning enhanced the fluid outflow to be used as a wound dressing for efficient healing the infected wounds [74].

The mechanical behavior of electrospun polyurethane was also studied by Pedicini and Farris. They examined the stress-strain behavior of PU in bulk and nanofibers forms and they discovered the electrospun fibers' molecular orientation causes a decrease in electrospun mat elongation to failure [75]. Lee and Obendarf have created a polyurethane-based protective textile material for agricultural laborers. They used electrospun polyurethane nanofibers to enhance the material's barrier properties [76]. SEM images of different polyurethane nanofibers with TEAB concentrations of 0.3, 0.87, and 1.82 wt%, respectively. Fiber diameter rises with increasing TEAB salt content, as demonstrated in these pictures (**Figure 9**).

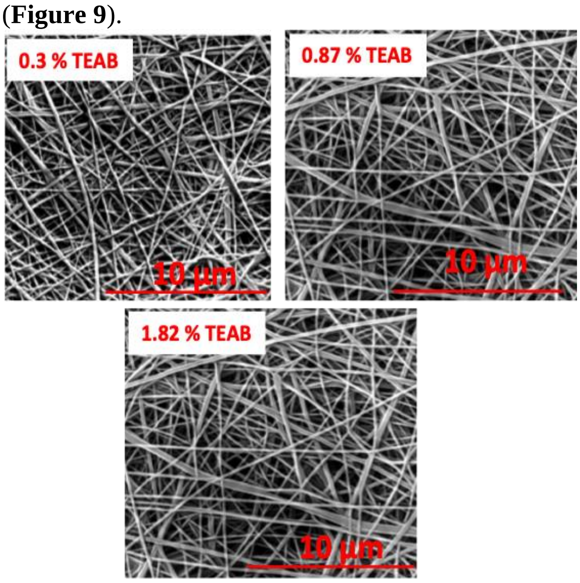

Figure 9: SEM images of nanofiber samples of PU includes TEAB with different % of salt and 27 % of RH [77]

Whereas other PU are thermosetting polymers (**Figure 10a**) [78, 79], PU melt while heating (**Figure 10b**) and are convenient to employ in industrial operations. The characteristics of PUs may be changed in a wide range by changing their structure [80]. Polyisocyanates react with hydroxyl-containing substances to generate PU. Selecting the kind of isocyanate and polyols, or a mix of isocyanates and polyols, can customize desired characteristics [80].

Polyurethanes are ideal for a range of applications in adhesives and coatings, as well as elastomers, foams, and medical applications, due to their high biocompatibility [81].

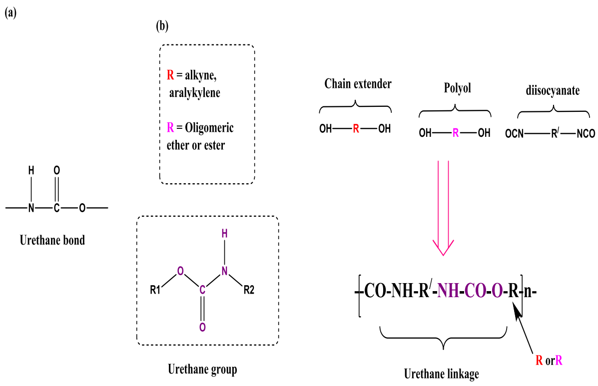

Figure 10: (a) Urethane group, (b) thermoplastic polyurethane general formula [82].

Because of its excellent barrier characteristics and oxygen permeability, it is widely utilized in wound dressing research. It has been claimed that wound healing is aided by semipermeable dressings, several of which are made of PU [83]. Melt electrospinning might potentially be used to produce degradable and biocompatible aliphatic PU scaffolds [84]. Aside from these biomedical uses, electrospinning was used to make PU nanofiber filters based on using 3D particle filtration modeling, some theoretical filtration efficacy estimations were generated [85, 86].

.Akçakoca Kumbasar et al., utilized dimethyl formamide (DMF) for the dissolution of PU and investigated the effect of PU concentration represented in **Figure 11** and **12** [82]. Their findings revealed that for smooth nanofibers, 6% of PU concentration is too low and 14 percent is too high, and that nanofiber diameter grew as PU concentration rose, as predicted.

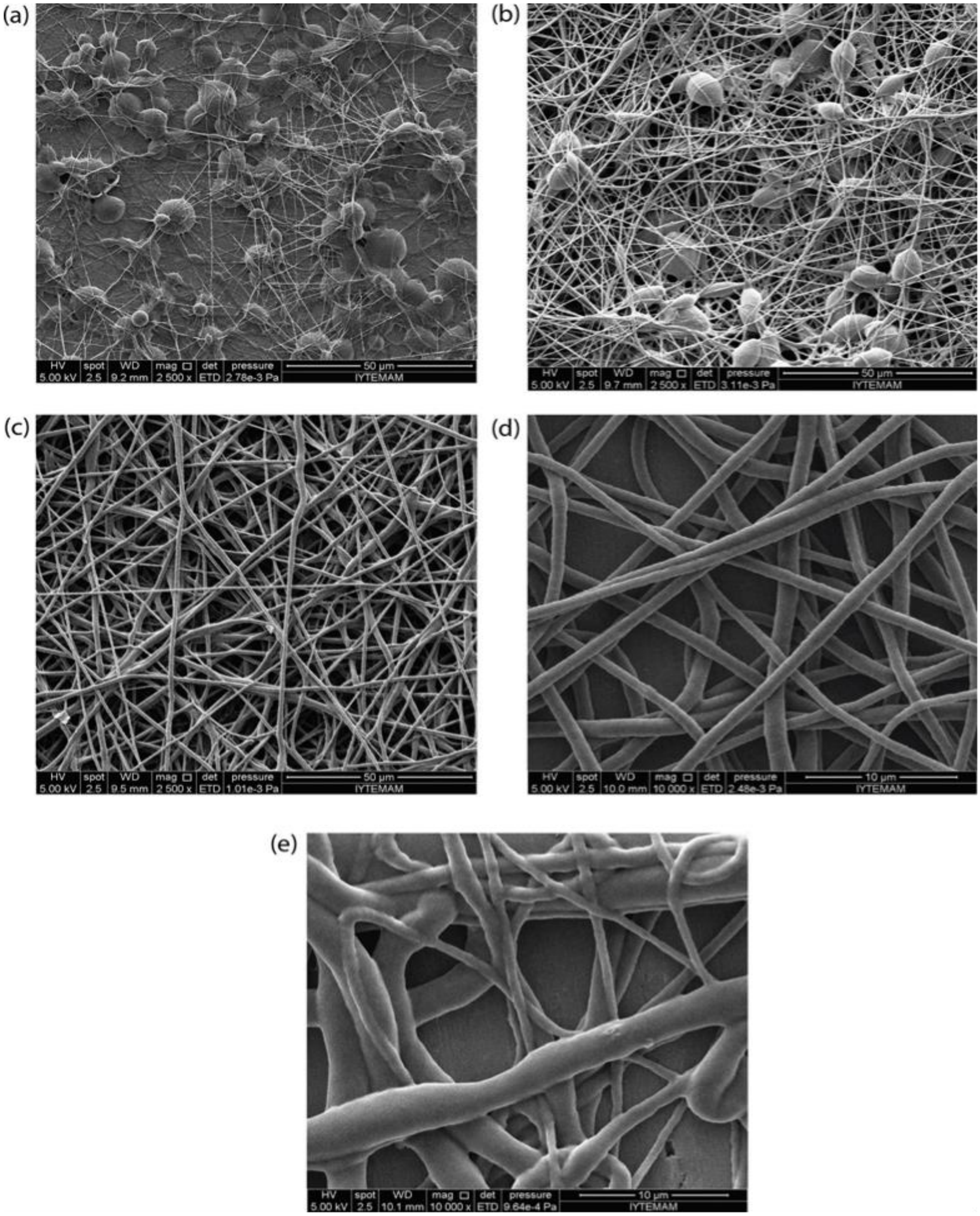

Figure 11: (a) 6%, (b) 8%, (c) 10%, (d) 12%, and (e) 14% w/w PU nanofibers [82].

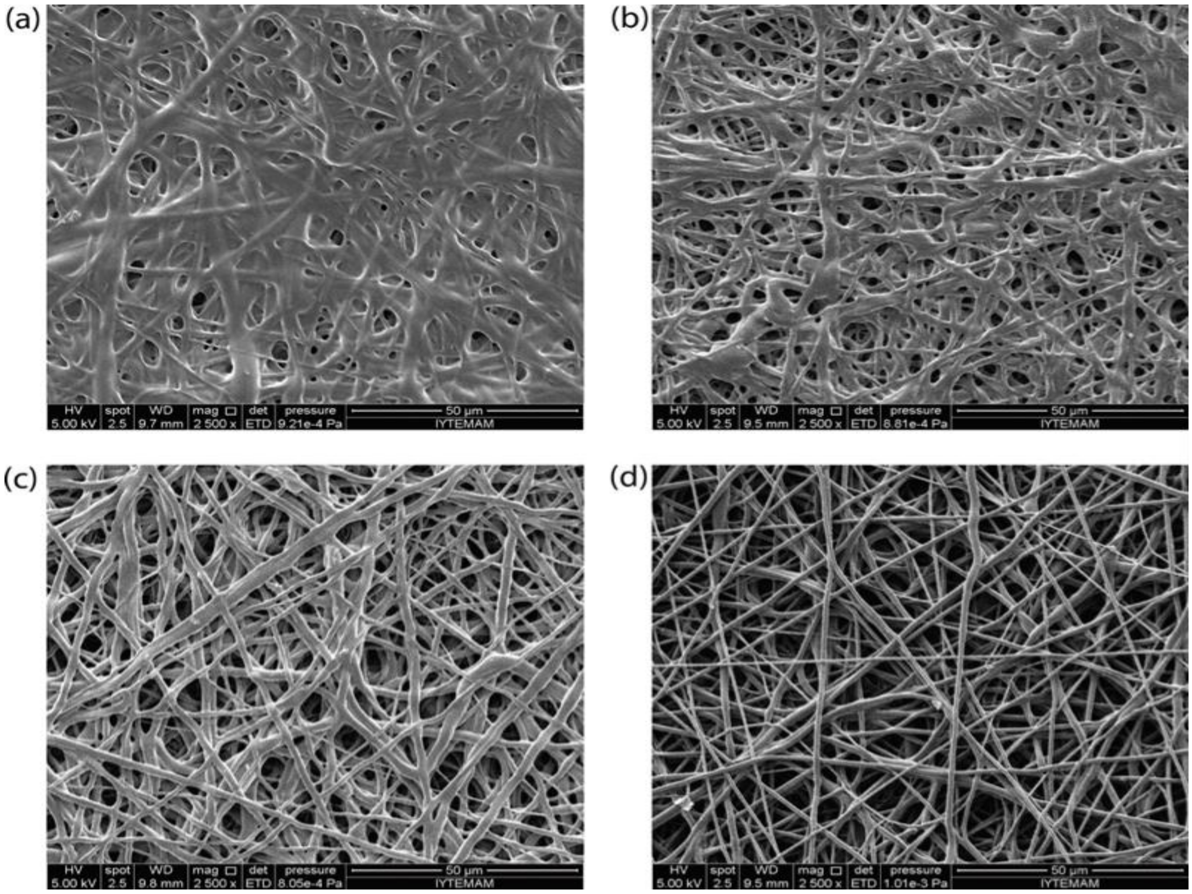

Figure 12: SEM images of the PU nanofibers at tip-to collector distance: (a) 8, (b) 10, (c) 12, and (d) 15 cm [82].

5.7. Polycaprolactone (PCL) nanofibers

As previously stated, several natural and synthetic biocompatible polymers have been electrospun and altered to fulfill diverse applications in accordance with the particular demands of various tissues [87, 88]. Polycaprolactone (PCL) as shown in (**Figure 13**) is biocompatible and biodegradable polymer has been formed in a fibrous structure and used for drug delivery, wound dressing, and tissue regeneration using the electrospinning method [89]. However, certain very hazardous solvents, including such chloroform, DMF, THF, and mixtures thereof, have been employed in the electrospinning of PCL in order to achieve bead-free nanoscale fibers [39, 90].

Indeed, Gholipour Kanani et al., [91] proposed the potential power of the fabricated PCL nanofibers that formed from the dissolution of PCl in 90% of glacial ethanoic acid. They overlooked the fact that when PCL was immediately dissolved in % acetic acid, the ester link of PCL would cleave in the aqueous acidic medium [92]. PCL degradation can result in uncontrolled polymer molecular weight and solution characteristics, which can affect repeatable process conditions.

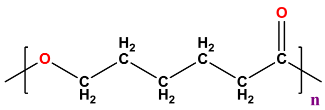

Figure 13: Chemical structure of PCL

Figure 14 shows the morphologies of PCL fiber webs. Optical microscopy photos could quickly define the coarse characteristics of the fibers, but SEM images were required to establish the precise diameters and morphologies [93]. Large beads with widths of approximately 15 m are randomly dispersed in fibrous webs with average diameters of about 211 nm at a concentration of 17 wt % (**Figure 14)**.

Low conductivity generates a tiny net charge on the surface of the droplets, making the jet stretch less effectively throughout electrospinning, and the shape of the fibers is then determined by the competition amongst surface tension and viscosity [93].

As a result, when the PCL concentration was less than 19 wt%, big beads formed due to surface tension dominance. Thick microfibers resulted in a significant viscosity when the PCL content was more than 21 wt %.

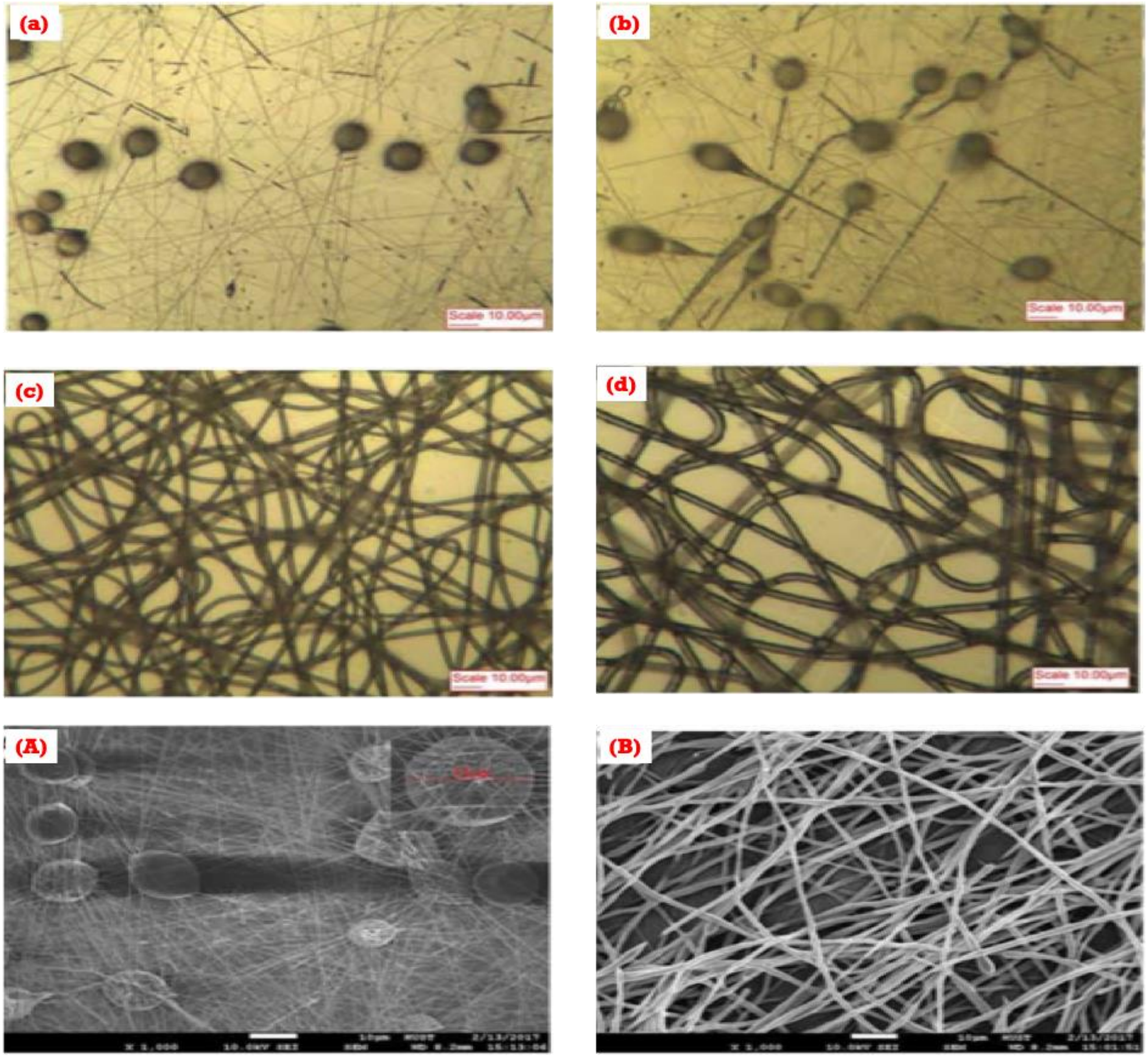

Figure 14: Optical images of fibers with different PCL concentrations: (a) 17 wt %, (b) 19 wt %, (c) 21 wt %, (d) 23 wt %. SEM images and fiber size histograms of fibers for (A) 17 wt %, (B) 21 wt % [94].

6. Morphology of Nanofibers

The morphology features deposited from the capillary onto the collection plate might vary significantly. Nanofibers with consistent diameters and smooth surfaces should be produced in the ideal case, permitting for homogeneous mass transfer across wide surface areas (**Figure 15**). Microphase separation of the polymer blends, however, may result in porous fibers depending on the process parameters and solution composition. Because the utilized solvent in electrospinning evaporates quickly, the surfaces may not be smooth, and if the solvents are not entirely evaporated, the fibers may fuse together, resulting in 3D networks with sponge like structures. Particulates or combinations of fibers and particles can also be deposited structures, as previously noted. One of the most important components of electrospinning is controlling the surface morphology.

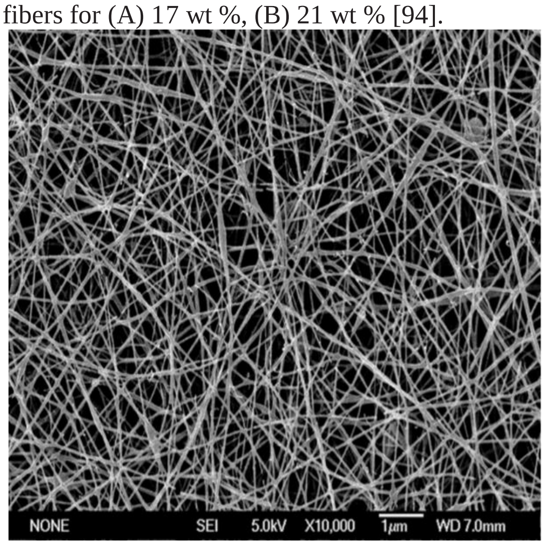

Figure 15: High magnification SEM image of chitosan/polyethylene oxide nanofibers [95]

7. Nanofiber Characteristics

Because of their high surface area-to-volume ratio and small fiber diameter, nanofibers stand out; this can vary from 40 nm to 2 µm. As a result, the usefulness of electrospun fibers is determined by surface characteristics rather than bulk qualities, resulting in a wide range of novel characteristics that are particularly useful in the biomedical fields. Thin porous nanofibers are also more accessible to reactive chemicals and have a lower diffusion barrier, make them an attractive system for adsorbents and catalysis, nanoreactors. Because of the shape of the final fiber deposit, utilized or wasted fibers may be easily recovered from the reaction medium. It is known that the finer fibers have greater strength properties and Young's moduli than larger diameter fibers, but bead flaws on the fiber surface degrade the microstructure and reduce mechanical properties. Furthermore, nanofibers made up of compounds which are susceptible to crystallization could have lower crystallinities because the solvent evaporates and cools quickly enough to keep the material amorphous. When compared to solution cast polymers, crystallization and recrystallization procedures increase the complexity of the nanofibrous structure and result in markedly different thermal and mechanical characteristics.

8. Nanomaterials

The difference among both nanoscience and nanotechnology is that nanoscience is concerned with the arrangement of atoms as well as their fundamental features at the nanoscale, whilst nanotechnology is concerned with the technology being utilized an regulate matters at the atomic level in order to synthesize completely new nanomaterials with unique applications [60, 96]. Nanotechnology is gaining attention in nearly all technical fields, but the general public is unaware of its existence in everyday life. Despite this, its widespread use in health, engineering, the environment, electronics, military, and security continues to grow **(Figure 16).** Even though this technology has been used for a lot of things, there is still room for new innovative nanomaterials to be developed in many sectors for the advancement of mankind. In terms of size, capacity, and expense, the researchers are enthralled and striving for the advancement of knowledge. As a result, significant attention is being paid to the shrinking of devices with low cost, primarily in the fields of health and electronics. Nanotechnology will govern humans in the areas of living, working, and communicating in the future. As a result, interest in the issue grows, leading to a debate of the fundamental and significant aspects of nanotechnology.

Figure 16: The role of nanoscience and nanotechnology in science and engineering [96].

The physicochemical characteristics of nanoparticles differ from those of bulk materials, which are intrinsically dependent on their size and form. Remarkably, by altering the form and size at the nanoscale level, nanomaterials generate a distinct character with new traits and capabilities. Nanomaterials come in a variety of forms, such as nanorods, nanoparticles, and nanosheets, and can be classified according to their dimensionality. The physical characteristics of two or more particles will change as a result of their contact. Bulk or three-dimensional nanomaterials are these particles made up of several components.

They are categorized as follows based on nanoscale dimensions (less than 100 nm):

(1) Nanomaterials with zero dimensions, (2) One-dimensional nanomaterial, (3) Two-dimensional nanomaterials and, (4) Bulk nanomaterials: These nanomaterials are not even in the nanoscale range in any dimension.

That is, they are >100 nm scale in three randomly selected dimensions. Nanocomposites, core shells, multi nanolayers, nanowire bundles, and nanotube bundles are among them [97]. Thus, nanomaterials are classified according to their shape, size, characteristics, and constituents.

8.1. Types of nanomaterials

8.1.1. Carbon based nanomaterials

Carbon is the most important component in this sort of nanomaterial. This class includes carbon nanotubes and fullerenes. Graphene sheets are inserted in the CNTs, which are then rolled into a tube. These are more and more durable than steel and can be used to improve structural integrity. There are two types of CNTs: single-walled and multi-walled. Fullerenes are carbon atoms arranged in a hollow cage structure containing sixty or more carbon atoms (carbon allotropes). It has a hollow football-like structure with pentagonal and hexagonal carbon units arranged in a regular manner. They have great strength, excellent electrical conductivity, and electron affinity [96].

8.1.2. Metal based nanomaterials

Divalent and trivalent metal ions are the starting ingredients for metal nanostructures. Metal nanoparticles may be produced in a variety of ways, including chemical and photochemical techniques. Metal ions are converted to metal nanoparticles utilizing reducing agents. These have a large surface area and are effective in adsorbing small compounds. They're often utilized in a variety of scientific fields, including environmental and bioimaging assessments. It is possible to size regulate not only a single nanoparticle but also a mixture of two or more nanoparticles. Even rare earth metals can have their main element properties changed by doping other metals. Various elements are doped in different constitutions, and their characteristics change as a result [98, 99].

8.1.3. Semiconductor nanomaterials

Metallic and nonmetallic characteristics that exist in semiconductor nanoparticles display broad band gaps and various characteristics. Group II-VI semiconductor materials encompass CdTe [100], ZnO [101], CdSe [102], and ZnS [103]. Recent research has focused on semiconductor grapheme nanocomposites. The physical and chemical characteristics of the semiconductor can be improved with graphene. Graphene composite materials with piezoelectric properties can be used for gas sensing sensitivity [86].

8.1.4. Nanocomposites

The three types of nanocomposites are Polymer Matrix nanocomposites, Ceramic Matrix nanocomposites, and Metal Matrix nanocomposites. In recent days, the polymer composite of graphene-based composites has developed to a significant extent in them. The carbon moiety makes up graphene. Carbon atoms in a single layer organized in a hexagonal matrix [96, 104]. It has a zero band gap, and electrons are almost massless particles that make up an excellent electrical medium in two dimensions [105].Graphene oxide (GO) is a precursor to graphene with a very low electrical conductivity [106]. As a result, converting graphene oxide (GO) to reduced graphene oxide (rGO) produces superior outcomes with higher conductivity.

To convert GO to rGO, several techniques such as chemical reduction [107, 108], CVD [96, 109], exfoliation, thermal reduction [110, 111], and multistep reduction approach [112, 113] have been used. Ametal oxide/grapheme nanocomposites and metal chalcogenide/grapheme nanocomposites are two forms of semiconductor graphene family nanocomposites. Metal oxides have a broad range of applications. They exhibit photocatalytic, gas sensors [96, 114], drug delivery [115], photovoltaic, batteries, antibacterials and cytotoxicity activities [116] in MnO_2 [117], In_2O_3 [118], TiO_2 [119], ZnO [120, 121], Fe_2O_3 [122] . The interaction of matter with its environment plays a crucial role in various applications.

9. Synthesis of nanomaterials

Nanoparticles can be synthesized using three distinct methods as mentioned below:

(1) Chemical techniques
(2) Biological approaches
(3) Physical techniques
(4) Biological approach is simple and straightforward, usually requiring just one step and is environmentally benign. In this case, we may employ microbes as well as various plant components to make nanomaterials [123].

9.1. Synthesis of nanomaterials using microorganisms

Various microorganisms, including such algae, bacteria and fungus can be utilized to make various nanomaterials using aqueous metal salt solutions.

9.1.1. Synthesis of nanoparticles using bacteria

Living organisms will participate in the biomineralization process by utilizing a protein to synthesize nanoparticles. Magnetotactic bacteria employ magnetosomes, that are protein-coated for the creation of nanosized magnetic iron oxide crystals, to produce magnetic particles as a pointer for the direction of their preferred habitat under anaerobic circumstances [124]. In vitro studies can create homogenous particles with a core diameter of 20–45 nm [125].. Despite this, magnetosomes demonstrate good magnetic characteristics in medicinal uses such as hyperthermia [126].

Photosynthetic bacteria such as Rhodopseudomonas capsulata are used. He et al. created gold nanoparticles (AuNPs) with a diameter of 10–20 nm outside of the cell. The bacterial enzyme; Nicotinamide Adenine Dinucleotide Hydride (NADH)-dependent reductase plays a vital role in the reduction of gold ions to AuNPs. The form and morphology of nanoparticles are controlled by the pH of the growing media, according to the researchers [127]. On the other hand, Schluter et al. demonstrated the extracellular synthesis of palladium nanoparticles utilizing Pseudomonas bacteria from the alpine location [128].

9.1.2. Synthesis of nanoparticles using fungi

The extracellular silver nanoparticles were made using the Fusarium oxysporum fungus. Due to the enzymatic activity of NADH-reductase, these nanoparticles are long-lasting. In comparison to bacterial cells, fungal cells secrete a greater quantity of protein [129].

9.1.3. Synthesis of nanoparticles using algae

The extracellular gold nanoparticles production from Sargassum wightii algae was proposed by Singaravelu et al, [130], 95% output was reached after only 12 hours of incubation. There hasn't been much research on the synthesis of nanoparticles using algae. The drawbacks of this technique are that some bacteria, fungus, and algae are harmful, necessitating the development of safety precautions.

9.2. Preparation of nanomaterials using different plant parts

The nanoparticles were also made with the help of plants and plant extracts. The phytochemicals found in plants help to decrease metal nanoparticles. Phytochemicals including such flavones, organic acids, and quinones function as natural reducing agents in the production of nanoparticles. Gold nanoparticles of various shapes are generated from the biomass of the Medicago sativa (alfalfa) plant 121] and the leaves of Pelargonium graveolens (Geranium) plant [131]. Azadirachta indica (neem) leaves are used to make bimetallic Au, Ag, and bimetallic Au core-Ag shell nanoparticles. This plant's sugars and/or terpenoids are reducing agents [132]. Aloe vera leaf extract [124] is used to create gold nanotriangles. Plants such as Indian mustard [133], and Roselle calyx extract [134] have also been used to manufacture nanoparticles of copper, silver, cobalt, nickel, and zinc.

9.3. Synthesis of nanomaterials using Physical routes

There are two types of physical techniques, namely, top-down and bottom-up approaches. Mechanical milling is used to disintegrate the bigger materials to smaller particles in a "top-down" methodology. The difficulty in obtaining the appropriate particle size and shape is the primary drawback of this technique [135]. Whenever compared to normal particles of the same size, the generated samples by milling procedure show a divergence in magnetic properties owing to flaws in lattice parameters produced during the milling operation [136]. Meanwhile, nanoparticles that are formed through the ‘‘bottom-up” approach in either a gaseous or liquid phase, with the bigger materials are involved in chemical interaction of the smaller ions.

9.3.1. Laser evaporation method

For the production of magnetic nanopowders, laser evaporation is a potential bottom-up approach. The laser was utilized to vaporize the raw metal oxides, which are the synthesis's starting ingredients. As a result of the strong temperature difference, nanoparticles developed beyond the evaporation zone by rapid condensation and nucleation [137]. The size of the nanoparticles and magnetic phase may be adjusted by changing the power of the utilized laser and also the composition of gas in the evaporation chamber [138].

9.3.2. RF plasma method

The RF Plasma technique, which needs a high temperature, is another physical method. The metal is heated above its evaporation point by employing high voltage RF coils enclosed around the evacuated unit. The system is subsequently filled with helium gas, which causes the coils in the region to heat up. The nucleation of metal vapor happens on the He gas atoms. It diffuses into the cooler collection rod, resulting in the formation of nanoparticles [139].

9.3.3. Thermal decomposition or thermolysis

As a result of the heat, the decomposition occurs. This is an example of an endothermic reaction. This heat causes the compound's chemical bonds to shatter and divide into smaller ones. The iron oxide nanoparticles were made by Hyeon et al using a thermal decomposition method [140]. Park et al produced monodispersed nanoparticles with a diameter of 13 nm [141], and the coordination compounds should be stabilized and caped before thermal decomposition.

The size and shape of the reaction change as the stabilizing and capping agents are changed, as well as the concentration of precursors, solvents, and reaction time. The stabilizing agent can also function as a capping agent in some cases. LiN_3 tiny lithium particles, for example, can be produced using lithium azide. The substance is put in an evacuated quartz tube and heated to 400 ºC. Around 370 ºC, LiN3 decomposes, producing N_2 gas. After a few minutes, all of the N_2 gas has been evacuated, resulting in a reduction in pressure. The lithium atoms that have been left out combine to create metal colloidal particles. This technique can produce nanoparticles with a size of less than 5 nm [142].

9.4. Chemical route for the synthesis of nanomaterials

The chemical approach demonstrates a range of bottom-up synthesis strategies for the production of nanoparticles. This technique is mostly suited to gas or liquid phases. This technique allows for the production of pure and regulated particle sizes. There are various techniques for producing nanoparticles via the bottom-up methodology. The optimal method for preparation was determined by the size, kind of nanomaterial, simplicity of process, and characteristics of nanocomposite. The diverse techniques of synthesis include the following subtitles.

9.4.1. Synthesis of nanoparticles using Co-precipitation method

This is the most basic and commonly used approach for producing a wide range of nanoparticles. The aqueous medium is required for precipitation in this technique. Using this method, uniform nanoparticles can be produced [142, 143]. In a summary, the co-precipitation technique entails combining two or more water soluble salts of metal ions that are typically divalent and trivalent. The soluble salts are usually found in trivalent metal ions. These water-soluble salts interact and are reduced, resulting in the precipitation of at least one water-insoluble salt. Continuous stirring of the solution is required, and the heat conditions may or may not be followed depending on the reaction circumstances and the reducing agent [144, 145].

9.4.2. Synthesis of nanoparticles using Sol–gel method

At beginning, the sol–gel technique was created for the low-temperature production of glass and ceramic materials. The metal alkoxide solution will be first hydrolyzed with alcohol or water under the influence of acid or base, accompanied by polycondensation. When all of the water molecules have been condensed, the gel phase transforms into a powder phase (**Figure 17**). To achieve the fine crystalline form of the powder, more heat is necessary [96, 146]. This technique might be used to make oxides, composites, and mixtures of inorganic and organic materials. The sol–gel technique is based on inorganic polymerization processes. The simplicity of this approach is its major benefit. However, due to the production of composites in this process, the purity is lower. As a result, post-treatment is necessary for sample purification.

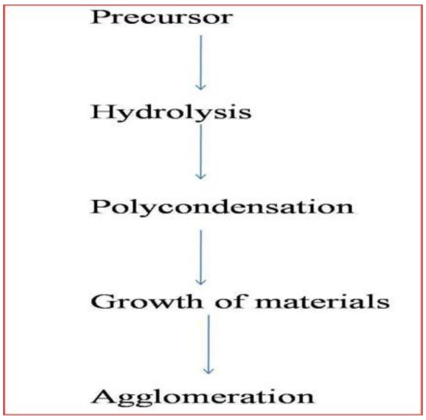

Figure 17: Schematic representation of Sol-Gel method [96]

9.4.3. Synthesis of nanoparticles using hydrothermal method

The solutions are exposed to high pressure and temperature in this technique. The major benefit of this approach is that it allows you to make high-quality crystals while regulating the composition. The divalent and trivalent transition metal salts are combined in 1:2 mol ratios [147, 148]. To make a homogenous solution, add the organic solvent to the aforementioned solution while constantly stirring. The solutions are then placed in a sealed vessel, sometimes known as an autoclave. Heating causes an autogenous increase in pressure, which causes the solvents to rise over their boiling points. The time and temperature adjustments are determined by the type of the produced nanoparticle [96]. Rather than the usual approaches, this attracted a large number of researchers. Oxides [149], various doped metals [150], Single crystals, selenides, sulphides and zeolites [151] can all be made utilizing such process.

9.4.4. Synthesis of nanoparticles using sonochemical method

Sonochemical technique is the most reliable and efficient. In order to generate cavities, this method employs ultrasonic irradiation in a liquid media. This ultrasonic energy disperses through the medium, increasing the enormous energy within the bubbles at the temperature of approximately 5000 K as well as a pressure of 20 MPa, and autogenously collapsing the bubbles, causing chemical excitation of the materials inside and outside [96].

9.4.5. Synthesis of nanoparticles using microwave-assisted technique

The microwave-assisted technique has been used since 1950s, but it has only recently achieved widespread popularity. Through heating with moveable electric charges and utilizing EMR, microwave radiations are transmitted directly to the materials. Electromagnetic energy is transformed to thermal energy in this process [152]. The frequencies used are between 1 and 2.5 GHz, resulting in a temperature of 100–200oC. It necessitates a faster reaction time so that longer reactions may be accomplished in a matter of seconds [153]. It is possible to create narrowly dispersed tiny size particles that use this approach.

10. Applications of nanoparticles and nanofibers

Biomedical [154], wastewater treatment, catalysis, and information technology are all examples of nanoparticles and nanofibers applications. They are utilized in electrochemical, optical, piezoelectric, and magnetic fields as sensors and biosensors [155, 156].

They may be used in energy storage devices [157], in the form of electrodes, which can be used to make batteries and supercapacitors. In terms of recording medium. They can also be used with audio and video cassettes. They may be used in energy storage devices [157] in the form of electrodes, which can be used to make batteries and supercapacitors. They can also be found in isolators, shifters, and circulators. They're also beneficial in the dyeing industries [158]. and wastewater treatment [159].

10.1. In medicine for diagnosis and drug delivery

Nanotechnology has been used in medicine since 1965. They are useful in medicinal imaging because of their diverse set of characteristics. It is primarily focused on four areas: molecular engineering, pharmaceutics, tissue engineering, and, biosensors and diagnostics. Nanoparticles are used in targeted medicines to treat diseases, particularly cancer tumors. The nanoparticle must be the smallest size possible for such utilization of delivering the medication to the desired location via blood circulation. Under stimulation, the nanoparticles will release the drug at the desired location. Physical–chemical, biological, thermal, and electrical stimuli are examples of diverse types of stimuli. The drug will be released based on these triggers. Quantum dots, gold nanoparticles (AuNPs), magnetic nanoparticles, and titanium nanoparticles are commonly utilized for drug delivery and targeting. AuNPs are by far the most efficient in targeting many of the drugs. AuNPs have distinctive optical characteristics that are significant in cancer photothermal treatment and diagnostics [160].Nanoparticles composed of silver [161], and magnetic materials [162] are also effective nanocarriers [163].

It has been reported that the nanocarriers are designed to carry anticancer drugs to the desired location [164, 165]. Nanoparticles have a significant penetration level and cause minimal disruption in healthy tissues. As a result, normal cells will be safe. As a result, nanoparticles play a crucial role in drug delivery. These nanoparticles occur in a variety of shapes and sizes, including Fe, Ni, and Co, as well as their oxides. Mesoporous silica nanoparticles are also useful in diagnosis and treatment [166].

10.2. In catalysts

The catalytic reaction takes place in a variety of methods, including lowering the activation energy, binding to reagents via polarized bonds, obtaining an effectual collision thru introducing reactive species closer together, and increasing product yield. Catalysts can be used to reduce the temperature of a process while also limiting the development of side reactions.

The surface area per unit mass is increased when the nanoparticles are smaller. This increases the surface area available for catalytic chemical reactions. As a result, the reactivity of nanocatalytic processes is higher than that of traditional catalytic reactions using bulk materials [167, 168]. Thin-layer nano catalysts, metal-based nanocatalysts carbon-based nanocatalysts, core–shell nano catalysts, quantum dots, and ceramic nanocatalysts are all examples of nanocatalysts [167, 168].

11. Synthesis, forms and application of gold nanoparticles

For their distinctive optical and physical characteristics, including such surface plasmon oscillations, imaging, and sensing, gold nanoparticles (AuNPs) are frequently utilized as outstanding properties throughout many disciplines. Biomedical applications have recently made significant progress, with improved biocompatibility in disease detection and treatments. Many functionalizing agents, including surfactants, polymers, ligands, dendrimers, DNA, RNA, peptides, oligonucleotides, and proteins might be used to synthesize AuNPs. Nanotechnology was first used by Mesopotamians in the 9th century to create a glossy appearance in pots.

Michael Faraday discovered ruby gold nanoparticles (AuNPs) for the first time in 1857, laying the groundwork for contemporary nanotechnology [169, 170]. After forty years, Zsigmondy combined his technology with Faraday's findings and created the so-called "seed mediated method," that are still used to synthesize different NPs today [171]. Zsigmondy also developed an ultramicroscope for studying the structure, shape, and size of the nanoparticles [172].

11.1. Synthesis of Various Types of Au Colloids

The form, size, and physical characteristics of AuNPs may be used to classify them. Au nanospheres were the first achievement in the field of AuNPs, but they were not perfectly spherical. Later, many additional forms, such as nanorods, nanoshells, and nanocages, were produced, as illustrated in (**Figure 18**). For many decades, synesthetic techniques were continually improved. As a result, various simple synthetic procedures were accessible, and their sizes and forms, such as nanocages, could be well controlled.

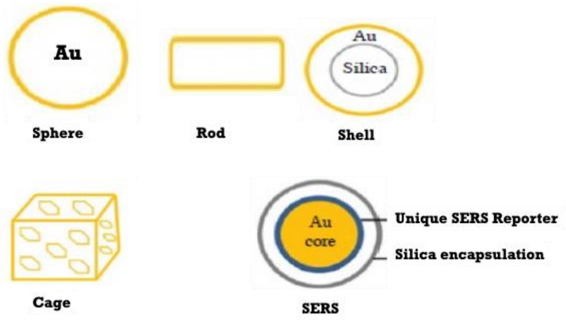

Figure 18: Schematic representation of various types Au nanomaterials [173]

11.1.1. Au Nanospheres

Au nanospheres is another name for Au colloid. The diameters may range from 2 to 100 nm, and they could be made by reducing an aqueous HAuCl4 solution using various reducing agents under various parameters and circumstances. The most broadly utilized reducing agent, citrate, generated monodisperse Au nanospheres [174, 175]. The smaller the concentration of citrate used, the more nanospheres produced. The size of the produced nanospheres may be controlled by adjusting the citrate and Au ratio.

11.1.2. Au Nanorods

For the production of Au nanorods, several methods were used. The template approach was utilized to produce Au nanorods by electrochemical deposition of Au within the pores of nanoporous polycarbonate or alumina template membranes [176]. The diameter of the Au nanorods may be ascertained by the size of the template membrane holes. The quantity of deposited Au within the membrane pores might determine the length of the Au nanorod. The primary drawback of the above approach, but from the other side, would have been the poor yields of Au nanorods, as just a single layer of nanorods might be produced [177, 178].

For reducing Au chloride, Au seed solution was usually prepared in the presence of a strong reducing agent, including such sodium borohydride. Such seeds would serve as the nucleation sites for nanorods [179–183].

12. Nanoemulsion

Nanoemulsions are biphasic distribution of two non-miscible liquids, generally containing of an oily system dispersed in an aqueous system (O/W), or an aqueous system dispersed in an oily system (W/O), creating droplets or oily phases of nanometric sizes. These arisen through as ultrafine dispersions whose difference drug loading; viscoelastic as well as visual properties may provide to a wide variety of functionalities comprising drug delivery. But there is still comparatively slight vision concerning growth, developed, manufacture and management of nanoemulsions which mainly stalks from the point that conservative features of emulsion establishment and stabilization only partly relate to nanoemulsions (**Figure 19**).

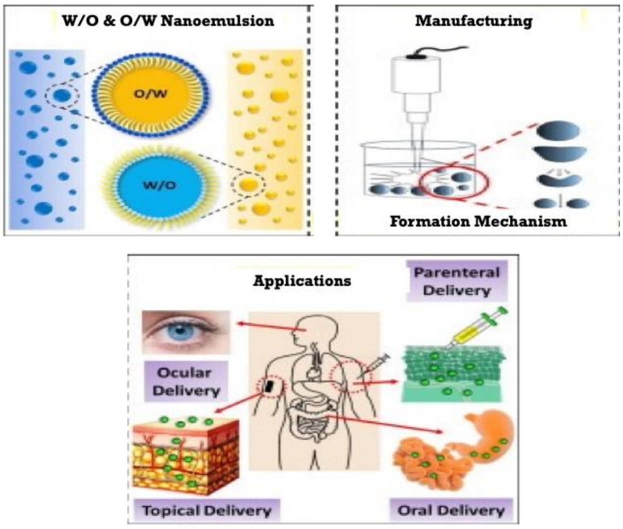

Figure 19: Schematic representation of nanoemulsion: concepts, development and applications in drug delivery [184]

13. Spearmint oil nanoemulsion

Spearmint oil, which is commonly used as an essential oil in health products, has a number of noteworthy properties, including anticancer properties. Spearmint oil, gained from *Mentha spicata* leave, is one of the usually usage essential oils for oral care products. Terpene derivatives consider the key active constituents of Spearmint oil which containing carvone (70%) plus limonene (15%) [185], that establish different pharmacological properties [186, 187] comprising antioxidant, anti-inflammatory, antibacterial, antispasmodic, antifungal, as well as antitumor actions. Concerning anticancer action, Spearmint oil has been displayed cytotoxicity contrary to diversity of tumor cells counting human mouth epidermal carcinoma, murine leukemia [179] , human epithelial type 2 [188] in addition human breast adenocarcinoma cell line [184] therefore it may be a safe plus possible cytotoxic agent for cancer treatment, specifically for local therapeutic of oral cancer. However, Spearmint oil displays inadequate water solubility as well as insufficient biocompatibility in form of natural oil and consequently needed a water compatible transporter with high oil loading for directing Spearmint oil to cancer cell.

Establishment of nanoemulsions has been effectively accomplished by numerous manufacture approaches comprising high and low energy technique. The high energy process requirements huge mechanical force as well as energy for the reduction of droplet size whereas low energy technique produces nanoemulsions through varying properties of system [189]. The high energy system reveals several good features in terms of simply fashioned nanoemulsions besides scalability; nevertheless it still displays some drawbacks comprising cost of specific apparatus and generation of extreme heat that occasionally affects the stability of drugs However, the creation and assets of matching nanoemulsions through this technique have been mainly prejudiced by the procedure and preparation factors that essential to be carefully explained to attain the exact conditions for every active constituent [190].

14. Application of nanofibers loaded nanoemulsion and nanoparticles

Nanofibers with great principles counting large surface area-to volume ratio, high inter fiber porosity, little interference for mass transfer, adaptable morphology, adjustable handling as well as suitable mechanical properties are appropriate for therapeutic patches, nanocarriers in drug delivery besides porous fibrous mats for biomedical applications. **Figure 20** demonstrates the possessions and the bio-physiochemical types of nano-carriers intended for drug delivery applications.

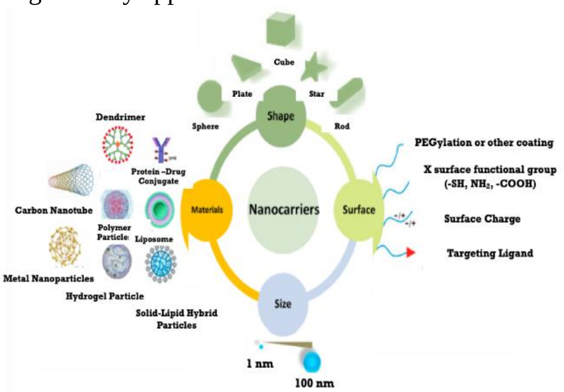

Figure 20: The nano-carriers for drug delivery method and the bio-physiochemical properties [191].

Antibacterial agents and antibiotics have been the most often encapsulated medicinal molecules in recent years, using diverse biopolymers and their combinations as carriers [192–199].

Various polymers, including such PLGA, PCL, and PLA, are primarily used in the electrospun fibers process of polymer for biodegradability. Synthetic and natural hydrophilic or hydrophobic polymers are also used to regulate the drug's release design. In one study tetracycline hydrochloride plus poly (ethylene-co-vinyl acetate) (PEVA). Electrospun fibers containing tetracycline HCl, PCL, and PEVA were developed for use in wound healing and skin-structure infections. When compared to commercially available drug test disks, the three-layered electrospun matrix showed regulated release as well as greater antibacterial efficiency [200]. They also claimed that the developed fiber blends have strong biological activity in composite biofilm building models. The fibers dissolved manufactured biofilms and produced thick colonies of Staphylococcus aureus, preventing the formation of new biofilms in the process. Pleurocidin, a novel broad-spectrum antibacterial peptide, is electrospun into PVA nanofibers for use in food packaging.

Wound dressings protect the wound from external germs while also absorbing and adsorbing the wound's exudate for a pleasing aesthetic look [201–207]. The use of a variety of components in wound dressings prevents infection and speeds up the healing process [5]. The bio-actives in the formula of the produced films, foams, hydrogels, and sponges are primarily the components contributing to the inert dressings [208]. Electrospun fiber mats owe the advantage of high specific surface area for effective absorption of exudates to wound healing; in addition to changing the humidity of the wound and assisting scar-free skin cell regeneration, these mats have porosity sufficient to supply oxygen for cell respiration, but insufficient for bacterial infections [209]. PVA and poly(vinyl acetate) (PVAc) electrospun nanofibers were produced independently and then combined in a 50:50 combination. The produced nanofibers, which were made from a two-polymer combination, continued to release the medication and were found to be satisfied due to substantial swelling [208].

Thakur et al. also used the twin spinneret electrospinning technique to create a single lidocaine and mupirocin scaffold [210]. To achieve different release characteristics, dual medicines with varying lipophilicities were developed. Ethylene-co-vinyl alcohol nanofibers were produced using a variety of antibacterial medicines as well as silver to create wound dressings that were more germ-killing. Chutipakdeevong et al., [211] have recently employed the hybridization technique to combine Bombyx mori silk fibroin with poly("-caprolactone) (PCL) electrospun fibers. Using the lyophilization technique, the PCL fiber surfaces were coated with silk fibroin protein and then enhanced with fibronectin to increase their biological activity. The surface-modified hybrid showed significant proliferation of common human dermal fibroblasts (NHDF), followed by the hybrid scaffold, and previously well-ordered PCL fibers.

15. Conclusion and future trends

In our current article review, we aimed to highlight on the electrospinning of biocompatible polymers to be used for wound dressing. The factors affecting the electrospinning process including such conductivity, molecular weight, surface tension have been extensively clarified. The article review outlined the numerous polymers that utilized for nanofibers formation. Some of these polymers are chitosan, cellulose, cellulose acetate, polyvinyl alcohol (PVA), polyvinyl pyrrolidone (PVP), polyurethane (PU) and polycaprolactone (PCL). In addition, in the present review, we also aimed to define the nanomaterials in a comprehensive manner and the various methods of their preparation including such chemical, physical and biological methods. It was also discussed the definition of nanoemulsions and the method of preparing them to arrive at how to prepare nanofibrous scaffold containing nanoparticles (gold nanoparticles) or colloidal emulsions with the aim of using them as dressings that have the ability to heal the infected wounds.

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