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REVIEW

Recent Updates on Biopolymers based Wound Dressings

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Wound dressing is designed to support the wound bed and protect it from the factors that may delay or impede its healing such as contamination and moisture thereby facilitating and accelerate the healing process. The material used to prepare wound dressing include natural and synthetic polymer as their combination in the form of film and sponges that may be extensively used in wound dressing material. Naturally occurring polymers having many importance because of high biocompatibility and environmentally finding properties. Polysaccharides are naturally occurring polymers that have been extensively used as wound dressing materials. Homopolysaccharide are a class of polysaccharides consists of only one type of monosaccharide. Naturally occurring polymers are used for wound dressing properties because of their extracellular matrix as good acceptance by biological system. Polysaccharide is type of naturally occurring polymers that offer the advantage of good hemocompatibility and low cost in comparison with other biopolymers. The current review intends to overview the studies in which wound dressings from naturally-occurring polymers including chitosan, silk fibroin, sodium alginate and hyaluronic acid were considered.

Keywords: Wound dressing, Healing, Chitosan, Silk Fibroin, Sodium alginate.

INTRODUCTION

In today's medical world, wound healing is still one of the unmet therapeutic challenges as it involves several factors playing a major role in the healing process [1]. Wound is classified as acute and chronic. Acute wounds are associated with an external irruption of intact skin consisting of surgical wounds, burns, major cuts, abrasions and heal within the predictable time. On the other hand, chronic wounds are characterized by endogenous mechanism due to predisposing conditions ultimately comprising of both dermal and epidermal tissue integrity [2].

Wound healing process phases are divided into four phases: hemostatis, inflammation, proliferation and remodelling. Hemostatis phase starts directly after the injury followed by excessive blood loss. Blood clots are formed as a barrier to prevent the influx of bacteria and facilitate platelet activation, adhesion, aggregation and clot formation [3]. Inflammation response is triggered immediately after the neutrophils passively transported from damaged blood vessel to wounds. The phase is characterized by the migration of leucocytes, release of chemicals, killing bacterial secretions, removal of cellular debris by macrophages and release of growth factors. Proliferation occurs between 4 to 21 days and is represented by angiogenesis, extracellular matrix formation and epitheliaztion. Remodeling is forth and last stage of healing and starts within 2 to 3 weeks after the onset of the lesion and continues for one year. It occurs after the formation of fibrin clot in the early proliferation phase which is replaced by the granulation tissue [4]. In last few years, health care professionals faced with an increasing number of patients suffering from wounds and burns difficult to treat and heal. During the wound healing process, the dressing protects the injury and contributes to the recovery of dermal and epidermal tissues [5].

Wound dressings: Wound dressing are intended to protect wounds from physical, thermal, chemical, biological and other traumas. The characteristics of an ideal wound dressing are shown in Fig. 1. Wound dressing materials act as physical barriers for moisture and oxygen, protect the wound mainly against microorganisms [6]. Dressings are classified upon depending on their functions (antibacterial, debridement, occlusive, adhe-

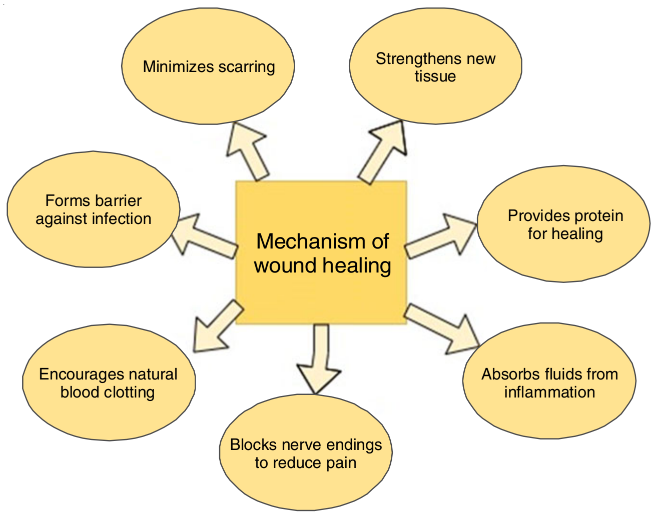

Fig. 1. The characteristic role of ideal wound dressings in healing

rence and absorbent); type of materials (hydrocolloids, collagen, alginate); and physical form (ointments, films, foam, gel) [7]. Dressings are further classified into primary, secondary and island dressings. Dressing which make direct physical contact with wound surface is referred to as primary dressing. Secondary dressings cover the primary dressing. Island dressing possess a central absorbent region that is surrounded by an adhesion portion [8].

Also, wound dressing classification includes traditional, modern and advanced dressings. Traditional dressings such as gauze, lint or cotton wool are most often as primary or secondary dressings to protect the wound from contamination [9]. Modern dressings are developed as an improvement upon the traditional wound dressings and possess essential characteristics to retain and create a moist environment around the wound to facilitate wound healing. The modern dressings are mainly classified according to the material from which they produced for example hydrocolloids, alginate and hydrogels and generally occur in the form of gel, thin films and foam sheets. Biological dressings are made from biomaterial that plays an active role in the wound healing process and also called bioactive dressing. Bioactive wound dressing also includes tissue engineered products derived from natural tissue or artificial sources. Because of promising properties such as biocompatibility, biodegradability and similarity to macromolecules recognized by the human body, some natural polymers such as polysaccharides (alginates, chitin, chitosan, heparin and chondroitin), pro-teoglycans and proteins (collagen, gelatin, fibrin, keratin, silk fibroin and eggshell membrane) are extensively used in wounds and burns management. Naturally occurring polysaccharides are the polymers offering good hemocompatability and lower cost than other biopolymers. Polysaccharides containing one monosaccharide are homopolysaccharides, whereas those containing more are as heteropolysaccharides. The homopolysaccharides/heteropolysaccharides based wound dressings may contain inorganic materials, antibiotics or medicinal plants. Natural polymers are used because of biocompatibility, biodegradability and involved in repair damaged tissue and stimulate healing process [10].

Some biopolymers with their use in wound dressings are discussed as below:

Chitosan based wound dressings: Various polymers are available but chitosan due to various biological properties such as biodegradability, biocompatibility, low toxicity, antimicrobial, low toxicity, anticancer and antioxidants. It is generally used in pharmaceutical and medical fields, cosmetics, food and agriculture industries and waste treatment [11]. Chitosan and its derivatives are getting attention due to its wound healing property and ease of into processing it into different forms (foams, gels, beads and membranes). All these properties make chitosan-based materials adaptable and promising for wound dressings [12]. Various nanocarriers or devices such as scaffolds, micelles, fibers, nanoparticles, composite hydrogels, solid lipid nanoparticles and films have been evidenced in literature and these can be impregnated on/in wound dressings for controlled and enhanced delivery of various drug molecules. Role of chitosan in wound healing is presented diagrammatically in Fig. 1.

The study reported optimized chitosan scaffold incorporating metformin hydrochloride *via* electrospinning method. The prepared scaffolds exhibited sufficient drug loading, sustained release of drug. Reduced scar formation and accelerated the wound healing was seen [13]. Further, composites of chitosan incorporating urethane were synthesized *via* solvent casting method. The prepared composites revealed antibacterial efficacy and proved effective carriers [14]. In 2020, another study [15] fabricated chitosan lecithin micelle by freeze drying and proved these carriers as novel delivery systems in nanomedicine showing effective wound healing. Abdel-Mohsen *et al*. [16] reported chitosan-glucan complex hollow fiber using the bovine collagen type I, dry collagen, mycelium, chitin-glucan fibers *via* homogenization technique, followed by centrifugation and finally Freeze-drying. Solid-state NMR spectroscopy, calcium ion measurement, degradation measurement and other evaluations proved this complex effective for skin wound healing and drug delivery applications. Lin *et al*. [17] reported histatin 1-modified thiolated chitosan hydrogels using L-cysteine hydrochloride monohydrate. Histological, immuno-histochemical and immunofluorescence analysis, *in vitro* and *in vivo* studies of formulated hydrogels revealed effective wound healing by accelerating epitheliaztion [17]. Further, ZnO and chitosan nanoparticles incorporating papain were prepared by co-precipitation method. Collagen hydrolysis, hemolysis, MTT assay in macrophages suggested this papain enzyme support system of zinc and chitosan as the best low cost alternative for wound healing [18]. Another study investigated the Gel-PDACur composite hydrogels using the chitosan, poly (ethylene glycol), tetrahydrofuran (THF) prepared *via* homogenization. PCR analysis, cell morphology and proliferation, wound healing studies concluded that antimicrobial hydrogel is simple and effective for promoting wound healing applications [19]. Arantes *et al*. [20] reported supporting using polyoxyl 20 cetyl ether, cholesterol, 3β-[*N*-(dimethylaminoethane)carbamoyl]-cholesterol, benethamine (*N*-benzyl-2-phenethylamine; BNT, 261742), polysorbates 80, triethanolamine, maprotiline hydrochloride. Further, solid lipid nanoparticles are prepared using the hot melting homogenization and sonication method. Optical and polarized light microscopy, film hydration, histological analysis and other studies proved effectiveness of the films in reducing leukocyte infiltration thereby contributing to faster closure of the wound. Optimized formulation can reduce leukocyte infiltration; this finding can contribute to faster closure of the wound [20]. In 2020, chitosan/carboxymethyl chitosan/AgNPs polyelectrolyte composite hydrogel was formulated as wound dressing material *via* ultrasonication. The prepared hydrogel proved as biosafe material with better antibacterial activity in wound dressing [21]. Further, Kalantari *et al*. [22] reported polyelectrolyte composites using *Z. officinale*, chitosan, polyvinyl alcohol, cerium oxide *via* freeze-thaw technique and sonication. Improved wound healing with biocompatibility was observed and no toxicity to fibroblast upto 5 days [23]. Fibrin nanoparticles incorporated in nanosponges were prepared by emulsification and sonication method. The formulation was found to be potential material for inducing angiogenesis in wound healing [23]. In 2019, curcumin films were prepared *via* cross-linking method using chitosan and polyvinyl alcohol. It was concluded that chitosan and its composite are best carrier for ideal wound dressing and helps in connective tissue formation [24]. A study investigated chitosan/PVA blends for burn wounds, which showed reduction of collagen deposition in preventing scar formation [25]. Further, chitosan films using chitosan, polyvinyl alcohol, polyethylene glycol 400 (PEG400) were prepared by QbD approach using solvent casting method and it proved potential wound dressing material in chronic wound healing applications [26]. A study reported nanofibers using chitosan, gelatin, polycaprolactone *via* electrospinning and these nanofibers showed remarkable potential for skin regeneration [27]. Huang *et al*. [28] prepared hydrogel of chitosan, poly(ethylene glycol) diacrylate, sodium β-glycerophosphate, e plasmid ANG-1/*N*-trimethyl chitosan chloride *via* homogenization with sufficient swelling and adhesion properties, cytocompatibility properties and characteristic wound healing properties. Hasan *et al*. [29] investigated nanofibrous mats of Chitosan, PVA and zinc oxide *via* electrospinning which can serve as a useful dressing material for diabetic wounds. Gallan gum hydrogels were prepared by lyophilization technique using chitosan, ethyl acetate and petroleum ether. The formulation was found to be effective in healing wounds [30]. Basha *et al*. [31] formulated cefadroxil loaded chitosan nanoparticles *in situ* gel by double emulsification method with immense ability to accelerate wound healing process. Chitosan-selenium scaffolds using nitric oxide, silver nitrate and glutamine were prepared by shaking method with enhance antibacterial activities [32]. Chitosan oleate nanoemulsion for wound healing was prepared *via* emulsification method. It was concluded that nanoemulsion prepared shown the promising result in wound fluids [33]. Oryan *et al*. [34] evidenced the rutin loaded emulsion using chitosan and propylene glycol *via* using sonication method and concluded its effectiveness in wound healing. Asfour *et al*. [35] fabricated polyurethane-chitosan hydrogel scaffolds using blending which proved promising wound dressings materials. Further, chlorhexidine sponges of chitosan were designed for wound dressing applications by freeze drying method and confirmed applicability of targeted wound dressing in the form of sponge [36]. Chitosan based self healable films were reported as promising agent in wound dressings [37]. Hydroxy propyl methyl cellulose chitosan cross-linked hydrogel films were revealed as successful wound dressing materials [38]. Khamrai *et al*. [39] reported chitosan and gelatin based sponges as promising biological materials which have applications as surgical wound dressing. Jiang *et al*. [40] fabricated norfoloxacin loaded collagen/chitosan scaffolds for enhanced wound healing with unnoticed inflammation or other side effects. Jacob *et al*. [41] formulated porous carboxymethyl chitosan superabsorbent films by solvent precipitation method which proved as a promising haemostatic wound dressing. Lu *et al*. [42] reported silver nanoparticles using regenerated cellulose and chitosan as an effective wound dressing materials. A study investigated composite film using chitosan and Eudragit RL by casting evaporation technique with sufficient mechanical properties, oxygen permeability, water uptake, water vapour permeability. The formulated optimized film revealed the controlled release applications in wound healing [43]. Table-1 summarized various drug delivery carriers fabricated using chitosan.

Hyaluronic acid: Hyaluronic acid due to its properties like biocompatibility, biodegradability and hydrophilicity used in wound dressing and in the form of sponges, hydrogel, electrospun membranes. El-Aassar *et al*. [44] reported nanofiber using polygalacturonic, hyaluronic acid, silver nitrate, polyvinyl alcohol using electrospinning and characterized. Wang *et al*. [45] prepared the bacterial cellulose membrane using hyaluronic acid, silk fibroin and sodium hydroxide, using *ex situ* and *in situ* approach. Water holding capacity and other parameters concluded that the system shows the best wound dressing properties. Movahedi *et al*. [46] reported nanofibers using hyaluronic acid, polyurethane, starch, fabricated with coaxial electrospinning technique and characterized. It was concluded that polyurethane/starch in a nanofibers system shows the remarkable results. Bazmandeh *et al*. [47] investigated nanofibrous gel using chitosan, gelatin and hyaluronic acid by electrospinning, characterized and concluded that chitosan-gel/hyaluronic acid represent system having superior healing properties. Hussein *et al*. [48] reported nanofiberes using polyvinyl alchol, hyaluronic acid, L-arginine and citric acid using electrospinning and concluded that prepared nanofibers could be employed as potentional wound dressing that can be significantly accelerate wound healing and tissue regeneration. Séon-Lutz *et al*. [49] prepared nanofibers using hyaluronic acid, cyclodextrin, polyvinyl alcohol and concluded that a sustainable drug release profile more than 48 h with a maximum of release during 24 h and prepared nanofibrous scaffold shows a ideal candidate to deliver directly to wound. Bazmandeh *et al*. [50] investigated nanofibers using chitosan, hyaluronic acid, glacial acetic acid, sodium hydroxide *via* electrospinning and it was concluded that prepared system shows the remarkable result in wound dressing. Hsu *et al*. [51] reported that hydrogel using gelatin and hyaluronic acid was fabricated using cross-linking and concluded that developed hydrogels show the significant results. Lin *et al*. [52] investigated wound dressing using hyaluronic acid, collagen and alginate using lyophilization, characterized and concluded that prepared antimicrobial wound dressing has the potential

TABLE-1
DRUG DELIVERY CARRIERS BASED ON CHITOSAN IN WOUND HEALING

Drug delivery carrier	Drug	Polymers and solvents	Method	Outcomes	Ref.
Scaffolds	Metformin hydrochloride	PVA, chitosan, PCL, Tween 80	Electrospinning method	It reduces scar formation and accelerates wound healing	[13]
Chitosan composites	Urethane	Chitosan, polyvinyl alcohol, Hexamethylene diisocyanate, sodium metabisulfite, acetone and nutrient broth	Cross-linking method	Showed powerful antibacterial efficiency against pathogenic bacteria and showed excellent hemostatic property	[14]
Chitosan-lecithin micelles	Thymoquinone	Chitosan, Soya lecithin, dimethyl sulphoxide	Freeze drying method	Showed excellent wound healing efficacy	[15]
Chitosan-glucan complex hollow fibers	Aloe-Vera	Bovine collagen type I, dry collagen, Mycelium, chitin-glucan	Freeze-drying method	Showed a great potential for clinical skin regeneration especially, chronic wounds and ulcers	[16]
Hydrogel	Histatin-1	L-cysteine hydrochloride monohydrate, β-glycero phosphoric acid, disodium salt pentahydrate, *N*-hydroxy succinimide	Lyophilization technique	It showed promising candidate for wound healing by enhancing cell adhesion, migration and angiogenesis	[17]
Hydrogel	Curcumin	Chitosan, poly (ethylene glycol)	Homogenization method	Showed hemostatis effect, antibacterial activity, anti-inflammation and angiogenesis.	[19]
Solid lipid nanoparticles	Retinoic acid	Polyoxyl 20 cetyl ether, cholesterol, 3β-[*N*-(Dimethylaminoethane)-carbamoyl]-cholesterol, benethamine (*N*-Benzyl-2-phenethylamine; BNT, 261742), polysorbarte 80, Triethanolamine, maprotiline hydrochloride	Sonication method	Used to treat diabetic wounds improving tissue healing	[20]
Hydrogel	Silver nanoparticles	Chitosan, carboxymethyl chitosan, Sodium alginate	Ultrasonication method	Potential candidate as wound dressing agent that decreases wound infection	[21]
Hydrogel	Cerium oxide, *Z. officiale*	Polyvinyl alcohol, chitosan	Freeze- thaw technique	Decreased wound infection	[22]
Sponges	Fibrin nanoparticles	Chitosan, hyaluronic acid, glutaraldehyde, fibrinogen	Emulsification and sonication method	Prepared sponges induce angiogenesis in wound healing	[23]
Films	Curcumin	Poly vinyl alcohol, tetra-ethyl orthosilicate, Gallic acid, sodium hydroxide, ammonium thiocynate	Cross-linking method	Helps in connective tissue formation	[24]
Membranes	–	PVA, chitosan, tetraethyl-orthosilicate, sodium hydroxide, sodium chloride	Cross-linking method	Accelerates granules and fibrous connective tissue formation	[25]
Films	Plants extracts	Chitosan, polyvinyl alcohol, Polyethylene glycol 400 (PEG)	Solvent- casting method	Accelerates wound healing.	[26]
Nanofibers	Curcumin	Chitosan, gelatin and polycaprolactone	Electrospinning method	It showed a excellent skin regeneration	[27]
Hydrogel	Plasmid Ang-1	Chitosan, poly (ethylene glycol) diacrylate, sodium β-glycero-phosphate, *N*-trimethyl chitosan chloride (TMC)	Homogenization method	Accelerates wound healing by reducing inflammation and promoting angiogenesis	[28]
Nanofibrous mats	Zinc oxide	Chitosan, PVA, zinc oxide, methanol, acetic acid	Electrospinning method	Effective in dressing materials for diabetic wound	[29]
Hydrogel	Gallan gum	Chitosan, ethyl acetate, petroleum ether	Lyophilisation technique	Effective in wound dressings	[30]
Nanoparticles	Cefadroxil	Chitosan, glyceryl monostearte, cellulose membrane	Double emulsification method	Accelerates wound healing process	[31]
Scaffolds	Selenium	Chitosan, PVA, sodium hydro-xide, glutaraldehyde, nitric oxide, silver nitrate, sodium chloride	Phase separation technique	It showed the enhanced antimicrobial wound dressing activity.	[32]
Nanoemulsion	α-Tocopherol	chitosan, oleic acid, acetone	Emulsification method	Prepared formulation showed remarkable properties in wound healing	[33]

Emulsion	Rutin	Chitosan, Propylene glycol, sodium hydroxide	Homogenization method	Emulsion showed effective property in wound healing	[34]
Scaffolds	Poly-urethane diol	Chitosan, acetic acid, sodium hydroxide	Cross linking method	Showed effective property in full thickness wound healing dressing	[35]
Sponges	Chlorhexidine	Chitosan, glacial acetic acid, citric acid, sodium hypophosphite	Freeze drying	Showed enhanced wound healing property	[36]
Films	Curcumin	Chitosan, ammonium persulphate (APS), sodium hydroxide	Sonication method	Showed antimicrobial activity and wound healing property	[37]
Films	–	HPMC, chitosan, Succinic anhydride	Cross-linking method	Potential wound dressing material	[38]
Sponges	Tannins and platelet rich plasma	chitosan, gelatin, tannic acid, ascorbic acid, acetic acid, glycerin, calcium chloride	Freeze drying	It is promising biological material that can be used as a surgical wound dressing	[39]
Scaffold	Norfloxacin	Chitosan, collagenase	Freeze-drying method	Formulation showed enhanced rate of wound healing	[40]
Films	Tripsin	carboxymethyl chitosan	Solvent precipitation method	Served as effective wound dressing material	[41]
Scaffold	–	Chitosan, polyethylene glycol	Cross-linking technique	Showed angiogenesis activity and promising candidate of wound healing	[42]
Fibrous membranes	Enrofloxacin	Polyvinylidene fluoride, chitosan	Electrospinning method	Showed excellent antibacterial activity and wound healing effect	[43]

for wound healing applications. Nejad *et al*. [53] reported hydrogel using dexamethasone sodium phosphate, lactide, glycolide, hyaluronic acid, ethyl diamine and ethylene glycol using emulsification-diffusion method, characterized and concluded that prepared nanoparticles can be applied as adhesion barrier, wound dressing and novel drug delivery system. Abou-Okeil *et al*. [54] prepared the biofilms using hyaluronic acid, sodium alginate, sulfadiazine sodium salt, silver nitrate using cross-linking using solvent casting and concluded that such films are suitable as topical wound dressings. Chanda *et al*. [55] prepared the bilayered scaffold using hyaluronic acid, formic acid, polycaprolactone and chitosan using electrospinning technique and concluded that chitosan/polycaprolactone hyaluronic acid based scaffold shows best results. Fahmy *et al*. [56] investigated the wound dressing efficacy by preparing it from chitosan, trisodium citrate, hyaluronic acid and silver nanoparticle by sonication technique and concluded that the dressing bases shows the remarkable results in the wound dressing. Further, Kaczmarek *et al*. [57] reported the scaffolds using collagen, chitosan, hyaluronic acid, nanohydroxyapatite *via* freeze drying method and concluded that nanohydroxyapatite on addition to chitosan, hyaluronic acid, collagen slow down the implant biodegradation process and create a scaffold with longer stability. Luo *et al*. [58] prepared the hydrogels using hyaluronic acid, hydroxy-methyl cellulose, sodium periodate, sodium hydroxide and sodium periodate using centrifugation and sonication techniques and concluded that hydrogel has a potentional applications in the field of wound dressing. Chen *et al*. [59] investigated the efficacy of novel hydrogel from hyaluronic acid, chitosan, *N*-isopropylacrylamide, poly-(*N*-isopropylacrylamide) prepared *via* sonication and concluded that prepared hydrogels exhibit the remarkable results in wound healing. A unique type of hyaluronic acid cryogel composite using polyethyleneimine, halloysite nanotubes, sodium diclofenac was prepared *via* cryopolymerization and concluded that hyaluronic acid based composite materials reported to be have a great potential in biomedical applications [60].

The hybrid scaffold prepared from nano-hydroxyapatite, chitosan chondrotin sulfate and hyaluronic acid using freeze drying technique and found that such scaffold will be promising candidate for bone tissue engineering applications [61]. Lu *et al*. [62] prepared the nanoparticles using chitosan, silver nitrate, hyaluronic acid, glutamic acid using drying technique and found the better antimicrobial activity of wound dressing which was due to the presence of silver nitrate. A novel nano-hybrid magnetic liposomes consisted of docetaxel, hyaluronic acid, citric acid, hexadecylamine, dipalmitoyl-sn-glycero-3-phosphocholine were prepared *via* rotary evaporator and found that this developed system exhibit the best results in wound dressing [63]. Bian *et al*. [64] prepared a hydrogel using hyaluronic acid, *N*-hydroxysuccinimide, dithiothreitol, dithiothreitol, cysteamine hydrochloride using cross-linking method and characterized by dynamic mechanical analysis (DMA). The cytotoxicity *in vitro*, cell viability and proliferation *in vitro* data showed the better biomedical applications. Hoyo-Gallego *et al*. [65] prepared the biofilms using chitosan, hyaluronic acid and ethylene diamine using sonication techniques and found that prepared biofilms shows enhanced antimicrobial activity. Entekhabi *et al*. [66] prepared novel scaffolds using hyaluronic acid, polycaprolactone and acetone using electrospinning technique and concluded that scaffold meet the requirement of neural tissue regeneration. Table-2 summarized various drug delivery carriers fabricated using hyaluronic acid.

Silk fibroin based wound dressings: Silk fibroin (SF) due to its properties like low toxicity, biodegradability, non-allergic proved to best delivery system. Sen *et al*. [67] fabricated scaffolds using the immunomodulatory potential of non-mulberry silk fibroin with polyurethane (PU) and silk worm, and PU/SF composite scaffolds were found useful for tissue engineering applications.Further, chamomile extract loaded nanofibrous mats shows best result in wound healing [68]. Fattahpour *et al*. [69] reported meloxicam loaded hydrogels using methyl cellulose, carboxymethyl chitosan, pluronic F127 with good encapsulation and to achieve targeted drug delivery.

TABLE-2
DRUG DELIVERY CARRIERS BASED ON HYALURONIC ACID (HA) IN WOUND HEALING

Drug delivery system	Drug	Method	Conclusion	Ref.
Nanofiber	Polygalacturonic, hyaluronic acid, silver nitrate, polyvinyl alchol	Electrospinning	Polygalacturonic/Hyaluronic acid nanofiber loaded with silver nanoparticles shows nanofiber for a quick healing of wound infections	[44]
Films	Hyaluronic acid and silk fibroin, sodium hydroxide,	*Ex situ* and *in situ* approach	Prepared film s shows the best wound dressing properties.	[45]
Nanofiber	Hyaluronic acid, polyurethane, starch	Electrospinning	Nanofiberes shows the promising result in wound healing	[46]
Nanofibrous gel	chitosan, gelatin, and hyaluronic acid	Electrospinning	Chitosan /HA prepared gels shows the better results in wound helaing	[47]
Nanofiber	Polyvinylalchol, hyaluronic acid and L-arginine, citric acid,	Electrospinning	Nanofibers could be employed as potentional wound dressing that can be significantly accelerate wound healing and tissue regeneration	[48]
Nanofiber	Hyaluronic acid, Cyclodextrin, Polyvinyl alchol	Electrospinning	Prepared nanofibrous scaffold shows a ideal candidate to deliver directly to wound.	[49]
Nanofiber	Chitosan, hyaluronic acid, glacial acetic acid, sodium hydroxide	Electrospinning	Nanofiberes prepared shows remarkable properties.	[50]
Hydrogel	Gelatin, Hyaluronic acid	Cross-linking	Prepared hydrogels shows better result in diabetic patients.	[51]
Wound dressing	Hyaluronic acid (HA), collagen (COL) and alginate (ALG)	Lyophilisation	Prepared antimicrobial wound dressing has the potentional for wound healing applications.	[52]
Hydrogel	Dexamethasone sodium phosphate, Lactide, glycolide, Hyaluronic acid	Emulsification-diffusion	Prepared nanoparticles can be applied as adhesion barrier, wound dressing and novel drug delivery system	[53]
Bio-films	Hyaluronic acid, sodium alginate, Sulfadiazine sodium salt, Silver nitrate	Solvent casting	Films are suitable as topical wound dressings.	[54]
Scaffold	Chitosan, Hyaluronic acid, Formic acid, Polycaprolactone	Electrospinning technique	Scaffolds shows the best promising results.	[55]
Nanoparticles	Trisodium citrate, Hyaluronic acid, Chitosan, silver nanoparticles	Sonication	Prepared dressing base shows the better wound dressing properties.	[56]
Scaffolds	Collagen, Chitosan, hyaluronic acid, nano-hydroxy apaptite	Freeze drying method	Nano-hydroxyapatite (Hap) on addition to chitosan, hyaluronic acid, collagen slow down the implant biodegradation process and create a scaffold that provide longer stability	[57]
Hydrogel	Hyaluronic acid, hydroxymethyl cellulose, sodium periodate, sodium hydroxide, hydrochloric acid, sodium periodate	Sonication	Hydrogel has a potentional application in the field of wound dressing	[58]
Hydrogel	Hyaluronic acid, chitosan, *N*-isopropylacrylamide, *n*-hexane, methanol, Mercaptoacetic acid (MAA), Poly(*N*-isopropylacrylamide)	Sonication	Prepared system shows remarkable wound dressing properties.	[59]
Cryogel composite	Hyaluronic acid polyethyleneimine (PEI), halloysite nanotubes (HNTs), sodium diclofenac	Cryopolymerization technique	Hyaluronic acid based composite materials reported to be have a great potentional in biomedical applications	[60]
Scaffold	nano hydroxy apatite, chitosan chondrotin sulfate, hyaluronic acid	Freeze drying	Scaffold shows good result in wound healing	[61]
Nanoparticles	chitosan, silver nitrate, hyaluronic acid, glutamic acid	Drying technique	Nanoparticles prepared shows the good results.	[62]
Liposomes	Docetaxel, DTX), hyaluronic acid hexadecylamine polymer, citric acid	Solvent evaporation	Liposomes prepared shows best wound dressing results.	[63]
Hydrogel	hyaluronic acid, *N*-Hydroxysuccinimide, dithiothreitol, dithiothreitol, cysteamine hydrochloride	Cross linking	Prepared shows the biomedical applications	[64]
Films	chitosan, hyaluronic acid, Ethylene diamine	Sonication	Prepared films shows enhanced antimicrobial activity	[65]
Scaffolds	Hyaluronic acid, polycaprolactone, acetone and fibers	Electrospinning	Scaffold meets the requirement of neural tissue regeneration.	[66]
Nanoparticles	Hyaluronic acid, chitosan, 3,3,3-trifluoroethanol, fetal bovine serum, gentamicin, kanamycin solutions	Electrospinning	Prepared biofilm shows a new bilayer membrane will promote wound healing process.	[67]

The potentialability of SF-poly (ethylene oxide) (PEO) matrices using electrospinning in periodontal applications was explored by Serôdio *et al*. [70]. Calamak *et al*. [71] reported that silk fibroin-polyethyleneimine based antibacterial bionano-textiles as wound dressing applications exhibited good results in wound healing. A unique dressing films were prepared by Teramato *et al*. [72] using bombyx silk cocoons solution *via* casting method and concluded that blended films did not show any chemical interaction and proved as best self care wound dressing material. Feng *et al*. [73] reported the better results in the wound dressing applications using silk fibroin and konjac glucomannan, which was physically cross-linked to form bio-compatible protein/polysaccharide sponges with tunable mechanical properties.

Garcia-Orue *et al*. [74] prepared the nanofibrous wound dressings based on PLGA and *Aloe vera* extract having the suitable characteristics, such as high porosity and high surface area-to-volume ratio. Babu *et al*. [75] reported the silver oxide nanoparticles embedded silk fibroin spuns using silk fibroin, mercaptoethanol and sodium bicarbonate using sonication and the dressing material proved to be good for the wound healing and antibacterial applications. Kheradvar *et al*. [76] prepared the nanofibrous mat as a new vitamin E delivery system based on silk fibroin/poly(vinyl alcohol)/aloe vera by the electrospinning method. The incorporation of vitamin E into the nanocomposite dressing enhanced antioxidant activity. Similarly, Amas *et al.* [77] reported the electrospun mats from poly(ε-caprolactone)/poly(ester amide)s miscible blends and concluded that prepared mats shows the better results in the wound dressing. Tonda-Turo *et al*. [78] reported the gelatin cross-linked nanofibers using silver nitrate by using green electrospinning approach. A new bilayer membrane for wound dressing was prepared by Türkkan *et al*. [79], which consisted of one layer of electrospun silk fibroin/PCL-PEG-PCL incorporating nanocalcium phosphate while the other layer consist of PCL membrane which can prevent the formation of non-functional scar tissue layer on defect site by undertaking as barrier role. The results confirmed the biocompatibility and potential applicability of proposed membranes for guided bone regeneration treatments.

He *et al*. [80] prepared a sericin/polyvinyl alcohol blend film containing silver nanoparticles was synthesized *via* UV-assisted green synthesis method. This novel AgNPs-sericin/PVA film shows great potentials in biomedical materials such as wound dressing and skin tissue engineering. Jang *et al*. [81] studied the effects of sericin concentration and ethanol on the gelation behaviour, rheological properties and sponge characteristics of sericin. The porosity and swelling ratio of the sericin sponge decreased and the mechanical properties of sericin sponge were remarkably improved, when the sericin concentration increased.

Bhattacharjee *et al*. [82] reported the hydroxyapatite in non-mulberry silk fibroin grafted poly(ε-caprolactone) nanofibrous scaffolds, which was prepared by electrospinning technique and provide the promising platform for bone healing and regeneration. Lee *et al*. [83] fabricated silk fibroin nanomatrix using electrospinning and evaluated as wound dressing material in a burn rat model. Abdel-Fattah *et al*. [84] reported two novel silk composites of phosphatic phases with nanosilver/chitosan. Hydroxyapatite and octa-calcium phosphates were synthesized *in situ* within silk fibroin/chitosan/nanosilver composites. Dyakonov *et al*. [85] prepared the reported the silk fibroin containing matrixes *via* spray-drying and film casting techniques and *in vitro* dissolution data demonstrated that silk fibroin β-sheet conformation regulates the release profile of naproxen. Sun *et al*. [86] encapsulated doxorubicin in silk fibroin particles and then folic acid was covalently grafted to the surface of the silk fibroin particles (FA-SFPs-DOX) as a target group to the folate receptor of tumor cells. The results showed that under low pH, high ionic strength and high enzyme concentration, the release of loaded drugs had stimulus response under various conditions. Table-3 summarized various drug delivery carriers fabricated using silk fibroin.

Alginate based wound dressing: Alginate is widely used polymer in wound dressings which upgrade the hydrophilic nature of wound dressing materials. It helps to create moist wound environment, speed up wound recovery and eliminates wound exudates. They can easily cross-link with both inorganic and organic materials.

Alshhab & Yilmaz [87] investigated the wound dressing based on bacterial cellulose impregnated with alginate using cross-linking method. It showed an enhanced water retention property and providing the smooth dressing. Khan *et al*. [88] fabricated the membranes for enhanced wound healing using sodium alginate, poloxamer 407 and polyvinyl alcohol by sonication method. Satish *et al*. [89] reported antibacterial nanofibres comprised of cellulose acetate/silver-sulfadiazine by electrospinning method. The results revealed the appreciable biocompatibility and promising product for wound dressing applications. Triiodothyronine impregnated scaffolds were also designed using alginate/gelatin/polyvinyl alcohol composites [90]. It was concluded that the prepared scaffolds based wound dressing was cost effective for chronic wounds. Chen *et al.* [91] prepared the cross-linked films of pectin and sodium alginate loaded with cefazolin nanoparticles, which showed an excellent antibacterial activity when applied as wound dressing. Afzal *et al*. [92] prepared composite membrane based on sodium alginate by drying method. The formulation was used to treat and repair open and infected wound infections. This membrane proved to be boom in wound dressing. Bueno & Moraes [93] prepared the novel hydrogels incorporating silver nanoparticles, which provides a relief to pressure ulcers through its use in wound healing. Khampieng *et al*. [94] developed a unique biopolymer wafers type dressing incorporated with colloidal silver for wound care using lyophilization method for reducing microbial infections and enhancing wound healing rate. Tabassum *et al*. [95] prepared a carrageenan containing hydrogel incorporating silver nanoparticles against common bacterias such as *S. aureus* and *P. aeruginosa* in wound infections. Zepon *et al*. [96] evaluated the novel dressing based on hyaluronan/silver nanoparticles fabrics against *E. coli*. Moreover, such fabrics were also used to treat wound as well as chronic ulcers. Nie *et al*. [97] prepared the nanofiber-polymer biomaterial, which possessed several abilities such as protein-adsorption, blood clotting, platelets aggregation, antibacterial and haemostatic

TABLE-3
DRUG DELIVERY CARRIERS BASED ON SILK FIBROIN (SF) IN WOUND HEALING

Drug delivery system	Drug and polymers	Technique	Conclusion	Ref.
Scaffold	Non-mulberry silk fibroin with polyurethane, silk worm, sodium dodecyl sulfate, polyethylene glycol, dibutylitin dilaurate, and isophorone diisocyanate, dimethyl sulphoxide	Lyophilization	PU/SF composite scaffold would be useful for other tissue engineering applications	[66]
Nanofibrous mats	Carboxyethyl chitosan, polyvinyl alchol, poly(ε-caprolactone), Chitosan, glutaraldehyde, Chamomile extract, Sodium hydroxide, acrylic acid	Electrospinning	Chamomile loaded mat can be appropriate for wound healing applications because of its antimicrobial, antioxidant, biocompatibility and mechanical properties	[67]
Hydrogel	Carboxy methyl chitosan, methyl cellulose, pluronic F127, Meloxicam, Monochloroacetic acid, Isopropanol	Electrospinning	Prepared systems exhibit the basic properties for wound healing	[68]
Multilayer membrane	Silk fibroin, chitosan, alginate, diclofenac sodium, acetic acid, Glycerol	Casting method	Multilayer membrane proved to be having potentional application in wound dressing.	[60]
Matrices	Silk fibroin (SF)/poly(ethylene oxide) (PEO) membranes sodium carbonate, silk fibroin, hydrochloric acid, sodium hydroxide and lithium bromide	Sonication	Potentional of electrospun SF based matrices in matrices in periodontal applications.	[70]
Wound dressing	Polyethyleneimine, glutaraldehyde, calcium chloride, methanol, pyridine, trypsin, chloro sulfonic acid, pencillin-streptomycin	Electrospinning	Prepared wound dressing exhibit remarkable properties in wound healing	[71]
Films	Bombyx silk cocoons, lithium bromide, beta-glucan powder, sodium carbonate, β(1-3)-D-glucan	Casting method	Prepared formulation shows the best model as purpose of constructing a self care wound dressing material.	[72]
Sponges	Bombyx mori, sodium bicarbonate, lithium bromide, ethanol, ammonium solution	Lyophilization	Prove the sample and potentional applicability in wound dressing.	[73]
Nanofibrous membranes	PLGA/Aloe vera using Hexafluroisopropanaolol, PLGA, Tween 80	Electrospinning technique	Nanofibrous preparation shows good result in wound healing.	[74]
Nanoparticles	Silk fibroin, silver nanoparticles, silver nitrate, mercaptoethanol, sodium bicarbonate	Sonication	Prepared spuns show the potentional material for wound healing and antibacterial applications	[75]
Nanofibrous dressing	Bombyx mori, lithium bromide, Tween 80, glutaraldhyde, sodium bicarbonate	Electrospinning	Prepared membrane shows the effective applicability of wound dressing materials.	[76]
Electrospun mats	Poly caprolactoneleucine, sodium bicarbonate, sodium chloride, dichloromethane	Electrospinning	Dressing prepared shows the remarkable result in wound dressing	[77]
Nanostructured scaffold	Silver nitrate	Crosslinking	Scaffold prepared using "green electrospinning approach" shows remarkable result in wound care management.	[78]
Nanosized bilayer membrane	Bombyx mori silkworm, Polyethylene glycol,	Electrospinning technique	Bilayer membrane shows the remarkable result in wound healing	[79]
Film	Silkworm cocoon, silver nitrate	electrospinning	Film offer more choice to be potentially applied in antibacterial materials such as wound healing and skin tissue engineering.	[80]
Sponge	Bombyx mori silk cocoons, sericin aqueous solutions, and ethanol	Freeze thraw method	that fabricated sponges can be utilized for cosmetic and biomedical applications like cosmetic packs, wound dressing and drug delivery if their mechanical properties are further enhanced	[81]
Nanofiberes	Polycaprolactone, glutaraldehyde, polyethylene glycol	Electrospinning	Nanosystems prepared show the best result in wound healing.	[82]
Gauze	Silk fibroin	Electrospinning technique	Gauzes prove to be boom in burn wound healing.	[83]
Scaffold	Collagen/chitosan Nor?oxacin	Freeze drying technique	Prepared scaffold show the promising results.	[84]
Scaffold	Chitosan, acetic acid, isopropanol, silk fibroin, calcium hydroxide, calcuim chloride, phosphoric acid	Centrifugation method	Scaffold prepared shows the remarkable properties in wound healing.	[85]
Nanofiberes	Coolgen, polycaprolactone, chtosan, dichloormethane	Electrospinning	Prepared nanofiberes shows the good result in wound healing	[86]

properties. Kyziol *et al*. [98] proposed a blends based on polyvinyl alcohol and calcium alginate as biomaterial and used in bioactive wound dressings. Abdel-Mohsen *et al*. [99] prepared a silver/hyaluronan bionanocomposite using gel casting technique. The synergistic effect of formulation such as adjustable degradation time, enhanced mechanical properties were also investigated. Ashfaq *et al*. [100] produced chitosan-alginate membranes for coatings of skin wounds, however gels prepared shows the better result in wound helaing [101]. Similarly, hydrogels prepared using polyvinyl alchol shows the remarkable result in wound healing [102]. In the same way, hydroclloids prepared system also shows the remarkable properties in wound healing [103]. Table-4 summarized various drug delivery carriers fabricated using sodium alginate.

Patent literature

Chitosan: It is observed that chitosan has been widely used in wound dressings. Presently, researchers reported chitosan-silver nanoparticles having antimicrobial activity. The formulation was prepared by encapsulating wound dressing with chitosan and silver. It showed an excellent property of releasing silver nanoparticles in a sustained manner [104]. A study reported chitosan alginate sponges prepared by encapsulating curcumin in a fluid phase of oleic acid *via* freeze drying method [105]. Nanocomposites were prepared by using *S. cumini* [106]. The formulation showed enhanced healing by reducing inflammation, enhancing angiogenesis, early collagen formation and enhanced rate of re-epitheliaztion [107]. Silver nanoparticles were mixed with chitosan solution to form dispersion by freeze drying method. The chitosan/silver nanoparticle matrix was useful in wound dressing [108]. Metallic nanoparticles were encapsulated in a matrix of chitosan based compounds. It showed enhanced wound healing activity [109].

Recently, Lucea *et al*. [110] prepared lipid nanoparticles consisting of antimicrobial peptide. The formulation showed increased rate of wound healing by topical administration.

TABLE-4
DRUG DELIVERY CARRIERS BASED ON SODIUM ALGINATE IN WOUND HEALING

Drug delivery system	Polymers	Technique	Conclusion	Ref.
Films	Alginate, calcium chloride, glycerol	Crosslinking	Films prepared shows remarkable properties in wound healing.	[87]
Wound dressings	Calcium alginate and antimicrobial agent	Sonication method.	The fabricated dressing after 32 months, confirmed antimicrobial and antifungal activity indicating prolonged release of drug for longer periods.	[88]
Hydrogel membranes	Polyvinyl pyrollidine, PVC	Sonication	Prepared membrane proved better results.	[89]
Films	Sodium alginate/Poly(4-vinylpyridine) PEC multilayers	Ionic interaction	Drug release via diffusion make them suitable matrices for transdermal delivery systems	[90]
Films	Cefazolin, chitosan, sodium, acetic acid	Crosslinking technique	Prepared system shows the best result in wound dressing.	[91]
Scaffolds	Alginate/Gelatin/Polyvinyl alcohol	Sonication	Scaffold prepared shows the role of release of bioactive materials.	[92]
Cefazolin nanoparticles	Chitosan, sodium alginate (SA), pectin (PC) and calcium chloride	Stirring method	Films prepared shows remarkable result in wound healing.	[93]
Composite membrane	Hydroxylated lecithin, complexed iodine/carboxymethyl chitosan/sodium alginate	Drying	Prepared system shows the high stability and controlled release of activated iodine component.	[94]
hydrogel	Carboxymethyl cellulose, sodium hydroxide, monochloroacetic acid, sodium hydroxide, ethylene glycol, Monochloro acetic acid, sodium nitrate	Sonication	Novel hydrogel have potentional application in wound dressing.	[95]
Wafers	Glycerol, sodium alginate, silver water, glacial acetic acid	Lyophilization	Wafers prepared show the wound healing properties.	[96]
Hydrogel	Hydroxide, silver nitrate, Potassium chlorate,	Sonication	Silver nanoparticles hydrogel showed antimicrobial efficacy.	[97]
Nanoparticles	Hyaluronan, silver nitrate, Isopropyl alcohol,	Sonication	Nanoparticles prepared shows the remarkable result in wound healing	[98]
Nanocomposites	Polyvinyl alcohol (PVA), bovine serum albumin (BSA)	Sonication	Nanocomposite shows the good result in wound healing.	[99]
Films	Polyvinyl alcohol, calcium alginate,	Casting technique	Hydrogel prepared shows the remarkable result in wound dressing.	[100]
Nanohybrid hydrogel	PVA and alginate, $CaCl_2$ and methanol	Gel casting technique	Gel prepared shows the enhanced properties.	[101]
Wound dressing	CMCTS-*g*-PAA, propyl sulfonic acid, isotonic saline, phenol, ethanol, dimethyl sulfoxide, trypsin	Solvent precipitation method	Due to presence of chitosan prepared system shows the better results.	[102]
Ammonium chitosan hydrogel	Monochloro acetic acid, sodium nitrite, polyvinyl alcohol, Polyethylene oxide	copolymerization method	HAAC/PEO/PVA hydrogel prove to be boom in wound healing	[103]

Messinger [111] prepared chitosan containing interlayer in which chitosan is present in the form of granules, a film or a porous matrix by freeze drying method. It showed that multi-layer construction increases stability under mechanical stress. Nordquist & Carubelli [112] prepared dried films with glycated chitosan. It helps in orthopedic surgery and tissue generation in dental surgery. A hydrogel was prepared by combining aqueous solutions of two polymers by cross-linking technique. It showed an effective wound healing and antibacterial activity [113]. Guo & Gregory [114] reported a fabrication of solid foam for hemorrhage control and wound repair for effective wound dressing. Redlinger *et al*. [115] prepared cellulosic moulded bodies according to the amine-oxide process, which showed an effective wound healing.

Some of the marketed formulations of chitosan used in wound dressings, which are discussed below:

(a) **HemCon® bandage:** It is manufactured by HemCon Medical Technologies, Inc. It is a sterile chitosan based dressing intended for external use and controls bleeding immediately after its application.

(b) **AQUANOVA super absorbent dressing:** It is manufactured by MedTrade Products. It is a mixture of chitosan, chitosan derivatives and structural materials to produce a soft pad woven dressing. AQUANOVA super-absorbent over the counter is available for superficial cuts, minor burns, minor irritations, lacerations and abrasions.

(c) **Axiostat:** It is manufactured by Axio Biosolutions and 100% chitosan haemostatic dressing approved with CE mark in Europe. It stops bleeding within just 2-3 min of its application.

(d) **Gel-e's Hemogrip™ patch:** It is a product of Foshan United Medical Technologies. A sterile topical bandage comprising a lyophilized chitosan based patch attached to a standard bandage backing with two adhesive strips on either side of the patch for secure attachment to skin. As wound exudates are absorbed into chitosan-based patch, the patch forms a gel, which maintains a moist environment for optimal wound healing and allows intact healing.

Patents based on hyaluronic acid: Various patents have been filed on hyaluronic acid based wound dressings. An invention is proposed a production of novel cross-linked hyaluronic acid derivatives with other polymers [116] and used for medical, cosmetic and pharmaceutical applications. Pharmaceutical compositions containing hyaluronic acid and its derivatives were prepared for topical use in form of liquid spray, foam or dry spray. The prepared composition is useful in treatment of sores, burns and ulcerations [117]. Lorenzi *et al*. [118] reported that hyaluronic acid behaves differently with different fractions. Hyaluronic acid having molecular weight of 50,000-100,000 is utilized for wound healing polymer while above 500,000 to 730,000 is used for intraocular and intraarticular injections. Multilayered non-woven tissue with a different layers was prepared with hyaluronic acid ester, one natural, synthetic, semi-synthetic polymer. The prepared tissue can be used for wide variety of sanitary and medical applications such as non-adhesive covering material and surgery materials. Valentini & Kim [119] prepared the hyaluronic acid scaffolds cross-linked with divinylsulfone and functionalized with active molecule. These scaffolds were used for various medical purposes such as tissue reconstruction, repair and wound healing. Longin & K. Schwach-Abdellaoui [120] prepared novozymes biopolymer by cros-slinking hyaluronic acid with divinylsulfone. Few marketed formulations based on hyaluronic acid are (i) Microdacyn wound care solution and hydrogel marketed by Oculus; (ii) Stimulen-Collagen wound care gel tube) marketed by Nine Enteral; (iii) Silva Kollagen gel (EA); and (iv) Jarrow formulas, 60 Veggie caps.

Patents filed on silk fibroin: Jiang *et al*. [121] proposed that hydrogels based on silk fibroin could be a promising platform for promoting the wound healing. A wound dressing material containing silk fibroin and sericin as an active ingredient was prepared by Tsubouchi [122]. The material was found to accelerate the regeneration of skin. The surface of skin is tightly wounded until the wound is cured and showed excellent properties [122]. Kaplan & Wang [123] proposed a controlled assembly of layered silk fibroin coatings used for vascular wound repair devices, patches, hemostatic dressings, sutures and glues. Similarly, silk fibroin matrices were also prepared, which possessed the adhesion properties [124]. These matrices can be used in biomedical applications like anti-thrombotic material. The details of marketed formulation based on silk fibroin are as follows:

(i) **Fibroheal silk protein based Asiaticoside derived wound healing sheets:** It is a sterile, biomodified, bilaminated product manufactured by Fibroheal. It provides safe, protective and breathable barrier leading to high cell attachment and faster tissue regeneration.

(ii) **Fibroheal ointment:** It is a silk protein and silver based topical antimicrobial ointment used to prevent infection and promotes wound healing in skin ulcers, cuts, blisters, burns, *etc*.

(iii) **Fibroheal microbicidal sprinkling powder:** It is used as surgical wound dressing for rapid healing with minimal scars in non-exudating and non-infected wounds such as skin ulcers, surgical wounds, *etc*. It promotes faster wound healing by collagen deposition and fibroblast proliferation.

(iv) **Fibroheal heal AG wound healing sheet:** This dressing is a sterile, reinforced non-mammalian source wound dressing which is effective against a broad spectrum of microorganisms and manufactured by Healthline Pvt. Limited.

Patents filed based on sodium alginate: Cohen & Mohajer [125] reported that alginate based wound dressing enhanced wound fluid absorption. It showed a potential in the treatment of chronic and non-healing wounds. Cole & Garbe [126] invented that alginate based hydrogel can easily absorbs wound exudates without any swelling. Similarly, Fenton *et al*. [127] also reported that alginate fibres showed its potential in ulcers and burns. Rippon & Jacques [128] reported that the multi-layered wound dressing based on alginate is utilized for highly exudating wounds. Edwards [129] reported that alginate dressings are suitable for partial and full thickness wounds with moderate to heavy exudates. It provides gelation and moist healing, which promotes re-epithelialization. Different ranges of alginate concentrations were selected to form gels in the form of moldable water-soluble fibrous paste. These kinds of gels are easier to handle than alginate gels and are utilized in wound dressing applications [130]. Few examples of marketed formulations of alginate are (i) Aticoat (manufactured by Smith & Nephew Co.), (ii) A Aquacel silver hydrofiber (manufactured by ConvaTe), (iii) Biatain silver (manufactured by Coloplast), (iv) Cutisorb (manufactured by BSN Medical), and (v) Promogran prisma (manufactured by Systagenix).

Future prospects: This review has considered various categories of wounds dressings including topical pharmaceutical agents, traditional wound dressings and modern dressings such as hydrocolloids, alginates and hydrogels. Wound dressings should fulfill the basic characteristics such as minimum inconvenience, low cost etc. Different polymers like chitosan, sodium alginate, silk fibroin can be used as potential biomaterial in wound healing due to its healing, anti-inflammatory and antibacterial nature. Several challenges remain that need to be taken into consideration in developing novel wound healing drug delivery formulations. For example, large variations in the rate of production of wound exudates, suggest the difficulty in finding a single ideal dressing capable of application to all wound types. It is ideal to have composite dressing which combines the different characteristics of current technologies.

Conclusion

Wound dressings are designed to support the wound bed and protect it from the factors that may delay or impede its healing such as contaminations and moisture loss, thereby facilitating and accelerating the healing process. The materials used to prepare wound dressings which include natural and synthetic polymers as well as their combinations in the forms of films, sponges and hydrogels. The development of wound dressings has partly improved the effect of wound management. This review highlights the main characteristics and properties of a natural polymer, which is widely used as biomaterial applications of these composite biomaterials, are discussed with emphasis on skin wound healing. The emerging technologies support the development of innovative dressings based exclusively on natural constituents, either polymeric or bioactive compounds.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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